Absorptive capacities and external openness in underdeveloped Innovation Systems:

A patent network analysis for Latin American countries 1970-2017

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Abstract:

This paper contributes to the literature on innovation and development by analysing the absorptive and connectivity capacities of Latin American innovation systems between 1970 and 2017. Applying network analysis to a USPTO database containing Latin American inventors, we build and analyse collaboration networks in the process of invention and knowledge appropriation. The structural properties and the evolution of such networks show that innovation systems in Latin America exhibit serious weaknesses that hinder the formation of a critical mass of interactive capabilities. Specifically, the networks exhibit low absorptive capacity and high external openness, which are critical linkages with external nodes in the network growth process. We identify different trajectories of innovation systems within the region, analysing specific paths of capability (de)accumulation and network maturity against the backdrop of national development trajectories.

Keywords: innovation systems; absorptive capacities; patent network, Latin America

JEL codes: B50 O31 O54

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1. Introduction

Two core features of the innovation system (IS) approach are the distributed property of knowledge and the interactive nature of innovation emergence and diffusion. The latter relies on the ability of agents to interact and absorb new knowledge, creating positive feed-back mechanisms (Lundvall, 1988).

Latin American studies of innovation and development have critiqued and enriched the IS concept from the underdevelopment perspective (Arocena and Sutz, 2000a). This stream of research has identified systemic flaws in critical feedback mechanisms (Erbes *et al*., 2010; Yoguel and Robert, 2010; Arocena and Sutz, 2010) and have characterized Latin American ISs as immature (Rapini *et al*., 2009). These authors stress the weakness of external connectivity and absorptive capacities in the region, mostly due to the lack of a local critical mass of innovative agents, which, in turn, hinders knowledge demand (Erbes *et al*., 2010; Yoguel and Robert, 2010; Arocena and Sutz, 2010; Dutrénit and Puchet, 2011). Relatedly, other works have emphasized that the peripheral position of Latin American ISs shapes both their participation in the global IS and the local dynamic of knowledge production and appropriation (Albuquerque, 2007). Building on the pioneering ideas of Furtado (1964), authors in this line of inquiry have proposed systems-based interpretations of underdevelopment, a situation they view as qualitatively different from development (Cassiolato and Lastres, 2008; Yoguel and Robert, 2010).

In this paper, we contribute to the understanding of the evolution of Latin American ISs by defining and measuring IS absorptive and connectivity capacities (Yoguel and Robert, 2010). By doing so, we identify different national paths of capability accumulation and offer

empirically grounded explanations that complement and enrich extant knowledge concerning Latin American ISs.

Previous research has advanced understanding at the level of individual countries or groups of countries, mostly based on in-depth national case studies (e.g. Dutrénit *et al*., 2010; Cassiolato *et al*., 2003). However, comprehensive longitudinal studies based on standardized data for the entire region are scarce (Confraria and Vargas, 2019; Castellacci and Natera, 2013). In addition, prior works have claimed that, to advance understanding of underdevelopment beyond the study of catching-up processes, the IS approach requires a theoretical basis that can identify the emergent properties that arise from the systemic interactions rather than simply identifying the institutional setting or the evolution of innovation investment (Arocena and Sutz, 2000a; Yoguel and Robert, 2010).

Following the complex systems approach (Yoguel and Robert, 2010; Antonelli, 2017), this paper aims to address these challenges by analysing collaboration networks derived from patenting activities in all Latin American countries during a period of 48 years. We apply network analysis to data from the US Patent & Trademark Office (USPTO). This allows us to take interactions as our unit of analysis and to contribute new measures of two IS building blocks: absorptive and external connectivity capacities (Yoguel and Robert, 2010).

We study national networks' internal cohesion as an indicator of the absorptive capacities in a given IS, and we analyse external connectivity capacities in terms of the degree of openness of the IS. These IS capacities are intrinsically intertwined because positive feedback between them—creating a virtuous cycle—is a necessary condition for the evolution of an IS (Yoguel and Robert, 2010).

By analysing these IS properties, this paper provides a novel comparative analysis of network structures in multiple and diverse ISs. Our findings illustrate that absorptive and connectivity capacities in Latin American ISs have increased, exhibiting, in most cases, a positive relationship between the two capacities. However, the evolution of each capacity and the correlation between them vary across different inventor networks and patent owner networks.

Moreover, the results of our analysis allow us to identify different levels of maturity among Latin American ISs according to the co-evolution of absorptive and connectivity capacities. Specifically, the three largest countries in the region (Argentina, Brazil and Mexico) exhibit the largest networks, similar evolutionary trajectories of absorptive and connectivity capacities and markedly different structural features in their collaboration networks. Among countries with medium-sized networks (Colombia, Chile, Cuba and Venezuela), we find different trajectories associated with structural features of ISs previously identified in the literature and evidence for the (de)accumulation of critical mass in Latin American ISs. Finally, we find that the remaining countries in the region exhibit small and extremely fragmented networks.

2. Innovation systems absorptive and connectivity capacities

Innovation has been defined as an uncertain and cumulative problem-solving process that is interactive in nature (Dosi, 1988). According to this view, solving complex problems requires a wide variety of knowledge distributed among a broad set of actors and innovative solutions emerge from the interactions of different agents acting under uncertainty due to incomplete information and partial understanding of the environment (Lundvall, 1988).

The complexity approach similarly defines innovation as an emergent property of the ISs (Antonelli, 2017). According to this view, innovation emerges from micro-level interactions among agents in the IS. This creates feedback loops between the system building blocks, which determine how the IS evolves. Erbes *et al*. (2010) and Yoguel and Robert (2010) highlight the external connectivity capacity of the system components, that is, the capacity to access and participate in varied knowledge flows. Moreover, a necessary condition for the development of external connectivity is the development of the absorptive capacities of the IS as a whole, which, in turn, is determined by the cohesion of internal systemic linkages. The internal cohesion of linkages reflects the critical mass of the system, which supports the exchange and use of knowledge within the IS (Rivera-Ríos *et al*., 2009; Erbes *et al*., 2010). Conversely, when an IS lacks a critical mass of interactions, the degree of cohesion reveals the extent to which an IS depends on one or more system components. In this sense, the concept of critical mass, which in physical systems refers to the amount of mass needed to make the system self-sustaining, has been used to refer, in social and economic systems, to the minimum amount of accumulated capacity needed to achieve positive feedback. Due to the endogenous evolution of ISs, this kind of threshold is a moving target that changes over time (Dutrénit and Puchet, 2011).

According to this view, the uneven evolution of ISs in developed and underdeveloped countries results from the interaction between a system's absorptive and connectivity capacities, which determine systemic outcomes that are not directly attributable either to a unique system component or to the sum of their isolated effects.

A cohesive and externally connected IS will develop a critical mass of interactions that, by process of creative destruction, changes the structure of the system in a virtuous circle

(Yoguel and Robert, 2010). On the contrary, underdeveloped ISs are characterized by weak interactions (Arocena and Sutz, 2010), whose cumulative effects hinder the formation of a critical mass, both in volume and diversity. This feed-back process, in turn, limits the development of absorptive and connectivity capacities (Erbes *et al*., 2010; Yoguel and Robert, 2010).

2.1. Absorptive and external connectivity capacities

The concept of absorptive capacities, originally coined to describe firm-level phenomena (Cohen and Levinthal, 1990), has also been applied to analyse ISs (e.g. Castelacci and Natera, 2013; Fillippetti *et al*., 2017). At both analytical levels, "absorptive capacities" refers to the collective ability to recognize and understand new knowledge and integrate it into production activities. Relatedly, Fagerberg and Srholec (2017) define "national absorptive capacities" as a sort of cumulative repository of capabilities that is greater than, and different from, the mere sum of the system's components.

Previous empirical studies have demonstrated the importance of national absorptive capacities that moderate the effects of access to external knowledge connections through international trade and investment fluxes (Criscuolo and Narula, 2008). Relatedly, Filipetti et al. (2017) measured national absorptive capacities in terms of human capital, infrastructure and openness and confirmed that it mediates the relation between foreign knowledge flows and national innovation outcomes. Other studies using econometric time-series techniques have shown that the evolution of an IS is determined by the coevolution of innovation capacities, measured in terms of scientific and technological inputs, and absorptive

capacities, measured, as in Filipetti et al. (2017), by different indicators of human capital, infrastructure and openness (Castellacci and Natera, 2013 and 2016).

Álvarez et al., (2019), taking an innovation function approach, have recently shown, based on empirical findings, that adequate absorptive capacity is a necessary condition for open ISs to achieve positive knowledge spillovers from trade and investment flows. For example, the authors argue that, despite the fact that Latin American countries have pursued different strategies to participate in the world economy, the liberalization process initiated in the 1990s, which expanded markets and fostered greater competition, has not led to an increase in innovation. On the contrary, the authors show that increases in innovation have only occurred in the presence of policies that actively promote innovation.

The empirical studies described above, which have focused on measuring innovation activities or outcomes, such as R&D investment, have advanced our understanding of the role absorptive and connectivity capacities play in the performance of Latin American ISs. However, these measures cannot capture the interactive nature of systemic innovation (Fagerberg and Srholec, 2017). To capture the interactive aspect of ISs, an alternative analytical approach is needed.

2.2. A social network approach to innovation system capacities

Network structures comprise interactions that represent systemic dynamics. Hence, network analysis helps overcome the constraints imposed by the production function approach to analysing systemic properties emerging from interaction (Foster, 2005).

A system's capacity to absorb external knowledge is determined by the degree of diversity of the agents and their interactions with external complementary agents (Graf, 2011; Savin and Egbetokun, 2016). Nevertheless, if external connectivity capacities are concentrated in one or a few agents, a critical mass of interactions might form only in restricted areas where some internal or external agents may regulate knowledge flows. Relatedly, the positive effects of openness to external information are only achieved by agents that absorb inbound knowledge flows while generating local knowledge flows, which, in turn, requires internal absorptive capacities. By contrast, if the flows are only inbound, openness can result in the system being dependent on the knowledge provided by external agents.

