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The tradeoffs of brokerage in innovation networks: a study of Latin American cities

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Resumen

La intermediación juega un rol crucial en la evolución de los sistemas de innovación. Sin embargo, acceder y difundir conocimiento dentro de un sistema implica costos y requiere capacidades. Usando datos de patentes para analizar la red de ciudades de Latinoamérica, revisamos el debate sobre los beneficios y los costos de las redes de conocimiento. Identificamos ciudades intermediarias, distinguiendo entre conexiones dentro de las ciudades y entre las ciudades, y estimamos los efectos de la intermediación en el patentamiento entre 2006 y 1017. Nuestros resultados revelan que las ciudades que ocupan posiciones centrales en la red muestran mayores niveles de patentamiento; pese a esto, intermediar, particularmente conectar a Latinoamérica con ciudades fuera de la región, afecta negativamente los niveles de patentamiento.

Palabras clave: redes de ciudades, patentes, intermediación, sistemas de innovación, Latinoamérica.

Código JEL: O31, O54, P48.

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Abstract

Brokers play a critical role in the evolution of innovation systems. However, accessing and diffusing knowledge into the system imply costs and requires capacities. Using patent data to analyze inter-city networks in Latin America, we revisit the debate on the benefits and costs of knowledge networks. We identify broker cities, differentiating between intra-regional and extra-regional connections, and we estimate the effects of brokerage on patenting outcomes between 2006 and 2017. Our findings reveal that cities holding a central position in the network show higher patenting activity; however, being broker, particularly bridging Latin America with extra-regional cities, negatively influences patenting outcomes.

Keywords: inter-city networks, patents, brokerage, innovation systems, Latin America.

JEL Classification: O31, O54, P48.

Introduction

Cities has gained growing attention in the research agenda of both regional and innovation studies (e.g. Cooke, 2001; Florida, Adler, & Mellander, 2017; Johnson, 2008; Neal, 2012). These intrinsically intertwined bodies of literature have analyzed cities as locally embedded networks, where interactive linkages transmit and reproduce knowledge within the network and develop collaborative channels with global networks. In these works, agglomeration features associated to demographic density, infrastructure facilities and localized capacity building processes, are considered mechanisms that determine the innovative performance of cities. In this regard, an extensive and plural stream of research has analyzed city networks as a critical resource for local development, territorial policies and human mobility, among others relevant topics (e.g. Fischer, Queiroz, & Vonortas, 2018; Johnson, 2008; Rantisi, 2002; Sigler & Martinus, 2017; Simmie, Sennett, Wood, & Hart, 2002; Verginer & Riccaboni, 2020).

A smaller but growing number of studies have recently analyzed inter-city networks, shedding light on the role of cities as components of national, regional or global knowledge networks (e.g. Fan, Lian, & Wang, 2020; Guan, Zhang, & Yan, 2015; Maisonobe, Grossetti, Milard, Eckert, & Hamilton, 2016; Yao, Li, & Li, 2020). Following a systemic approach, our paper aims to contribute to this literature by analyzing brokerage in Latin-Americans inter-city patenting networks. We revise recent contributions that highlight the positive effects of knowledge centrality and brokerage in innovation networks (Yao et al., 2020), adding the analysis of the relative costs of networking, mostly inspired in the current discussion on the nonlinear effects of external knowledge sourcing from the firm's innovation studies (e.g. Arora, Athreye, & Huang, 2016; Laursen & Salter, 2014). As a result, our general research question aims to identify the effects of the inter-city collaborative network on innovation processes.

Laursen & Salter (2014) used the term "openness paradox" to describe, mostly for firms, the tradeoffs that innovation agents face when looking for external knowledge. External knowledge is a critical resource for innovation systems (IS). However, accessing and using it, imply costs and require internal capacities (Arora et al., 2016; Laursen & Salter, 2014). Hence, according to their capacities, different agents will face different relative costs in these processes. In addition, due to the attributes of knowledge, networks will spur heterogeneous effects in the whole system rather than only influencing the connected agent (Antonioli, Marzucchi, & Savona, 2017; Grimpe & Kaiser, 2010; Kauffeld-Monz & Fritsch, 2013). Therefore, fulfilling the role of broker –i.e. intermediating among disconnected agents– implies benefits, mostly associated with access to diverse, non-redundant knowledge. However, it also implies costs related to time and resources necessary to maintain links with different actors that are disconnected from each other (Antonioli et al., 2017; Kauffeld-Monz & Fritsch, 2013).

We aim to contribute to the literature by adapting these concepts about the tradeoffs of networking, which were developed in research on firms' innovation, and adapting them to the studies on regional ISs. We also aim to focus on the brokerage role that certain cities can play in inter-city networks on a continental scale. Hence, we consider cities as innovation agents participating in the collaborative knowledge fluxes within the Latin-American IS. We focus on the brokerage role of Latin American cities, comparing their intra-regional connections to their extra-regional collaborations. Analyzing the role of broker cities located in a peripheral region, as it is the case of Latin America, is particularly relevant given the great dependence the continent has on foreign connections in its innovation processes (Montobbio & Sterzi, 2011).

Using patent data, we build inter-city collaboration networks between 2006 and 2017. Based on the work of Gould & Fernandez (1989), we distinguish two types of brokerage roles that can be played by Latin American cities in the collaboration network at the regional scale: (1) those brokers that intermediate between other cities in the region (i.e. coordinators), and (2) those that intermediate between Latin American and extra-regional cities (i.e. gatekeepers). We estimate negative binomial models that allow us to determine the influence of networks, particularly the brokerage effects, on patenting outcomes registered by cities. We also estimate the influence of intra-regional vs. extra-regional links on patenting levels of Latin American cities.

