Determinants of university and industrial patents in Brazilian regions: a Spatial Panel Approach

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Resumo: Academia e indústria têm normas e incentivos diferentes para participar do processo inovativo que se reflete em diferentes focos e especializações. Considerando a crescente importância das patentes universitárias em um grande número de países, a partir de uma Função Regional de Produção de Conhecimento esse trabalho analisa separadamente as patentes industriais e universitárias para o Brasil de 1998 a 2018 usando um painel espacial para 133 regiões. Este trabalho visa definir o papel desempenhado pelos diferentes determinantes citados na literatura sobre patenteamento universitário e industrial de inovação em países em desenvolvimento com um painel mais amplo e mais recente utilizando um recorte regional hierárquico-funcional. Nossos resultados incluem diferenças entre inovações acadêmicas e industriais em relação aos esforços de P&D, aglomeração urbana e conexões de rede. Além disso, encontramos uma grande fonte de heterogeneidade e diferenças na inovação, como perfil tecnológico complementar. Além disso, encontramos especificidades para as regiões Norte e Sul do Brasil em relação aos padrões de inovação e exploramos a heterogeneidade dos dados de patentes para patentes internacionais (PTC), patentes co-inventadas e modelos de utilidade. Esses resultados são importantes para entender o real efeito de cada tipo de patente, ajudando a direcionar políticas públicas de inovação específicas para desenvolver indústrias e conhecimento universitário em regiões periféricas.

Palavras-chave: Função de Produção do Conhecimento Regional; País em desenvolvimento; Patentes; Redes.

Código JEL: C31, O31, O33, R1.

Área Temática: 4.5 Geografia do Conhecimento e da Inovação

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Abstract: Academia and industry have different norms and incentives to participate in the innovative process which reflects in different focuses and specializations. Considering the growing importance of university patents in great number of countries, we use a Regional Knowledge Production Function to evaluate industrial and university patents separately for Brazil from 1998 to 2018 using a spatial panel for 133 regions. This work aims to define the role played by the different determinants cited in the literature on university and industrial patenting of innovation in developing countries with a broader and more recent panel using a hierarchical-functional regional cut. Our results include differences between academic and industrial innovations regarding R&D efforts, urban agglomeration and network connections. Also, we find a great source of heterogeneity and differences in innovation, like complementary technological profile. Moreover, we find specificities for the North and South regions of Brazil regarding innovation patterns and explore heterogeneity of patent data for international patents (PTC), co-invented patents and utility models. These results are important to understand the real effect of each type of patent, helping to direct public innovation policies specific to develop industries and university knowledge in peripheral regions.

Keywords: Regional Knowledge Production Function, Developing Countries, Patents, Networks.

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1. Introduction

It is widely known in the innovation literature that academia and industry have different norms and incentives to participate in the innovative process reflecting in different focuses and specializations (MERTON, 1973; PARTHA; DAVID, 1994).

At the same time, the relationship between university and industry regarding innovation is very relevant and has been the focus of extensive analysis, especially with the increasing complexity of the knowledge. These studies analyze formal relationship channels such as university-industry cooperation (ANATAN, 2015; PERKMANN *et al.*, 2013; PÓVOA; RAPINI, 2010), informal channels, such as knowledge spillovers (BARRA; MAIETTA; ZOTTI, 2019; MESSENI PETRUZZELLI; MURGIA, 2020), or even indirect relationships such as the training of qualified personnel (FLORIDA, 1999; ZUCKER; DARBY; BREWER, 1998).

In addition, the university has increasingly assumed a direct role in innovation, especially in the generation of new patents. This change is associated with legal changes such as the Bayh Dole Act of 1980 in the USA (MOWERY *et al.*, 2001), but also with the change in the view of universities as important players in innovation ecosystems such as the paradigm Triple-Helix and the increase in the number of Technology Parks or TTOs (ETZKOWITZ; LEYDESDORFF, 2000). As a result, almost every country has seen an increase in the relevance of universities in terms of total patents.

In fact, there has been a growing literature on patents dealing with the patenting of academics and universities (DIAS; PORTO, 2018; GEUNA; NESTA, 2006; LISSONI *et al.*, 2013) and how these changes have changed the number and profile of university patents. In this context, it's expected that there would be an interest in the literature on Regional Innovation in analyzing not only patents as a whole, but in evaluating industrial and university patents separately.