Following Yoguel and Robert (2010), we conceive absorptive capacity as the presence of a critical mass of interactions within an IS. To our knowledge, in spite of the rich literature on absorptive and connectivity capacities and their effects on national performance, no prior works have used network analysis to study these critical capacities at the national level.

From a network approach, the critical mass of interactions from which absorptive capacities emerge can be observed by considering *network cohesion*. Degree of cohesion denotes the extent to which nodes in the system are connected to each other, forming cohesive groups as opposed to being separate components isolated from each other. There exists an extensive literature analysing the influence of network cohesion and connectivity on innovation processes (see Galaso (2018) for a review). This literature shows that cohesive networks facilitate information access, making information more reliable and facilitating knowledge spillovers (Schilling and Phelps, 2007; Whittington *et al.,* 2009; Fritsch and Kauffeld-Monz, 2010), while fragmented networks restrict the flow of ideas, which can hamper innovation (Fleming *et al*., 2007).

External connectivity capacity can be assessed by analysing the network's openness, which denotes the extent to which local nodes are connected to actors located in other territories. In national collaboration networks, openness indicates the degree to which a country is connected with foreign inventors or owners (Andersson *et al*., 2019). Studies within the social network literature have also found evidence that connections with external nodes can infuse new ideas into the local community, serving as non-redundant information channels (Lobo and Strumsky, 2008) and providing access to novel information that, otherwise, would not be available to local actors (Breschi and Lenzi, 2016; Crespo *et al*., 2016).

Figure 1 summarizes our analytical framework, showing how we translate the theoretical definitions of the two building blocks of the IS approach (absorptive capacity and connectivity capacity) into measurement instruments for analysing the structural properties of the networks.

Figure 1. From theoretical definition to measurable network properties

		Interactive critical mass ⇕	
Building blocks of an IS (Erbes et al. 2010; Yoguel and Robert 2010)	***Absorptive capacity:*** Ability to recognize the value of new knowledge, assimilate it, and apply it.	***Feedback loops*** ⟺	***Connectivity capacity:*** Capacity to access and participate in varied knowledge flows.
Network structures (indicators)	***Cohesion:*** The extent to which nodes in national networks are connected to each other. (Structural holes; Average degree; Largest component)		***Openness:*** The extent to which local nodes are connected to external actors. (No-resident linkages; no-resident/resident)

Source: Authors

3. Data and methods

We use US patent records retrieved from the PatentsView platform (see: https://www.patentsview.org). PatentsView collects and organizes data from the USPTO, including patents granted since 1976.

We select a database that includes 17,942 Latin American patents registered between 1970 and 2017. We consider the application date to define the period under analysis, and use the place of residence listed for the inventor(s) as the demarcation criterion. Thus, we select for analysis patents with, at least one inventor located in a Latin American country (Table 1). In addition, we consider the owners of the patents (assignees), who may be companies, universities or individuals.[1]

Our database covers two major phases of the world intellectual property regime. In the first phase, global patenting activity was mostly regulated by national regimes. This situation changed after adoption of the Trade-Related Aspects of Intellectual Property Rights (TRIPS) agreement by members of the World Trade Organization at the end of the twentieth century. During this new phase, Latin American countries gradually adopted the global intellectual property regime.

[1] A detailed explanation of the data selection and processing up to the reconstruction of our networks can be found in *Authors own*.

Table 1. USPTO patents registered by Latin American inventors 1970-2017

Country	Patents	Inventors	Owners
Argentina	2338	1942	248
Bolivia	52	31	3
Brazil	6715	7760	969
Chile	950	1066	208
Colombia	589	662	95
Costa Rica	414	223	21
Cuba	179	819	54
Dominican Rep.	80	56	4
Ecuador	129	82	8
El Salvador	28	26	4
Guatemala	65	46	6
Honduras	39	24	1
Mexico	5184	5598	477
Nicaragua	11	9	NA
Panama	137	70	30
Peru	210	166	24
Paraguay	19	18	2
El Salvador	28	26	4
Uruguay	171	146	31
Venezuela	1094	908	57

Source: Authors, based on PatentsView data.

We elaborate both networks of inventors and networks of patent owners. 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 who have patented the same product or process. In co-owner networks, the nodes are the patent assignees and two or more owners are connected if they have worked with the same inventor. Thus, inventors are used as links connecting owners in this type of network (Graf and Henning, 2010). We also include in the national networks those foreign actors who collaborate directly with local inventors or owners.

Regarding the temporal evolution of the networks, we consider eight-year windows. For each temporal window, we trace the type of networks described above, considering only nodes and links that occur within that time period.

We describe the size, evolution and structural properties of the networks as follows. To characterize network cohesion in a way that captures the absorptive capacities, we calculate three indicators:

- Average degree: average number of edges adjacent to each vertex.
- Size of largest component: the largest set of nodes whose members are directly or indirectly connected to each other and disconnected from the rest of the network.
- Significance of filled structural holes: value of the first decile of the inverse of Burt's (2004) constraint indicator.

We propose this last indicator because it is particularly useful for analysing fragmented patent networks such as ours. Such networks tend to comprise teams of highly interconnected actors (inventors or owners) who are disconnected from the rest of the network. Thus, by assessing the intensity of the structural holes filled by some nodes, we manage to capture the extent to which the whole network succeeds in bringing together relatively unconnected groups of actors.

To measure network openness in a way that captures the external connectivity capacity of an IS, we use two simple network indicators:

- The share of external nodes that are part of the national networks.
- The share of links between local and foreign nodes over the total number of links in the network.

The combination of these two indicators allows us to measure the extent to which a national network is open and connected to external actors.

This methodology has a number of limitations. It offers only a partial picture of ISs as it only observes that aspect of innovation captured in patenting activity. That is, we analyse collaborative ties in knowledge-creation activities and knowledge-appropriation processes related to patentable knowledge. However, this empirical approach captures neither informal knowledge exchanges nor knowledge appropriated through other protection mechanisms. Thus, our work captures formalized and research-based knowledge links conducted by firms and institutions that are able to participate in the world patent system.

Furthermore, it should be noted that the empirical evidence presented here is mainly descriptive. Much previous research has analysed in depth different national and sectoral cases, showing the structural roots of Latin American ISs while analysing the main drivers and barriers to the production, diffusion and use of knowledge in these countries. Therefore, we present the evolution of the collaborative patenting networks in Latin American countries and, specifically, the coevolution of absorptive and connectivity capacities, against the backdrop of this prior research.

4. Addressing Latin American ISs through collaborative networks

In line with global trends (WIPO, 2018), the number of patents obtained by Latin American actors grew during the period under study. However, the region still lags far behind North America, Europe and Asia (WIPO, 2018).

Latin American ISs have traditionally been open systems. The larger countries of the region (e.g., Argentina, Brazil, Mexico) feature strong, relatively dynamic and globally integrated research systems that support the formation of critical mass of scientific actors in some specific fields (Cohen, 1995; Dutrénit and Puchet, 2011). In addition, Latin American co-invention networks between 1970 and 2017 consistently include a large number of inventors from outside the region. However, the share of external inventors in Latin American ISs has stopped growing and, indeed, seems to have declined since 2000. On the other hand, appropriability networks show a greater involvement of external owners and an increase in percentage of foreign owners after 1990, which accords with the economic openness process of the late twentieth century as exemplified by the launch of the first TRIPS agreements. In parallel with this increasing openness, the growth of patent activity in the region has been supported by growth in the absolute number of local actors, both owners and inventors.

These results reflect the strong economic liberalization policies Latin American countries pursued after the structural reforms of the 1990s. In this context, our results suggest that the market expansion and increased competition associated with economic liberalization have not increased invention and innovation in the region, but they have shown the limits of knowledge reception capacity in the absence of strong local absorptive capacities (Montobbio and Sterzi, 2011; Campi and Dueñas, 2019), which, in turn, require strong public support (Álvarez *et al*., 2019).

As shown in Figures 2a-2d, most countries exhibit a positive correlation—robust to different indicators (figures 2e-2h)—between absorptive and connectivity capacities. However, this correlation is weaker in owner networks than in inventor networks. This is arguably attributable to the lower growth of both absorptive and connectivity capacities in the former

than in the latter networks. Moreover, we find some interesting exceptions, such as the case of Chile, which exhibits a negative correlation between absorptive and connectivity capacities in the inventor network, as well as Venezuela and Colombia, where we observe a negative correlation in the owner networks.