In line with previous research, our results show that cities holding a central position in the network are likely to be more innovative. Moreover, we show that most central cities in Latin America maintain linkages with external agents. Hence, there are a number of Latin

American cities which seem to be playing a particularly relevant role in shaping the regional network, as well as in connecting the region to global centers of innovation. Such Latin American cities can thus be considered as *relational cities*, i.e. cities that intermediate between global and regional knowledge networks (Sigler & Martinus, 2017).

However, we find that not all collaborative links have the same effect on innovation: while links with other Latin American cities do not seem to influence innovation, connections with cities in other parts of the world do generate positive impacts. In addition, we find that being a broker or a gatekeeper city seems to negatively affect future patenting levels. Hence, while knowledge networks can show mostly benefits for the whole system, those cities that intermediate both within the region and between the region and other parts of the world experiment negative effects in their innovation performance.

Analyzing these results on the backdrop of the current wisdom about Latin-American ISs functioning, we find large evidence highlighting the systemic weaknesses and the outward orientation of this IS. Latin American ISs have been characterized as immature with actors and territories operating mainly in isolation (Rapini et al., 2009). Such systems are composed by heterogeneous agents, and most dynamic activities have usually been concentrated around regional nodes, regularly composed by public research institutes and dynamics firms. This situation has received great attention, in particular regarding the concentration and unequal development of research and innovation capacities at the regional level (de Araújo, Gonçalves, & Taveira, 2019; Fischer et al., 2018; German-Soto & Gutiérrez Flores, 2015; Montaño & González, 2007; Niembro, 2020). However, this issue has rarely been studied from a continental systemic approach (Confraria & Vargas, 2019).

Our results corroborate that, even though a growing number of innovators are collaborating from different cities in the region, the Latin American innovation network still reflects great concentration in its main metropolitan regions. We contribute to this extensive literature by showing that most dynamic agents (i.e. broker cities) face high costs associated to coordination efforts as well as to knowledge access and diffusion.

Theoretical framework

According to the building blocks of the systemic approach to innovation, ISs are dynamic networks of agent's interactions, where internal and external knowledge are exchanged, used and reproduced (Freeman, 1991). This approach also emphasizes the ISs dynamic nature, describing the uneven ISs' evolution paths where different components play different roles allowing a final emergent (i.e. innovation) which is not equal to the sum of the components (Erbes, Robert, & Yoguel, 2010).

These IS's attributes are basic milestones in systems approach that are potentially observable in any system (Katz & Ronda-Pupo, 2019). This approach is particularly relevant for the study of the Latin American IS for several reasons. First, from the extensive accumulation on innovation and development in Latin America, we know that heterogeneity prevails in the continent. Meanwhile the whole regional system shows, on average, a low innovation intensity, especially associated to the lack of systemic linkages between research and innovation spheres. There are also poles of high research and innovation capabilities (Arocena & Sutz, 2010; Castellacci & Natera, 2016; Confraria & Vargas, 2019). These poles have emerged around cities, usually where main universities, research centers, industry or public services are located (de Araújo et al., 2019). Second, due to its peripheral position in the global knowledge network, Latin American IS is critically dependent on external knowledge flows (Delvenne & Thoreau, 2017; Montobbio & Sterzi, 2011). To better understand these dynamics of interaction, we propose to study inter-city knowledge networks.

Cities as nodes in knowledge networks

As Johnson (2008) has posed, cities work as a solving problem environment in a national or regional IS. According to this view, cities are one type of IS, where the internal dynamics are determined by the city's specialization and by the benefits that such specialization generates on the agents that compose the IS. But, especially, by the interactive dynamics between collocated people and organizations that exchange and produce knowledge. Johnson's contributions are in line with more recent works from urban and regional studies that highlight cities as complex collective agents. According to this view, cities manage to build a particular environment associated to their specific specialization, which is usually due to the main organizations located in the city and the public policies at both regional and local levels. Furthermore, such environment is related to the cumulative knowledge interaction that is intrinsically associated to the historical process of each urban territory and is hardly transferable to other places (e.g. Breschi & Lenzi, 2015; Makkonen, Merisalo, & Inkinen, 2018).

Many of these knowledge interactions take place on a local scale, connecting actors located in the same territory. Yet, other collaborations transcend territories and connect actors located in different cities and even countries. These connections create inter-city networks, in which the nodes are localities and the links represent collaborative relationships, associated with innovation processes carried out by actors located in different cities (Fan et al., 2020; Maisonobe et al., 2016). Links in inter-city networks, as in other innovation networks, can generate both benefits and costs for the interconnected cities. And these benefits and costs each city will obtain will depend on the role it plays in the network.

In this regard, it is expected that different cities play different roles and the functioning of the urban IS will depend on with whom the city interacts and exchange knowledge (Johnson, 2008). This simple but consistent theoretical basis from the IS' approach meet the contribution from network studies, which identifies different roles as well as different internal and external effects associated with the position of nodes in networks.

As a general hypothesis we propose that intercity networks are relevant to determine the city innovation outcomes. The number of links connecting to a node determines its centrality in the network. This property, which has been widely studied by the literature, essentially reflects the prominence or relative importance of nodes, their capacity to influence other nodes and also their capacity to access the resources that flow through the network (Borgatti, 2005; Wasserman & Faust, 1994). Therefore, we can expect that occupying a central position in the network, through the maintenance of different collaborative links with other cities, will improve innovation performance.