At its origin, the Regional Knowledge Production Function (RKPF) considers the role of universities in the generation of patents as a whole (JAFFE, 1989) and, even some recent works continue to evaluate this role (GONÇALVES; MATOS; ARAÚJO, 2019; SANTOS; MENDES, 2021). However, the literature did not show an effort to delve into the different determinants of industrial and university innovation and, above all, they did not seek to assess the specificities of innovation of universities or industry in regions.

In this sense, the objective of this work is to analyze the different determinants of university and industrial patents in Brazil using an RKPF with data from 1998 to 2018. This aims to define the role played by the different determinants cited in the literature such as R&D efforts, urban agglomeration and network connections for the generation of new university and industrial patents.

The growth of university patents alone would justify this effort (30% of patents in Brazil in 2018), in addition, a rich source of heterogeneity and differences in innovation in an environment that have a complementary technological profile are neglected (LISSONI, 2012). Furthermore, using a single indicator such as total patents implies assessing the overall average effect, which could misdirect public innovation policies. Also, this paper aims to fill the gap in the RKPF literature for developing countries.

The inventive activity has been growing continuously in Brazil. The annual number of patents filed by Brazilian inventors grew 118% between 1998 and 2018. At the same time, the patenting activity that was previously concentrated in the two large metropolitan areas (São Paulo and Rio de Janeiro) went through a process of geographic deconcentration with the emergence of new medium-sized regions with relevant innovative activity.

This paper is divided into 4 sections besides this introduction. In the first section, we present a literature review on Regional Innovation that adopts the RKPF as an analysis tool, focusing on literature for developing countries. In the second section, we present the model and the empirical strategy adopted. In the third section, we detail the variables used in this version and describe the methodological options for composing the spatial data. Finally, in the fourth section, we present the preliminary results.

2. Literature Review

In his seminal article, Jaffe (1989) established what became known as Regional Knowledge Production Function (RKPF). The author found that the regional innovation measured by patents was associated with local human capital and Industrial and University R&D. Since this study, there has been great interest in defining the determinants of local innovation.

The studies that followed it were progressively including to the RKPF more regional controls (AUDRETSCH; FELDMAN, 1996) and adopting variables and models of spatial econometrics (ACS; ANSELIN; VARGA, 2002; VARGA, 2000). Among these elements, it is worth highlighting the effects of urban agglomeration (CARLINO; CHATTERJEE; HUNT, 2007; CRESCENZI; RODRÍGUEZ-POSE; STORPER, 2012; LOBO; STRUMSKY, 2008; VARGA, 2000), industrial specialization/diversification (CAPELLO, 2002; CRESCENZI; RODRÍGUEZ-POSE; STORPER, 2012; MORENO; PACI; USAI, 2006; Ó HUALLACHÁIN; LESLIE, 2007), interregional spillovers (CHARLOT; CRESCENZI; MUSOLESI, 2015; FLEMING; KING; JUDA, 2007; MIGUÉLEZ; MORENO, 2013a; Ó HUALLACHÁIN; LESLIE, 2007) and path-dependence (FLEMING; KING; JUDA, 2007; GONÇALVES; DE OLIVEIRA; ALMEIDA, 2020). In the most recent period, there are also works that used co-patent networks (DE NONI; GANZAROLI; ORSI, 2017; MIGUÉLEZ; MORENO, 2013b; STRUMSKY; THILL, 2013), the concept of relatedness (BALLAND *et al.*, 2019; BOSCHMA; BALLAND; KOGLER, 2015; HE; FALLAH, 2014) or economic complexity (ANTONELLI; CRESPI; QUATRARO, 2020).

However, these studies focus on developed countries, especially the United States and Europe, with a few on developing countries, generally, concentrated in China (WANG *et al.*, 2016; YING, 2008), India (CRESCENZI; RODRÍGUEZ-POSE; STORPER, 2012) and Russia (CRESCENZI; JAAX, 2017), in addition to Brazil. Overall, their results indicate a geographic concentration of inventive activity in developing countries is higher than the average in developed ones. Crescenzi, Rodríguez-Pose and Storper (2012) find differences in the spatial dynamics of regional innovation spillovers between China and India and credit this to the configurations of their NISs and to the context of these countries. It is also worth highlighting the role of MNCs as regional innovation gateways and the long-term regional path-dependence found by Crescenzi and Jaax (2017) for Russia.

