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Shaping the effects of related and unrelated variety on innovation

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Abstract:

The aim of this paper is to investigate the impact of related and unrelated variety on innovation considering regional heterogeneity across locations. The literature regarding innovation and relatedness presents empirical evidence of the effects of related and unrelated variety on innovation but it demands further clarification, and this paper sheds light on these relations by looking at specific macro-regions. The empirical analysis uses a regional knowledge production function with panel data of Brazilian micro-regions between 2002 and 2017. Related and unrelated variety entropy measures are calculated using employee data. Utility models and patents are used as proxies for incremental and radical innovations, respectively. Our results show that related variety is associated with both measures of innovations while unrelated variety has stronger effects on radical innovation. Furthermore, heterogeneity across regions affect the relation between relatedness and innovation.

Keywords: Geography of Innovation; Related Variety; Unrelated Variety, Regional Innovation; knowledge spillovers

Código JEL: O31; R11; R12

Área Temática: 4.5 Geografia do Conhecimento e da Inovação

1. Introduction

The literature has intensively discussed the roles of both incremental and radical innovation key factors for economic growth (FAGERBERG; SRHOLEC; VERSPAGEN, 2010) and acknowledges that the combination and recombination of previously unconnected knowledge can lead to new knowledge production, introduce new technological trajectories, and result in economic growth. At the regional level, studies have examined this issue by focusing on the importance of local knowledge spillovers, which can be an important tool to foster interactive learning and innovation at the regional level. However, this issue is not yet fully outlined by the literature. The vast majority of scholars claim that knowledge spillovers on diversified industrial locations is more supportive of innovations built on the recombination of knowledge across sectors, such as Jacobs externalities.

Research increasingly recognizes that the relatedness of technologies plays a role in technological change, leading to economic competitiveness, diversification, and branching (FRENKEN; VAN OORT; VERBURG, 2007). Diversity in related industries is one of the main ways to improve knowledge spillovers, especially among industries that are cognitively proximate (FRENKEN; VAN OORT; VERBURG, 2007). Thus, studies should divide diversity into related and unrelated variety. This conceptualization of diversity and the initial empirical evidence have led to many empirical investigations, especially in European countries (BOSCHMA; MINONDO; NAVARRO, 2011; FRENKEN; VAN OORT; VERBURG, 2007; FRITSCH; KUBLINA, 2018; KRAFFT; QUATRARO; SAVIOTTI, 2014; NOOTEBOOM, 1999).

In line with this, this paper aims to investigate the impact of related and unrelated variety on innovations and how these relationships differ across regions. We contribute in three different ways. First, we address questions related to the effects of related and unrelated variety on fostering regional innovation, especially their role in the generation of radical innovation in regions. The role of relatedness in the economic growth of regions is widely debated, but only a few studies have presented empirical evidence on the impacts on regional innovation (AARSTAD; KVITASTEIN; JAKOBSEN, 2016; CASTALDI; FRENKEN; LOS, 2015; HESSE; FORNAHL, 2020; MIGUELEZ; MORENO, 2018; TAVASSOLI; CARBONARA, 2014). The literature has noted that new research should follow the original related-variety theory, which argues that relatedness spurs product innovation (CONTENT; FRENKEN, 2016). Hence, insofar as innovation leads to employment growth, the original related-variety hypothesis still holds (CASTALDI; FRENKEN; LOS, 2015).

Second, considering regional heterogeneity, we present new empirical evidence that the relation between relatedness and innovation, both incremental and radical. There are claims in the literature that it is important to consider the conditioning local factors that facilitate more related or unrelated diversification in regions (BOSCHMA, 2017; QUATRARO; USAI, 2017), including in less developed and peripheral regions (ASHEIM; ISAKSEN; TRIPPL, 2019).

Third, we provide new empirical evidence on a developing country. Different institutional environments certainly exert different impacts on the ways in which new knowledge is generated and disseminated in regions; thus, new empirical evidence is required (ASHEIM; ISAKSEN; TRIPPL, 2019; TRIPPL; ZUKAUSKAITE; HEALY, 2019). This subject has mostly been analysed in developed countries, with few studies in developing countries (SILVA; GONÇALVES; ARAÚJO JUNIOR, 2020). Given this lack of attention, new studies are required to provide empirical evidence on how these factors impact the evolutionary trajectory of regions and their capabilities.

Our results show that innovation in Brazilian regions benefits from both related and unrelated variety but in different ways for each type of innovation. Related variety has similar impacts on radical and incremental innovations, while unrelated variety has a more pronounced impact on radical innovations. In addition, there are specific macro-regions that shape the relation between relatedness and innovation. This empirical evidence fills gaps in the literature by increasing the understanding of the characteristics of relatedness and the regional heterogeneity that affect incremental and radical innovation.

The paper is structured as follows. The next section presents the conceptual background regarding variety, diversity, and innovation. The third section provides a brief description of the data and the main methodological issues, including the measurement of related and unrelated variety. The fourth section presents the exploratory analysis and some descriptive results from the Brazilian institutional context. The fifth section presents the overall results and discusses the main findings regarding the effect of related and unrelated variety on innovation in Brazilian regions. The final section presents final remarks, limitations, and policy implications.

2. Theorical background: Variety, diversity, and innovation

Innovation has been increasingly recognized as an important factor for economic growth. Technological innovation is a path-dependent process since it is linked to the continuous accumulation of knowledge, in which existing knowledge is recombined to create new products, new services and new processes. The innovation process can lead to both radical and incremental innovations. Radical innovations are usually defined as technological breakthroughs. Through the creation of new artefacts or a new technological approach, radical innovation can lead to a new technological trajectory. On the other hand, incremental innovation can be defined by the development of new devices and technological solutions along current and well-known trajectories. The main effect of incremental improvements is that they enhance existing technologies (FAGERBERG; SRHOLEC; VERSPAGEN, 2010; NELSON, 2008; ROSENBERG, 1982).