Hypothesis 1. Centrality in the collaboration network improves the city's innovation performance

However, being central by having many links does not necessarily means playing a brokerage role. The concept and typologies of brokerage allows to understand how certain actors contribute to disseminate knowledge among the components of ISs and/or manage to introduce external knowledge into the local IS. We define broker cities as those that link others that are disconnected from each other, intermediating in knowledge flows within the regional IS. This role is associated with the formation of a regional network and contributes to the dissemination of knowledge on a Latin American scale. The challenge now is to analyze the effects of knowledge networks in the light of the costs and benefits involved in playing that role.

On the tradeoffs of brokerage

Innovation is an essentially interactive process that relies heavily on collaborative networks (Freeman, 1991). Network's linkages operate as a sort of channel where knowledge and information are exchanged in a more or less inbound/outbound fluxes composition.

Critical attributes of knowledge affect both the structure and the effects of these channels and process. First, a rich long run debate on the codified and tacit properties of knowledge have converged to a non-dichotomist but gradualist and continuum definition of knowledge, were pure tacit or codified knowledge are theoretical tools rarely observed in the empirical research (Johnson, Lorenz, & Lundvall, 2002; Malerba & Orsenigo, 2000). Therefore, channels involving knowledge and information exchange embrace both codified and tacit knowledge, which imply different capacities and costs. While knowledge codification soft access barriers to general principles potentially usable in many context; tacit knowledge usually requires high capacities and repeated interactions, but always, except theoretical scenarios, knowledge accessing require a minimal threshold of capacities to understand the code (language) and resources to sustain the channels (interactive linkages) (David & Foray, 1996).

Second, considering the attributes of knowledge as an economic good, many authors have stressed that the social (systemic) benefits may be greater than the private ones, due to the non-rivalry and partially excludable properties of knowledge (Foray, 2004). These attributes of knowledge may explain why more connected agents may incur in relatively higher cost because they soft access costs for their followers. By connecting other agents who would otherwise be disconnected, the actors who fulfill the role of broker can make a particularly valuable contribution to knowledge dissemination.

In peripheral regions of the world economy, such as Latin America, brokers are especially relevant for two reasons. First, because, due to external orientation of knowledge flows, networks normally have less internal connection between their nodes. In this sense, brokers contribute to keep the network connected at a regional level. Second, because innovation processes depend substantially on other regions of the world. In this sense, brokers can bring knowledge flows to the region from leading cities in other parts of the world (Confraria & Vargas, 2019; Reis, Gonçalves, & Taveira, 2018).

The literature has argued that brokerage positions in the networks can entail both costs and benefits for the broker (Kauffeld-Monz & Fritsch, 2013). On the benefits side, the links can provide access to valuable information and knowledge. In this sense, broker cities may have good access to non-redundant knowledge, which can be very valuable in innovation processes (de Araújo et al., 2019; Yao et al., 2020). However, holding a broker position implies maintaining links with cities that are disconnected from each other, which requires important coordination efforts. In the particular case of peripheral cities (such as our cities in the Latin American network), these coordination costs associated with brokerage may exceed the benefits in terms of access to knowledge flows. There are two reasons supporting this argument. First, on the cost side, the heterogeneity and disconnection inherent in Latin American ISs requires greater coordination efforts to keep the system's agents connected. Second, on the benefits side, the wealth and diversity of knowledge that flows in intra-regional collaborations may be of limited value, given the region's structural lag in research and innovation activities.

Hypothesis 2. Being a broker in the inter-city network reduces innovation results.

The effects that networks can generate on innovation in cities will depend substantially on where the interconnected cities are located, since the available knowledge and innovative capabilities vary substantially from one region of the world to another. In our study, the network integrates both Latin American cities and cities located outside the region, some of them in the world centers of innovation development. As a result, we can ask if intra-regional links influence innovation in the same way as links connecting to cities outside Latin America.

Given the region's weaknesses in generating knowledge and innovations, we can expect the effects of networks on Latin American cities to differ, depending on whether we consider the links they maintain with other cities in the region or those that connect them to cities in other parts of the world, particularly with global centers of technological development.

Hypothesis 3. Extra-regional collaborations improve innovation while intra-regional collaborations do not.

Data and methods

We use data from the US Patent & Trademark Office (USPTO) retrieved from the PatentsView database. Such database incorporates disambiguated identifiers for inventors and innovators, which is critical for building collaboration networks. Since our research focus is on Latin American cities, we search for patents involving at least one inventor located in a Latin American country.[1]

The nodes of our networks are the cities where the owners of the selected patents are located. Patent owners are mostly firms, but research centers, universities, public agencies and even individuals can also own patents. Some inventions are co-patented by different innovators (i.e. patent owners), which often reflects a collaborative innovation process involving different actors. When these actors are located in different cities, then we establish a collaboration link between those cities. Some of the selected patents are co-owned by actors located outside Latin America. This leads us to include in our networks not only Latin American cities, but also locations from other parts of the world, which allows analyzing intra-regional vs. extra-regional collaboration links.[2]

[1] A detailed explanation on the process of data extraction and processing can be found in Bianchi et al. (2020).

[2] Depending on where the interconnected cities are located, the links in our networks can be classified into three broad categories: (1) intra-regional links, (2) links from Latin American cities to other parts of the world and

In order to focus on the most relevant nodes and links, we apply backbone extraction methods, which allows to determine statistically significant links between the innovators (patent's owners), based on the number of co-patents (Z. Neal, 2014).[3] Once the existence of each connection between cities has been determined through this method, our networks consider only binary, unweighted links.

