Foreign Direct Investment spillovers, regional innovation, and the role of industrial diversity

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Abstract:
Inward Foreign Direct Investment (FDI) can generate important knowledge spillovers on local economies, fostering regional innovation, especially in developing countries. In this paper, we analyze how regional industrial structure shapes the effects of inward FDI spillovers on the innovative performance of Brazilian regions. Prior literature has analyzed the effects of FDI spillovers on the productivity of host countries' firms, while less attention has been given to the corresponding effects on regional innovation. Thus, we use data on the investments of Multinational Companies (MNCs) in Brazilian regions for 2003–2014 and relate these data to the innovative performance measured by patents. Our results show that inward FDI positively influences innovation at the regional level since Brazilian regions that receive inward FDI present stronger innovative performance. In addition, the positive effects of inward FDI on local innovation are reinforced by the diversity of the regional industrial structure. Diversified regions that receive inward FDI are therefore better able to leverage the benefits of inward FDI spillovers.

Keywords: Geografia da Inovação; Investimento Estrangeiro Direto (IDE); Transmissões de conhecimento; Inovação regional; Diversificação

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Área Temática: 4.3 Sistemas de inovação – nacional, regional, setorial, tecnológico

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Investimento direto externo, inovação regional e o papel da diversidade industrial

Resumo: O Investimento Direto Externo (IDE) pode gerar importantes transbordamentos de conhecimento sobre as economias locais, com efeitos positivos sobre a inovação regional. Neste artigo, analisamos como a estrutura industrial regional impacta sobre os efeitos de transbordamentos de conhecimento relacionados com a entrada de IDE sobre o desempenho inovador das regiões brasileiras. A literatura prévia analisou os efeitos dos transbordamentos de IDE sobre a produtividade das empresas dos países anfitriões, porém menos atenção foi despendida aos efeitos correspondentes sobre a inovação regional. Assim, a partir dos dados dos investimentos de Empresas Multinacionais (EMNs) nas regiões brasileiras no período 2003-2014, nós avaliamos os efeitos sobre o desempenho inovador das regiões, medido pelas patentes. Nossos resultados mostram que a entrada de IDE influencia positivamente a inovação regional, uma vez que as regiões brasileiras que receberam IDE apresentam um superior desempenho inovador. Além disso, os efeitos positivos do IDE na inovação local são reforçados pela diversidade da estrutura industrial regional. Regiões diversificadas que recebem IDE são, portanto, mais capazes de aproveitar os benefícios dos transbordamentos de IDE.

Palavras-chave: Geografia da Inovação; Investimento Estrangeiro Direto (IDE); Transmissões de conhecimento; Inovação regional; Diversificação

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1. Introduction

In recent decades, the world has experienced rapid changes in the innovation landscape. Some emerging countries have displayed rapid catch-up trajectories by incorporating new and important capabilities (Lee and Malerba 2017). However, most developing countries and their regions continue to suffer from a lack of domestic technological capabilities and rely mainly on technology transferred from advanced countries (Fagerberg, Srholec, and Verspagen 2010). This forces domestic firms to search for learning channels that allow them to access sources of new external knowledge. The main learning channels that are traditionally available to domestic firms in emergent countries include technology licensing, reverse engineering, labor mobility, information and knowledge exchange with suppliers and buyers, learning from trade exchange and Foreign Direct Investment (FDI) spillovers (Amendolagine et al. 2019).

Regarding sources of knowledge creation, the literature has focused on the role of FDI as an engine of regional growth and technological catch-up and innovation. Knowledge spillover effects from FDI have been studied at the firm, regional, and national levels. The literature in this line of research has also pointed out the main conditions that enable major knowledge spillovers from FDI in recipient regions. Regional factors such as the regional industrial structure, local absorptive capacity, and FDI investment characteristics are commonly noted as conditioning factors for the extension of FDI spillovers (Fu 2008; Moralles and Moreno 2020; Crescenzi and Iammarino 2017; Rojec and Knell 2018; Ascani, Balland, and Morrison 2020; Wang et al. 2016). Based on this literature, the aim of this paper is to analyze how regional industrial structure shapes the effects of inward FDI spillovers on the innovative performance of Brazilian regions.