Regarding the determinants of regional innovation in Brazil, besides the usual factors such as agglomeration, virtually all papers find inter-regional spillovers, path-dependence and sectorial specificities (ARAÚJO, Veneziano de Castro; GARCIA, 2019; GONÇALVES *et al.*, 2018; GONÇALVES; DE OLIVEIRA; ALMEIDA, 2020; GONÇALVES; FAJARDO, 2011; GONÇALVES; MATOS; ARAÚJO, 2019) Furthermore, Gonçalves; De Oliveira; Almeida (2020) highlight the role of intra- and inter-regional co-patenting networks in local innovation.

So, in spite of the increasing importance of developing countries in the Global Innovation Networks, there are still few works that apply the RKPF framework to developing countries. Specifically, there is a gap in the literature because its evidence is concentrated in a short time window (between 1999 and 2011) and, in general, it adopts political-administrative regional aggregation levels and in several cases with broad geographical aggregation levels such as states or provinces.

In a sense, we seek to reassess these determinants for Brazil from geographical units that are more disaggregated and related to the urban functional structure with a longer and more recent panel (1998-2018). Also, we try to explore the heterogeneity related to its dependent variable by estimating models with all patents and with specific cuts such as utility models (YING, 2008), university patents (LISSONI *et al.*, 2013), international patents PCT (RODRÍGUEZ-POSE; WILKIE, 2019; YING, 2008).

3. Model

According to the Literature, considering the interregional knowledge, heterogeneity is fundamental to assess the regional innovation spatial dynamics. So, we estimate an RKPF using patents per capita as our dependent variable and regional innovation effort and socioeconomic context as our independent variables. The panel has 133 intermediate regions, and the periods are aggregated into 7 triennials. We estimate an RKPF using the following Spatial Error Model:

$$I_{r,t} = \beta_0 + \beta_1 R_{r,t-1} + \beta_2 Z_{r,t-1} + \beta_3 N_{r,t-1} + \beta_4 C_{r,t-1} + \beta_5 I_{r,t-1} + \lambda W u_t + \varepsilon_t$$

Where $I_{r,t}$ is the number of patents per capita in each region r, in period t. The $R_{r,t-1}$ vector indicates the local innovative effort, the $Z_{r,t-1}$ vector represents the socioeconomic and industrial characteristics, the $N_{r,t-1}$ vector specifies the co-patent networks. The lagged dependent variable ($I_{r,t-1}$) is used to capture the path-dependence effects, in addition to controls ($C_{r,t-1}$). The residual term u_t is calculated with the autoregressive parameter λ, which specifies the extent of the spatial autocorrelation. In this case, W is a normalized inverse distance Spatial Weight Matrix, which was selected by minimizing Akaike Information Criteria test (Appendix A1) following Zhang and Yu (2018). While ε_t represents the random error. So, we are trying to capture the path-dependence and inter-regional heterogeneity effects on Regional Innovation.

Dependent variable: Patent per capita

We generate patent data per capita from the count of patents applied in Brazil. Patent application and granting data are aggregated in a database for statistical purposes by the National Patent Office (INPI - Statistical Database on Intellectual Property – BADEPI). It is created from administrative records on intellectual property that include the nature of the deposit (patents or utility model), data on the depositor, the inventor, adherence to the PCT system and technological field. For the present work, fractional patent counts were generated from the inventor's data, after a process of geolocation and fractional attribution to the patent co-inventors' network. The number of geolocalized patents along the period is 71,177, which represents about 79% of the dataset. Patents have long been considered the best, though not perfect, output for innovation activity at the regional level possessing the advantage of being immediately available, measurable and comparable, both over time and across space (ASCANI *et al.*, 2020; KANG; DALL'ERBA, 2016; MIGUELEZ; MORENO, 2018)

Vector R: Regional R&D efforts

There are no regional variables for the expenditure of R&D activities in Brazil, so we measure local R&D efforts using proxies for Industrial and University R&D, R&DInd and R&DUniv, respectively. R&DInd is calculated using 'technical and scientific personnel' (PoTec) in the region. R&DUniv is composed of the number of graduate students in STEM careers in the region divided by total population, since these researchers are more linked to research efforts associated with innovation (ARAÚJO, Bruno César; CAVALCANTE; ALVEZ, 2009; GONÇALVES; DE OLIVEIRA; ALMEIDA, 2020; KANG; DALL'ERBA, 2016).