Between 2006 and 2017, particularly until 2014, the region experienced a process of economic growth, largely driven by increased international demand and prices for raw materials. Along with economic growth, the region increased its patenting levels during those years (Bianchi, Galaso, & Palomeque, 2020; WIPO, 2018). This is the main reason for choosing this period of analysis, since, although data is available prior to 2006, the number of Latin American inventions is very low, so that the networks prior to our period have very few cities and are highly disconnected.

We build four-year windows and elaborate one network for each time window.[4] We then calculate different network statistics that measure each city brokerage roles and compare intra-regional collaborations with connections towards other regions of the world.

We test our hypotheses using panel data regression models that allow us to estimate how brokerage and intra-regional vs. extra-regional connections may influence the innovative performance of cities. The dependent variable in our models is an indicator of innovation results of cities: the number of patents registered by actors located in each city in each sub-period. The use of patents as an indicator of innovation has been widely discussed

(3) links connecting pairs of cities outside of Latin America. While our data allows to adequately measure the first two types of links, in the third type (i.e. connections between non-Latin American cities) our data only measure a portion (presumably very small) of all the existing collaborative links. However, this is not a problem for our research since both our analytical approach and our methodology is focused on the first two types of links.

[3] The approach followed for the backbone extraction is the "agent-degree conditioned threshold", which compares the observed number of co-patents, with a null model that controls for the number of patents each innovator has (Z. Neal, 2013).

[4] Time windows are used in the literature since it is assumed that the actors involved in co-patents collaborate before and after the patent application date (see e.g. Andersson, Galaso, & Sáiz, 2019; Breschi & Lenzi, 2015; Fleming, King, & Juda, 2007).

in the literature (Archibugi, 1992; Griliches, 1990) and has been used by similar studies (De Noni, Ganzaroli, & Orsi, 2017; Yao et al., 2020). Being aware of its limitations, we consider that this indicator is consistent since it captures knowledge creation involving Latin American innovators and, even under registering the wide variety of non-patentable innovation outcomes, it offers homogeneous information for the entire regional IS. In addition, at Latin-American scale, there are no other indicators that allow us to compare the evolution of innovation activities in cities.

The independent variables used in our models measure the relative position of each city in the network as well as the connections it maintains with different regions of the world. All these variables (along with the control variables that will be explained later) are calculated with a lag of one period. Thus, our models estimate whether the network characteristics at time *t* influence the level of patenting obtained by cities at time *t*+1.

In order to test our first hypothesis, we measure centrality of Latin American cities in the network and their brokerage role. *Degree centrality* measures the number of links adjacent to each city. It is used as a measure of its prominence or relative importance in the network (Wasserman & Faust, 1994). The brokerage role played by cities is measured using Gould & Fernandez´s (1989) indicators. To do so, we group the cities in two broad categories: Latin American and non-Latin American locations. This allows us to measure two different brokerage roles. First, the *coordinator* role accounts for intermediation between pairs of Latin American cities. Second, the *gatekeeper* role measures the intermediation between extra-regional cities and other Latin American cities. The formal definition and calculation of these network indicators can be found in Gould & Fernandez (1989).[5]

In order to test our third hypothesis, we use variables that account for intra-regional vs. extra-regional connections. In particular, we calculate the number of links connecting each city with other Latin American cities, and the number of links with cities located in other parts of the world. Finally, we disaggregate this last variable, differentiating between

[5] Based on our data, a third type of broker role proposed by Gould and Fernández could also be calculated: the *itinerant* role (i.e. Latin American cities that mediate between cities located outside the region). However, such position does not represent a brokerage role on a regional scale, since it does not intermediate between any Latin American city. Therefore, we decided not to include it in our analysis.

connections with European cities, links with cities located in the United States and Canada and links with East Asian cities.

Of course, other factors may determine the propensity to patent in cities. To account for these factors, our models include the following control variables. First, to control for the size of the city and the agglomeration of innovators, we consider the number of inventors and the number of patent owners located in each city. Second, we account for the number of technological fields in which the city patents in order to control for the technological specialization and diversification of cities. Third, the number of patents in the previous year is used to account for other unobserved heterogeneity in cities' propensity to patent, such as the evolution of local economic activity or investments in technology. Finally, in line with the argument elaborated above, we include city fixed effects in order to control for unobserved structural dimensions of cities related to their accumulation of capacities that may be influencing their patenting levels (e.g. the educational level, the institutional framework or the industrial atmosphere).

The number of patents, inventors, innovators and technologies are strongly correlated, which may lead to collinearity problems. Therefore, we perform a factor analysis in order to group them into fewer dimensions. We find that a single factor is adequate to replace these four control variables, even maintaining more than 90% of the variance that they provide (see Appendix A1). Consequently, we create the variable *factor* that will be included in the models, as the control variable, along with the city fixed effects.

Since the dependent variable (i.e. the number of patents) is a count variable that takes strictly positive integer values and presents overdispersion, negative binomial models are the most suitable for our regressions. Such models are extensively used in the literature studying patent data (Fleming, King, & Juda, 2007; Galaso & Kovářík, 2020; Owen-Smith & Powell, 2004; Schilling & Phelps, 2007; Yao et al., 2020). Furthermore, in our estimations we follow the so-called within-between approach (Allison, 2009; Bell, Fairbrother, & Jones, 2019; Schuknecht & Siegerink, 2020). This approach allows us to explicitly model variations in patenting levels explained by cities' characteristics as well as by variations in such characteristics through time. Within-between models combine the advantages of fixed- and random-effects models, while partially offsetting their respective disadvantages (Schulz, 2020).