Figure 2. Network cohesion and openness in Latin American ISs

Figure 2a. Plot of structural holes vs. share of foreign nodes in invention networks

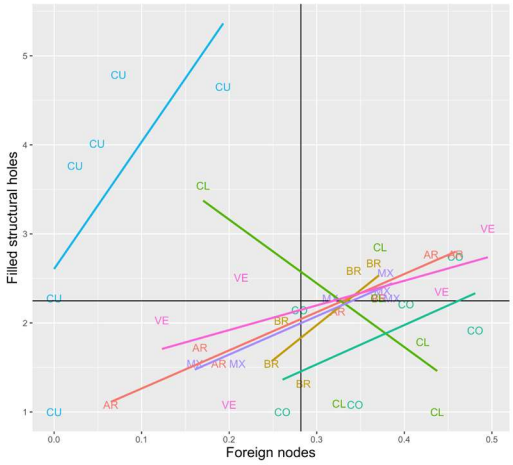


Figure 2b. Plot of structural holes vs. share of foreign links in invention networks

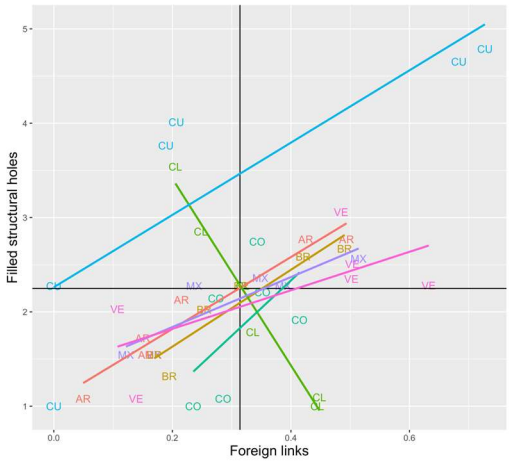


Figure 2d. Plot of average degree vs. percentage of foreign links in invention networks

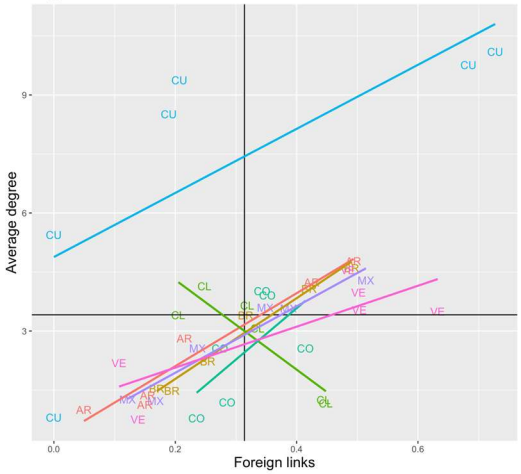


Figure 2e. Plot of structural holes vs. share of foreign nodes in owner networks

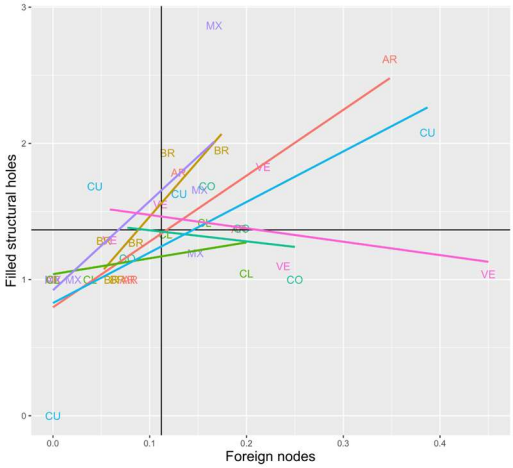


Figure 2c. Plot of average degree vs. share of foreign nodes in invention networks

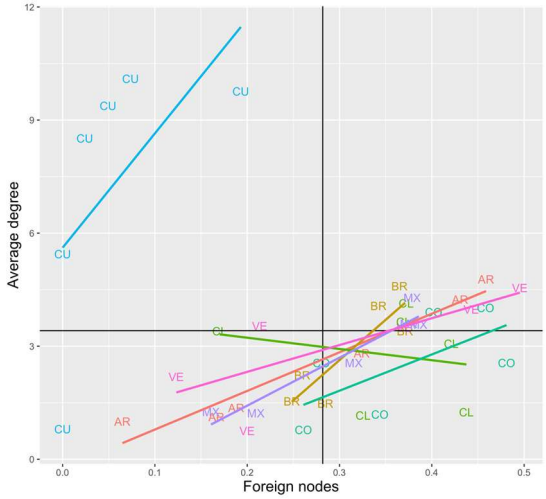


Figure 2f. Plot of structural holes vs. share of foreign links in owner networks

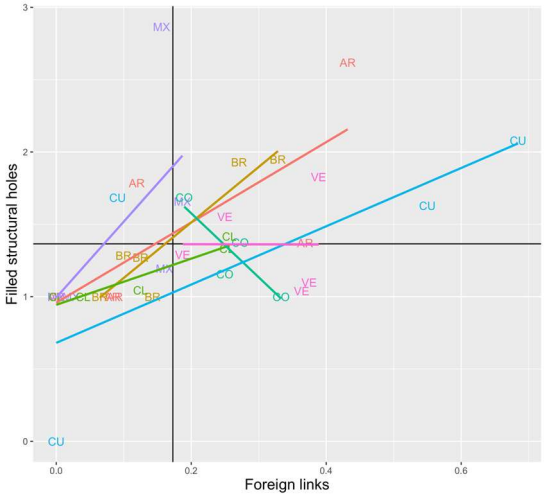


Figure 2g. Plot of average degree vs. share of foreign nodes in owner networks

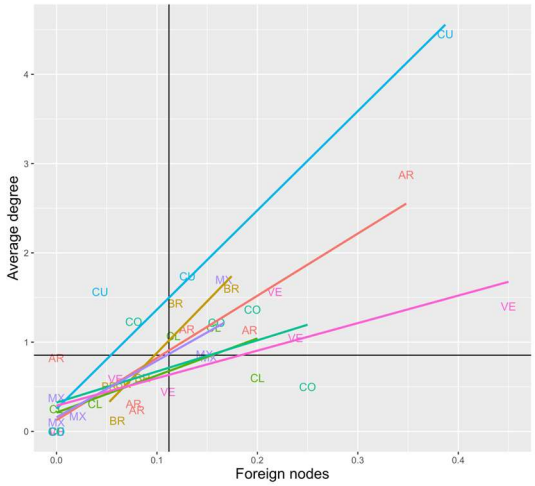
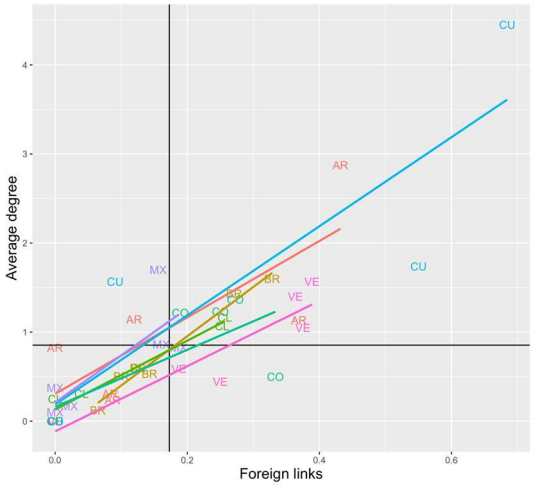


Figure 2h. Plot of average degree vs. foreign links in owner networks



Source: Authors, based on PatentsView data.

Notes: cohesion indicators on y-axes, openness indicators on x-axes. AR=Argentina; BR= Brazil; CL=Chile; CO= Colombia; CU= Cuba; MX=Mexico; VE= Venezuela.

4.2 The big three: Brazil, Mexico and Argentina.

The largest countries of the region differ greatly in terms of geographical location, productive structure, trade specialization, and research infrastructure (Cimoli and Katz, 2003; De Negri, 2010). However, despite the fact that their long-run development trajectories that have not

prioritized innovation, these countries have built national innovation capacities, sometimes anchored in large national development projects (Katz, 2000).

In addition, during the 48 years analysed here, these three ISs all exhibit a positive correlation between absorptive and connectivity capacities in inventor networks as well as a consistent increase in both capacities during this period (Figures 3a, 3b and 3c). On the other hand, the owner networks in these countries also show a mostly positive but nonmonotonic correlation between absorptive and connectivity capacities (Figures 3d, e and f).