A growing body of literature analyses the role of inward FDI knowledge spillovers. However, most of this literature has focused on the effects of FDI spillovers on the productivity growth of firms in recipient regions (Crespo and Fontoura 2007; Huynh et al. 2021; Kim 2015; Moralles and Moreno 2020; Ascani and Gagliardi 2020), and other studies increasingly focus on the effects on regional innovation (Fu 2008; Huang, Liu, and Xu 2012; Ning, Wang, and Li 2016; Ascani, Balland, and Morrison 2020; Wang et al. 2016). Despite the growing literature on inward FDI spillovers, we still have a limited understanding of how regional industrial structure shapes the relation between inward FDI and regional innovation. Studies exploring patterns of industrial diversity and specialization are limited and restricted to a focus on a handful of developing economies. Moreover, in addition to studies of developed countries (García, Jin, and Salomon 2013; Ascani and Gagliardi 2020; Ascani, Balland, and Morrison 2020; Amendolagine et al. 2019), increasing research analyses the effects of FDI spillovers in developing countries (Cui and Xu 2019; Fu 2008; Kim 2015; Huang, Liu, and Xu 2012; Huynh et al. 2021; Ning, Wang, and Li 2016; Wang et al. 2016). However, with few exceptions (Cabral and Alvarado 2020; Moralles and Moreno 2020), most studies focus on Asian countries.
Accordingly, there is still room to investigate the impact of inward FDI spillovers on the innovative performance of host regions, specifically, by considering the role of regional industrial structure. Presenting new empirical evidence to fill this research gap, the contribution of our paper is twofold. First, our analysis focuses on the effects of inward FDI on innovation at the regional level based on how the characteristics of regional industrial structure shape the effect of inward FDI spillovers. Second, our research is applied to a developing country, Brazil, and thus extends the current focus on Asia. We also use a more disaggregated geographic unit than previous studies, since we use mesoregions (equivalent to EU NUTS-2), while some previous studies use states as the geographic unit of analysis (Huang, Liu, and Xu 2012; Fu 2008; Wang et al. 2016). Our spatial panel approach allows us to find new empirical evidence at a high level of geographic disaggregation. Thus, our analysis presents stronger empirical evidence of the existence of FDI spillovers in host regions, reinforcing and deepening the findings of previous studies. Notably, Multinational Companies (MNCs) also play a very important role in the domestic productive structures of emerging countries.

To achieve these aims, we use a Regional Knowledge Production Function specification using two main data sources. The first source is the fDi Markets-Financial Times database for 2003–2014, which comprises all greenfield investments announced by MNCs in Brazil. Second, we use data on Brazilian patents from the Brazilian Intellectual Property Office for the 2006–2017 period. By using these data, we present the state of inward FDI in Brazilian regions by identifying regions that received more investments and the sectoral industry profiles of these investments. We also provide an assessment of the effects of FDI investments in Brazilian regions on regional innovative performance by considering the role of regional industrial structure. Our empirical findings show that Brazilian regions that have received inward FDI present better innovative performance according to disaggregated geographic units of analysis. Moreover, the effects of inward FDI spillovers are amplified in diversified regions, demonstrating the role of more complex and diversified capabilities in these regions.

The paper is structured as follows. The next section presents the main conceptual background regarding the relation between inward FDI and the innovative performance of regions and the role of regional industrial structure. The third section provides a brief description of the data used and of the main methodological issues, including our measure for inward FDI. The fourth section discusses our main findings regarding the effect of inward FDI on innovation in Brazilian regions and the moderating role of regional industrial structure. The final section presents final remarks, limitations, and policy implications.

1. Literature Review: Inward FDI and Regional Innovation

There is widespread recognition in the literature that inward FDI has positive effects on the technological and organizational knowledge of host countries (Reddy 2011; Amendolagine et al. 2019). This knowledge is embedded as tacit or codified knowledge in technology products or processes of foreign firms, and it represents new knowledge to the host country or region. Hence, inward FDI is an important external knowledge source that can contribute to regional innovation by bringing new technological knowledge to a region and by generating FDI technological spillovers to local firms. FDI spillovers can occur through imitations of foreign firms' products and technologies; labor market mobility of skilled workers; 'demonstration effects', whereby new products and technologies developed in other markets are employed by local producers; and even local firms' copying strategies (Fu 2008; Wang et al. 2016). Several types of linkages and interactions between foreign companies and local firms can generate local knowledge spillovers, which can improve regional knowledge and capabilities.