Results

A descriptive analysis of our networks is presented in Table 1. Latin American cities represent only between a quarter and a fifth of the network's nodes. Furthermore, extra-regional links (i.e. collaborations between Latin American cities and cities in other parts of the world) are three times more numerous than intra-regional connections. This evidence gives us a first overview of the weak collaboration between the cities of the region and the strong dependence that innovation in Latin America has on connections with other parts of the world.

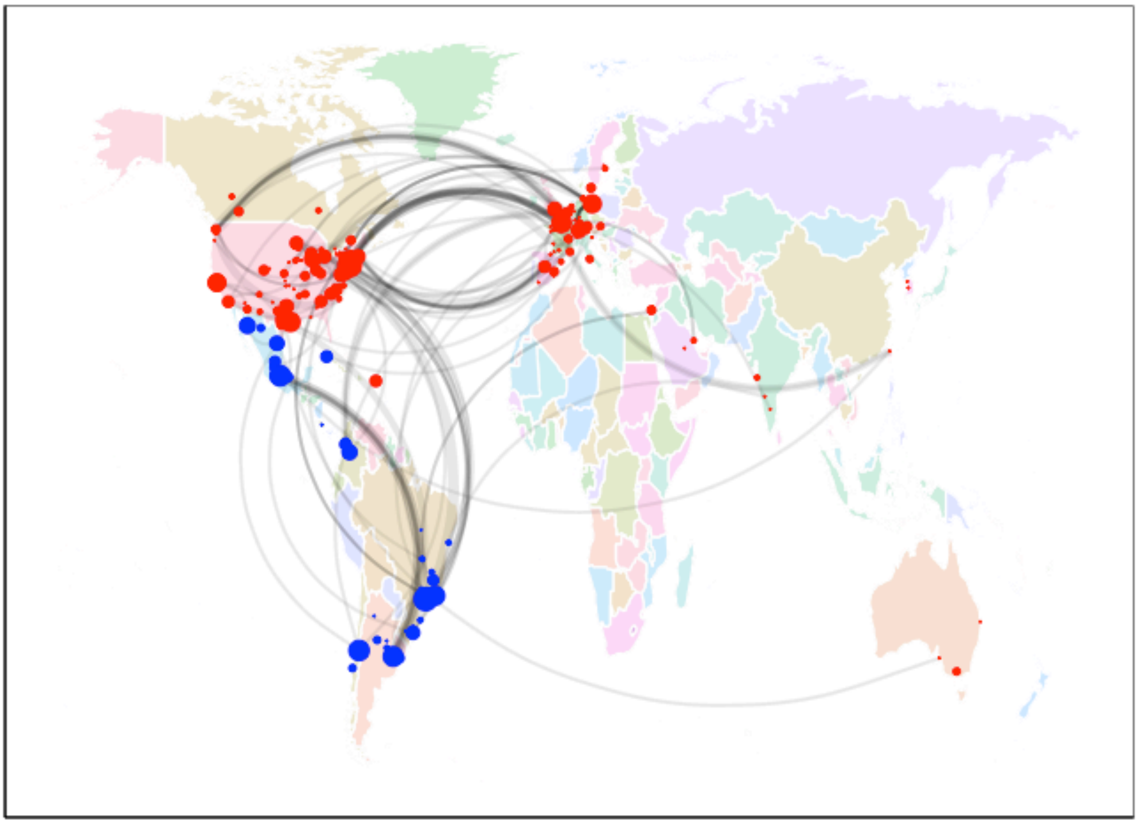
Table 1. Inter-city Network Characteristics

	2006-2009	2010-2013	2014-2017
Number of cities (nodes)	254	348	284
Latin American (LA) cities	62	71	51
European cities	70	86	72
North American cities	111	151	149
East Asian cities	5	26	3
Cities in the rest of the world	6	14	9
% LA cities	*24.4*	*20.4*	*18.0*
% non LA cities	*75.6*	*79.6*	*82.0*
Links	623	979	762
LA-LA links	47	75	42
LA-Europe links	46	89	76
LA-North America links	115	124	127
LA-East Asia links	0	10	4
LA-non LA links	163	233	216
non LA-non LA links	413	671	504
% LA-LA links	*7.5*	*7.7*	*5.5*
% LA-non LA links	*26.2*	*23.8*	*28.4*
% non LA- non LA links	*66.3*	*68.5*	*66.1*

Source: authors based on PatentsView data.

Figure 1 depicts a representation of the network in the last period (between 2014 and 2017). In addition, a list of the Latin American cities that are part of our network, along with their levels of patenting, can be found in Appendix A2. The network map corroborates the disconnection among Latin American cities, that are mainly linked to cities in the United States and (although to a lesser extent) to cities in Europe and other parts of the world. The map also allows to observe some strong connections between Latin American cities, such as the links between Mexico City and South American cities, in particular with Buenos Aires (Argentina), which is arguably the result of the long tradition of Mexican research on both outward and inward Latin American collaboration networks (Morales Valera & Sifontes, 2014).

Figure 1. Inter-city collaboration network in Latin America



Source: authors based on PatentsView data.

In order to test our hypotheses, we estimate the influence of different network variables on patents outcomes. Descriptive statistics and correlations between variables are available in Appendix A3. Models 1-3, reported in Table 2, allows us to test the first two hypotheses by analyzing the effects of centrality and brokerage on patenting results. The between-city effects indicate how the average level recorded by cities for each independent variable influences their average level of patenting. On the other hand, the within-city effects can be interpreted as the influence of variations that each city records in its independent variables on changes in its future level of patenting.