Vector Z: Industrial and socioeconomic context

To capture the socioeconomic and industrial context of the region we used human capital, agglomeration variables and industrial structure. For Human Capital (HK) we use the proportion of workers with a higher education degree in manufacturing. DensPop is the population data divided by the total area of the region and $DensPop^2$ is its quadratic term. HHI is the Hirschman–Herfindahl index that measures the sectorial diversification for the region (CHARLOT; CRESCENZI; MUSOLESI, 2015; GONÇALVES; DE OLIVEIRA; ALMEIDA, 2020; WANG *et al.*, 2016).

Vector N: Co-patent Networks

Finally, to measure the network's linkages, we use Betweenness which accounts for the position of the region in the whole network and Closeness that is calculated by the centrality level of the region in the co-patenting network. For that purpose, following Ter Wal (2013), we generate co-patent networks in a cumulative way assuming that social links between inventors persist over time.

These variables are summarized in the table below (Table 1).

Table 1 – Variables description

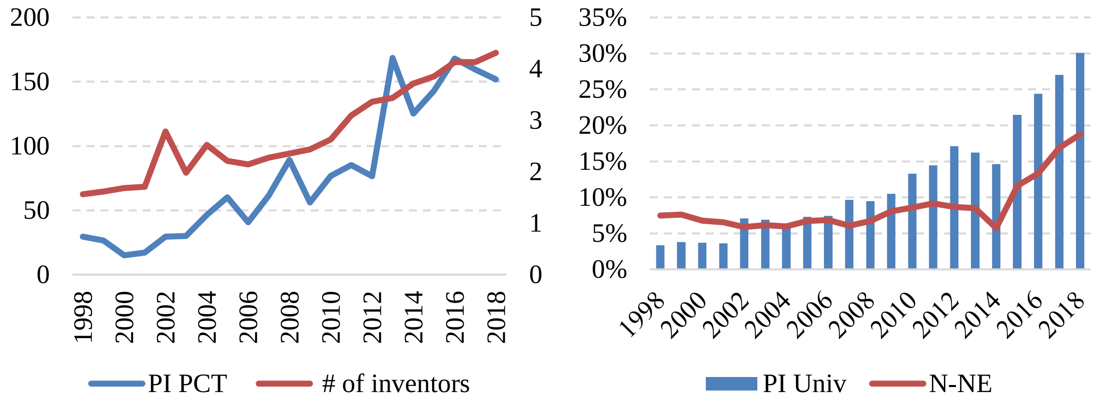
Variable	Description	Source
$PI_{r,t-1}$	Number of fractional patents per 100,000 inhabitants of the region in log form	BADEPI
$R\&DInd_{r,t-1}$	Number of 'technical and scientific personnel' (PoTec) of the region in log form	RAIS
$R\&DUniv_{r,t-1}$	Number of graduate scholarships in STEM per 100,000 inhabitants of the region in log form	CAPES
$HK_{r,t-1}$	Share of higher education personnel for the region employment	BADEPI
$DensPop_{r,t-1}$	Population density for the region	IBGE
$HHI_{r,t-1}$	Hirschman–Herfindahl index for the region employment in manufacturing	BADEPI
$Closeness_{r,t-1}$	Centrality level of the region in the co-patenting network	BADEPI
$Betweenness_{r,t-1}$	Position of the region in the whole network	BADEPI
Dummies UF	Dummies for Federal States	IBGE

Source: Own elaboration

In addition, it is important to highlight other methodological aspects relating to the territorial division adopted. For the study of regional innovation, the use of geographic units designed from a hierarchical-functional structure is particularly suitable. In its 2017 version, REGIC is divided into two main levels: 510 immediate regions and 133 intermediate regions. The immediate level corresponds to the delineation of urban centers by means of daily population flows for their immediate needs (labor, public and private services, etc.). The intermediate level groups some immediate regions into a pole of higher hierarchy differentiated from private and public management flows and the existence of more complex urban functions (IBGE, 2017). In this work, we chose intermediate regions that present sufficient granularity to assess regional innovation that allows comparison with studies for other countries.