In the global landscape, FDI has grown substantially in the last three decades (Crescenzi and Iammarino 2017). MNC networks have significantly affected regions, contributing to uneven developments of regional capabilities in different parts of the world. Previous studies have found positive effects of inward FDI spillovers. Scholars have paid greater attention to how an increase in FDI can affect the innovative performance of regional economies (Fu 2008; Ning, Wang, and Li 2016; Ascani, Balland, and Morrison 2020; Wang et al. 2016). While there is broad recognition in the literature regarding the positive effects of inward FDI spillovers on regional innovation, some authors point out that empirical evidence on FDI spillovers offers mixed results (Rojec and Knell 2018). Therefore, we provide the following hypothesis:

H1: Inward FDI positively affects regional innovation.

However, there is a growing recognition that regional economic and local innovation trajectories do not depend exclusively on local knowledge assets but on the capacity of local agents to combine local capabilities with external sources of knowledge (Crescenzi and Iammarino 2017). The extents of inward FDI spillovers and their effects on innovation are shaped by local factors, such as the absorptive capacity of local agents and regional industrial structure. New knowledge from inward FDI does not exist in a "territorial vacuum," and the evolution of a region is increasingly dependent on its capacity to search for and absorb external knowledge, which circulates in global circuits of knowledge creation (Crescenzi and Iammarino 2017). Regions with limited capabilities and a poor knowledge base are unable to absorb external knowledge from inward FDI (Ubeda and Pérez-Hernández 2017; Moralles and Moreno 2020; Fu 2008; Cui and Xu 2019).

Regional industrial structure also moderates the extents of FDI local knowledge spillovers (Gao 2004; Crespo and Fontoura 2007; Ascani and Gagliardi 2020; Ning, Wang, and Li 2016; Wang et al. 2016). The need to consider regional industrial structure is widely acknowledged in the extant literature. Recent research has recognized that FDI spillovers can have quite different effects in developed and emerging countries, mainly due to the overwhelming differences in the productive bases of these countries (Valacchi, Doytch, and Yonzan 2021). The heterogeneity of local firms is another factor that has been indicated as a conditioning factor for FDI spillovers (Rojec and Knell 2018), i.e., an industry's impulse to capture learning opportunities related to inward FDI at the regional level (Ascani and Gagliardi 2020). Studies in Asian countries have also pointed out that regional innovation environment (Li, Li, and He 2018) and agglomeration economies (Song and Zhang 2017) are moderating factors of the impacts of inward FDI spillovers on regions.

Specifically, regarding local industrial diversity, prior literature has identified two types of local positive externalities that can play an important role in processes of knowledge creation and diffusion: specialization, also associated with MAR externalities, and diversity, which is linked to Jacobs externalities (Beaudry and Schiffauerova 2009; Mascarini, Garcia, and Roselino 2019). The diversity of regional industrial structures is an important way to generate knowledge spillovers, especially among cognitively similar industries (Frenken, Van Oort, and Verburg 2007; Hesse and Fornahl 2020). Regional industrial structure can also imply different intensities of the FDI effect on local innovation.

However, there is little research on the effects of inward FDI spillovers that consider regional diversification or specialization. In addition, existing empirical studies offer mixed evidence. Gao (2004) has found not only that inward FDI has strong positive effects on regional industrial growth but also that regional industrial structure has no significant effect on local innovation. On the other hand, Ning et al. (2016) have found that specialized industrial structures present advantages for assimilating inward FDI externalities due to their highly specialized knowledge bases. Thus, prior specialized knowledge and local experience can enable the absorption of formally codified foreign knowledge and the comprehension of FDI embedded tacit knowledge, creating more immediate opportunities for the recombination of knowledge and learning (Ning, Wang, and Li 2016). In contrast, Wang et al. (2016) have found that industrial specialization reduces the positive effects of FDI spillovers, whereas industrial diversity enhances inward FDI knowledge spillovers. More diversified regions may have a broader knowledge base that can play an important role in absorbing knowledge spillovers from MNCs. A diversified knowledge base may be more able to introduce new knowledge from multiple fields, leading to a cross-fertilization of the new knowledge brought by FDI and the local knowledge base, with positive effects on innovation and learning (Wang et al. 2016). Based on this debate, we outline our second hypothesis:

H2: Regional productive structure shapes the relation between inward FDI spillovers and regional innovation.

