*Cambridge Journal of Economics* 2023, 1 of 31
https://doi.org/10.1093/cje/bead034



# Absorptive capacities and external openness in underdeveloped innovation systems: a patent network analysis for Latin American countries 1970–2017

Carlos Bianchi, Pablo Galaso and Sergio Palomeque*

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 allow us to measure critical attributes of the Latin American innovation systems. 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.

*Key words:* Innovation systems, Absorptive capacities, Patent network, Latin America
*JEL classifications:* B50, O31, O54

## 1. Introduction

Development studies from Latin America have widely discussed the relevance of the national capabilities to produce and exchange knowledge to achieve productive and social developmental goals (e.g. Sagasti, 2005; Sabato and Botana, 2021). Relatedly, since the last decades of the twentieth century, the concept of innovation system (IS)

Manuscript received 11 February 2021; final version received 24 March 2023
*Address for correspondence*: Carlos Bianchi, Institute of Economics, School of Economics and Administrative Sciences, University of the Republic Uruguay, Lauro Muller 1921, P.C. 11200, Monvetiveo, Uruguay; email: carlos.bianchi@fcea.edu.uy

*Institute of Economics, School of Economics and Administrative Sciences, University of the Republic Uruguay. We acknowledge the financial support of the National Agency of Research and Innovation, Uruguay (*Maria Viñas* Applied Research Program, project number FMV_3_2018_1_148242). Moreover, we acknowledge the work of the PatentsView team and their generous technical collaboration. We are grateful for the useful comments and criticism from participants in the European Association for Evolutionary Political Economy Annual Conference 2020 and from participants of the Research Seminar at the Postgraduate Program in Economics at the Federal University of Uberlandia and at the Federal University of Minas Gerais, Brazil.

and, in particular, the national IS approach have been integrated, with criticism, in the developmental studies in Latin America (Chudnovsky, 1999; Arocena and Sutz, 2000A; Chaves *et al.*, 2020).

Studies from Latin America have characterised Latin American ISs as incomplete or immature (Arocena and Sutz, 2000A; Rapini *et al.*, 2009) and stressed the weakness of external connectivity and absorptive capacities in the region (Arocena and Sutz, 2000A; Erbes *et al.*, 2010;Yoguel and Robert, 2010; Dutrénit and Puchet, 2011). Moreover, other works have emphasised 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; Chavez *et al.*, 2020; Bianchi *et al.*, 2021).

Previous research has advanced understanding of the evolution of the Latin American ISs at the level of individual countries or groups of countries, mostly based on in-depth national case studies (e.g. Cassiolato *et al.*, 2003; Dutrénit *et al.*, 2010). However, comprehensive longitudinal studies based on standardised data for the entire region are scarce (Castellacci and Natera, 2016; Confraria and Vargas, 2019). 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 to analyse the emergent properties which arise from the systemic interactions rather than simply identify 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), in this paper, we contribute to the understanding of the evolutionary paths of Latin American ISs by defining and measuring their absorptive and connectivity capacities. The concept of absorptive capacities was first coined in management studies (Cohen and Levinthal, 1989, 1990) and subsequently applied in studies of innovation and development at the national level (Castellacci and Natera, 2016; Filippetti *et al.*, 2017). Both, at the firm level and at the national level, refers to the collective ability to recognise, understand and integrate new knowledge into problem-solving activities. This ability refers to a sort of cumulative repository of capabilities (Fagerberg and Srholec, 2017), a systemic attribute that is greater than and different from the mere sum of the system's components. External connectivity capacities, meanwhile, are a systemic attribute associated with one of the central challenges identified by development studies: the ability to access and participate in varied knowledge flows. These IS attributes are intrinsically intertwined because positive feedback between them is a necessary condition for the evolution of an IS (Erbes *et al.*, 2010;Yoguel and Robert, 2010; Chaves *et al.*, 2020).

Since these system attributes are non-directly observable phenomena, to address them it is necessary to build systemic measures based on the interactions between the systems' components (Britto *et al.*, 2021; Balland *et al.*, 2022). We observe these interactions by using data from the US Patent & Trademark Office (USPTO) in order to build and analyse collaboration networks connecting inventors and patent owners in all Latin American countries during a 48-year period, from 1970 to 2017. Applying social network analysis techniques, we study, on the one hand, national networks' internal cohesion as an indicator of the absorptive capacities in a given IS. On the other hand, we analyse external connectivity capacities in terms of the degree of openness maintained by the national network through connections with other countries.

By studying these two IS properties, this paper provides a novel comparative analysis of national capacity accumulation and offers empirically grounded explanations that complement and enrich extant knowledge concerning Latin American ISs. Our findings illustrate that both absorptive and connectivity capacities in Latin American ISs have increased, exhibiting, in most cases, a positive relationship between the two capacities. We identify different trajectories among Latin American ISs according to the coevolution of these systemic attributes and according to structural features of the national ISs. However, as a general pattern, we observe that collaboration networks are mostly fragmented and outward oriented.

## 2. Systemic disconnections in Latin American ISs

Innovation has been defined as an uncertain and cumulative problem-solving process that is interactive in nature. 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 (Dosi, 1988; Lundvall, 1988). The complexity approach similarly defines innovation as an emergent property of the ISs, which results from micro-level interactions among agents in the IS (Antonelli, 2017; Balland *et al.*, 2022). This creates feedback loops between the system's building blocks, which determine how the IS evolves.

The (under)development path of Latin America has been associated to the inability to overcome structural disconnections within the national ISs that operate between different subsystems, hindering learning processes. Building on the pioneering ideas of Furtado (1964), authors in this line of inquiry have proposed theoretical interpretations of underdevelopment, a situation they view as qualitatively different from development and associated to a differentiated systemic evolution compared to developed countries (Arocena and Sutz, 2000A; Cimoli and Porcile, 2009; Yoguel and Robert, 2010).

Trajectories of underdevelopment have been associated to uneven paths, signed by the inability to overcome structural restrictions to development, including the production and use of knowledge. Considering the typical indicators of ISs at national level, we may observe that, 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). In the same vein, since the end of the twentieth century, scientific production of Latin American countries has increased, achieving just over 5% of worldwide scientific publications (Confraria and Vargas, 2019). However, the region continues playing a peripheral role in the global research system (Bianchi *et al.*, 2021), registering structural delays with respect to more developed regions (Crespi and Dutrenit, 2014).

These outcome indicators are clearly associated to resources devoted to innovation in Latin America. Average national expenditure in R&D is well below that of most dynamic regions, remaining in most Latin American countries below 1% of GDP (UNESCO, 2015; OECD, 2020). Moreover, in Latin America, the public sector leads with around 60% of the investment in R&D activities. Meanwhile, in developed countries, most of these investments come from business organisations (OECD, 2020). Similarly, the number of researchers in the economically active population is five times less in Latin American countries than in small OECD' countries (UNESCO, 2015). In addition, most researchers and PhD degree holders work in academia while very few work in the private sector. This aspect, together with the structure of R&D expenditure, has been considered a major developmental constraint in the region. These constraints hinder the evolution of interactive feedbacks of creation, exchange and use of knowledge, reproducing disarticulated subsystems (Yoguel and Robert, 2010; Teixeira *et al.*, 2020; Sábato and Botana, 2021) and hindering the formation of absorptive capacities in the region (Castellacci and Natera, 2016).

The original concept of absorptive capacities highlights the 'two faces' of knowledge-creation processes inside firms. Knowledge-creation activities create technical solutions but, also, allow exchanging and absorbing knowledge (Cohen and Levinthal, 1989, 1990). This means that in order to learn interactively, the firm must know about the characteristics and potential uses of the knowledge exchanged, and, in turn, to know, it is necessary for the firm to engage in knowledge-creation activities. Hence, the firm's capacities are built in an interactive and cumulative trajectory according to their previous knowledge base (Teixeira *et al.*, 2020).

Following these theoretical premises, the concept of absorptive capacities was adapted in empirical studies at the national systems level (Filipetti *et al.*, 2017). According to this literature, not only firms but also countries could have the capacity to recognise, assimilate and apply valuable knowledge. However, it is not easy to translate these complex concepts to indicators that fully capture their main attributes.

Previous studies used input and output indicators of science, technology and innovation to approximate the concept of absorptive capacities at national level, stressing the importance of national absorptive capacities to access external knowledge fluxes (Criscuolo and Narula, 2008; Castellacci and Natera, 2016; Filipetti *et al.*, 2017). In the same vein, empirical evidence has recently shown that adequate absorptive capacity is a necessary condition for open ISs to achieve positive knowledge spillovers from trade and investment flows (Álvarez *et al.*, 2019).

These empirical studies, which have focussed on measuring innovation activities or outcomes using different econometric techniques, 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. Therefore, we propose a different analytical approach aimed at reflecting interactions among actors involved in innovation processes and, particularly, at analysing the systemic disconnections widely observed in the (under)development path of Latin American countries.

## 3. Absorptive and connectivity capacities in ISs

External connectivity to access knowledge flows and local absorptive capacity are two critical building blocks in the functioning of ISs. The interaction between these system components in developing countries may be associated to the peripheral conditions of their ISs, which affect their access to frontier knowledge. In addition, in Latin America, these two capacities are constrained by the structural heterogeneities (i.e. systemic disconnections) that hinder virtuous learning cycles between knowledge production and the productive infrastructure (Cimoli and Porcile, 2009; Srinivas 2018; Chaves *et al.*, 2020).