Figure 3. Coevolution of absorptive and connectivity capacities

Figure 3a. Brazil inventor network

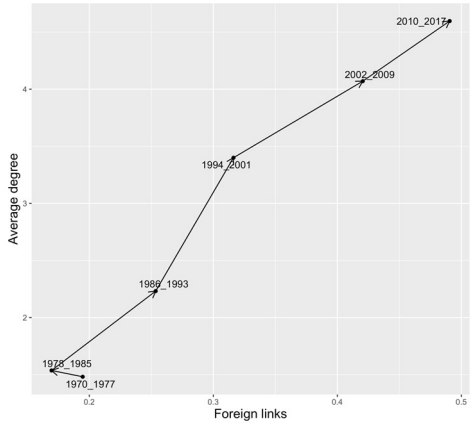


Figure 3b. Mexico inventor network

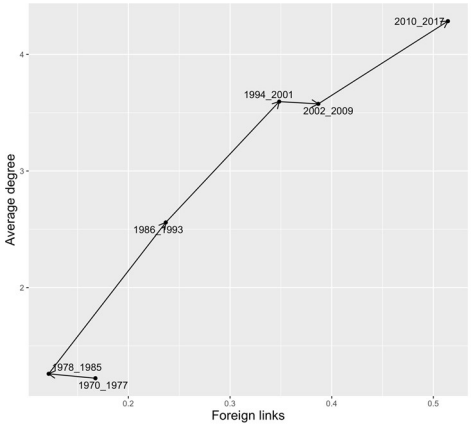


Figure 3c. Argentina inventor network

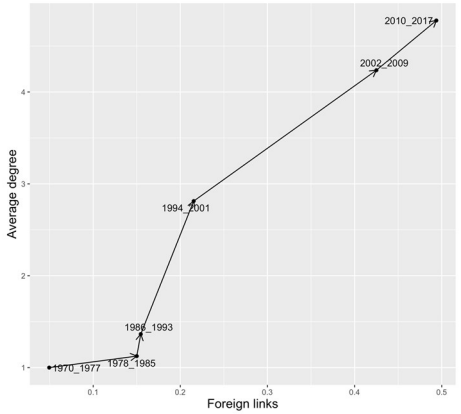


Figure 3d. Brazil owner network

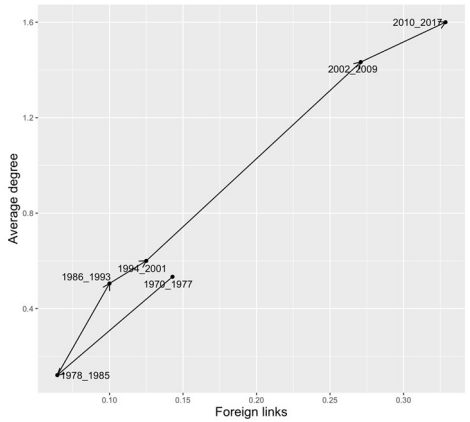


Figure 3e. Mexico owner network

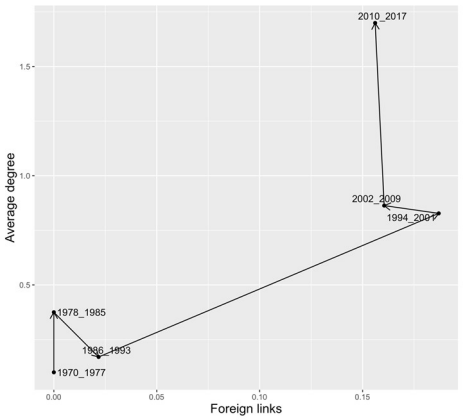
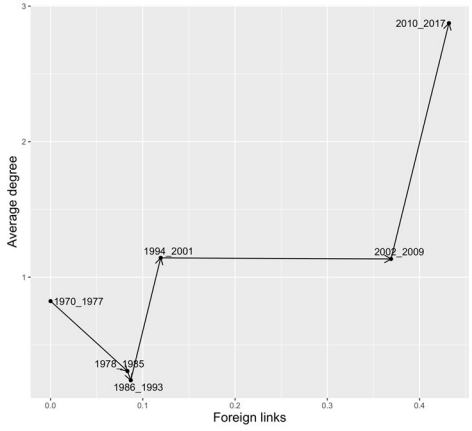


Figure 3f. Argentina owner network



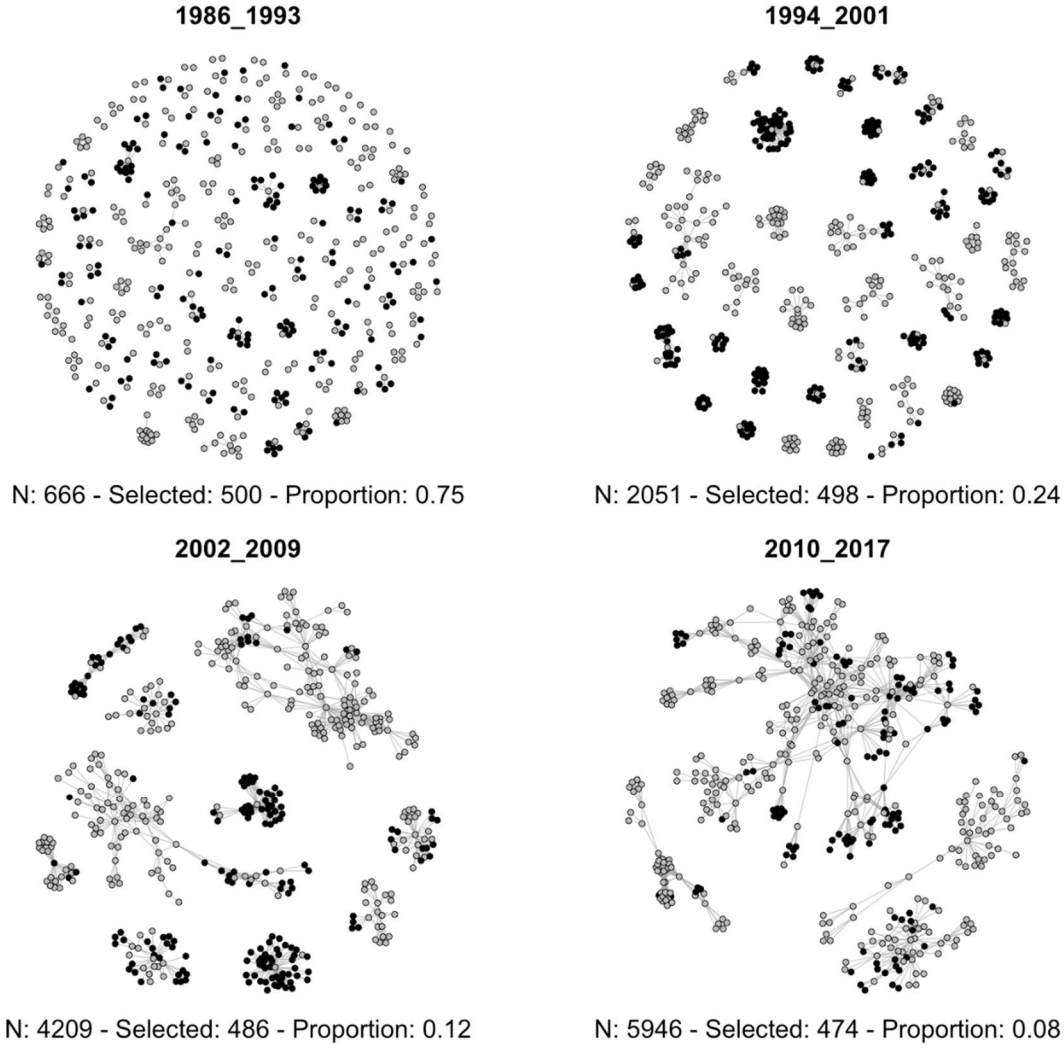
Source: Authors, based on PatentsView data.

Several studies have analysed these cases in depth (De Negri, 2011), showing that their ISs are highly heterogeneous, with a low density of internal linkages and the existence of some highly developed fields, usually geographically concentrated in the most affluent regions of the country (de Araújo *et al*., 2019).

According to our results, these ISs exhibit relatively large and cohesive co-invention and co-appropriation networks. Network analysis also shows that absorptive capacities have evolved similarly in Brazil and Mexico. These countries improved the average degree and substantially increased the size of the largest components in both inventor and owner networks. Meanwhile, in co-appropriation networks, Argentina exhibits an impressive growth of the largest component, showing considerable improvement of inventors network cohesion (Appendix, Table A1). Moreover, in the three cases, we observe the formation of large, complex components indicating actors who may facilitate the circulation of knowledge within these ISs. However, the largest components represent only a very small proportion of the total network, indicating a prevalence of weak systemic interactions co-existing with a few relatively large and well-connected components (Rivera-Ríos *et al*., 2009; Fernándes *et al*., 2010).

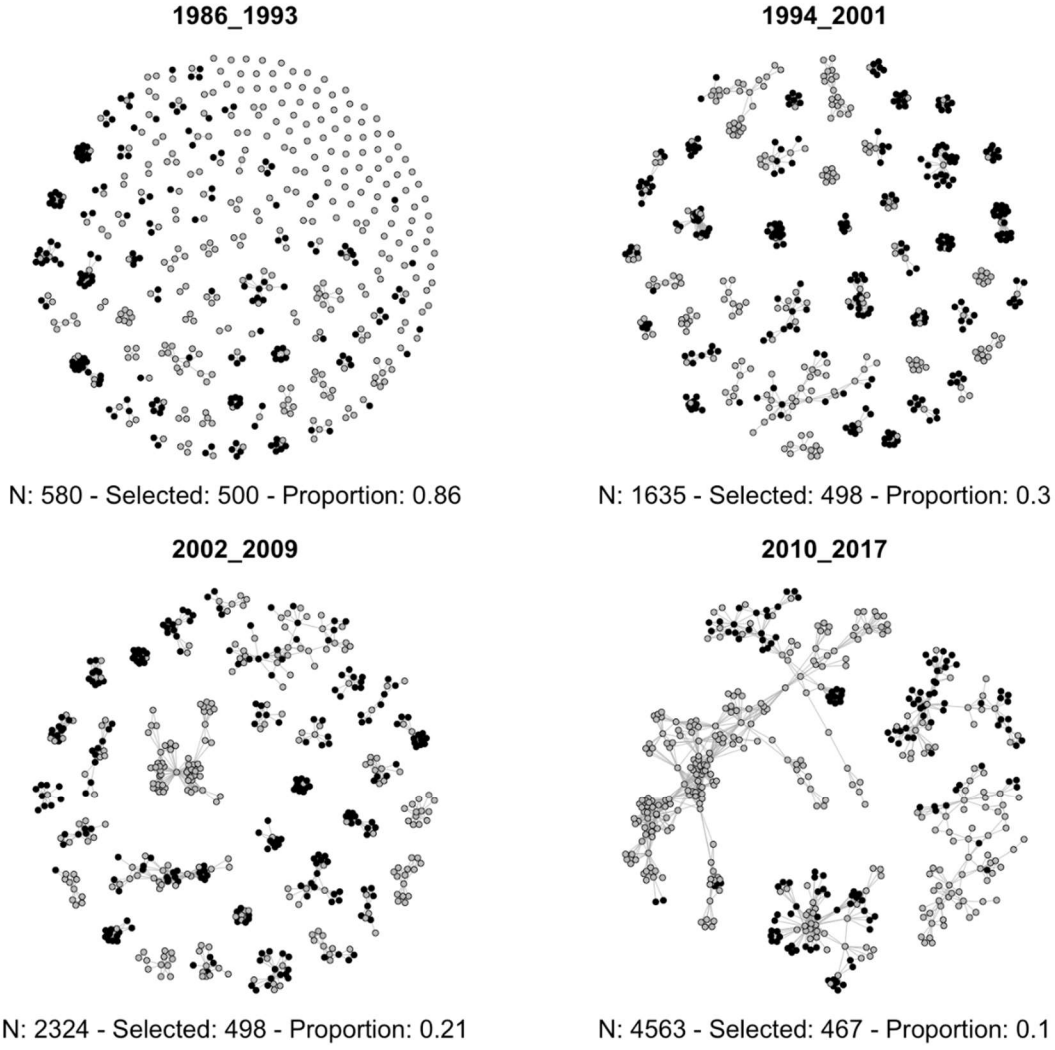
These three largest ISs have relatively few foreign nodes (Figures 4-6). However, the proportion of local inventors in the Argentinean and Mexican networks has been steadily decreasing, from approximately 75% in the 1970s to less than 60% in the 2000s. By contrast, the proportion of local inventors in Brazil's networks has systematically increased, from 54% in the 1970s to 63% in the 2000s.