At the regional level, innovation, whether radical or incremental, is unevenly distributed over space. Given the cumulative characteristic of innovation, regions with higher absorptive capacity, higher technological capabilities and more skilled human capital are better able to accelerate innovation. Innovation strongly draws from geographically localized knowledge sources, showing the importance of local knowledge spillovers (AUDRETSCH; FELDMAN, 2004; PUGA, 2010). Local knowledge spillovers represent a key issue in this subject, but they but its role is not fully resolved in the literature (BEAUDRY; SCHIFFAUEROVA, 2009; DE GROOT; POOT; SMIT, 2009). In general, they find that a diversified industrial structure is more conducive to innovation since it can provide better conditions for the recombination of knowledge across industries, or so-called Jacobs externalities (FRITSCH; KUBLINA, 2018).

The impact of localized knowledge on innovation can be explained through the notion of knowledge variety. Knowledge that is created over time and embedded in regional organizations leads to a variety of knowledge in an economy, which is a crucial factor of economic growth (HESSE; FORNAHL, 2020). At the regional level, recombinant innovation can also help explain the extent to which innovation draws on geographically localized knowledge. Regions that present a more diverse stock of knowledge have greater potential for innovation (CASTALDI; FRENKEN; LOS, 2015).

Knowledge variety is often divided into related and unrelated variety (FRENKEN; VAN OORT; VERBURG, 2007). Related variety describes the process in which actors in a region engage in industries with similar knowledge bases, and local knowledge is applied in related industries that can more easily engage in recombinant innovation. It is draw from different but not completely disconnected knowledge bases (CASTALDI; FRENKEN; LOS, 2015; FRENKEN; VAN OORT; VERBURG, 2007). Related variety enables the rapid diffusion of knowledge spillovers across industries, since reduced cognitive distance among agents enables effective linkages among agents and fosters a local interactive learning process. Existing complementarities among local agents enable the sharing of knowledge, competences, and capabilities. Related variety assumes that there is some degree of cognitive proximity among local agents (ASHEIM; BOSCHMA; COOKE, 2011; BOSCHMA, 2005; GARCIA et al., 2018) and is considered a key source of regional branching in which new industries grow out of existing ones through endogenous processes that take place within a region (GRILLITSCH; ASHEIM; TRIPPL, 2018).

Previous empirical studies have shown that variety in related industries is usually built on the basis of an accumulated knowledge base and leads to knowledge diffusion and economic growth in regions (BOSCHMA; MINONDO; NAVARRO, 2011; CORTINOVIS; VAN OORT, 2015; FRENKEN; VAN OORT; VERBURG, 2007; FRITSCH; KUBLINA, 2018; LAZZERETTI; INNOCENTI; CAPONE, 2017; QUATRARO, 2010). However, most of these studies examined the effects of related variety on regional growth, and few studies have evaluated the impact of related variety on innovation (CASTALDI; FRENKEN; LOS, 2015; MIGUELEZ; MORENO, 2018; TAVASSOLI;

CARBONARA, 2014). In fact, researchers have suggested returning to the original related-variety formulation, which argues that related variety spurs product innovation (CASTALDI; FRENKEN; LOS, 2015; CONTENT; FRENKEN, 2016). Based on these assumptions, we draw the following hypothesis.

H1: Related variety is positively associated with innovation.

On the other hand, unrelated variety refers to the combination of non-similar knowledge. It is more closely related to the benefits resulting from Jacobs' externalities, since it describes a situation in which a region hosts firms and capabilities from unrelated industries. Jacobs' externalities are expected to enable radical innovation, as knowledge from different industries can be recombined and lead to the introduction of new technologies and new products (FRENKEN; VAN OORT; VERBURG, 2007). Regions hosting unrelated industries with different but connected knowledge bases can introduce new and recombinant knowledge innovation, although it is more difficult for the combination of unrelated knowledge to succeed in creating new ideas. This situation may lead to a slow-down in the diffusion of new ideas since it may involve drawing on different and non-complementary knowledge bases, which will increase the uncertainty and costs of engaging in recombinant innovation (MIGUELEZ; MORENO, 2018; NEFFKE; HENNING; BOSCHMA, 2011).

Empirical findings concerning the effects of unrelated variety have generated a demand for further deepening and clarification (BOSCHMA; MINONDO; NAVARRO, 2011; HESSE; FORNAHL, 2020). Some studies examining the impact on innovation find significant effects only for unrelated variety (CASTALDI; FRENKEN; LOS, 2015). Others find that both related and unrelated variety have positive effects on innovation in general (MIGUELEZ; MORENO, 2018) and on radical innovation, in particular (HESSE; FORNAHL, 2020). Comparing the impacts of related and unrelated variety, some studies show that related variety has a stronger effect on innovation (TAVASSOLI; CARBONARA, 2014), while others find that unrelated variety has a stronger effect on radical innovation (HESSE; FORNAHL, 2020). Consequently, the effects of related and unrelated variety on radical innovations are need further clarification. However, in general, studies tend to agree that unrelated variety can foster innovation, particularly radical innovation (CASTALDI; FRENKEN; LOS, 2015; HESSE; FORNAHL, 2020; MIGUELEZ; MORENO, 2018). This leads us to another hypothesis.

H2: Unrelated variety is positively associated with radical innovation.

Finally, the effects of related and unrelated variety on innovation can differ across regions since locational aspects can shape the relation between variety and innovation. Different regional performances need to be studied since agglomeration externalities may trigger distinctive development paths (MARROCU; PACI; USAI, 2013). Heterogeneities in regional innovative profiles in peripheral regions can be seen even in developed countries (CRAWLEY; HALLOWELL, 2020; TRIPPL; ZUKAUSKAITE; HEALY, 2019). Previous studies analysing the evolution of the productive structure of several regions have revealed important specificities in regions that present different characteristics (ASHEIM; ISAKSEN; TRIPPL, 2019). These studies have shown that the innovation performance of different regions strongly depends on their wider spatial environments, including the main features of the local industrial structure and macro environmental conditions (GRILLITSCH; ASHEIM; TRIPPL, 2018). Thus, it is important to consider the conditioning factors that facilitate more related or unrelated diversification in regions (BOSCHMA, 2017; MONTRESOR; QUATRARO, 2017), even in less developed and peripheral regions (ASHEIM; ISAKSEN; TRIPPL, 2019). We present the following hypothesis.