We understand that the development of the absorptive capacities of an IS is determined by the cohesion of internal systemic linkages, as counterpart of the structural disconnections affecting learning processes in developing countries. The internal cohesion of linkages reflects the critical mass of the system, which supports the exchange and use of knowledge within the IS. Conversely, when an IS lacks a critical mass of interactions, the degree of cohesion reveals systemic disconnections and the extent to which an IS depends on one or some system components (Erbes *et al*., 2010; Dutrénit and Puchet, 2011; Srinivas, 2018).

According to this view, the uneven evolution of ISs in developed and underdeveloped countries may be observed 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, through a process of creative destruction, changes the structure of the system in a virtuous circle that connects formerly separated subsystems. On the contrary, underdeveloped ISs are characterised by weak interactions, whose cumulative effects hinder the formation of a critical mass, both in volume and diversity. These feedback processes, in turn, limit the development of absorptive and connectivity capacities, so the systems of production and exchange of knowledge remain locked in, usually around relatively less complex problems, in disconnected subsystems (Cimoli and Porcile, 2009; Yoguel and Robert, 2010; Srinivas, 2018; Hartmann *et al.*, 2021).

### *3.1 A social network approach to IS capacities*

The ISs and social network analysis approaches are strongly intertwined and have been mutually influenced (Dolfsma and Leydesdorff, 2011), in particular regarding the study of systemic and networks properties which emerge from interactions.

The IS approach, beyond its strengths, presents some limitations to empirically identify and measure interactive effects, mainly in underdeveloped context, where ISs usually lack interactive dynamics (Chudnovsky, 1999; Arocena and Sutz, 2000A). Conversely, the social network analysis approach is particularly suitable to capture the effects of interactive behaviour, considering the interactions in the whole system as a unit of analysis. Previous studies have found evidence that certain network structural properties facilitate innovation processes by improving cooperation mechanisms and information diffusion. In line with previous definitions based on the IS approach (Fagerberg and Srholec, 2017), such network structures comprise interactions and represent some sorts of collective capacities that belong to (and depend on) the interaction between agents who are simultaneously embedded in a certain network (Galaso, 2018).

Following this stream of research, we conceive that absorptive capacity emerges from recurrent interactions between the IS's agents (Figure 1). Hence, from a network approach, the absorptive capacity can be approximated by considering *network cohesion*. The 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. In other words, a cohesive network is one in which its nodes maintain many links with each other so that different connections can be established and knowledge can flow easily from one to another. Preceding literature shows that cohesive networks facilitate information access, making information more reliable

| | | | |
|---|---|---|---|
| **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. | ***Interactive critical mass*** ⇕ ***Feedback loops*** ⟺ | ***Connectivity capacity:*** capacity to access and participate in varied knowledge flows. |
| **Underlying Mechanisms** | ***Recurrent interactions :*** mechanism to contrast ideas | | ***System openness:*** knowledge exchange with external nodes to avoid lock-in processes. |
| **Network structures (indicators)** | ***Cohesion:*** the extent to which nodes in national networks are connected to each other. (Average degree; Largest component) | | ***Openness:*** the extent to which local nodes are connected to external actors. (Share of external nodes that are part of the national networks and average of connections of local nodes with foreign nodes) |

Source: Authors

**Fig. 1.** *From theoretical definition to measurable network properties.*

and facilitating knowledge spillovers (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 openness*, which denotes the extent to which local nodes are connected to actors located in other territories. In national collaboration networks, system openness indicates the degree to which a country is connected with foreign inventors or owners (Andersson *et al.*, 2019). Studies within the social network analysis 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).

In peripheral regions, openness is essential for IS to access and absorb new knowledge. However, studies at both country and firm level (Marín and Bell, 2006; Filipetti *et al.*, 2017) have found heterogeneous effects of openness strategies, showing that the positive effects of external openness to knowledge flows are only achieved by agents that absorb inbound knowledge while generating local knowledge flows. In contrast, if the fluxes are only inbound, the openness process can derivate in knowledge dependence on external agents.

Figure 1 summarises 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 indicators for analysing the structural properties of the networks.

## 4. Data and methods

We use US patent records retrieved from the PatentsView platform (https://www.patentsview.org) which collects and organises data from the USPTO. We select a database that includes 17,942 Latin American patents registered between 1970 and 2017, considering the application date to define the period under analysis. We study patents with at least one inventor, individuals who claim to have invented the patented technology, residing in a Latin American country (see Supplementary Appendix, Table A1). In addition, we consider the owners of the patents (assignees), who can be organisations (i.e. firms, universities or research centres) or individuals.[1]

We elaborate both networks of inventors and networks of patent owners. 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.

To capture the absorptive capacity of IS, we calculate two indicators (Table 1). First, the average degree, which measures in a simple and clear way the average level of interaction between network actors. This indicator is particularly suitable for comparing cohesion in networks of different sizes (unlike others also used in the literature which are very sensitive to network size, such as the density index). Our second indicator of cohesion is the size of the largest component of the network. Some types of networks (such as patent networks) are fragmented into different groups of nodes, forming a sort of constellation of components. When the largest component agglutinates a high proportion of the nodes, then the network is less fragmented. The literature on the evolution of networks has found that as the number of links in a network increases, the network becomes progressively more cohesive, forming larger and larger components. This process of gradual cohesion changes when a tipping point is reached abruptly, and the emergence of a 'giant component' brings a significant proportion of the nodes together (Fleming, *et al.*, 2007; Jackson, 2008).

**Table 1.** *Network measures for the key concepts*

| Concept | Measure | Description |
|---|---|---|
| Absorptive capacities | Average degree | The average degree is the average number of links connecting to each node in the network |
| | 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 |
| Connectivity capacities | Foreign actors | The share of external nodes that are part of the national networks |
| | Foreign links | The share of links between local and foreign nodes over the total number of links in the network |

*Source*: Authors.

[1] A detailed explanation of the data selection and processing up to the reconstruction of our networks can be found in Bianchi *et al.* (2020).

To measure network openness (external connectivity capacity), we use two simple network indicators: foreign nodes and foreign links. In the Latin American patent networks, there are some actors (inventors or owners) located in foreign countries that maintain collaborative links with the local actors of the network. Taking this into account, the first indicator of connectivity capacity, the number of foreign links, is measured in terms of the number of connections that local actors maintain with foreign actors. The second indicator focuses on the number of foreign actors that participate in local patents by collaborating with local actors. 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 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.

On the other hand, an extensive literature has documented that patents are a problematic indicator of innovation outputs because most innovations are not patented and only around half of the patents owned by firms are used or licensed. Moreover, the use of a patent system to protect invention rights is highly heterogeneous (Nagaoka *et al.*, 2010). In particular, in developing countries, the firms' incentives to patent are lesser than in the developed ones (Dolfsma and Leydesdorff, 2011).

However, using patent information to trace collaborative inventive activities produces a consistent—albeit partial—measure of systemic knowledge exchanges (Dolfsma and Leydesdorff, 2011). Furthermore, the use of a common patent regime allows an adequate comparison of inventive activities between countries, avoiding problems associated with the institutional differences among national patent offices. In this regard, the US patent system has the advantage of being the world centre of the market for technology, at least during the period studied.

It should be noted that the empirical evidence presented here is mainly descriptive. A great deal of previous research has analysed in depth different national and sectoral cases. Therefore, we analyse the evolution of the collaborative patenting networks in Latin American countries, as indicators of critical attributes of the Latin American ISs, against the backdrop of this prior research.

## 5. Addressing Latin American ISs through collaborative networks

Patent collaboration networks of Latin American countries are very heterogeneous in terms of size. These networks grew during the period under study, since their number of both nodes and links increased. This is observed for both inventor and owner networks, and for all countries in the region; however, as we will see below, this growth is not constant in all networks and some countries even experienced some years of network retraction (Supplementary Appendix, Figure A1).

Table 2 shows the overall results of the absorptive and connectivity capacities of Latin American ISs. First, with respect to absorptive capacities, we can observe that, although the average degree increases during these years, network cohesion remains very low. This can be also observed with the largest component indicator, which, in most countries, accounts for only a small proportion of the nodes, indicating that patent networks in Latin American countries are highly fragmented, that is, made up of a constellation of small components isolated from each other.