Figure 4. Evolution of Brazil inventor network



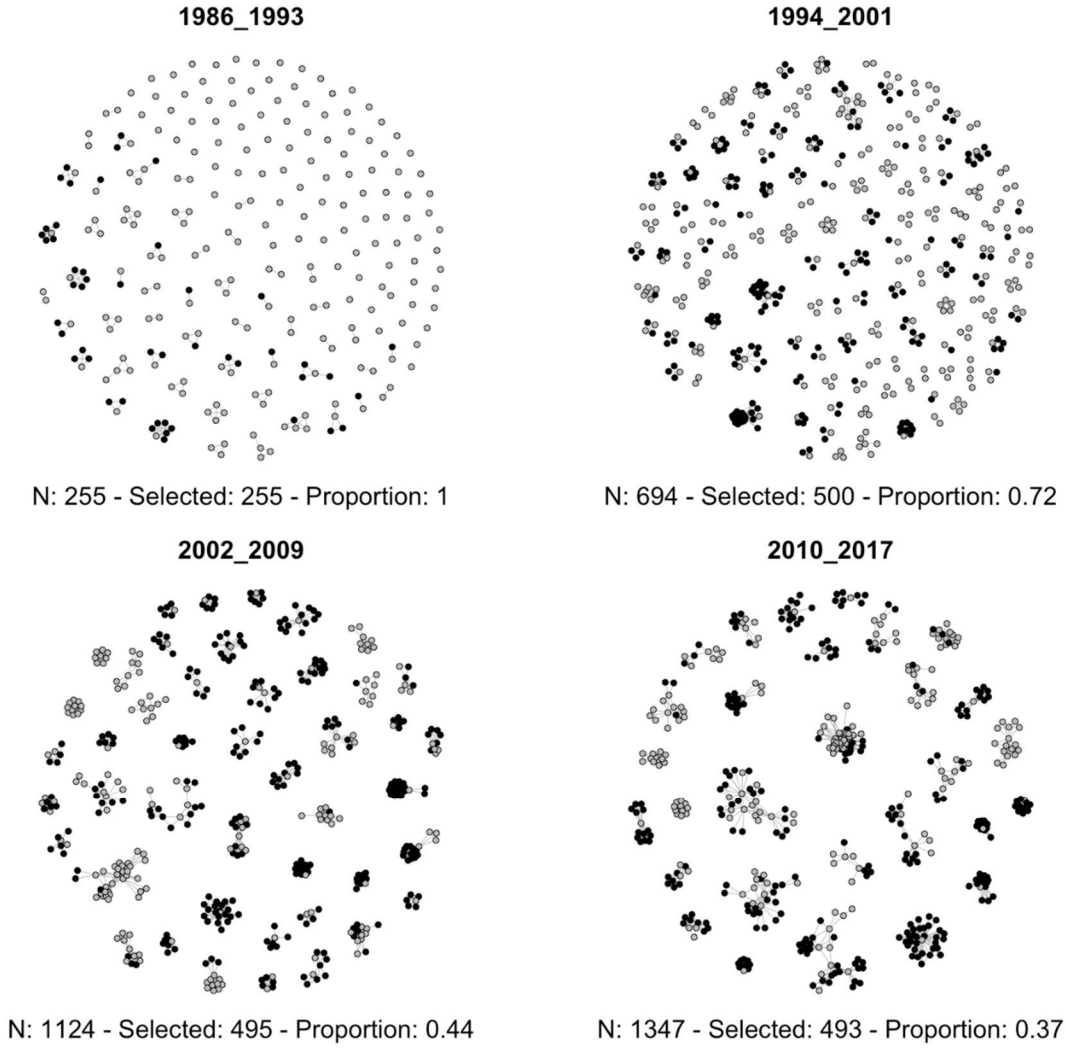
Note: Grey nodes represent Latin American inventors; black nodes represent foreign inventors. N: total number of nodes in each period; Selected: number of nodes represented in each graph; Proportion=Selected/N.
Source: Authors, based on PatentsView data.

Figure 5. Evolution of Mexico inventor network



Note: Grey nodes represent Latin American inventors; black nodes represent foreign inventors N: total number of nodes in each period; Selected: number of nodes represented in each graph; Proportion=Selected/N.
Source: Authors, based on PatentsView data.

Figure 6. Evolution of Argentina inventor network



Note: Grey nodes represent Latin American inventors; black nodes represent foreign inventors. N: total number of nodes in each period; Selected: number of nodes represented in each graph; Proportion=Selected/N.
Source: Authors, based on PatentsView data.

In sum, our results confirm that the Brazilian IS is the most mature IS in the region. It is strongly supported by national policies that promote research and innovation and is connected with global research and innovation hubs. Brazil has been progressively incorporated into the global system of knowledge exchange, exhibiting increasing collaboration with Asian partners in addition to long-standing collaborations with partners in Europe and the U.S. (Ponomariov and Toivanen, 2014; Reis *et al*., 2018). Meanwhile, Mexico seems stuck in an unbalanced relationship with the United States that hinders the formation of a local critical mass (Shadlen, 2011; Dutrénit and Puchet, 2011). As for Argentina, the most intriguing finding is its highly cohesive owner network, which is inconsistent with, and arguably contrary to, previous evidence for a lack of collaborative innovation linkages in the Argentinean IS (Erbes *et al*., 2010; Chudnovsky, 1999).

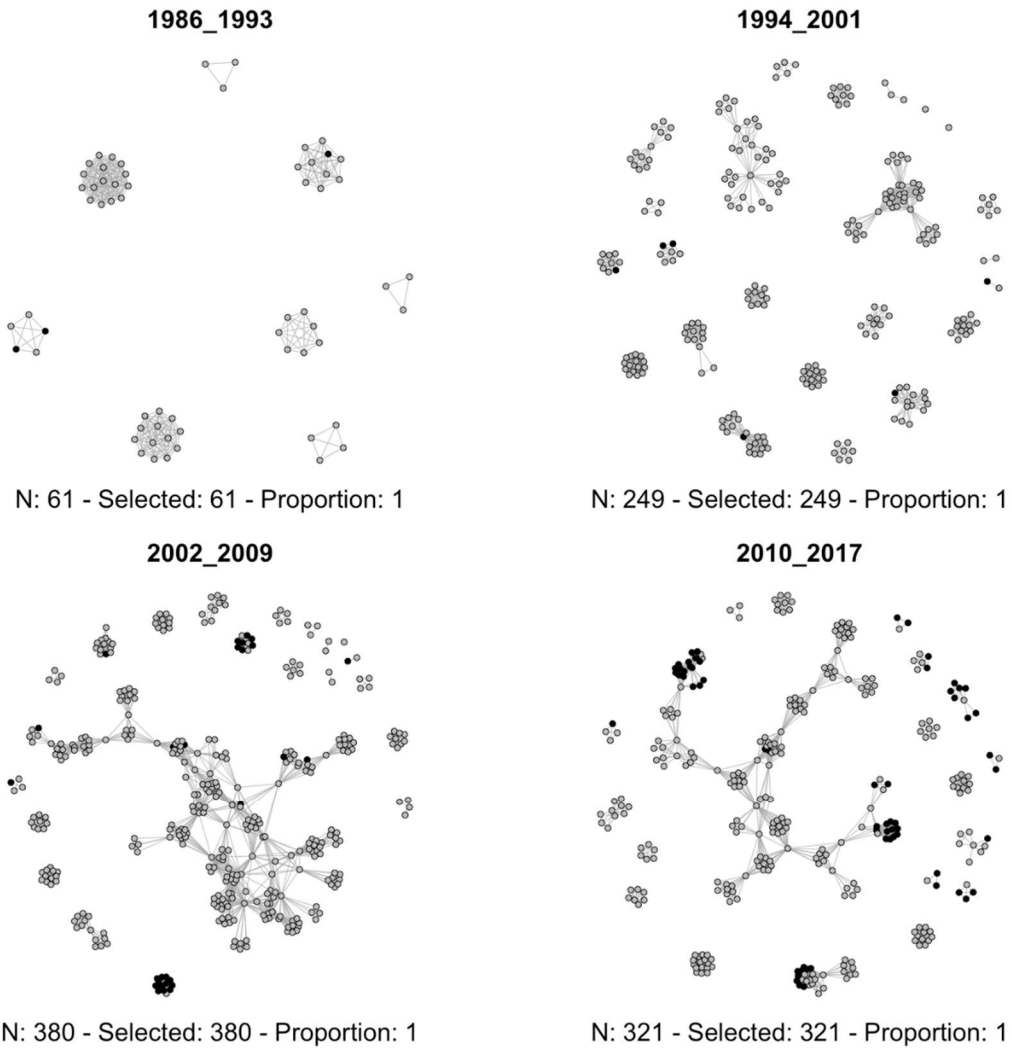
4.3 Chile and Cuba: a tale of two development projects

The evolution and current state of networks in Cuba and Chile seem related to explicit national projects in each country. The former is noteworthy for the structure of its inventor network and the latter for the structure of its owner network.