4. Descriptive Analysis of Brazilian Heterogeneity

Patenting activity has been growing in Brazil, not only in terms of the number of patents, but also in their quality and in the density of inventor networks. As argued by Higham, De Rassenfosse and Jaffe (2021), international patents (PCT) can be considered as a proxy for higher level patents. Therefore, the continuous increase in PCT patents in Brazil – from 29 in 1998 to 151 in 2018, cf. Graph 1a – shows a significant expansion of qualified innovation in the country. In addition, it appears that innovations in the country also started to be more developed in collaborative environments, since the average number of inventors increased from 1.6 to 4.3 between 1998 and 2018.



(a) Average number of inventors vs. international patents

(b) Share of university patents vs. share of patents in North-Northeast region

Graph 1: Growth in patenting activity (1998-2018)

Source: Own elaboration

Besides the growth of the patenting activity, it is interesting to note the geographic distribution in Figure 1 below. It indicates a strong concentration in the South-Southeast region of patents per capita.

This technological inequality is well known, and it helps to illustrate the spatial dynamics of innovation and reinforces the need to deal with macro-regional spatial heterogeneity.

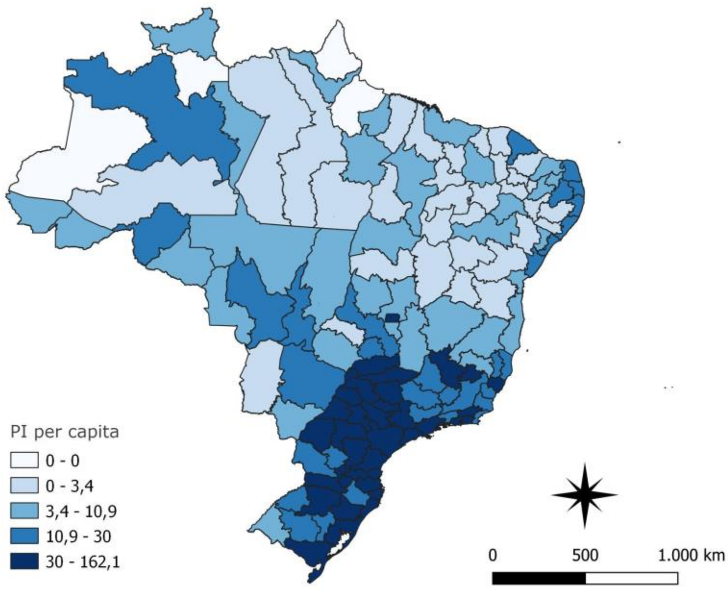
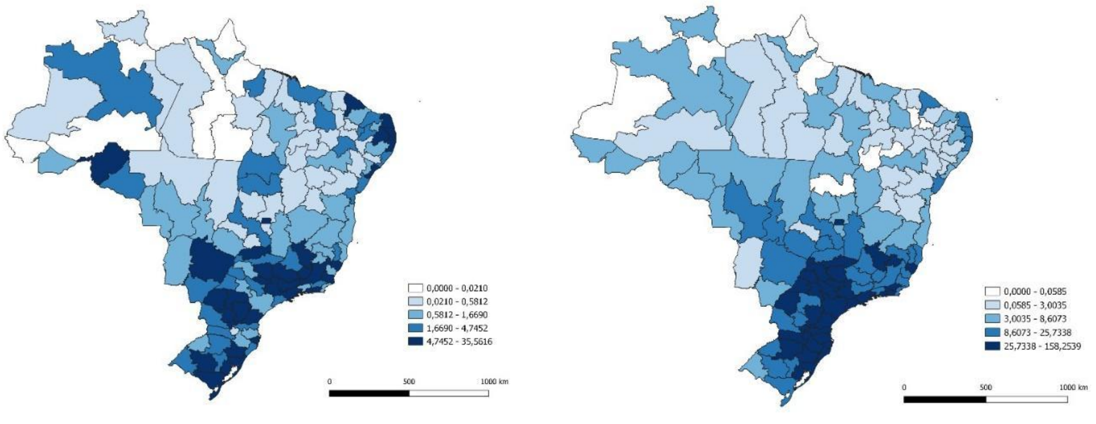


Figure 1: Patents per 100,000 inhabit. by intermediate region (1998-2018)
Source: Own elaboration

As seen in Graph 2a, there was an increase in the relevance of academia in patenting. In 1998, universities and PRIs accounted for 3.4% of patents filed in Brazil, which is very low by international standards (DE MORAES SILVA; FURTADO; VONORTAS, 2018). In 2018, this share rose to 30.1%, closer to countries with more developed university systems and in line with the increase in expenditure on training graduate students and on R&D at universities. Since the university system is better spatially distributed than the manufacturing activity, this process seems to be associated with a change in the geography of patenting in Brazil. North-Northeast regions that had a 7.5% share of patents filed in 1998 reached a share of 18.7% in 2018.