**Table 2.** *Summary of network statistics in Latin American countries*

| | Inventors networks | | Owners networks | |
|---|---|---|---|---|
| | 1970–77 | 2010–17 | 1970–77 | 2010–17 |
| Absorptive capacities | | | | |
| *Av. Degree* | | | | |
| Mean | 1.705 | 5.146 | 0.208 | 1.922 |
| Median | 1.222 | 4.551 | 0 | 1.600 |
| Max. | 5.444 (CU) | 9.763 (CU) | 0.824 (AR) | 4.452 (CU) |
| Min. | 0.7556 (VE) | 3.907 (CO) | 0 (CL/CO/CU/VE) | 0.444 (VE) |
| *Share of largest component* | | | | |
| Mean | 0.147 | 0.114 | 0.354 | 0.277 |
| Median | 0.089 | 0.042 | 0.200 | 0.143 |
| Max. | 0.5 (CU) | 0.533 (CU) | 1 (CL) | 0.806 (CU) |
| Min. | 0.038 (BR) | 0.035 (CL) | 0 (CU) | 0.053 (MX) |
| Connectivity capacities | | | | |
| *External links* | | | | |
| Mean | 0.176 | 0.467 | 0.020 | 0.328 |
| Median | 0.168 | 0.491 | 0 | 0.257 |
| Max. | 0.444 (CL) | 0.683 (CU) | 0.1429 (BR) | 0.684 (CU) |
| Min. | 0 (CU) | 0.248 (CL) | 0 (MX/AR/CL/CO/CU/VE) | 0.156 (MX) |
| *External nodes* | | | | |
| Mean | 0.208 | 0.381 | 0.010 | 0.215 |
| Median | 0.209 | 0.379 | 0 | 0.167 |
| Max. | 0.438 (CL) | 0.495 (VE) | 0.067 (BR) | 0.387 (CU) |
| Min. | 0 (CU) | 0.193 (CU) | 0 (MX/AR/CL/CO/CU/VE) | 0.111 (VE) |

*Source*: Authors, based on PatentsView data.

Fragmentation is particularly high in inventor networks—except in the case of Cuba, which is a clear outlier in this aspect—since in all countries the largest component never reaches 20% of nodes and for most countries, it does not even reach 10%. As reference values, Bettencourt *et al.* (2007), Breschi and Lenzi (2016) and Casper (2013) document values above 50% in inventor networks in several US regions. More recently, Pinto *et al.* (2019) report the largest component with almost 80% of the nodes (except for isolated inventors) for the network of all USTPO inventors.

On the other hand, the owner networks are slightly more cohesive, since the proportion of nodes connected to the largest component is higher, which is in line with previous studies in other countries. For example, Galaso and Kovářík (2021) and Graf and Henning (2010) documented the largest components of similar sizes in Spanish and German regions, respectively. However, these owner networks present very small and simple structures. That is, with few exceptions, they are essentially made up of groups of owners that collaborate on a single patent but are not linked to any others, and, therefore, these groups remain isolated from each other.

The fragmentation of national networks into isolated teams of actors represents an important barrier to the circulation of ideas and the absorption of new knowledge. This suggests that collaborative networks replicate the IS structure composed of disconnected subsystems (Cimoli and Porcile, 2009; Srinivas, 2018).

Regarding connectivity capacities, Latin American ISs have traditionally been open systems. Co-invention networks between 1970 and 2017 consistently include a large number of inventors from outside the region. However, since 2000, the share of external inventors has stopped growing, and, indeed, it seems to have declined in several countries. Despite this, the proportion of external inventors at the end of the period is high, with values above 40% in most countries and above 50% in some of them. These proportions are significantly higher than those reported in inventor networks in the USA (Fleming *et al.*, 2007; Lobo and Strumsky, 2008). On the other hand, owner networks show a greater involvement of external actors and an increase in the percentage of foreign owners after 1990, which accords with the economic openness process of the late twentieth century. 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 effects of structural reforms Latin American countries pursued after the 1990s. In this context, our results suggest that the market expansion and increased competition associated with economic liberalisation 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).

We now focus on analysing the absorptive and connectivity capacities in those countries with the largest networks in Latin America. Table 3 presents the indicators of these capacities for these countries at the end of the period (2010–17) and a summary of the distinctive features of their networks. The relationship between absorptive and connectivity capacities at different points in time for each country are presented in Supplementary Appendix, Figure A2.

This analysis yields two main findings. First, we see some diversity in inventor and owner networks, with some countries, such as Cuba, standing out particularly for their inventor network.

Second, we appreciate a positive correlation between connectivity and absorptive capacities (Supplementary Appendix, Figure A2), which is robust when different indicators are used. The intensity of this relationship seems to vary from country to country, and we also find some interesting exceptions, such as Chile, which exhibits a negative correlation between absorptive and connectivity capacities in the inventor network.

### *5.1 The big three: Brazil, Mexico and Argentina*

The largest countries of the region differ greatly in terms of geographical location, productive structure, trade specialisation and research infrastructure. However, these countries share a regional leader position. Since the period of state-led industrialisation, these countries have built national innovation capacities, sometimes anchored in large national development projects (Cimoli and Katz, 2003; De Negri, 2010). Jointly

**Table 3.** *Summary of absorptive and connectivity capacity indicators, 2010–17*

| Country | Network's key features | Absorptive capacities | | | | Connectivity capacities | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Inventors | | Owners | | Inventors | | Owners | |
| | | Share the largest component | Average Degree | Share the largest component | Average Degree | Foreign links | Foreign nodes | Foreign links | Foreign nodes |
| Brazil | The largest networks in the region. Rapid growth. | 0.05 | 4.596 | 0.143 | 1.6 | 0.491 | 0.365 | 0.329 | 0.174 |
| Mexico | Large networks and rapid growth, especially in the inventors' network. | 0.042 | 4.285 | 0.053 | 1.699 | 0.514 | 0.379 | 0.156 | 0.167 |
| Argentina | Well-cohesive network of owners, where a giant component has emerged. | 0.037 | 4.778 | 0.348 | 2.874 | 0.494 | 0.459 | 0.432 | 0.348 |
| Chile | Large and well-cohesive network of owners. | 0.035 | 4.141 | 0.127 | 1.164 | 0.248 | 0.372 | 0.257 | 0.157 |
| Cuba | Both networks are very cohesive. Inventors' network is the only one on the continent with a giant component. Well connected to foreign nodes. | 0.533 | 9.763 | 0.806 | 4.452 | 0.683 | 0.193 | 0.684 | 0.387 |
| Colombia | Small (relative to the country size) and poorly connected networks. | 0.042 | 3.907 | 0.13 | 1.217 | 0.352 | 0.402 | 0.19 | 0.159 |
| Venezuela | Emergence and subsequent disintegration of a giant component in the inventors network. | 0.059 | 4.551 | 0.333 | 0.444 | 0.485 | 0.495 | 0.25 | 0.111 |

*Source*: Authors based on PatentsView data.

with the formation of the scientific systems in the 1950 and 1960 decades, these processes support the formation of a critical mass of scientific actors in some specific fields (Dutrénit and Puchet, 2011).

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 (Figure 2). On the other hand, the owner networks in these countries also show a mostly positive but non-monotonic correlation between absorptive and connectivity capacities (Supplementary Appendix, Figure A6).

Several studies have analysed these cases in depth (e.g. De Negri, 2010), showing that their ISs are made up of heterogeneous agents, 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. The network indicators also show 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. This is especially clear in the Brazilian inventor network where its largest component has grown to around 300 nodes by the end of the period (Supplementary Appendix, Figure A3). Meanwhile, in co-appropriation networks, Argentina exhibits an impressive growth of the largest component, showing a considerable improvement of owner network cohesion (Appendix, Figure A4).

However, in these networks, the largest components represent only a very small proportion of all the nodes. This indicates that none of the three countries has yet experienced the emergence of a giant component, so their networks, as a whole, are still very fragmented, with a prevalence of weak systemic interactions co-existing with a few relatively large and well-connected components (Rivera-Ríos *et al.*, 2009). The owner network in Argentina is an exception to the above, since the largest component brings together more than a third of its nodes. Thus, we could consider that a giant component has emerged in this network. This feature should substantially facilitate the circulation of knowledge among patent owners, which implies a strength in the absorptive capacity of the Argentine IS.

Regarding the connectivitycapacities, these three largest ISs have relatively few foreign nodes (Supplementary Appendix, Figures A3–A5). However, the proportion of foreign inventors in the Argentinean and Mexican networks has been steadily

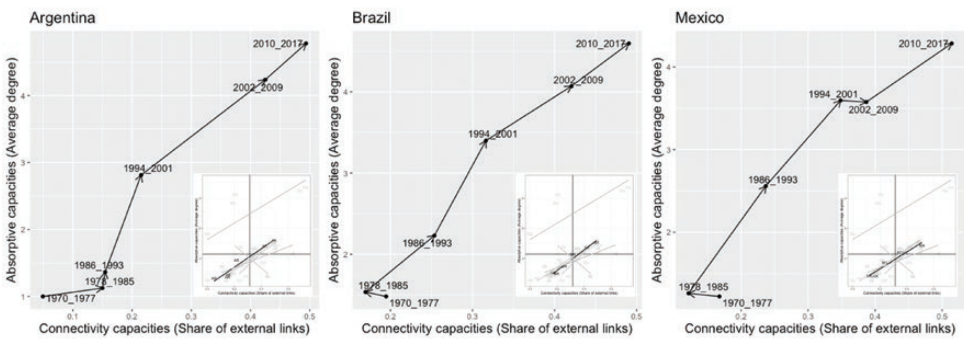


**Fig. 2.** *Coevolution of absorptive and connectivity capacities in Brazil, Mexico and Argentina.*
*Source*: Authors, based on PatentsView data.

increasing, from approximately 25% in the 1970s to more than 40% in the 2000s. In contrast, the proportion of foreign inventors in Brazil's networks has systematically decreased, from 46% in the 1970s to 37% in the 2000s.

In sum, our results confirm that the Brazilian IS, which is strongly supported by national policies, is the most mature IS in the region. Brazil has progressively accessed the global system of knowledge, exhibiting increasing collaboration with Asian partners in addition to long-standing collaborations with partners in Europe and the USA (Ponomariov and Toivanen, 2014; Reis *et al.*, 2018). Meanwhile, Mexico seems stuck in an unbalanced relationship with the USA that hinders the formation of a local critical mass (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 of a lack of collaborative innovation linkages in the Argentinean IS (Chudnovsky, 1999; Erbes *et al.*, 2010).