Table 2. Negative Binomial Regressions: Models 1, 2 and 3

	Model 1	Model 2	Model 3
Intercept	2.486 ***	2.488 ***	2.482 ***
	(0.109)	(0.097)	(0.096)
Between-city effects			
Degree centrality	0.357	0.939 ***	0.927 **
	(0.255)	(0.273)	(0.298)
Coordinator	-1.019 ***		-0.055
	(0.245)		(0.374)
Gatekeeper		-1.758 ***	-1.693 **
		(0.317)	(0.561)
Factor	1.597 ***	1.793 ***	1.794 ***
	(0.278)	(0.251)	(0.251)
Within-city effects			
Degree centrality	0.035	0.089	0.130 *
	(0.059)	(0.081)	(0.056)
Coordinator	0.073		0.056
	(0.054)		(0.038)
Gatekeeper		-0.111	-0.091
		(0.069)	(0.059)
Factor	-0.103 .	-0.049	-0.097 **
	(0.056)	(0.038)	(0.034)
Pseudo-R^2 (fixed effects)	0.774	0.823	0.811
Pseudo-R^2 (total)	0.946	0.946	0.947
AIC	431.969	423.065	435.081
BIC	451.113	442.209	458.480
Log Likelihood	-206.985	-202.532	-206.541
Num. obs.	62	62	62
Num. groups: name	31	31	31
Var: name (Intercept)	0.263	0.187	0.212

Standard errors in parentheses; *** p<0.001; ** p<0.01; * p<0.05; . p < 0.1.

Source: authors based on PatentsView data.

The estimations show that the within-city effects are clearly more relevant than the between-city effects. Most importantly, these results provide empirical evidence to support our first two hypotheses. We observe that being a central city in the network (measured by its degree centrality) is associated with obtaining better innovative performance (measured by its number of patents). Second, we find that being a broker in the network seems to negatively influence patenting levels of cities. The negative effect of being a broker is observed for both types of roles: coordinator and gatekeeper. Yet, model 3 reveals that playing a gatekeeper role, i.e. intermediating between extra-regional cities and other Latin

American cities, seems to be particularly costly in terms of the lower patenting levels involved.

Further investigating the geographical scope of collaborations, we find that the effects of networks on innovation vary when we differentiate between intra- and extra-regional collaboration links. This evidence, reported in Table 3, supports our third hypothesis: links with other Latin American cities do not seem to influence innovation, while connections with cities outside the continent do generate positive impacts on patenting levels. Again, only the between-city effects are relevant.

Table 3. Negative Binomial Regressions: Models 4, 5 and 6

	Model 4	Model 5	Model 6
Intercept	2.487 ***	2.488 ***	2.486 ***
	(0.106)	(0.097)	(0.097)
Between-city effects			
Intra-regional links	0.463	0.203	0.138
	(0.281)	(0.220)	(0.282)
Extra-regional links	0.075	0.771 **	0.877 *
	(0.229)	(0.239)	(0.371)
Coordinator	-1.213 ***		0.219
	(0.285)		(0.595)
Gatekeeper		-1.737 ***	-1.987 **
		(0.327)	(0.760)
Factor	1.622 ***	1.760 ***	1.759 ***
	(0.278)	(0.257)	(0.258)
Within-city effects			
Intra-regional links	-0.064	-0.059	-0.100
	(0.069)	(0.066)	(0.079)
Extra-regional links	-0.025	-0.156	-0.153
	(0.075)	(0.167)	(0.163)
Coordinator	0.058		0.080
	(0.089)		(0.089)
Gatekeeper		0.084	0.133
		(0.150)	(0.154)
Factor	-0.044	-0.010	-0.044
	(0.065)	(0.051)	(0.062)
Pseudo-R^2 (fixed effects)	0.786	0.822	0.821
Pseudo-R^2 (total)	0.946	0.946	0.946
AIC	433.896	427.716	430.814
BIC	457.294	451.114	458.467
Log Likelihood	-205.948	-202.858	-202.407
Num. obs.	62	62	62
Num. groups: name	31	31	31
Var: name (Intercept)	0.245	0.189	0.192

Standard errors in parentheses; *** p<0.001; ** p<0.01; * p<0.05; . p < 0.1.

Source: authors based on PatentsView data.

Given the crucial role that extra-regional collaborations seem to play on Latin American innovation, we finish our analysis investigating further the orientation of these inter-city connections. To do so, we analyze separately the effects of collaborating with cities located in Europe, in Anglo-Saxon North America and in Asia.

Table 4 summarizes our findings from such analysis. As reported here, we find that extra-regional links also have different impacts on innovative performance, depending on the region of the world to which Latin American cities are connected. In particular, we observe that links with western regions, Europe and North America, that historically play a central role in the Latin American research and innovation landscape, appear to be associated with higher patenting levels. However, connections with Asia are associated with poorer innovation performance of cities. This finding seems to indicate a kind of cumulative effects that knowledge exchanges could have on the patenting results of cities in the region.

In these models, we also obtain an interesting –and unexpected– finding when comparing the between-city and within-city effects: the results show opposite outcomes for these effects. In particular, we find that, while maintaining a high number of links with European and North American cities is associated with having high patent levels, increasing the number of links with such regions reduces patenting levels in further periods. In the case of links to Asia, the exact opposite is true. Complementing the conjecture presented in the last paragraph, these results seem to indicate differences between the additional costs and benefits of establishing new extra-regional collaborations versus the additional costs and benefits of having already consolidated extra-regional connections.