(a) University patents (b) Industrial patents

Figure 2: University and Industrial patents per 100,000 inhabit. by intermediate region (1998-2018)
Source: Own elaboration

5. Results

Table 2 presents the result of the estimation with data covering the years 1998 to 2018 for the 133 intermediate Brazilian regions.

Table 2 – Regression results. Patent per capita as dependent variable

	(1)	(2)	(3)	(4)
$PI_{r,t-1}$	0.846***	0.683***	0.677***	0.657***
	(0.0218)	(0.0273)	(0.0277)	(0.0283)
$R\&DInd_{r,t-1}$		0.0311***	0.0290***	0.0287***
		(0.00557)	(0.00632)	(0.00660)
$R\&DUniv_{r,t-1}$		0.0275***	0.0260***	0.0214***
		(0.00534)	(0.00577)	(0.00603)
$HK_{r,t-1}$			-0.00956	-0.00502
			(0.0213)	(0.0214)
$DensPop_{r,t-1}$			0.000206	6.83e-05
			(0.000168)	(0.000172)
$DensPop^2_{r,t-1}$			-1.34e-07	-1.29e-07
			(9.10e-08)	(9.04e-08)
$HHI_{r,t-1}$			-0.0453	-0.0351
			(0.0609)	(0.0606)
$Closeness_{r,t-1}$				0.00624
				(0.0466)
$Betweenness_{r,t-1}$				3.092***
				(0.933)
Wu_t	0.826***	0.838***	0.839***	0.845***
	(0.0492)	(0.0563)	(0.0556)	(0.0575)
Constant	0.154***	0.0441	0.0872	0.0815
	(0.0530)	(0.0540)	(0.0781)	(0.0781)
Dummies UF	Yes	Yes	Yes	Yes
N	798	798	798	798
n	133	133	133	133
T	6	6	6	6
AIC	-384.1	-463.6	-461.1	-468.1

Note: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1
Source: Own elaboration

The coefficients for R&DInd and R&DUniv are positive and significant, confirming that R&D efforts for industries and universities are relevant determinants of local innovation. The position of the region in the co-patent network (Betweenness) has a positive and significant effect. However, it is not possible to affirm any relationship between the relative local industrial specialization-diversification and innovation. Finally, the lagged dependent variable is positive and significant, reinforcing the role of path-dependence of local innovation. Spatial error term is significant for all specifications - Reinforce the evidence that regional spatial heterogeneity is relevant for regional innovation in Brazil (GONÇALVES; ALMEIDA, 2009).

6. Heterogeinity

Since there is a lot of heterogeneity in regional innovation in Brazil, we chose to explore possible sources of RKPF heterogeneity by estimating regressions for some separate samples. First, we change the estimation dependent variable by segregating university patents from industrial patents. It is expected that there are differences in the role of determinants of these two types of patents, which may be even more accentuated with the expansion and decentralization of University R&D in the period. A second exercise involves estimating separate regressions for the North and South portions of the country to consider that there is a large regional technological disparity in Brazil as pointed out by Santos and Mendes (2021) and illustrated by Figures 1 and 2.

Table 1 – Heterogeneity results. University and Industrial patents as dependent variables

	(5) PI Univ	(6) PI Ind
PI $Univ_{r,t-1}$	0.871***	
	(0.0419)	
PI $Ind_{r,t-1}$		0.673***
		(0.0252)
$R\&DInd_{r,t-1}$	0.00282	0.0270***
	(0.00416)	(0.00597)
$R\&DUniv_{r,t-1}$	0.0306***	-0.00250
	(0.00423)	(0.00540)
$HK_{r,t-1}$	-0.0301**	0.0152
	(0.0140)	(0.0190)
$DensPop_{r,t-1}$	-0.000158	0.000264*
	(0.000111)	(0.000155)
$DensPop^2_{r,t-1}$	2.97e-08	-2.03e-07**
	(5.84e-08)	(8.14e-08)
$HHI_{r,t-1}$	0.00489	-0.0517
	(0.0394)	(0.0545)
$Closeness_{r,t-1}$	0.0216	-0.0278
	(0.0303)	(0.0419)
$Betweenness_{r,t-1}$	1.375**	2.405***
	(0.661)	(0.831)
Wu_t	0.846***	0.779***
	(0.0454)	(0.0745)
Constant	0.165***	-0.0447
	(0.0506)	(0.0691)
Dummies UF	Yes	Yes
N	798	798
n	133	133
T	6	6
AIC	-1152.7	-639.3