The Cuban co-inventor network has no isolated actors and its inventors have, on average, twice as many connections as do the next-most-cohesive ISs in the region. In the other Latin American countries, the largest connected components of co-inventor networks include only a small proportion of the nodes. In the Cuban network, however, the largest component

accounts for more than 50% of the nodes (Appendix, Table A1). Moreover, Cuba is the only Latin American country in which a giant component has emerged since 2002 (Figure 7).[2]

Figure 7. Evolution of Cuba inventor network



Note: Grey nodes represent Latin American inventors; black nodes represent foreign inventors. N: total number of nodes in each period; Selected: number of nodes represented in each graph; Proportion=Selected/N.
Source: Authors, based on PatentsView data.

[2] A component of a network is considered to be a "giant" component if it connects a non-trivial share of the nodes in the network (Jackson, 2008).

Despite the exceptional cohesion in the Cuban co-inventor network, its national co-owner network is quite small, but even more connected. The difference between the co-inventor and the co-appropriation networks reflects the structural features of the Cuban IS, where a high degree of scientific development coexists with a relatively weak and extremely concentrated business ecosystem, life sciences being the country's strongest sector (Núñez and Montalvo, 2014). In fact, patenting activities in Cuba are conducted by a number of state-owned enterprises that pursue a national strategy of innovation that survived a deep crisis following the dissolution of the socialist bloc (Caballero and López, 2017). Nowadays, exports of pharmaceutical and biotech products are part of the island's international trade strategy, (Kwon *et al*., 2019) which contributes critically-needed revenue to the national economy.

Conversely, Chile stands out because its owner networks are better connected than are its co-inventor networks. We observe in the Chilean case that absorptive capacities in co-inventor networks have not improved since 1986, while the co-owner network has greatly increased its size and internal connectivity. Previous studies have shown evidence of the improvement and increased dynamism of Chile's system of entrepreneurship during the last decade (Klerkx *et al*., 2015) and the relative success of using public funds to support firms' interactive innovation projects (Crespi *et al*., 2020). However, a number of empirical studies have emphasized the weak cohesion of the Chilean IS (Pinto *et al*., 2019) and the low level of private investment, even in highly competitive industries (Bas and Kunc, 2009). As mentioned above regarding the Argentinean owner network, our results do not fully accord with the extant evidence on the cohesion and interactive dynamics of the business sectors in these countries. Explaining this discrepancy is a task for future research.

Cuba exhibits interesting results regarding external connectivity capacity, On the one hand, according to the share of foreign nodes in its network, Cuba exhibits the least externally oriented network in the region. Meanwhile, the Cuban network ranks highest in the region for number of links with external actors. Because of a well-known national development project, the Cuban IS exhibits a uniquely high level of absorptive capacity together with focussed external connectivity capacities, where certain nodes seem to play the role of gatekeeper (Graf, 2011).

Figure 8. Coevolution of absorptive and connectivity capacities

Figure 8a. Chile inventor network

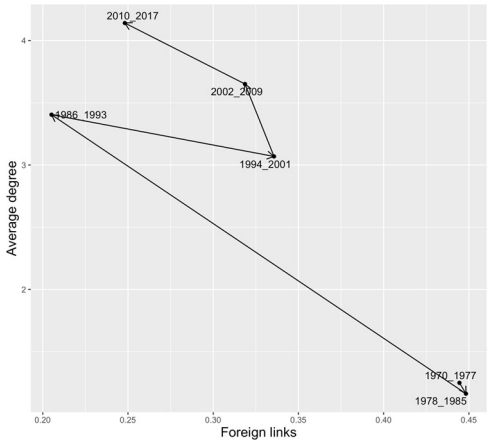
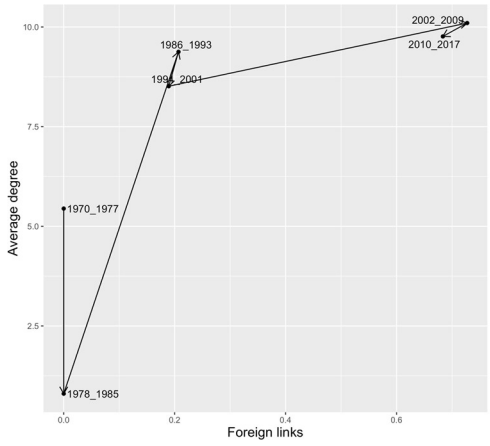


Figure 8b. Cuba inventor network



Source: Authors, based on PatentsView data

Relatedly, these two countries show a unique relationship between absorptive and connectivity capacities. Chile is the only case in the region that exhibits a negative correlation between the two dimensions (Figure 8a), which is reflected in its changing trajectory: it started out relatively open and has been able to build greater absorptive capacity among inventors. Cuba, by contrast, exhibits the opposite trajectory; it started out relatively closed

to foreign collaboration and remained so until the 1980s, after which it exhibits increasing openness together with increasing cohesiveness of the inventor network (Figure 8b).

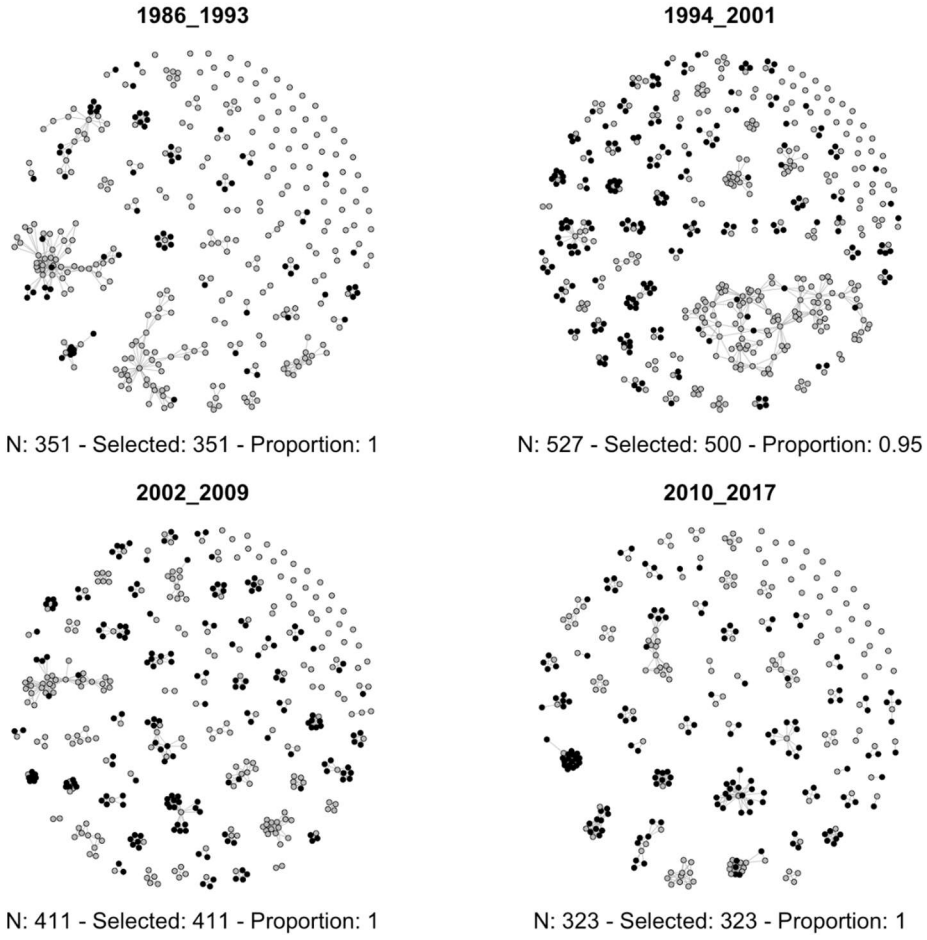
4.4. Uneven trajectories: The Venezuelan and the Colombian innovation systems

Patent network analysis reveals difference in the evolution of the Colombian and the Venezuelan ISs. These two countries have experienced internal and external pressures that have affected their political stability and level of violent conflict. However, while Venezuela had traditionally been seen as a relatively advanced IS in the region, its recent experience—in particular, its recent national policies and political conflict—have adversely affected research and innovation activities in the country (Jimenez and García, 2017). By contrast, Colombia's policy on research and innovation is currently viewed as a regional benchmark for its novel approach to linking innovation and research with development goals (Colciencias, 2018). However, our results accord with the most recent research on the Colombian IS, showing a highly fragmented network (Correa *et al*., 2014; Gómez, 2018) and an erratic accumulation of both absorptive and connectivity capacities. In fact, although Colombia is the third-most-populous country in the region and its investment in research and innovation has recently grown, its networks are relatively small and its connectivity levels are also low. Our results suggest that the Colombian IS has failed to generate and maintain a critical mass of local inventors and innovators. Arguably, as recent studies of this country suggest, these results may be related to the fact that the national patent network is highly concentrated around the national petroleum company (Gómez, 2018), providing another case of a relatively high level of development associated with a strategic resource for the country and the public policy created to support its development.

On the other hand, the case of Venezuela is particularly interesting because of the evolution of its network cohesion. Both co-invention and co-appropriation networks experienced positive evolution until about halfway through period and then a strong reduction in size and loss of connectivity in recent years, which seems to reflect a de-accumulation or de-learning process. While this sort of decay is viewed as a chronic curse of innovation processes in Latin America (Arocena and Sutz, 2000b; Sagasti, 2005), our analysis does not find it in any other country patent network in the region. In Venezuela's co-invention network, we find that a large component (more than 100 inventors representing 20% of the nodes) emerged in 1994 and, subsequently, disintegrated until in the most recent eight-year period it included only 19 nodes (Figure 9).