### *5.2 Chile and Cuba: a tale of two development projects*

The evolution and current state of collaborative patent networks in Cuba and Chile seem to be related to explicit national projects, which have been recently discussed in each country (Atria *et al.*, 2013; Rodríguez and Núñez, 2021). The former is noteworthy for the structure of its inventor network and the latter for the relative importance of its owner network.

The Cuban co-inventor network is, by far, the most cohesive network in the region: it has no isolated actors and its inventors have, on average, twice as many connections as the next-most-cohesive ISs in the region. In the rest of 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 (Table 3). In fact, Cuba is the only Latin American country in which a giant component has emerged since 2002 (Table 3; Supplementary Appendix, Figure A7).

Despite the exceptional evolution of the Cuban co-inventor network, its national co-owner network is quite small but very cohesive. The difference between the co-inventor and the co-owner 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 (Kwon *et al.*, 2019). In fact, patenting activities in Cuba are mostly conducted by a number of state-owned enterprises that pursue a national strategy of innovation that survived a severe crisis following the dissolution of the socialist bloc (Blanco, 2020). Nowadays, exports of pharmaceutical and biotech products are part of the island's international trade strategy, which contributes critically needed revenue to the national economy (Kwon *et al.*, 2019).

Conversely, Chile stands out because its owner networks are better connected than its co-inventor networks. We observe in the Chilean case that absorptive capacities in co-inventor network have not improved since 1986, while the co-owner network has greatly increased its size and cohesion. 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 emphasised 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 the national development project (Rodríguez and Núñez, 2021), the Cuban IS exhibits a uniquely high level of absorptive capacity together with focussed external connectivity capacities. Certain nodes, in particular state-owned firms, seem to play the role of gatekeepers (Graf, 2011), that is, they intermediate between local nodes and external actors (Rodríguez and Núñez, 2021). Gatekeepers may contribute to overcoming subsystems' previous disconnection, as interpreted by Cuban authors (Blanco, 2020; Rodríguez and Núñez, 2021). However, intermediary state-owned firms may also operate by controlling the diffusion of external knowledge along the Cuban IS.

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 3, left), which is reflected in its changing trajectory: it started out relatively open and has been able to build greater absorptive capacity among inventors. Cuba, in contrast, exhibits the opposite trajectory; it started out relatively closed to foreign collaboration and remained so until the 1980s, after which it has exhibited increasing openness together with increasing cohesiveness of the inventor network (Figure 3, right).

### *5.3 Uneven trajectories of two neighbours: the Venezuelan and the Colombian ISs*

Patent network analysis reveals differences in the evolution of the Colombian and the Venezuelan ISs. These two countries have experienced internal and external pressures

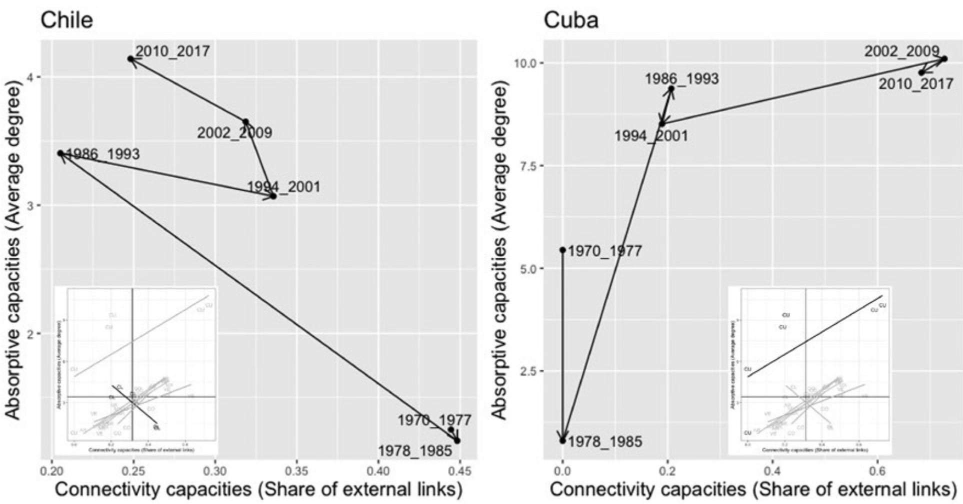


**Fig. 3.** *Coevolution of absorptive and connectivity capacities in Chile and Cuba.*
*Source*: Authors, based on PatentsView data..

that have affected their economic and social stability. However, while Venezuela was traditionally seen as a relatively advanced IS in the region, its recent experiences—in particular, its recent national policies and political conflict—have adversely affected research and innovation activities in the country (Jimenez and García, 2017). In contrast, Colombia's policy on research and innovation is framed by a novel approach 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 patent owners. Arguably, as recent studies of this country show, these results may be related to the fact that the national patent network is highly concentrated around the national petroleum company (Gómez, 2018).

Around petroleum research and production, the cases of Colombia and Venezuela provide new evidence on the relatively high level of development associated with a strategic resource for the country and the public policy created to support its development. However, these cases also reinforce the perception of disconnected subsystems, with heterogeneous levels of maturity and development, cohabiting within the same national IS.

The case of Venezuela is particularly interesting because of the evolution of its network cohesion. Both co-invention and co-appropriation networks evolved until about halfway through the period considered in this research and then they suffered a strong reduction in size and loss of cohesion 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 network in the region. In Venezuela's co-invention network, we find that a giant 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 (Supplementary Appendix, Figure A8).

The rise and fall of a giant component in the Venezuelan co-invention network is contrary to what is expected from the network evolution literature where, after the emergence of a giant component, networks tend to remain cohesive (Jackson, 2008). Meanwhile, it is evident that the Venezuelan network has disintegrated. This finding seems to reflect the effects of the 2002 political crisis, associated to major strikes in the state-owned petroleum firm, and the massive emigration of scientists (Requena and Caputo, 2016). In fact, during the 1976–2010 period 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.

Moreover, this country has exhibited a strong tendency towards international collaborations since 1986, which may indicate a weakening of its national collaboration networks and, therefore, a greater dependence on foreign actors.

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

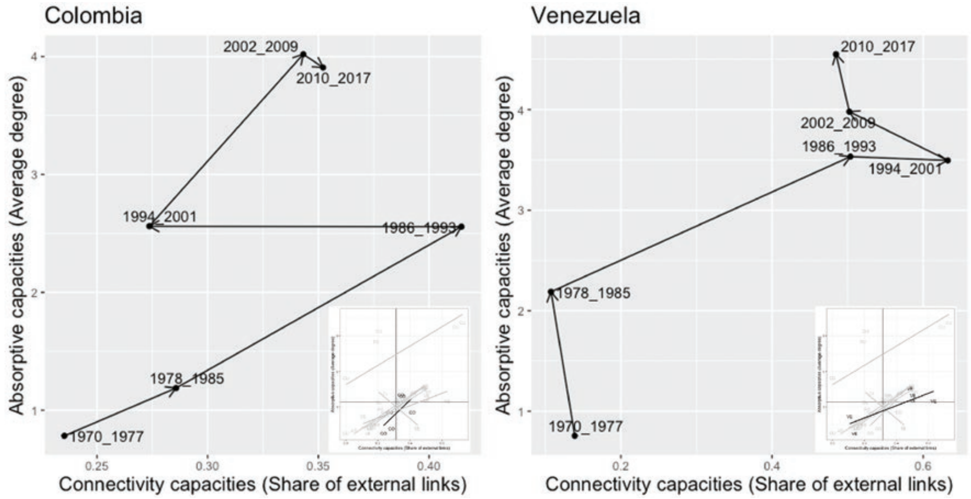


**Fig. 4.** *Coevolution of absorptive and connectivity capacities in Colombia and Venezuela.*
*Source*: Authors, based on PatentsView data.

(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 4).

## 6. 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 and identify recent critical changes in Latin American ISs. In addition, we apply a theoretical framework which maps system-theoretic properties onto critical IS attributes that are observable through network analysis. In particular, we contribute to measuring and analysing 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 emphasis. 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 actors. According to network evolution models, networks tend to grow increasingly connected, as more links appear, until they form complex, cohesive structures (Jackson, 2008). However, the networks in our analysis still do not 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 actors. Third, networks show a large number of international collaborations, indicating that many of the interactions associated with invention processes in Latin America are outward oriented. Finally, arguably the most important finding is that, with the exception of Venezuela, all the largest Latin American ISs, despite exhibiting relatively low absorptive capacities, show a cumulative trend of increased systemic capacity. However, persistent signals of structural disconnections, attributable to disconnected subsystems, are registered.

Future research should seek to provide more in-depth national networks analyses that incorporate the characteristics of the agents involved in the interaction as well as the technological fields in which they operate.