Finally, we obtain an analogous result regarding the role of coordinator: the negative and significant between-city effect is maintained (as in the rest of our models), while models 8 and 10 also report positive and significant results in the within-city effect of this brokerage role. This result slightly nuances our conclusion regarding our second hypothesis, indicating that, although occupying coordinator positions is associated with registering, on average, lower levels of patenting, achieving improvements in the coordinator level can lead cities to subsequent increases in their patenting results.

Table 4. Negative Binomial Regressions: Models 7-10

	Model 7	Model 8	Model 9	Model 10
Intercept	2.848 ***	2.482 ***	2.483 ***	2.481 ***
	(0.269)	(0.097)	(0.094)	(0.094)
Between-city effects				
Intra-regional links	-0.235 *	0.073	0.025	-0.014
	(0.098)	(0.311)	(0.274)	(0.303)
Links to Europe	0.043	0.101	0.235 *	0.256 .
	(0.058)	(0.115)	(0.118)	(0.143)
Links to North America	0.074 *	0.227	0.572 ***	0.640 *
	(0.037)	(0.183)	(0.173)	(0.297)
Links to East Asia	-1.059 ***	-0.402 *	-0.125	-0.097
	(0.306)	(0.182)	(0.212)	(0.247)
Coordinator		-0.903 **		0.169
		(0.291)		(0.676)
Gatekeeper			-1.463 ***	-1.676 .
			(0.403)	(0.975)
Factor	1.589 ***	1.841 ***	1.856 ***	1.847 ***
	(0.292)	(0.271)	(0.261)	(0.260)
Within-city effects				
Intra-regional links	-0.035	-0.140 *	-0.022	-0.120 .
	(0.044)	(0.059)	(0.051)	(0.063)
Links to Europe	-0.036 *	-0.051 .	0.093	0.018
	(0.014)	(0.028)	(0.087)	(0.092)
Links to North America	-0.069 *	-0.075	-0.099	-0.047
	(0.034)	(0.098)	(0.102)	(0.104)
Links to East Asia	0.233 *	0.163 *	0.328 **	0.236 *
	(0.113)	(0.073)	(0.114)	(0.119)
Coordinator		0.185 **		0.165 **
		(0.058)		(0.063)
Gatekeeper			-0.336 .	-0.146
			(0.172)	(0.186)
Factor	-0.100	-0.077 *	-0.022	-0.075 *
	(0.258)	(0.036)	(0.030)	(0.036)
Pseudo-R^2 (fixed effects)	0.751	0.806	0.819	0.820
Pseudo-R^2 (total)	0.948	0.946	0.946	0.947
AIC	449.894	435.796	439.017	436.298
BIC	477.547	467.703	470.924	472.460
Log Likelihood	-211.947	-202.898	-204.508	-201.149
Num. obs.	62	62	62	62
Num. groups: name	31	31	31	31
Var: name (Intercept)	0.314	0.218	0.198	0.198

Standard errors in parentheses; *** p<0.001; ** p<0.01; * p<0.05; . p < 0.1.

Source: authors based on PatentsView data.

Discussion and Conclusion

Research on innovation and regional development follows a fascinating path that often opens up more questions than conclusive answers. Knowledge networks have been widely studied from different approaches making relevant contribution to the topic. In this sense, recent research on inter-city networks analyzed the effects of knowledge networks on the performance of localities. This article contributes to this stream of research by shedding light on the trade-off effects that knowledge networks can imply for cities performing brokerage roles.

We interpret the brokerage role played by some cities as a function that builds and sustains the infrastructure for knowledge channels (David & Foray, 1996). Departing from some basic elements of the IS approach, we examine the trade-offs of brokerage from a non-dichotomist perspective. That is, beyond considering the costs or benefits of brokerage, we seek to understand the complex non-linear effects on innovation processes that are carried out by heterogeneous agents from different geographical locations. Moreover, we exploit recent methodological advances from social network analysis to deepen this complex interaction, identifying intra- and inter-regional knowledge connections, and distinguishing different brokerage roles.

In this sense, the evidence reported here allows corroborating some structural characteristics of the Latin American IS, largely expressed in previous research. In particular, our networks reveal the extra-regional orientation of collaboration links, which is in line with a peripheral position of the region in global knowledge networks.

However, instead of describing the already known external dependencies and internal heterogeneities of the region, we analyzed the role of cities as systemic agents. We corroborated for the Latin American IS, the positive effects on patenting shown by the central nodes in inter-city networks (Yao et al., 2020). However, unlike these authors, we shed light on the trade-offs faced by broker cities in the region. These cities seem to face relatively higher costs than the benefits they obtain from knowledge networks. Although these conclusions are consistent with the extensive research background on regional and national

IS in Latin America, to the best of our knowledge, the trade-off effects reported here has not been previously measured or estimated at the continental level.

In our latest set of models, we also find opposite results for the within-city and between-city effects of extra-regional links on innovation. It is worth discussing these findings from a dynamic perspective and in the light of firm-level innovation studies. Based on this approach, we can conjecture that the effects of links with cities located in advanced regions have a non-linear effect on the patent production of Latin American cities. An effect that varies according to time and the accumulation of local interactive capacity. For example, maintaining links with North America and/or Europe seems to positively affect innovation performance to a certain extent. From that point onwards, new collaborations may imply an investment and capacity allocation effort that disproportionately increases the cost of collaboration, until the probability of obtaining patentable results in the immediately following period is reduced. On the other hand, new collaborations established with emerging Asian countries appear to bring even more benefits than costs, as they are associated with improvements in patenting levels during the years following the collaboration.