The disintegration of the giant component in the Venezuelan co-invention network seems to reflect "brain drain" related to the emigration of scientists and engineers working in the petroleum industry (Freitez, 2011). In fact, during the period 1976-2010, 80% of the Venezuelan patents registered in the USPTO (Requena, 2011) and 40% of the patents registered in the national intellectual property office (Hall, 2005) were attributable to the national petroleum research institute. Meanwhile, it is evident that, after the major strikes in the state-owned petroleum firm (2002) and the recent massive emigration of scientists, (Requena and Caputo, 2016), the Venezuelan network has disintegrated. Moreover, this country has exhibited a strong tendency towards openness since 1986, which may indicate a weakening of its national collaboration networks and, therefore, a greater dependence on external actors.

Figure 9. Evolution of Venezuela inventor network.



Note: Grey nodes represent Latin American inventors; black nodes represent foreign inventors. N: total number of nodes in each period; Selected: number of nodes represented in each graph; Proportion=Selected/N.
Source: Authors, based on PatentsView data.

In spite of the differences between these two countries, the Colombian and Venezuelan networks share a highly uneven relationship between absorptive and connectivity capacities. Due, likely, to the political and civil crises in these countries (Jiménez and García, 2017), both inventor and owner networks exhibit a significant decrease in accumulated absorptive capacity and, after 2010, an even greater decrease in connectivity capacity in owner networks (Figure 10).

Figure 10 Coevolution of absorptive and connectivity capacities

Figure 10a. Colombia inventor network

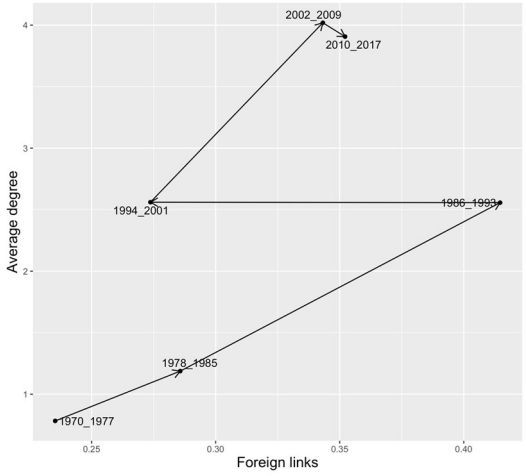
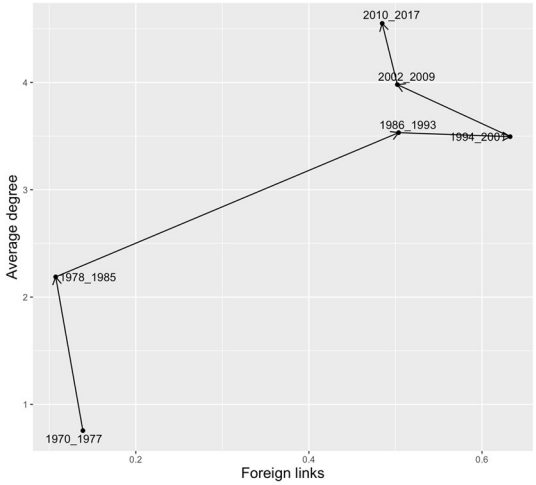


Figure 10b. Venezuela inventor network



Source: Authors, based on PatentsView data.

5. Final remarks and conclusions

This paper presents novel empirical evidence concerning patents and collaboration networks in Latin American countries between 1970 and 2017. Based on a dataset of patents registered with USPTO and using social network analysis techniques, we confirm certain structural features of the ISs in the region and identify recent critical changes in Latin American ISs. In addition, we apply a simple, consistent theoretical framework, which maps system-theoretic properties onto critical IS functions that are observable through network analysis. In particular, we contribute to the measure and analysis of the elusive concept of national absorptive capacities (Criscuolo and Narula, 2008) using indicators that take interaction as the analytical unit. This allows us to analyse the critical mass of interactions as an emergent property that enables self-sustained system functioning.

Four major findings of this research merit emphasizing. First, collaboration networks in Latin America are not cohesive. We find a constellation of separate groups in national networks where the largest components encompass only a small share of network links. According to network evolution models, networks that, in initial stages, are highly fragmented, tend to grow increasingly connected, as more links appear, until they form complex, cohesive structures (Jackson, 2008). However, the networks in our analysis do not yet show either complex structures or the critical mass of interaction needed for self-sustained system functioning (Dutrénit and Puchet, 2011). Second, despite this general lack of connectivity, certain national exceptions can be found. As we noted above, Cuba has a strongly cohesive co-invention network, while Argentina and Chile exhibit highly cohesive networks of owners. The differences we found between co-invention and co-appropriation networks illustrate distinctive features of national ISs, in particular the relatively low participation of private sector actors. Third, networks show a large number of international collaborations. Finally, the arguably most important finding is that, with the exception of Venezuela, the largest Latin American ISs, despite exhibiting relatively low absorptive capacities, all exhibit a cumulative trend of increased systemic capacity.

As noted above, analysing innovation in Latin America based on USPTO patents has its limitations. These limits notwithstanding, we demonstrate the utility of using a standardized data source that covers the entire region. Future research should seek to provide more in-depth national analyses that integrate the characteristics of the agents involved in the interaction as well as the technological fields in which they operate.

References

Albuquerque, E. 2007. Inadequacy of technology and innovation systems at the periphery. *Cambridge Journal of Economics*, vol. 31. no 5, 669-690.

Alvarez, R., Benavente, J., and Crespi, G. 2019. 'Innovation in the Global Economy: Opening-Up Latin American Innovation Systems'. Inter-American Development Bank, Washington, DC. available at https://publications.iadb.org/publications/english/document/Innovation_in_the_Global_Economy_Opening-Up_Latin_American_Innovation_Systems_en.pdf [date last accessed 20 December 2020]

Andersson, D., Galaso, P., and Sáiz, P. 2019. Patent collaboration networks in Sweden and Spain during the Second Industrial Revolution. *Industry and Innovation*, vol. 26, no 9, 1075-1102.

Antonelli, C. 2017. *Endogenous innovation: The economics of an emergent system property*. London, Edward Elgar Publishing.

Arocena, R., and Sutz, J. 2000a. Looking at national systems of innovation from the South. *Industry and Innovation*, vol. 7, no 1, 55-75.

Arocena, R., and Sutz, J. 2000b. 'Interactive learning spaces and development policies in Latin America'. Department of Industrial Economics and Strategy, Copenhagen Business School. Available at: http://webdoc.sub.gwdg.de/ebook/serien/lm/DRUIDwp/00-13.pdf [date last accessed 20 December 2020]

Bas, T. and Kunc, M. 2009. National systems of innovations and natural resources clusters: evidence from copper mining industry patents. *European Planning Studies*, vol. 17, no 12, 1861-1879.

Breschi, S., and Lenzi, C. 2016. Co-invention networks and inventive productivity in US cities. *Journal of Urban Economics,* 92, 66–75.

Burt, R. 2004. Structural holes and good ideas. *American Journal of Sociology* vol.110, 349-399.

Caballero, I., and López. L. 2017. La Historia del CIM Contada por sus Trabajadores. *Ekotemas*, vol.3, no 1, 61-77.

Campi, M., and Dueñas, M. 2019. Intellectual property rights, trade agreements, and international trade. *Research Policy*, vol.48, no 3, 531-545.

Cassiolato, J. and Lastres, H. 2008. Discussing innovation and development: Converging points between the Latin American school and the Innovation Systems perspective? Globelics Working paper series 08-02. Available at http://www.globelics.org/wp-content/uploads/2016/06/GWP2008-02.pdf [date last accessed 20 December 2020]

Cassiolato, J. Lastres, H. and Maciel, M. (Eds.). 2003. *Systems of innovation and development: evidence from Brazil*. London, Edward Elgar Publishing.

Castellacci, F., and Natera, J. 2016. Innovation, absorptive capacity and growth heterogeneity: Development paths in Latin America 1970–2010. *Structural Change and Economic Dynamics*, vol.37, 27-42.

Castellacci, F., and Natera, J. 2013. The dynamics of national innovation systems: A panel cointegration analysis of the coevolution between innovative capability and absorptive capacity. *Research Policy*, vol.42, no 3, 579-594.

Chudnovsky, D. 1999. Science and technology policy and the National Innovation System in Argentina. *CEPAL Review*. vol.67, 157-176

Cimoli, M. and Katz, J. 2003. Structural reforms, technological gaps and economic development: a Latin American perspective. *Industrial and Corporate Change*, vol.12, no 2, 387-411.

Cohen, J. 1995. Latin America's elite looks north for scientific partners. *Science*, vol.267, no 5199, 809-811.

COLCIENCIAS 2018. *Libro Verde 2030: Política Nacional de Ciencia e Innovación para el Desarrollo Sostenible.* COLCIENCIAS, Gobierno de Colombia, Bogotá. Available at http://repositorio.colciencias.gov.co/handle/11146/33995 [date last accessed 20 December 2020]

Confraria, H. and Vargas, F. 2019. Scientific systems in Latin America: performance, networks, and collaborations with industry. *The Journal of Technology Transfer*, vol.44, no 3, 874-915.

Correa, J., Tejada, M., Cayon, E., and Ordoñez, G. 2014. Science and technology policy in Colombia: a comparative review. *European Journal of Scientific Research*, vol.121, no 3, 267-285.

Crespi, G., Garone, L., Maffioli, A., and Stein, E. 2020. Public support to R&D, productivity, and spillover effects: Firm-level evidence from Chile. *World Development*, vol. 130, 104948.

Crespo, J., Suire, R., and Vicente, J. 2016. Network structural properties for cluster long-run dynamics: Evidence from collaborative R&D networks in the European mobile phone industry. *Industrial and Corporate Change*, vol. 25, no 2, 261–282.