## Bibliography


Albuquerque, E. 2007. Inadequacy of technology and innovation systems at the periphery, *Cambridge Journal of Economics*, vol. 31, no. 5, 669–90

Álvarez, R., Benavente, J. and Crespi, G. 2019. *Innovation in the Global Economy: Opening-Up Latin American Innovation Systems*, Washington, DC, Inter-American Development Bank. 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, 1075–102

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. http://webdoc.sub.gwdg.de/ebook/serien/lm/DRUIDwp/00-13.pdf [date last accessed 20 December 2020]

Atria, F. *et al.* 2013. *El otro modelo: Del orden neoliberal al régimen de lo público*, Santiago de Chile, Random-House-Mondadori

Balland, P. A. et al. 2022. The new paradigm of economic complexity, *Research Policy*, vol. 51, no. 3, 104450

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, 1861–79

Bettencourt, L., Lobo, J. and Strumsky, D. 2007. Invention in the city: increasing returns to patenting as a scaling function of metropolitan size, *Research Policy*, vol. 36, no. 1, 107–20

Bianchi, C., Galaso, P. and Palomeque, S. 2020. 'Invention and Collaboration Networks in Latin America: Evidence from Patent Data'. Serie Documentos de Trabajo; 04/20. Instituto de Economía, Facultad de Ciencias Económicas y Administración, Universidad de la República, Uruguay. https://hdl.handle.net/20.500.12008/24894 [date last accessed 6 January 2023]

Bianchi, C., Galaso, P. and Palomeque, S. 2021. Patent collaboration networks in Latin America: extra-regional orientation and core-periphery structure, *Journal of Scientometric Research*, vol. 10, no. 1s, s59–70

Blanco, H. 2020. Treinta años de la empresa estatal en Cuba: recuento y reflexiones sobre su transformación, *Economía y Desarrollo*, vol. 164, no. 2, e6

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

Britto, J., Ribeiro, L. and Albuquerque, E. 2021. Global systems of innovation: introductory notes on a new layer and a new hierarchy in innovation systems, *Innovation and Development*, vol. 11, no. 2–3, 259–79

Campi, M. and Dueñas, M. 2019. Intellectual property rights, trade agreements, and international trade, *Research Policy*, vol. 48, no. 3, 531–45
Casper, S. 2013. The spill-over theory reversed: the impact of regional economies on the commercialization of university science, *Research Policy*, vol. 42, no. 8, 1313–24
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
Chaves, C. et al. 2020. Innovation systems and changes in the core-periphery divide: notes on a methodology to determine countries' trajectories using science and technology statistics, *CEPAL Review*, vol. 130, 43–61
Chudnovsky, D. 1999. Science and technology policy and the National Innovation System in Argentina, *CEPAL Review*, vol. 1999, 157–7
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.
Cimoli, M. and Porcile, G. 2009. Sources of learning paths and technological capabilities: an introductory roadmap of development processes, *Economics of Innovation and New Technology*, vol. 18, no. 7, 675–94
Cohen, W. and Levinthal, D. 1989. Innovation and learning: the two faces of R&D, *The Economic Journal*, vol. 99, no. 397, 569–96
Cohen, W. and Levinthal, D. 1990. Absorptive capacity: a new perspective on learning and innovation, *Administrative Science Quarterly*, vol. 35, no. 1, 128–52
COLCIENCIAS 2018. *Libro Verde 2030: Política Nacional de Ciencia e Innovación para el Desarrollo Sostenible*, Bogotá, COLCIENCIAS, Gobierno de Colombia. 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. *et al.* 2014. Science and technology policy in Colombia: a comparative review, *European Journal of Scientific Research*, vol. 121, no. 3, 267–85
Crespi, G. and Dutrénit, G. 2014. *Science, Technology and Innovation Policies for Development: The Latin American Experience*, Cham, Springer International Publishing
Crespi, G. et al. 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, 261–82
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, 235–80
De Negri, F. 2010. Estratégias tecnológicas na Argentina, Brasil e México, *Revista Economia & Tecnologia*, vol. 6, no. 1, 127–38
Dolfsma, W. and Leydesdorff, L. 2011. Innovation systems as patent networks: the Netherlands, India and nanotech, *Innovation*, vol. 13, no. 3, 311–26
Dosi G, 1988 The nature of innovative process,, pp 221–238 in Dosi G et al., (eds.) *Technical Change and Economic Theory*, London, Pinter Publisher
Dutrénit, G. *et al.* 2010. *El sistema nacional de innovación mexicano: estructuras, políticas, desempeño y desafíos*, Mexico, UAM
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. 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]

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, 719–41

Fagerberg, J. and Srholec, M. 2017. Capabilities, economic development, sustainability, *Cambridge Journal of Economics*, vol. 41, no. 3, 905–26

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, 413–39

Fleming, L., King III, C. and Juda, A. I. 2007. Small worlds and regional innovation, *Organization Science*, vol. 18, no. 6, 938–54

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, 571–90

Galaso, P. and Kovářík, J. 2021. Collaboration networks, geography and innovation: local and national embeddedness., *Papers in Regional Science*, vol. 100, no. 2, 349–77

Gómez, R. 2018. Tendencias de la innovación tecnológica en Colombia 1991-2013 a partir del análisis de patentes, *Investigación Bibliotecológica*, vol. 32, no. 77, 133–50

Graf, H. and Henning, T. 2010. Public research in regional networks of innovators: a comparative study of four East-German regions, pp. 97–128 in Freytag, A. and Thurik, R. (eds). *Entrepreneurship and Culture*, Berlin, Springer

Graf, H. 2011. Gatekeepers in regional networks of innovators, *Cambridge Journal of Economics*, vol. 35, no. 1, 173–98

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

Hartmann, D. *et al.* 2021. Why did some countries catch-up, while others got stuck in the middle? Stages of productive sophistication and smart industrial policies, *Structural Change and Economic Dynamics*, vol. 58, 1–13

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, 151–72

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, 101898

Lobo, J. and Strumsky, D. 2008. Metropolitan patenting, inventor agglomeration and social networks: a tale of two effects, *Journal of Urban Economics*, vol. 63, 871–84

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*, London, Pinter Publisher

Marín, A. and Bell, M. 2006. Technology spillovers from foreign direct investment (FDI): the active role of MNC subsidiaries in Argentina in the 1990s, *The Journal of Development Studies*, vol. 42, no. 4, 678–97

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

Nagaoka, S., Motohashi, K. and Goto, A. 2010. Patent statistics as an innovation indicator, pp. 1083–1127 in Hall, B. and Rosenberg, H (eds.) *Handbook of the Economics of Innovation*, vol. 2, North-Holland, Amsterdam

Organisation for Economic Co-operation and Development (OECD) (2020) *2020 Policy Note on Latin America. Leveraging the Impact of New Technologies*, Paris, OECD. https://www.oecd.org/dev/EMnet-Latin-America-Policy-Note-2020.pdf [date last accessed 21 April 2022]

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, 588–96

Rapini, M. S., Albuquerque, E., Chaves, C., Silva, L. A., Antunes de Souza, S. G., Righi, H. M., and Silva da Cruz, W. M. 2009. University–industry interactions in an immature system of innovation: evidence from Minas Gerais, Brazil, *Science and Public Policy*, vol. 36, no. 5, 373–86

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, 341–7

Requena, J. and Caputo, C. 2016. Pérdida de talento en Venezuela: migración de sus investigadores, *Interciencia*, vol. 41, no. 7, 444–53

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

Rodríguez, A. and Núñez, J. 2021. El Sistema de Ciencia, Tecnología e Innovación y la actualización del modelo de desarrollo económico de Cuba, *Revista Universidad y Sociedad*, vol. 13, no. 4, 7–19

Sábato, J. and Botana, N. 2021 [1968]. 'Science and technology in the future development of Latin America'. Documento de Trabajo de CiTINDe No 1, Montevideo, Universidad de la República. https://citinde.ei.udelar.edu.uy/publicacion/la-ciencia-y-la-tecnologia-en-el-desarrollo-futuro-de-america-latina/ [date last accessed 20 April 2022]

Sagasti, F. 2005. *Knowledge and Innovation for Development: the Sisyphus Challenge of the 21st Century*, London, Edward Elgar Publishing

Srinivas, S. (2018), Evolutionary demand, innovation and development, in Nathan, D., Sarkar, S. and Tewari, M. (eds.) *Development with Global Value Chains: Upgrading and Innovation in Asia*, London, Cambridge University Press

Teixeira, A., Rapini, M. and Caliari, T. 2020. Organizational determinants and idiosyncrasies of firms' absorptive capacity in a developing country, *Science and Public Policy*, vol. 47, no. 3, 384–95

UNESCO (2015) *UNESCO Science Report: Towards 2030*, Paris, UNESCO. https://www.unesco.org/reports/science/2021/en/report-series/ [date last accessed 21 April 2022]

World Intellectual Property Organization (WIPO) 2018. *World Intellectual Property Indicators 2018*, Geneva, World Intellectual Property Organization

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. 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.