H3: The relation between related and unrelated variety and innovation is different considering regional heterogeneity.

It is important to test the effects of both related and unrelated variety on regional innovation by looking at specific group of macro-regions.

3. Methodological approach

3.1. Data and variables

We use intellectual property data from the Brazilian Patents Office (INPI - National Institute of Industrial Property) with inventions information. The data contain information on the region of the applicant and the type of protection, separated by utility model and patent. We also use data on the sectoral composition of the regional workforce from the Brazilian Ministry of Labour; data on regional GDP and population from the Brazilian National Census Bureau (IBGE); and data on regional human capital qualification from the Brazilian Ministry of Education. Overall, our database covers 556 Brazilian micro-regions corresponding to the European NUTS-3. The period of analysis is 2002-2017.

Several studies have used patent-based indicators to investigate both radical and incremental innovations (CASTALDI; FRENKEN; LOS, 2015; HESSE; FORNAHL, 2020; MIGUELEZ; MORENO, 2018; TAVASSOLI; CARBONARA, 2014). Patent applications are used to trace innovation because they are widespread and have several advantages regarding the measurement and classification of inventive output. Patents represent formal novelty requests that must be met for intellectual protection to be granted, and they are assigned to technological classes by autonomous and knowledgeable professionals.

Inventions can be protected through two main forms of registration: utility models and patents. Utility models are linked to so-called "minor inventions", which require conformity with less rigorous requirements, involve easier procedures and have shorter-term protection. Although utility models are recognized as minor improvements of existing products, they may play an important role in a local innovation system since they offer an important way to disseminate innovation. This allows us to call utility models incremental innovations. On the other hand, patents can be associated with "major inventions" because they represent an upper class of innovation, although we should recognize that not all patents represent disruptions in ongoing technological trajectories. Nevertheless, given the characteristics of developing countries, which have immature innovation systems, patents represent an important way to generate and disseminate new knowledge among firms and main local agents. Our dependent variable is defined by the characteristics of regional innovation. We take the number of patents in a region and classify them into incremental innovations using utility models applied by the region's applicants and upper-level innovations based on patents over a three-year period per capita.

In our modelling strategy, we analyse the relations between innovation and the two types of variety. Following Frenken et al. (2007), we use the entropy measure to indicate related and unrelated variety at different levels of sectoral aggregation. We use the number of employees in manufacturing industries in Brazilian micro-regions in the 5-digit SIC industries with data from the Ministry of Labour. Related and unrelated variety are calculated as follows:

$$RV_r = \sum_{c=1}^{C} P_c H_c \ with \ H_c = \sum_{d \in S_c} \frac{P_d}{P_c} log_2(\frac{P_c}{P_d}) \qquad UV_r = \sum_{c=1}^{C} P_c log_2(\frac{1}{P_c}) \ with \ P_c = \frac{p_i}{\sum_c p_i}$$

Related variety measures the average degree of variety of employment in subsectors (5-digit SIC industries) belonging to the same sectors. The value of related variety ranges from 0 (employment in each sector is concentrated in only one of its subsectors) to 3.52[1]. Unrelated variety measures the average degree of variety of the sectors (2-digit SIC industries). The value of unrelated variety can vary from 0 (all employment is concentrated in only one sector) to 4.57 (all sectors employ an equal number of employees)[2]. The lower the value of the (un)related variety index, the less evenly employment is spread across sectors/subsectors, indicating a lower share of (un)related industries in a region (FRENKEN; VAN OORT; VERBURG, 2007; KRAFFT; QUATRARO; SAVIOTTI, 2014; NOOTEBOOM, 1999).

We also include control variables that are usually considered to affect innovation, including research universities, income, industrial and university R&D, population density, and dummies for the south and southeast regions, and we control the previous number of utility models and patents.

3.2. Empirical strategy

Our data allow us to construct a panel with 4 time periods since we have four observations for each micro-region relating to the three-year periods 2003-2005, 2007-2009, 2011-2013 and 2015-2017.

[1] Our empirical analysis is based on 310 subsectors in 5-digit industries (D) within 29 sectors in 2-digit industries (G), and the maximum limit for related variety is log_2(D)-log_2(G).

[2] Our empirical analysis is based on 29 sectors in 2-digit industries (G), and the maximum limit for unrelated variety is log_2(G).

Our database covers 556 Brazilian micro-regions with 1,662 observations. The basic structure of the empirical model is as follows.

$$INNOV_{r,T+3} = \beta_1 RV_{r,t} + \beta_2 UV_{r,t} + \beta' X'_{r,t} + \lambda_i + \nu_{it}$$

$INNO_{r,T+3}$ denotes the number of innovations protected by patents (***PAper***) or the utility model (***UMper***) over a three-year period (*T+3*) granted by the Brazilian Patent Office divided by the population in micro-region *r*; we determine the micro-region of a patent based on the applicant's address.

$RV_{r,t}$ and ***$UV_{r,t}$*** are measures of the related and unrelated variety in region ***r*** at time ***t*** one year prior to ***T+3***.

$X'_{r,t}$ is a vector for regional characteristics composed of five variables that reflect a region's overall level of development at time t: the micro-region wealth measure by gross domestic product per capita (*lnGPDper*), dummies for the existence of research universities in the region (*D_RU*) and for the south and southeast regions (*D_S*), university R&D (*RDuniv*); industrial R&D (RDind), population density (Pop Density), and the measure of previous patterns of regional technological capabilities, which may reflect differences in the region's propensity for innovative capability (*L1PAper* or *L1UMper*).