Note: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1
Source: Own elaboration

Tab 3. presents the results of the estimation of separate regressions for university and industrial patents. In terms of differences, the coefficients of the R&D variables have statistical significance only for the respective type of patents. In other words, local Industrial R&D explains only industrial patents and local University R&D only explains university patents. The result for industrial patents is noteworthy because there is no evidence of spillover from university research to innovation in industry. This can be related to a separation between the scientific and technological efforts of academia and industries in Brazilian regions.

For industrial patents, the variables DensPop and $DensPop^2$ have statistically significant, positive and negative coefficients, respectively. Corroborating the expectation of agglomerative advantages in industry innovation for other countries and for Brazil (GONÇALVES; DE OLIVEIRA; ALMEIDA, 2020). This agglomeration result does not occur for university patents. Furthermore, even though the presence of more qualified workers in the industry should not imply more university patents, the coefficient of this estimation for HK is negative and significant, which is counterintuitive. However, this may be evidence of the separation between Academia and industry, and it is important to bear in mind that, in Brazil, as in other countries, the main university research centers are public and their location does not result from typical agglomeration sources, but they are the result of industrial and technological policy.

In terms of similarities between the regressions, it is found, as well as models 1 to 4, the existence of technological path-dependence of regions, importance of network connections and the occurrence of spatial heterogeneity, measured by the coefficient of the error term.

Table 2 – Heterogeneity results. Patent per capita as dependent variable

	(7) S-SE-CO	(8) N-NE
$PI_{r,t-1}$	0.659***	0.347***
	(0.0365)	(0.0700)
$R\&DInd_{r,t-1}$	0.0454***	0.0156**
	(0.0120)	(0.00774)
$R\&DUniv_{r,t-1}$	0.0138	0.0477***
	(0.00842)	(0.00992)
$HK_{r,t-1}$	0.0573	-0.00234
	(0.0476)	(0.0205)
$DensPop_{r,t-1}$	-0.000145	0.000703
	(0.000240)	(0.000552)
$DensPop^2_{r,t-1}$	-9.16e-09	-1.24e-06
	(1.24e-07)	(1.30e-06)
$HHI_{r,t-1}$	-0.134	-0.00862
	(0.111)	(0.0614)
$Closeness_{r,t-1}$	0.000862	0.00514
	(0.0740)	(0.0552)
$Betweenness_{r,t-1}$	1.736	7.529***
	(1.198)	(1.692)
Wu_t	0.743***	0.801***
	(0.0909)	(0.0657)
Constant	0	0.179**
	(0)	(0.0710)
Dummies UF	Yes	Yes
N	414	384
n	69	64
T	6	6
AIC	-137.4	-381.6

Note: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1
Source: Own elaboration

As pointed out by Araujo and Garcia (2019) and Santos and Mendes (2021), there is a great industrial and technological disparity between the North and South regions of Brazil, with innovative and manufacturing activities being much more concentrated in the southern portion, from an industrial rather than a university point of view, in part due to public efforts to provide different regions of the country with centers of excellence in research. In this sense, we chose to estimate two separate regressions, one for the South, Southeast and Center-West regions (model 7), and another for the North and Northeast regions (model 8).

First, the R&DInd coefficient is positive and significant for both regressions, pointing out that Industrial R&D efforts are driving factors for innovation in Brazilian regions, regardless of their location. However, the coefficient in the South is almost triple that of the North, which points to greater innovative industrial efficiency in this part of the country.

The results for the university research show that its effect is only positive for the North, since the P&DUniv coefficient is positive and significant only in this regression. This may be linked to the spatial dispersion of universities and their greater relevance for innovation in this part of the country, as illustrated in Figure 2a.