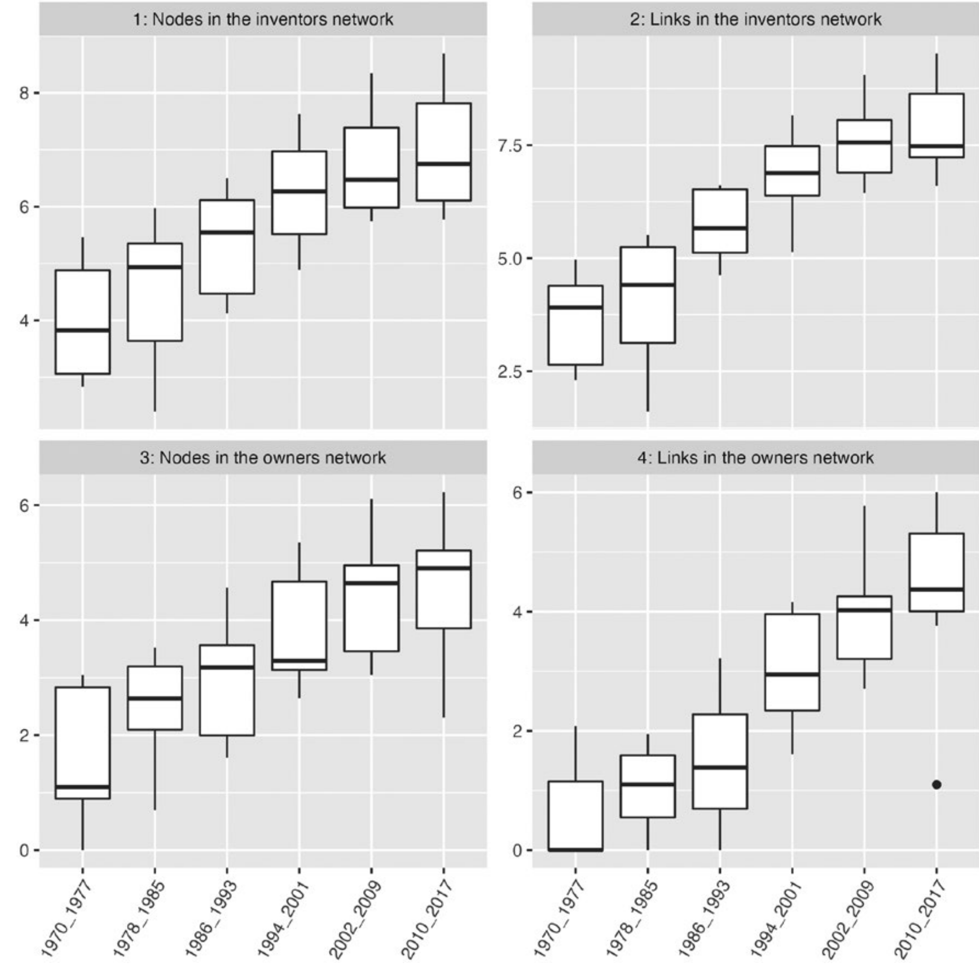


**Fig. A1.** *Evolution of the size of country networks*

*Notes*: The size of the boxes represent the interquartile range (IQR), the horizontal line inside each box represents the mean, the vertical lines represent the minimum and maximum excluding outliers, the dots represent outliers. The outliers are observations that lie over the Q3 + 1.5*IQR, or bellow Q1-1,5*IQR.

*Source*: Authors

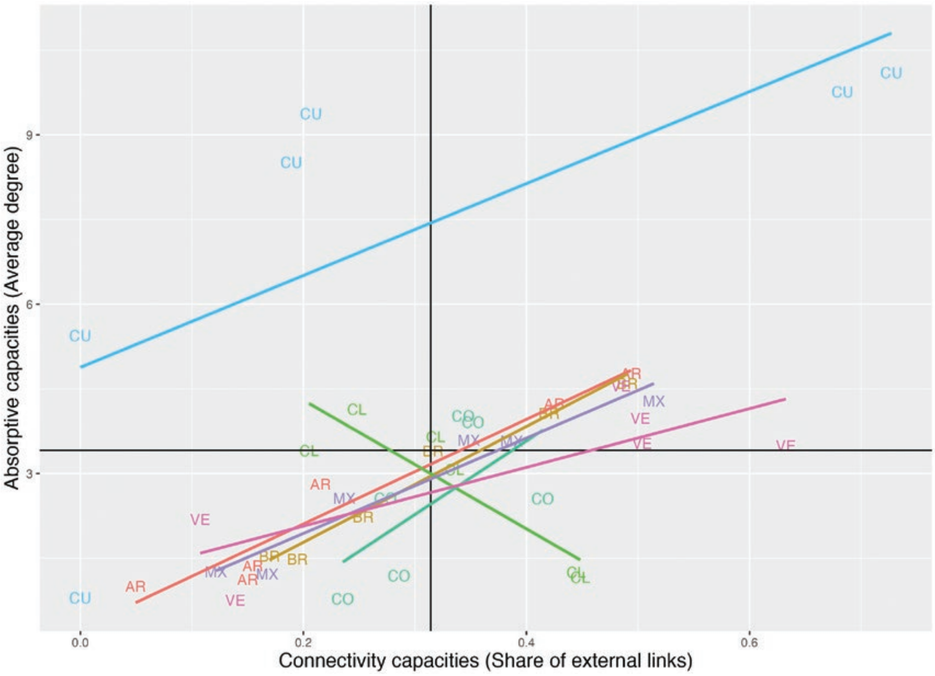


**Fig. A2. Network cohesion and openness in Latin American ISs. a. Plot of average degree vs. percentage of foreign links in invention networks. b. Plot of average degree vs. foreign links in owner networks**

*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.

*Source*: Authors, based on PatentsView data.