λ_r are the unobservable effects specific to each region, and ν_{rt} are the remaining unobservable effects that vary both across regions and over time.

Table 1 summarizes the variables used in the empirical modelling.

Table 1 - Definition of variables

Variables		***Definition***
Types of Regional Innovation (INNOV)	*PAper*	*Number of inventions protected by Patent over the respective three-year period per capita*
	UMper	*Number of inventions protected by Utility Model over the respective three-year period per capita*
Related Variety	*RV*	*Weighted sum of 5-digit entropy within 2-digit sectors.*
Unrelated Variety	*UV*	*Entropy across 2-digit*
University R&D	*RDuniv*	*Natural logarithm of number of people with higher education*
Industrial R&D	*RDind*	*Natural logarithm of average wage of employees in S&T*
Local Wealth	*lnGDPper*	*Natural logarithm of gross domestic product divide population*
Population Density	*Pop Density*	*Number of individuals per unit area*
Research universities Dummy	*D_RU*	*Dummy 1 for research universities*
Regional Dummy	*D_S*	*Dummy 1 for south and southeast regions*
Previously accumulated knowledge	*L1PAper*	*Initial number of inventions protected by Patent over the respective three-year period per capita*
	L1UMper	*Initial number of inventions protected by Utility Model over the respective three-year period per capita*

We estimate the effect of related and unrelated variety, and a random-effects Tobit model for panel data is developed. A Tobit procedure is estimated because of the presence of left-censoring of the dependent variable in the data. The dependent variable, as a proportion of the innovations protected by utility models or patents by the population in micro-region, must always be greater than zero Therefore, this censoring occurs because it is not possible to find a value of the innovation proportion less than zero (MADDALA, 1983). In the data set, we have 938 uncensored observations and 724 observations censored at zero for patents and 874 uncensored observations and 788 observations censored at zero for the utility model. To mitigate the potential endogeneity problem, we measure the exploratory variables at time t (2002, 2006, 2010 and 2014), which is not included in the three-year period of the dependent variable.

4. Descriptive and exploratory analysis

Innovative activities are becoming increasingly important in the Brazilian innovation system. Although innovative indicators are still limited in Brazil in comparison to developed countries, private firms are increasing their R&D expenditures and increasingly collaborating with the main sources of knowledge generation, such as universities and public research institutes. As a result, an increase in patenting is observed in Brazil (ALBUQUERQUE et al., 2015). However, at the regional level, patenting is still highly concentrated (Figure 1).

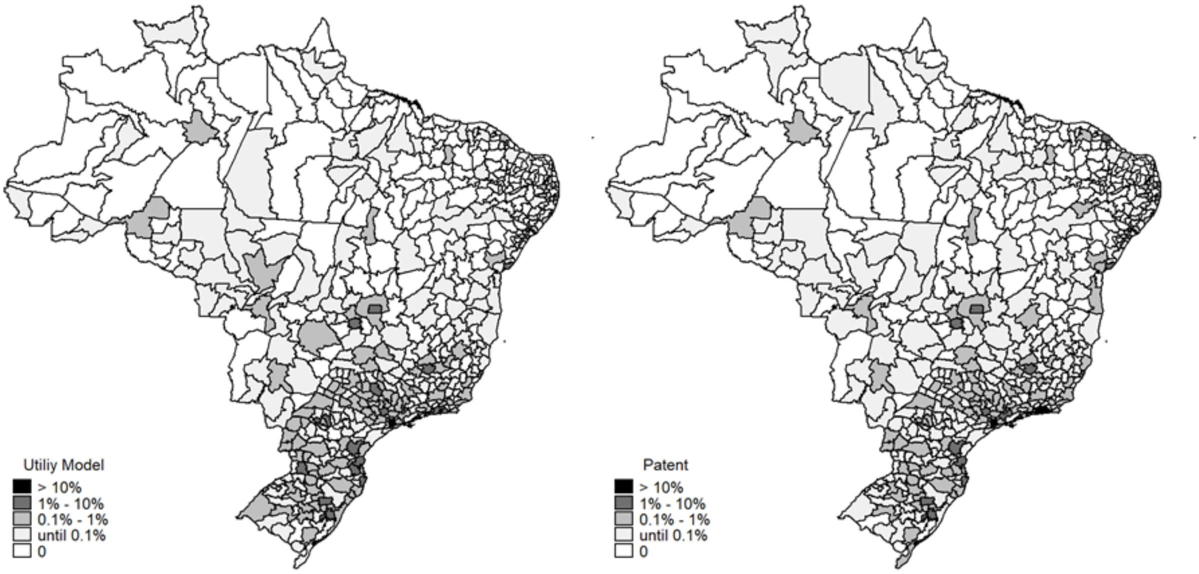

Figure 1 - Innovation Distribution between Brazilian Micro Regions (2015-2017)

The regional distribution of innovation in Brazil shows a strong tendency towards an unequal concentration in a few regions, especially in the south and southwest regions (GARCIA et al., 2015; GONÇALVES; ALMEIDA, 2009). The most important region is São Paulo, accounting for 14.7% of patents and 16.4% of utility models. Other important regions include large cities such as Rio de Janeiro, Belo Horizonte, Curitiba, Porto Alegre and Campinas. The most innovative Brazilian regions are in the southern part of the country. The regional concentration of patent applications can also be seen in the descriptive statistics of our database (Table 2).