Criscuolo, P., and Narula, R. 2008. A novel approach to national technological accumulation and absorptive capacity: aggregating Cohen and Levinthal. *The European Journal of Development Research*, vol.20, no 1, 56-73.

de Araújo, F., Gonçalves, E., and Taveira, J. 2019. The Role of Patent Co-inventorship Networks in Regional Inventive Performance. *International Regional Science Review*, vol.42, no 3-4, 235-280.

De Negri, F. 2010. Estratégias tecnológicas na Argentina, Brasil e México. *Revista Economia & Tecnologia*, vol.6, no 1. 127-138.

Dosi G, 1988 The nature of innovative process. In: Dosi G, *et al*., (ed) *Technical change and economic theory*. Pinter Publisher, London pp 221-238.

Dutrénit, G., and Puchet, M. 2011. 'Approaching the measurement of the critical mass of science, technology and innovation: how far off is Mexico.' 9th Globelics Conference. Buenos Aires. Available at https://www.researchgate.net/profile/Martin_Puchet_Anyul/publication/265042185_Approaching_the_measurement_of_the_critical_mass_of_science_technology_and_innovation_how_far_off_is_Mexico/links/540694770cf2bba34c1e4cf5/Approaching-the-measurement-of-the-critical-mass-of-science-technology-and-innovation-how-far-off-is-Mexico.pdf [date last accessed 20 December 2020]

Dutrénit, G., Capdevielle, M., Corona, J., Puchet, M., Santiago, F., and Vera-Cruz, A. 2010. *El sistema nacional de innovación mexicano: estructuras, políticas, desempeño y desafíos*. UAM, Mexico.

Erbes, A., Robert, V., and Yoguel, G. 2010. Capacities, innovation and feedbacks in production networks in Argentina. *Economics of Innovation and New Technology*, vol.19, no 8, 719-741.

Fagerberg, J., and Srholec, M. 2017. Capabilities, economic development, sustainability. *Cambridge Journal of Economics*, vol.41, no 3, 905-926.

Filippetti, A., Frenz, M., and Ietto-Gillies, G. 2017. The impact of internationalization on innovation at countries' level: the role of absorptive capacity. *Cambridge Journal of Economics*, vol.41, no 2, 413-439.

Fleming, L., King, C., and Juda, A. 2007. Small worlds and regional innovation. *Organization Science*, vol. 18, no 6, 938–954.

Freitez, A. 2011. La emigración desde Venezuela durante la última década. *Revista Temas de Coyuntura,* vol.63.

Foster, J. 2005. From simplistic to complex systems in economics. *Cambridge Journal of Economics*, vol.29, no 6, 873-892.

Fritsch, M., and Kauffeld-Monz, M. 2010. The impact of network structure on knowledge transfer: an application of social network analysis in the context of regional innovation networks. *The Annals of Regional Science*, Vol. 44, no 1, 21–38.

Furtado, C. 1964. *Development and underdevelopment*. Berkley, University of California Press.

Galaso, P. 2018. Network topologies as collective social capital in cities and regions: A critical review of empirical studies. *European Planning Studies*, Vol 26, no 3, 571–590.

Gómez, R. 2018. Tendencias de la innovación tecnológica en Colombia 1991-2013 a partir del análisis de patentes. *Investigación bibliotecológica*, vol.32, no 77, 133-150.

Graf, H. 2011. Gatekeepers in regional networks of innovators. *Cambridge Journal of Economics*, vol.35, no 1, 173-198.

Graf, H., and Henning, T. 2010. 'Public research in regional networks of innovators: a comparative study of four East-German regions'. In: Freytag, A. and Thurik, R. (Eds) *Entrepreneurship and Culture*. Springer, Berlin. pp. 97-128.

Hall, B. 2005. 'Government policy for innovation in Latin America'. Report to the World Bank Available at https://eml.berkeley.edu/~bhhall/papers/BHH05_LAC_innov.pdf [date last accessed 20 December 2020]

Jackson, M. 2008. *Social and Economic Networks*. Princeton; Oxford: Princeton University Press.

Jiménez, E., and García, R. 2017. Venezuela: alto PIB en ciencia y tecnología y baja producción de patentes. *Revista Venezolana de Análisis de Coyuntura*, vol.23, no 1, 151-172.

Katz, J. 2000. '*Pasado y presente del comportamiento tecnológico de América Latina*.' Serie Desarrollo Productivo nº 75, CEPAL, Santiago de Chile.

Klerkx, L., Álvarez, R., and Campusano, R. 2015. The emergence and functioning of innovation intermediaries in maturing innovation systems: the case of Chile. *Innovation and Development*, vol.5, no 1, 73-91.

Kwon, D. Li, D., and Sohn, S. 2019. Identifying innovation in socialist countries through patent analysis focused on Cuba and Vietnam. *World Patent Information*, vol.59.

Lobo, J., and Strumsky, D. 2008. Metropolitan patenting, inventor agglomeration and social networks: A tale of two effects. *Journal of Urban Economics*, Vol. 63, 871–884.

Lundvall, B-Å. 1988. 'Innovation as an Interactive Process: From User Producer Interaction to National systems of Innovation'. Dosi *et al*., (ed) *Technical change and economic theory*. Pinter Publisher, London

Montobbio, F., and Sterzi, V. 2011. Inventing together: exploring the nature of international knowledge spillovers in Latin America. *Journal of Evolutionary Economics*, vol.21, no 1, 53-89.

Nuñez, J. and Montalvo, L. 2014. Science, technology, and innovation policies and the innovation system in Cuba: Assessment and prospects. In: Brundenius, C. and Torres-Perez, R. *No More Free Lunch*. Springer, Cham. pp. 153-172

Pinto, P. Vallone, A., and Honores, G. 2019. The structure of collaboration networks: Findings from three decades of co-invention patents in Chile. *Journal of Informetrics*, vol.13, no 4, 100984.

Ponomariov, B., and Toivanen, H. 2014. Knowledge flows and bases in emerging economy innovation systems: Brazilian research 2005–2009. *Research Policy*, vol.43, no 3, 588-596.

Rapini, M., Chaves, C., Albuquerque, E., Silva, L.A., Souza, S., Righi, H., and Cruz, W. 2009. University–industry interactions in an immature system of innovation: evidence from Minas Gerais, Brazil. *Science and Public Policy,* vol.36, 373–386.

Reis, R., Gonçalves, E., and Taveira, J. 2018. Determinants of inventive collaborations in Brazilian interregional and international networks. *Revista Brasileira de Inovacao*, vol.17, no 2, 287-316.

Requena, J. 2011. Decay of technological research and development in Venezuela. *Interciencia*, vol.36, no 5, 341-347.

Requena, J., and Caputo, C. 2016. Pérdida de talento en Venezuela: migración de sus investigadores. *Interciencia*, vol.41, no 7, 444-453.

Rivera-Ríos, M. Robert, V., and Yoguel, G. 2009. Cambio tecnológico, complejidad e instituciones: el caso de Argentina y México. *Problemas del Desarrollo*, vol.40, no 157, 75-109.

Sagasti, F. 2005. *Knowledge and innovation for development: the Sisyphus challenge of the 21st century*. Edward Elgar Publishing. London.

Savin, I., and Egbetokun, A. 2016. Emergence of innovation networks from R&D cooperation with endogenous absorptive capacity. *Journal of Economic Dynamics and Control*, vol.64, 82-103.

Schilling, M., and Phelps, C. 2007. Interfirm collaboration networks: The Impact of Large-Scale Network Structure on firm innovation. *Management Science*, vol. 53, no 7, 1113–1126.

Shadlen, K. C. 2011. 'Propiedad intelectual para el desarrollo en México'. In: Gallagher, K. Wise, T. and Peters, E. *El futuro de la política de comercio en América del Norte: Lecciones del TLCAN*. Ed. Porrúa. México DF.

WIPO 2018. 'World Intellectual Property Indicators 2018'. Geneva: World Intellectual Property Organization.

Whittington, K., Owen-Smith, J., and Powell, W. 2009. Networks, propinquity, and innovation in knowledge-intensive industries. *Administrative Science Quarterly*, Vol. 54, 90–122.

Yoguel, G. and Robert, V. 2010. Capacities, Processes, and Feedbacks: The Complex Dynamics of Development. *Seoul Journal of Economics*, vol.23, no 2, 187-237.

Appendix.

Table A1. Absorptive and connectivity capacity indicators. Selected countries 2010-2017

	Absorptive						Connectivity			
	Inventors			Owners			Inventors		Owners	
Country	**Share largest component**	**Filled structural holes**	**Average Degree**	**Share largest component**	**Filled structural holes**	**Average Degree**	**Foreign links**	**Foreign nodes**	**Foreign links**	**Foreign nodes**
Argentina	0,04	2,77	4,78	0,35	2,62	2,87	0,49	0,46	0,43	0,35
Brazil	0,05	2,67	4,60	0,14	1,95	1,60	0,49	0,37	0,33	0,17
Chile	0,04	2,85	4,14	0,13	1,42	1,16	0,25	0,37	0,26	0,16
Colombia	0,04	2,21	3,91	0,13	1,69	1,22	0,35	0,40	0,19	0,16
Cuba	0,53	4,65	9,76	0,81	2,08	4,45	0,68	0,19	0,68	0,39
Mexico	0,04	2,56	4,29	0,05	2,87	1,70	0,51	0,38	0,16	0,17
Venezuela	0,06	3,06	4,55	0,33	1,55	0,44	0,48	0,50	0,25	0,11

Source: authors based on PatentsView data

"Share largest component" is the largest group of nodes that are directly or indirectly connected to each other and disconnected from the rest of the network. "Filled structural holes" is the value of the first decile of the inverse of Burt's (2004) constraint indicator. "Average degree" is the average number of edges adjacent to each vertex. "Foreign links" is the share of links between local and foreign nodes over the total number of links in the network. "Foreign nodes" is the share of the national network that comprises external nodes.