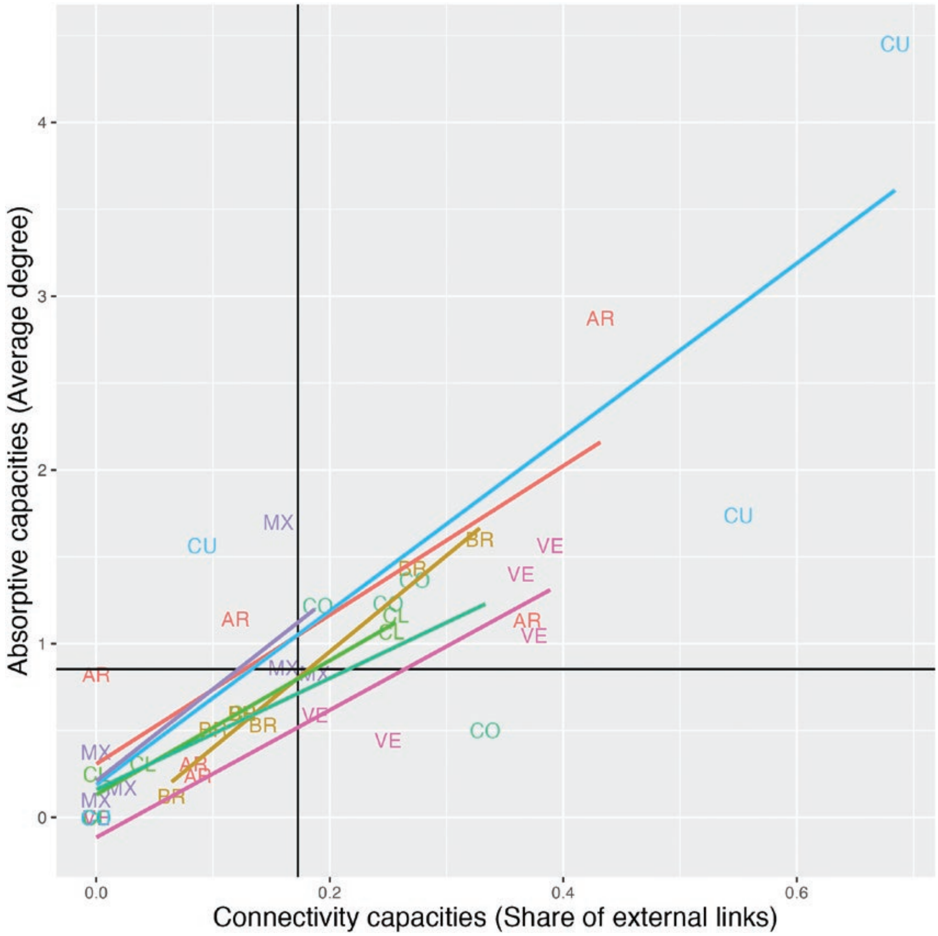


*Fig. A2. Continued*

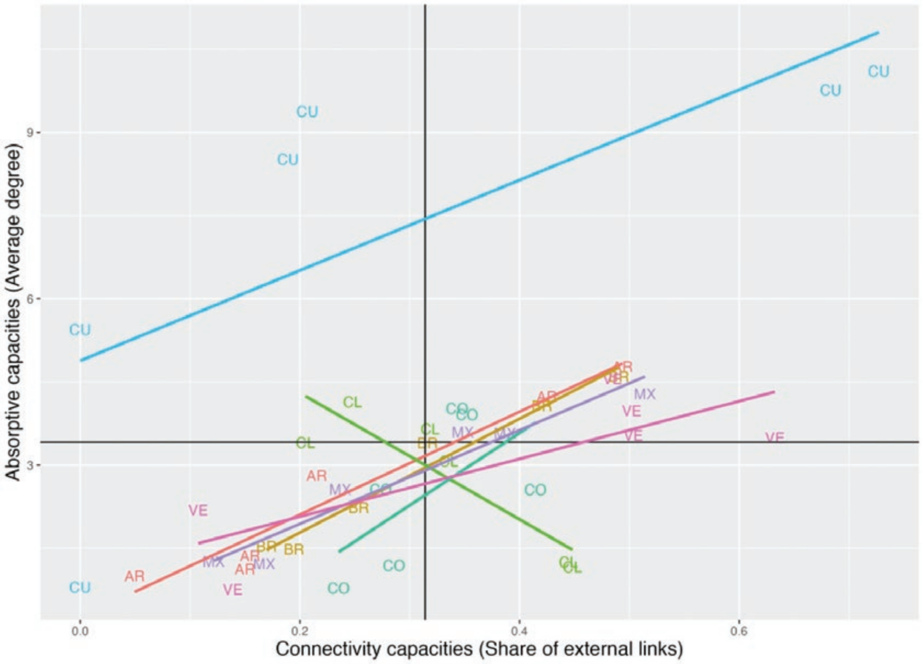


*Fig. A2. Continued*

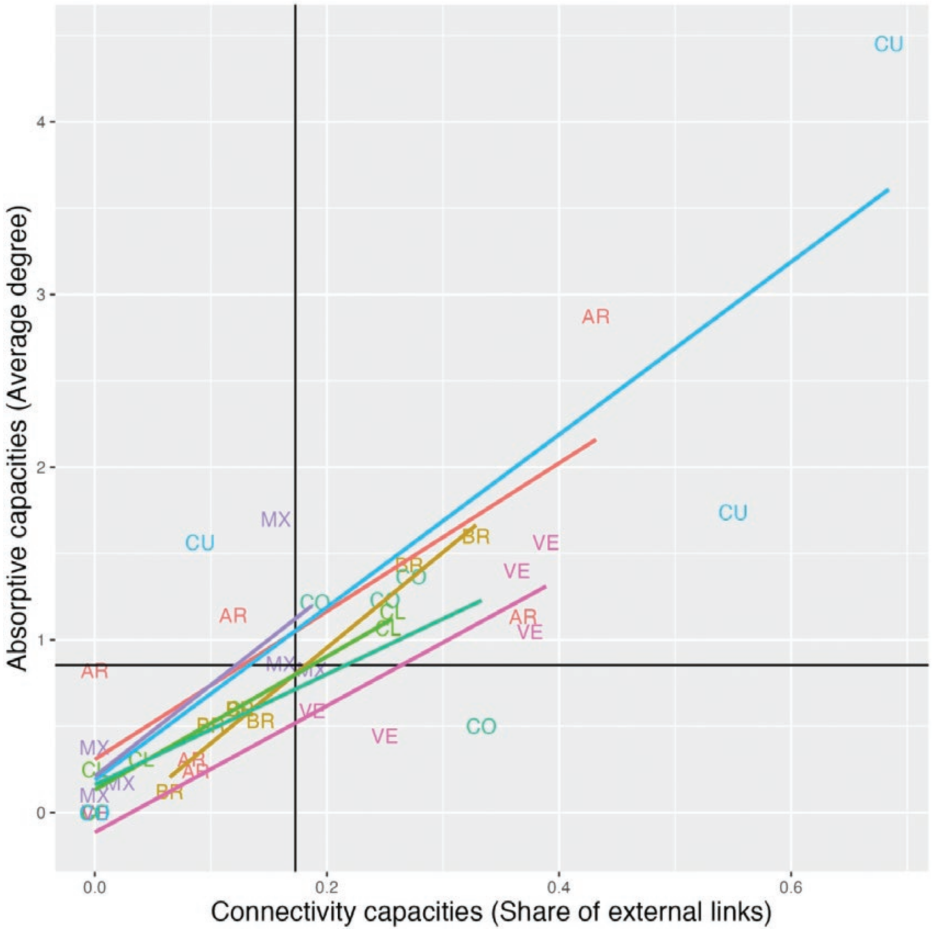


*Fig. A2.* *Continued*

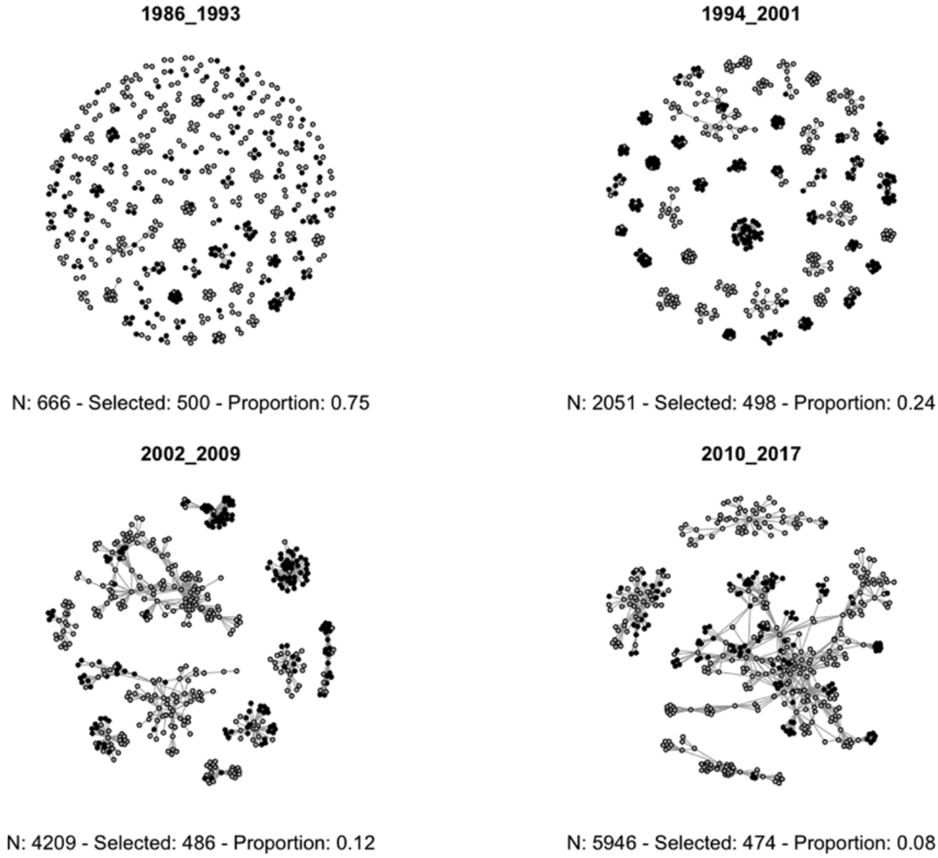


**Fig. A3. Evolution of Brazil inventor network**
*Note*: Grey nodes represent Latin American inventors; black nodes represent foreign inventors. N: total number of nodes in each period; Selected: number of nodes represented in each graph; Proportion=Selected/N.
*Source*: Authors, based on PatentsView data.

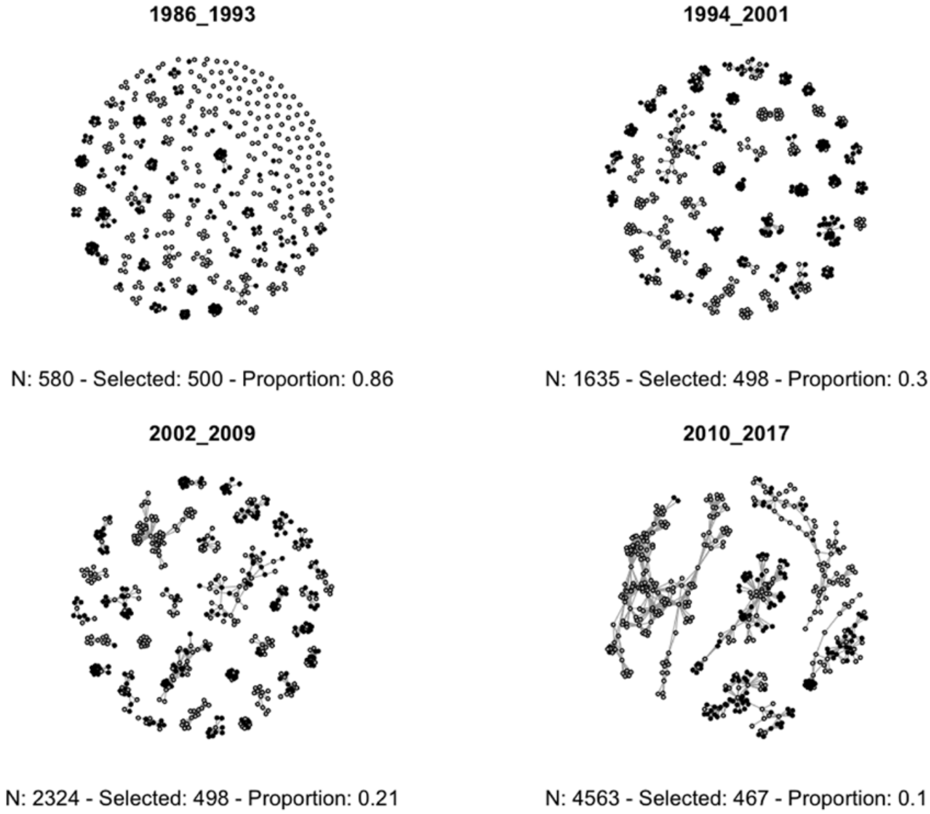


**Fig. A4. Evolution of Mexico inventor network**
*Note*: Grey nodes represent Latin American inventors; black nodes represent foreign inventors N: total number of nodes in each period; Selected: number of nodes represented in each graph; Proportion=Selected/N.
*Source*: Authors, based on PatentsView data.