Table 2 - Descriptive Statistics

Variable		Mean	Std.Dev.	Min	Max	Observations
PAper	overall	0.247	0.434	0.000	4.331	N=1,662
	between		0.404	0.000	3.276	n=556
	within		0.159	-0.811	1.576	T-bar=2.989
UMper	overall	0.194	0.362	0.000	4.103	N=1,662
	between		0.340	0.000	3.478	n=556
	within		0.123	-0.845	1.861	T-bar=2.989
RV	overall	1.185	0.623	0.000	2.893	N=1,662
	between		0.609	0.000	2.800	n=556
	within		0.145	0.570	2.363	T-bar=2.989
UV	overall	2.375	0.852	0.000	4.116	N=1,662
	between		0.832	0.000	4.095	n=556
	within		0.216	1.141	4.250	T-bar=2.989
RDuniv	overall	0.272	0.697	0.000	4.116	N=1,662
	between		0.653	0.000	3.630	n=556
	within		0.241	-2.222	2.431	T-bar=2.989
RDind	overall	6.820	3.249	0.000	10.267	N=1,662
	between		2.925	0.000	9.828	n=556
	within		1.465	0.588	13.143	T-bar=2.989
Densid~e	overall	102.933	365.174	0.245	6,180.068	N=1,662
	between		364.536	0.280	5,926.979	n=556
	within		13.378	-67.471	356.022	T-bar=2.989
lnGDPper	overall	2.421	0.736	0.629	5.528	N=1,662
	between		0.639	1.087	4.517	n=556
	within		0.368	0.744	3.910	T-bar=2.989
D_RU	overall	0.244	0.430	0.000	1.000	N=1,662
	between		0.403	0.000	1.000	n=556
	within		0.150	-0.422	0.911	T-bar=2.989
D_S	overall	0.458	0.498	0.000	1.000	N=1,662
	between		0.499	0.000	1.000	n=556
	within		0.000	0.458	0.458	T-bar=2.989
L1PAper	overall	0.211	0.395	0.000	4.331	N=1,662
	between		0.368	0.000	2.897	n=556
	within		0.144	-2.086	2.245	T-bar=2.989
L1UMper	overall	0.191	0.391	0.000	4.279	N=1,662
	between		0.368	0.000	3.842	n=556
	within		0.133	-1.270	1.471	T-bar=2.989

The means for our dependent variables are 0.25 per 10,000 inhabitants for patents and 0.19 per 10,000 inhabitants for utility models. Innovation output strongly varies across regions, with the maximum being 4.33 for patents and 4.10 for utility models. In addition, a high share of Brazilian regions presents zero patents (156/558 micro-regions) or zero utility models (168/558 micro-regions).

Our explanatory variables are related and unrelated variety. The theoretical upper limit for related variety is 3.52, given the number of industrial 2-digit sectors and 5-digit subsectors. In our sample, related variety has an average value of 1.19 and a maximum value of 2.9, indicating that Brazilian regions are generally less diversified. For unrelated variety, the theoretical upper limit is 4.57. The sample average is 2.37, and the maximum value is 4.12, implying that most regions have limited diversification in their productive structure at this level of aggregation. Additionally, a map reveals the distribution of related and unrelated variety indexes across regions (Figure 2).

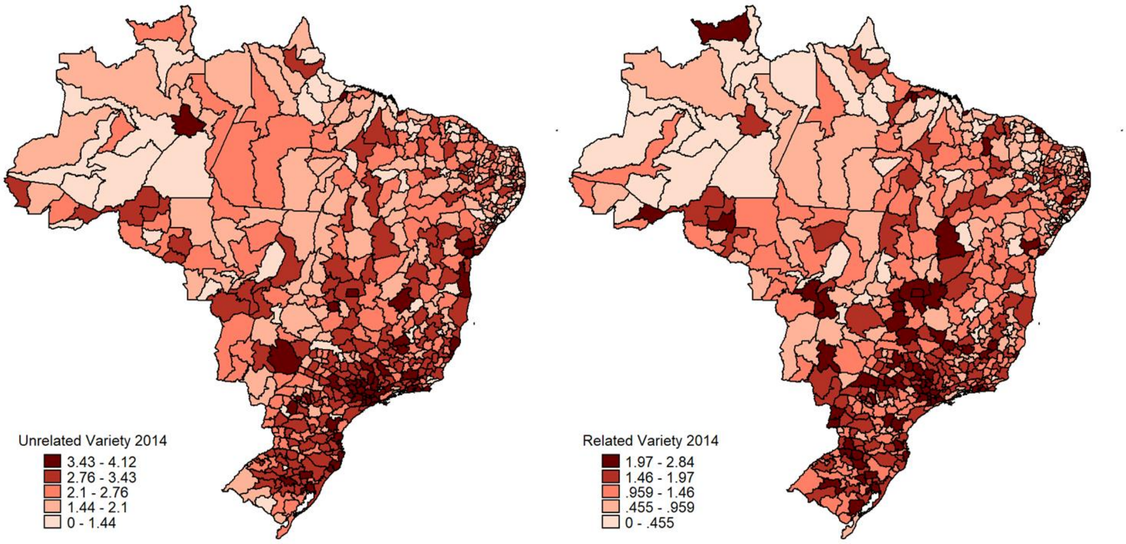

Figure 2 - Distribution of related and unrelated variety in Brazilian micro-regions, 2014

Higher entropy indexes for both related and unrelated variety can be found in the southern part of the country. Nevertheless, regions with higher related and unrelated variety are the same in that they that present better innovation indicators, suggesting that there is a relation between them.

5. Results and discussion

We estimate two different models using a random-effects Tobit model for panel data to analyse the effects of related and unrelated variety on regional innovation in Brazil. The first model uses our proxy for upper-level innovation, patents, as the dependent variable. The second model uses our proxy of incremental innovation, utility models (Table 3).