In addition, the variable that measures the technological path-dependence is positive in both cases, but the coefficient for model 7 is almost double that of model 8 (0.659 vs. 0.347) which points to a lower historical dependence in the Northern part, in line with the fact that technology centers were established more recently in this part of the country. Spatial error terms are also significant, reinforcing the presence of spatial heterogeneity, even in these spatial subsamples.

Finally, the coefficient of the Betweenness variable is positive only for model 8, which demonstrates that networks are very important for this region, especially considering that the South can count on the greatest endowment of factors to generate innovation locally, without relying on external connections.

7. Robutsness Check

Considering that our variable of interest is all patents registered in the national office, it is possible to argue that it is a very broad or strict proxy for innovations, depending on the case, and that the results found may be sensitive to this choice. In this sense, in order to ensure the quality of our results, we chose to perform a robustness test regressing three alternative versions of our dependent variable. The first only international patents - PCT (model 9); the second with patents with co-inventors (model 11); and the last one with utility models replacing patents (model 10). In the first two cases, the objective is to use a stricter innovation proxy and obtain a measure of higher quality patents, as pointed out by Higham, De Rassenfosse and Jaffe (2021). The utility model, on the other hand, aims to verify whether more incremental innovations present the same regional dynamics as patents that tend to be more radical. As can be seen in Table 5, the results are in line with what was previously found, with small differences.

Table 3 – Robustness check results. Patent per capita as dependent variable

	(9) PI PCT	(10) PI CoInv	(11) UM
PI $PCT_{r,t-1}$	0.504***		
	(0.0541)		
PI $CoInv_{r,t-1}$		0.770***	
		(0.0311)	
$UM_{r,t-1}$			0.767***
			(0.0215)
$R\&DInd_{r,t-1}$	0.00280***	0.0145***	0.0173***
	(0.00108)	(0.00506)	(0.00542)
$R\&DUniv_{r,t-1}$	-0.00128	0.0278***	0.00263
	(0.000991)	(0.00483)	(0.00500)
$HK_{r,t-1}$	-0.000946	-0.0216	0.0148
	(0.00316)	(0.0170)	(0.0176)
$DensPop_{r,t-1}$	7.16e-05**	-0.000110	3.97e-06
	(2.99e-05)	(0.000136)	(0.000143)
$DensPop^2_{r,t-1}$	-4.57e-08***	-2.01e-08	-2.12e-08
	(1.57e-08)	(7.17e-08)	(7.47e-08)
$HHI_{r,t-1}$	-0.00533	-0.00289	-0.0105
	(0.00998)	(0.0479)	(0.0506)
$Closeness_{r,t-1}$	-0.0113	-0.0116	-0.0176
	(0.00700)	(0.0368)	(0.0389)
$Betweenness_{r,t-1}$	0.756***	2.354***	0.113
	(0.153)	(0.758)	(0.762)
Wu_t	0.730***	0.854***	0.789***
	(0.0886)	(0.0481)	(0.0680)
Constant	-0.00156	0.103*	-0.0354
	(0.0126)	(0.0614)	(0.0636)
Dummies UF	Yes	Yes	Yes
N	798	798	798
n	133	133	133
T	6	6	6
AIC	-3564.8	-840.5	-761.5

Note: Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1
Source: Own elaboration

Finally, the definition of the matrix of spatial weights (W) in empirical works is always a delicate task because, in these cases, the matrix W is usually unknown. We used an inverse distance spatial weight matrix in the previous main results, but we also perform a robustness check with a queen contiguity matrix with similar results as presented in Table A.2 in Appendix.

8. Conclusions

A set of studies in the economic geography literature examines the determinants of regional innovation. However, there is still a limited understanding the heterogeneities of university and industrial patents and regional regimes. Based on this gap, our main contribution is to present new empirical evidence for how university and industrial R&D effects of inward FDI knowledge spillovers on regional innovation. In this way, our findings show that local Industrial R&D explains only industrial patents and local University R&D only explains university patents.

In addition, the R&DInd coefficient is positive and significant for both regressions of regional heterogeneities. The university research effect is only positive for the North-Northeast, which may be related to the spatial dispersion of universities and their greater relevance for innovation in this part of the country. The presented results are highly relevant to other developing countries that, similar to Brazil, have regional spatial heterogeneity regarding to the distribution of the patenting activity and local endowment of R&D.

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