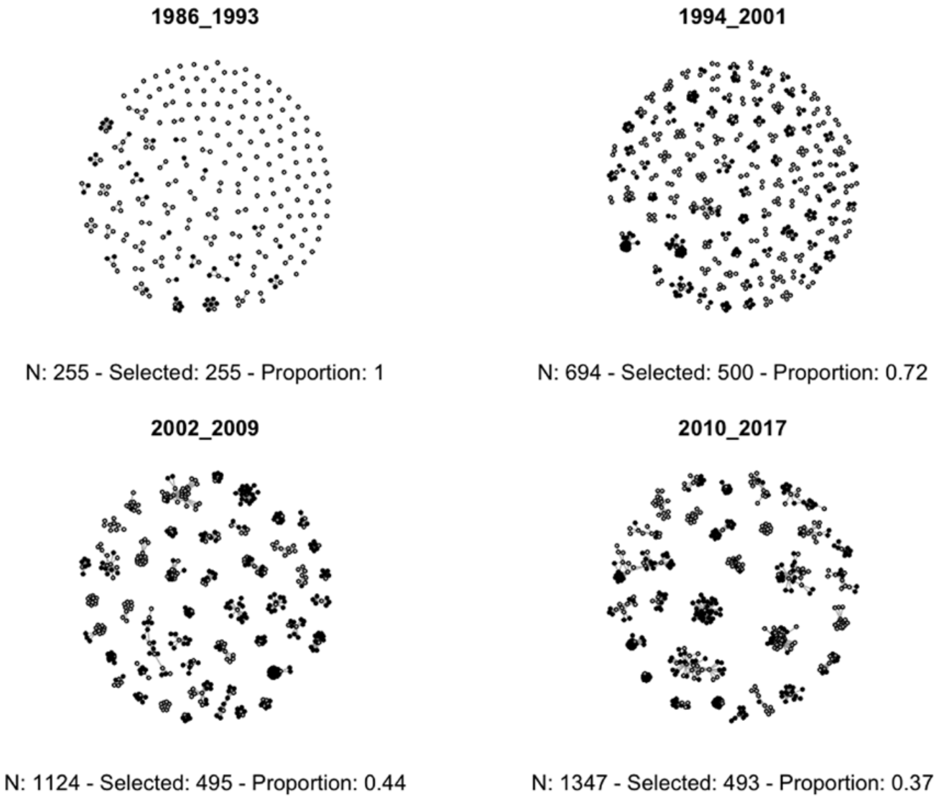


**Fig. A5. Evolution of Argentina inventor network**

*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.

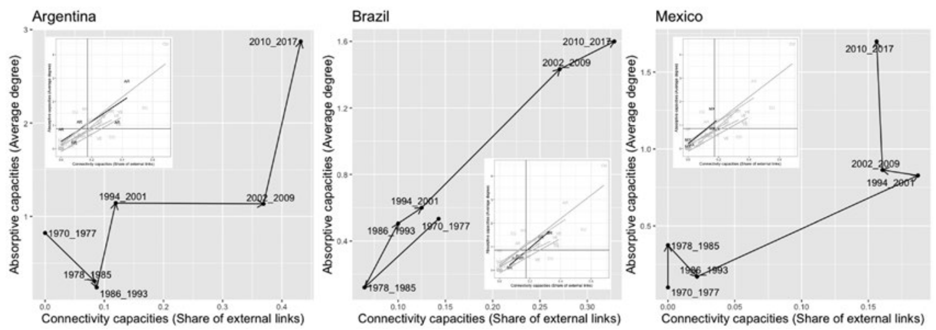


**Fig. A6. Coevolution of absorptive and connectivity capacities in owner networks**

*Source*: Authors, based on PatentsView data.

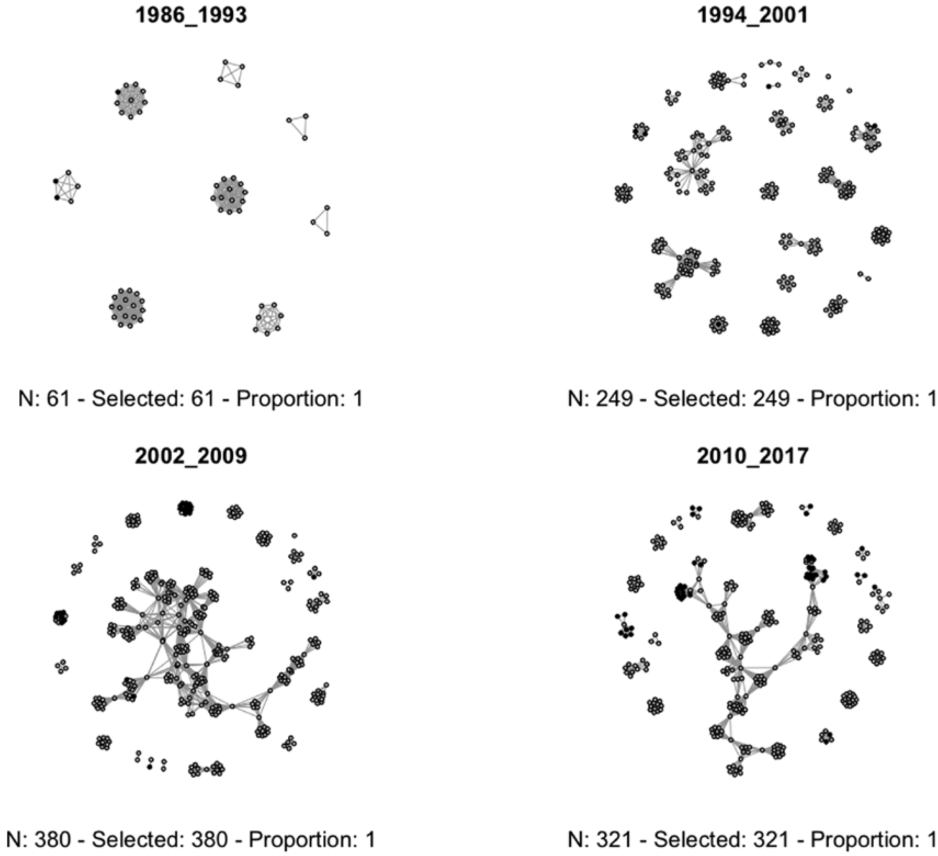


**Fig. A7. Evolution of Cuba inventor network**

*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.

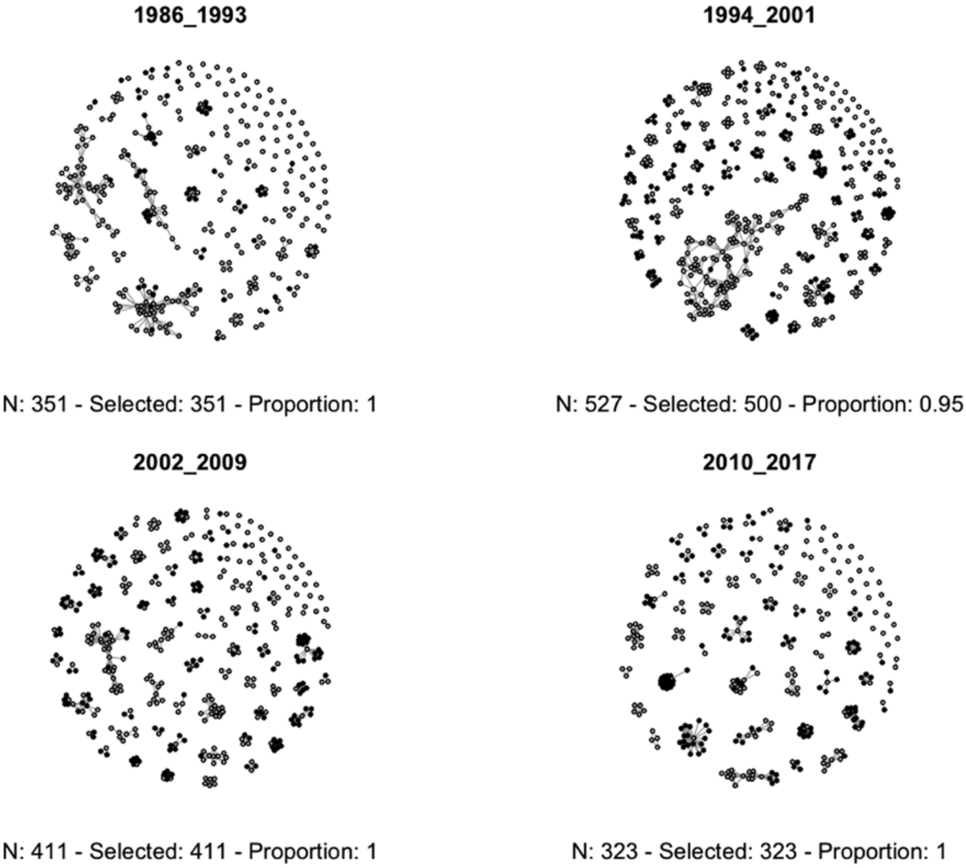


**Fig. A8. Evolution of Venezuela inventor network**
*Note*: Grey nodes represent Latin American inventors; black nodes represent foreign inventors. N: total number of nodes in each period; Selected: number of nodes represented in each graph; Proportion=Selected/N.
*Source*: Authors, based on PatentsView data.