Table 3 - Results from Estimated Models for regional innovation

Variables	*PAper*	*PAper*	*UMper*	*UMper*
RV		0.0658***		0.107***
		(0.0196)		(0.0189)
UV		0.0589***		0.0343**
		(0.0149)		(0.0143)
RDuniv	0.0132***	0.0108***	0.0143***	0.0117***
	(0.00385)	(0.00380)	(0.00370)	(0.00380)
RDind	0.140***	0.127***	0.0368***	0.0266**
	(0.0145)	(0.0135)	(0.0125)	(0.0125)
lnGDPper	0.143***	0.123***	0.130***	0.114***
	(0.0157)	(0.0152)	(0.0145)	(0.0146)
Pop Density	3.65e-05	-4.57e-06	-1.14e-05	-4.84e-05**
	(2.34e-05)	(2.17e-05)	(1.98e-05)	(2.02e-05)
D_RU	0.0597**	0.0146	0.0524**	0.000156
	(0.0234)	(0.0232)	(0.0214)	(0.0222)
D_S	0.175***	0.129***	0.189***	0.161***
	(0.0217)	(0.0199)	(0.0187)	(0.0191)
L1PAper	0.707***	0.720***		
	(0.0313)	(0.0241)		
L1UMper			0.710***	0.681***
			(0.0204)	(0.0206)
Constant	-0.629***	-0.751***	-0.626***	-0.748***
	(0.0401)	(0.0455)	(0.0388)	(0.0453)
Observations	1,662	1,662	1,662	1,662
Number of id	556	556	556	556
N_unc	938	938	938	938
ll	-471.4	348.8	-413.7	-383.3

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

5.1. Related and unrelated variety

The first result shows that the coefficients of related variety are positive and significant in both models. This means that related variety positively affects innovation, whether it is radical or incremental, thus confirming H1. The more diversified a region is within a set of related technologies; the more innovative local firms are. This finding shows the importance of correlated technologies for the generation of new knowledge, for interactive learning, and for innovation. Additionally, this finding is supported by previous studies providing evidence that related variety positively influences innovation (CASTALDI; FRENKEN; LOS, 2015; MIGUELEZ; MORENO, 2018; PONDS; VAN OORT; FRENKEN, 2007). This result expands previous findings because related variety encourages innovation that is developed incrementally, and it also promotes upper-level innovations, including breakthrough innovation for technological discoveries. The higher the number of related technologies in a certain region, the more knowledge spreads among local agents. Related variety fosters local knowledge spillovers and therefore learning opportunities among existing related industries within a region (MIGUELEZ; MORENO, 2018; TAVASSOLI; CARBONARA, 2014). Learning opportunities created by the variety of local capabilities inside a region are important when such capabilities are related and finally engender more knowledge externalities across local agents.

The effect of related variety is even stronger for incremental innovations, as observed in the magnitude of the effects of related variety. As the coefficients reveal, there is a more pronounced impact on incremental innovation than on radical innovation. This finding confirms theoretical expectations (BOSCHMA; CAPONE, 2015; FRENKEN; VAN OORT; VERBURG, 2007) and previous empirical results (CASTALDI; FRENKEN; LOS, 2015), suggesting that incremental innovations benefit most from related industrial composition. We observe that there are important differences between the types of innovations that are induced by spillovers from related industries. The positive effect of related variety shows that it is easier to combine related knowledge pieces when they are unconnected but came from related industries with complementary capabilities and when their knowledge structures overlap.

Regarding our findings for unrelated variety, the results of the models reveal significant and positive impacts on both incremental and upper-level innovation at the regional level, confirming our theoretical expectations (BOSCHMA; CAPONE, 2015; FRENKEN; VAN OORT; VERBURG, 2007). However, previous empirical research presents mixed evidence on the role of unrelated variety in innovation. Some studies have shown that unrelated variety supports innovation at the regional level (TAVASSOLI; CARBONARA, 2014), while others have not found a connection between unrelated variety and innovation output (CASTALDI; FRENKEN; LOS, 2015; MIGUELEZ; MORENO, 2018). The divergent results regarding the impact of unrelated variety on regional innovation in Brazil can be ascribed to two possible reasons. First, previous studies have examined this issue in the United States (CASTALDI; FRENKEN; LOS, 2015) and the European Union (MIGUELEZ; MORENO, 2018). In Brazil, previous studies have found that the regions with higher incremental or radical innovation outputs are the most diversified regions (GARCIA et al., 2015; GONÇALVES; ALMEIDA, 2009). This shows that complementary and thus unrelated knowledge is important for regional innovation in Brazil. The second reason is a methodological issue related to the geographic level of analysis. Previous studies have examined the relationship between unrelated variety and innovation at the state level in the US (CASTALDI; FRENKEN; LOS, 2015) and for NUTS-2 regions in the EU (MIGUELEZ; MORENO, 2018). By contrast, our study was carried out based on Brazilian micro-regions, which are equivalent to the EU's NUTS-3; similarly, Tavassoli and Carbonara (2014) examined 81 Swedish regions. As noted, differences in the level of geographical aggregation can exert a significant impact on the examination of local knowledge spillovers (BEAUDRY; SCHIFFAUEROVA, 2009).

Patents, our proxy for upper-level innovation, are positively and significantly affected by unrelated variety, confirming H2. This result meets our theoretical expectations (BOSCHMA; CAPONE, 2015) and aligns with previous empirical studies (CASTALDI; FRENKEN; LOS, 2015; MIGUELEZ; MORENO, 2018) showing that unrelated variety positively impacts radical innovations at the regional level. This finding suggests that radical and upper-level innovation often requires the combination of different knowledge bases. Innovation is about making connections between previously unrelated ideas, and unrelated variety is an important tool to enhance regional innovation.

This result is confirmed by the magnitude of the effects of unrelated variety. As the estimated coefficients reveal, there is a more pronounced impact on a higher degree of regional upper-level innovation than on incremental innovation. Thus, even in a developing country's institutional context, the recombination of different types of technological knowledge is required to produce upper-level innovation, including radical and breakthrough innovation. Meanwhile, more incremental innovation along a well-defined technological trajectory benefits largely from recombining knowledge about closely related technologies. In Brazil, regions with a more diversified productive structure and a more diversified set of capabilities are more likely to generate upper-level innovations. The recombination of different but complementary capabilities intensifies the generation of local knowledge spillovers, fostering innovation at the regional level.