Further research on inter-city networks from a regional IS approach is essential. In particular, because, unlike networks at the national level, in continental regional systems, cities do not interact according to a single systemic coordinator –that is, according to a national state– as may be the case with cities in countries of continental size but centrally planned development strategies (Fan et al., 2020; Yao et al., 2020). This type of research, particularly for the Latin American region, is relevant in light of the great effort made by the region's governments to promote innovation and patenting during the last decades, and the secular concern in the region for integrative continental projects that contribute to such national plans. Thus, future research in this area will be very relevant inputs to these projects.

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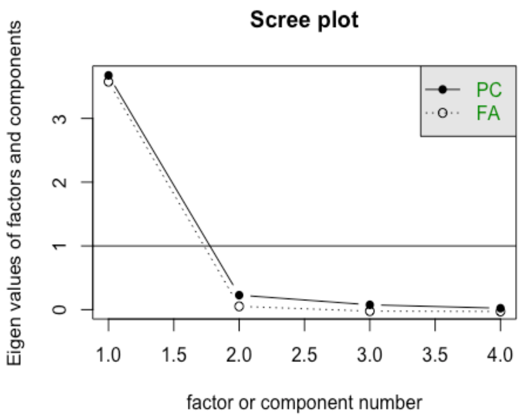
APPENDIX

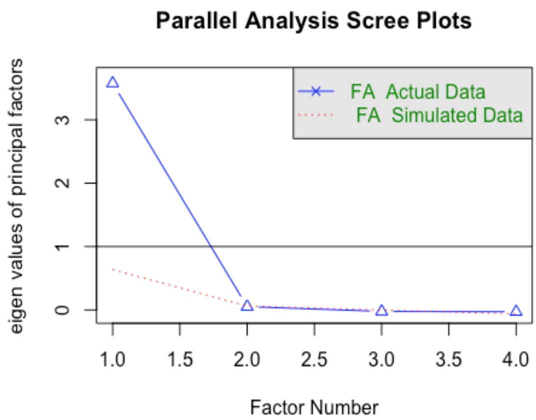
A1. Factor analysis tests and results

Kaiser-Meyer-Olkin factor adequacy
Call: KMO(r = controls)
Overall MSA = 0.8
MSA for each item

Number of patents	Number of owners	Number of inventors	Number of technological fields
0.72	0.82	0.79	0.93

Bartlett test of homogeneity of variances
data: controls
Bartlett's K-squared = 528.8, df = 3, p-value < 2.2e-16





Source: authors based on PatentsView data.

Note: both the MSA and the Bartlett test results (above) indicate that performing a factor analysis with our data is perfectly adequate. Regarding the most appropriate number of factors, both the Scree plot curve and the Parallel Analysis Scree Plots (below) suggest the use of one single factor.

A2. Latin American cities included in our knowledge networks

City	Country	Number of patents (2006-2017)
São Paulo	Brazil	596
Mexico City	Mexico	322
Rio de Janeiro	Brazil	270
Santiago	Chile	235
São José dos Campos	Brazil	167
Buenos Aires	Argentina	152
Monterrey	Mexico	94
Cadereyta Jiménez	Mexico	85
La Habana	Cuba	81
Bogotá	Colombia	55
Hermosillo	Mexico	50
Jundiaí	Brazil	47
Porto Alegre	Brazil	44
Campinas	Brazil	41
Camaçari	Brazil	28
Belo Horizonte	Brazil	27
Montevideo	Uruguay	25
Brasilia	Brazil	21
Medellín	Colombia	21
Corinto	Brazil	18
Ciudad Apodaca	Mexico	16
Florianópolis	Brazil	14
Heroica Veracruz	Mexico	14
Concepción	Chile	12
Santa Fe	Argentina	12
San Nicolás de los Garza	Mexico	11
Rosario	Argentina	10
Valparaíso	Chile	10
Araraquara	Brazil	5
Juiz de Fora	Brazil	5
Valparaíso de Goiás	Brazil	4

Source: authors based on PatentsView data.

A3. Statistical Summary and Correlation Analysis

		Mean	SD	Min.	Max.	1	2	3	4	5	6	7	8	9	10
1	Number of patents	26.63	41.38	1	219	1									
2	Factor	0.05	1.08	-0.62	4.64	0.95	1								
3	Degree Centrality	0.03	0.03	0.00	0.17	0.79	0.87	1							
4	Intra-regional links	2.50	2.83	0	15	0.76	0.82	0.79	1						
5	Extra-regional links	5.19	8.46	0	50	0.65	0.77	0.95	0.62	1					
6	Links to Europe	1.77	3.02	0	14	0.32	0.46	0.57	0.37	0.65	1				
7	Links to North America	3.06	6.09	0	32	0.64	0.72	0.91	0.59	0.93	0.34	1			
8	Links to East Asia	0.16	0.91	0	6	0.47	0.58	0.66	0.38	0.78	0.41	0.73	1		
9	Coordinator	4.23	14.25	-0.65	96.57	0.80	0.84	0.72	0.88	0.53	0.35	0.48	0.31	1	
10	Gatekeeper	3.81	13.08	-0.88	84.28	0.74	0.87	0.92	0.75	0.91	0.56	0.84	0.81	0.73	1

Source: authors based on PatentsView data.