Regarding controls, we can see that industry and university R&D are significant, as expected, showing that regions with more R&D efforts are more likely to few patent or model utility, even after controlling for the presence of research university. Also, higher income areas are positively related to innovation. However, population density is not significant for patents and even negative and significant for utility model, what suggest that small and medium size regions could had an innovation system more related to incremental innovation. Regional dummy for South and Southeast regions is positive and significant in line with previous evidence.

5.2. Regional heterogeneity and innovation

The previous literature on the geography of innovation has pointed out that the specific characteristics of a region affect local innovation (ASHEIM; ISAKSEN; TRIPPL, 2019; GRILLITSCH; ASHEIM; TRIPPL, 2018; MARROCU; PACI; USAI, 2013). The effects of related and unrelated variety on innovation can also differ according to the main features of a region. In the case of Brazil, the uneven distribution of innovative inputs between regions reveals important differences in the effects on innovation (GARCIA et al., 2015; GONÇALVES; ALMEIDA, 2009). These differences can be seen in the descriptive statistics for the two regions (Table 4).

Table 4 - Descriptive Statistics by Regions

South and Southeast Regions (SSE)						
	Variable	**Mean**	**Std.Dev.**	**Min**	**Max**	**Observations**
PAper	overall	0.458	0.542	0.000	4.331	N=762
	between		0.501	0.000	3.276	n=254
	within		0.207	-0.600	1.787	T=3
UMper	overall	0.378	0.461	0.000	4.103	N=762
	between		0.429	0.000	3.478	n=254
	within		0.171	-0.661	2.045	T=3
RV	overall	1.451	0.527	0.028	2.893	N=762
	between		0.517	0.095	2.737	n=254
	within		0.106	1.094	1.811	T=3
UV	overall	2.794	0.675	0.708	4.116	N=762
	between		0.658	0.953	4.095	n=254
	within		0.154	1.614	3.594	T=3
North, Northeast and Middle-West Regions (NNE-MW)						
	Variable	**Mean**	**Std.Dev.**	**Min**	**Max**	**Observations**
PAper	overall	0.068	0.173	0.000	1.962	N=900
	between		0.141	0.000	0.837	n=302
	within		0.100	-0.603	1.260	T-bar=2.980
UMper	overall	0.038	0.096	0.000	1.053	N=900
	between		0.077	0.000	0.598	n=302
	within		0.058	-0.560	0.493	T-bar=2.980
RV	overall	0.959	0.610	0.000	2.821	N=900
	between		0.587	0.000	2.800	n=302
	within		0.172	0.344	2.137	T-bar=2.980
UV	overall	2.019	0.826	0.000	3.993	N=900
	between		0.794	0.000	3.991	n=302
	within		0.257	0.786	3.895	T-bar=2.980

The southern regions present considerably better innovative indicators. On average, the southern regions have seven times more patents (0.46 vs 0.07) and ten times more utility models (0.38 vs 0.04) than the northern regions. Related and unrelated variety indicators are also higher in the southern regions, with values of 1.45 and 2.79, respectively, than in the northern regions, with values of 0.96 and 2.02, respectively.

These differences between the northern and southern parts of the country are also present in the control variables. Considering this distinction and following H3, we estimate two other models: one for the south and southeast (SSE) regions, which include the most advanced regions in overall terms, and another for the northern, northeast, and mid-west (NNE-MW) regions, which present worse innovation indicators. The results of the empirical model, using a random-effects Tobit model for panel data, also show these differences (Table 5).

Table 5: Results from Estimated Models for regional innovation

	SSE		**NNE-MW**	
Variables	*PAper*	*UMper*	*PAper*	*UMper*
RV	0.0724**	0.0843***	0.0377*	0.0836***
	(0.0319)	(0.0280)	(0.0205)	(0.0185)
UV	0.0440*	0.0199	0.0576***	0.0299**
	(0.0237)	(0.0212)	(0.0156)	(0.0139)
RDuniv	0.126***	0.0332**	0.117***	0.0117
	(0.0181)	(0.0157)	(0.0208)	(0.0185)
RDind	0.0117	0.00772	0.00628**	0.00754**
	(0.00833)	(0.00734)	(0.00314)	(0.00297)
lnGDPper	0.144***	0.113***	0.0899***	0.0994***
	(0.0244)	(0.0221)	(0.0157)	(0.0139)
Pop Density	-2.21e-05	-4.37e-05*	7.75e-05**	-1.24e-05
	(2.92e-05)	(2.59e-05)	(3.52e-05)	(2.85e-05)
D_RU	0.00205	-0.0331	0.0234	0.0377
	(0.0323)	(0.0295)	(0.0288)	(0.0252)
L1PAper	0.712***		0.681***	
	(0.0390)		(0.0875)	
L1UMper		0.706***		0.448***
		(0.0236)		(0.0765)
Constant	-0.649***	-0.486***	-0.551***	-0.560***
	(0.0898)	(0.0780)	(0.0467)	(0.0459)
Observations	762	762	900	900
Number of id	254	254	302	302
N_unc	635	629	303	245
ll	-265.3	-234.9	371.5	-96.25

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

The coefficients for related variety are positive and significant for both incremental and upper-level innovation in two models (SSE and NNE-MW). This means that related variety is positively associated with innovation in both regional contexts. Thus, the findings also show that knowledge flows between related industries are important in fostering innovations, regardless of regional characteristics.

The results for unrelated variety, however, slightly differ from the previous models. In southern regions, the findings show that unrelated variety has a positive and significant impact on upper-level innovations, but we cannot identify relations with incremental innovations. The results confirm theoretical expectations (BOSCHMA; CAPONE, 2015) and align with empirical research in which unrelated variety positively impacts radical innovation (CASTALDI; FRENKEN; LOS, 2015;

MIGUELEZ; MORENO, 2018). Radical and upper-level innovation frequently requires the combination of different, and unrelated, knowledge bases. In the northern regions, on the other hand, unrelated variety positively affects both radical and incremental innovations.

Considering that northern indicators are overall lower, positive effects on innovation may be associated with the existence of low-density productive structures and therefore with a reduced set of capabilities. In this way, among the northern regions, those with the larger set of knowledge in non-correlated industries are more likely to generate new combinations of knowledge for incremental or upper-level innovation. Our evidence indicates that the relation between relatedness and innovation differs between the northern and southern regions of Brazil.

6. Final remarks, limitations, and policy implications

Recently, researchers cited the need for research to return to the original formulation of related-variety theory, arguing that relatedness encourages innovation (CONTENT; FRENKEN, 2016). Based on this claim, some scholars have examined the impact of technological variety on both incremental and radical innovation (CASTALDI; FRENKEN; LOS, 2015; HESSE; FORNAHL, 2020; MIGUELEZ; MORENO, 2018; TAVASSOLI; CARBONARA, 2014). However, there is still room for new research regarding the roles of related and unrelated knowledge capabilities in incremental innovation and especially radical innovation. Furthermore, it remains unclear how these effects play out in developing countries and how regional differences affect the impacts of relatedness. In this paper, we sought to shed new light on this issue and contribute to debate in three ways. First, we addressed the role of relatedness in fostering innovation, especially for radical innovation. Second, we presented new empirical evidence the impact of regional heterogeneity on the relations between related and unrelated variety and regional innovation. Lastly, our analysis was applied to a developing county, thus contributing to a branch of the literature for which empirical evidence is limited.

Furthermore, there are specific characteristics of the regions that distinguish these relationships.

While our empirical analysis is limited to Brazil, we believe that our results are general enough to be applied to other contexts. There are two main reasons for the generalizability of the main findings. First, as in other countries, Brazilian firms have sought new sources of knowledge to support their innovative efforts. In the context of new knowledge-intensive technologies, which are often associated with so-called Industry 4.0, firms have been forced to intensify their search for new technological knowledge, related or unrelated, with their current knowledge base. Second, several countries also present important regional heterogeneity (CRAWLEY; HALLOWELL, 2020; TRIPPL; ZUKAUSKAITE; HEALY, 2019), and these regional differences need to be considered when analysing the effects of factors that affect innovation at the regional level. This is the case for technological relatedness, which plays an important role in fostering incremental and upper-level innovation at the regional level.

However, our investigation of the role of technological relatedness in incremental and radical innovation has some limitations. The first limitation is associated with the main characteristics of the Brazilian national system of innovation, for which innovative indicators are still limited compared with developed countries. Private firms in Brazil are increasing their R&D expenditures and expanding collaboration with the main sources of knowledge generation. However, the main sources of innovation for firms are still the purchase of capital goods and the incorporation of new technologies from suppliers. The second limitation is the assumption that patents are associated with radical innovation. Even if we can consider patents an upper class of innovation, we should recognize that not all patents are major disruptions in current technological trajectories. Thus, it would be important, as a further investigation, to classify and separate patents that represent breakthroughs on ongoing technological trajectories by using, for example, patent technological complexity indicators. Furthermore, given the shortcomings of patent data, future research could analyse other data, such as the degree of novelty of innovation and trademarks.

Regarding the research agenda, it is plausible to deepen the understanding of the temporal effects of technological unrelated variety on the generation of breakthrough innovations. It seems reasonable to think that the recombination of formerly unrelated technologies may require some time to be fulfilled (MIGUELEZ; MORENO, 2018; TAVASSOLI; CARBONARA, 2014). Thus, it would be interesting to analyse the impact of related and unrelated variety in fostering radical and breakthrough innovation over time. It is also necessary to research the role of cross-regional and external linkages in promoting the recombination of local knowledge. New external knowledge could be a powerful tool in fostering innovation at the regional level since it can break down local agents' capabilities' lock-in in the ongoing technological trajectory.

Finally, our results have several policy implications. Our main results show that related industries within a region enhance innovation since local knowledge spillovers and local interactive learning foster the recombination of existing knowledge. This implies that regions would be smart to develop a range of complementary industries, which means that they must have local related variety. Policymakers should establish measures to create and to attract related industries to the region, even though locational private decisions are a self-selection process. To do so, policymakers should look at the past, identify potential related industries and remove the potential bottlenecks that may prevent those firms from entering the region (NEFFKE; HENNING; BOSCHMA, 2011; TAVASSOLI; CARBONARA, 2014). Policy should also encourage knowledge-related variety in a region by attracting creative class entrepreneurs to the region. Diversity is a tool to foster creativity and to strengthen local knowledge spillovers.

The positive effects of unrelated variety in boosting upper-level and radical innovation are in line with the former policy implication. However, policymakers should create ways to bring together local firms and sources of "outside-the-box" knowledge, such as universities and public research institutions, to support radical innovations. These institutions could set up procedures to further support cross-innovations stemming from different technological domains (HESSE; FORNAHL, 2020). This includes public funding for R&D joint projects with partners from different cognitive and geographical backgrounds to foster the recombination of unrelated knowledge.

Our findings also offer policy implications for specific regions that have different local industrial structures. More developed regions have a broader set of related and unrelated knowledge. Policy should aim to mobilize local resources in order to foster interactive learning, especially among agents with unrelated knowledge bases. These initiatives would strengthen local capabilities through information dissemination and encourage the recombination of local knowledge, stimulating upper-level and radical innovation. On the other hand, in less developed regions with low-density knowledge structures, we find that related variety can foster innovation. In such cases, policymakers must act on two complementary fronts. First, policymakers should create mechanisms to stimulate interactive learning between agents in order to strengthen the generation of local knowledge spillovers. Second, policymakers should stimulate the creation, or the attraction, of new agents who have complementary capabilities to those of current agents. These new agents can be new firms or new sources of knowledge for local agents, such as universities, public research institutes and training institutions. New players will be able to boost the recombination of existing regional knowledge through external linkages.

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