2. Data and methodology

2.1 The assembly of the database

We use two main sources to assemble our dataset. The first source is Brazilian Intellectual Property Office (BADEPI/INPI, Portuguese acronym) data, which comprise patent applications for the period 2006-2017. In Brazil, a significant share of innovation is related to exploration in its domestic market; thus, patenting activity typically occurs in the Brazilian patent office. We use patent geolocation for a fractional count of inventors' addresses. The second dataset used is the fDi Markets-Financial Times database for 2003 to 2014, which comprises all announced greenfield investments made by MNCs in Brazil. We assign data to 137 Brazilian mesoregions, which is comparable to EU NUTS-2.

Notably, MNCs play an important role in the domestic productive structures of emerging countries. They usually occupy a high share in the domestic manufacturing industry, especially in high-tech sectors, and they are responsible for a significant share of domestic R&D expenditures (Suzigan, Garcia, and Assis Feitosa 2020). Emerging economies usually suffer from the lack of domestic capabilities, and MNCs can represent an important source of new knowledge that positively impacts regional development. Furthermore, several countries and their regions have strong policies for attracting FDI (Crescenzi and Iammarino 2017). Impacts of inward FDI, however, are different in developed and emerging countries (Valacchi, Doytch, and Yonzan 2021).

The geographic distribution of patent applications in Brazil shows a strong concentration in the southern regions of the country (Figure 1). In other regions, patents are concentrated in larger cities, mainly in state capitals. Several studies have shown the geographic concentration of innovation in Brazil (Araújo and Garcia 2019; Gonçalves, de Matos, and de Araújo 2019).

FIGURE 1 ABOUT HERE

Regarding FDI in Brazil, inward FDI grew from approximately 63 billion USD in 2003–2005, reached a maximum of 120 billion USD in 2009–2011, and totaled 74 billion USD in 2012–2014. During this period, the Brazilian economy faced considerable economic growth, which attracted strong FDI, even after the international financial crisis. Despite the great inflow of FDI, as in other countries (Crescenzi and Iammarino 2017; Wang et al. 2016), investments were both regionally skewed and unevenly distributed among Brazilian regions (Figure 2). In Brazil, 59 of 137 mesoregions received FDI inflows.

FIGURE 2 ABOUT HERE

Additionally, FDI was concentrated in southern Brazilian regions and close to major cities. The FDI localization pattern shows that these investments are strongly market-oriented, since regions that received the highest investments were those with the largest consumer markets. Even among regions that received FDI, the value of investments varied greatly. The average regional inward FDI was 1.37 billion USD across the whole period (2003–2014) (Appendix 1). The region that received the most FDI in Brazil in the analyzed period was Rio de Janeiro, whose investments are mainly related to oil, energy and chemical complexes located in the Industrial Complex of Petrobras, the Brazilian oil and gas state-owned enterprise (SOE).

2.2 Empirical Strategy

To analyze the effect of inward FDI on innovation, our dependent variable in the empirical model is the fractional patent count per 1 million inhabitants in mesoregion r and period t ($PI_{r,t}$). To prevent annual sporadic event effects, our measure of regional innovation was calculated from fractional patent applications of each region for a 3-year time window, providing us with data for four subsequent periods (2003–2005, 2006–2008, 2009–2011, and 2012–2014). The use of patent data as a proxy of innovation output is common in the innovation literature (Miguelez and Moreno 2018; Kang and Dall'erba 2016; Corsatea and Jayet 2014; Araújo and Garcia 2019).

Our main independent variable of interest is inward FDI, which allows us to examine how inward FDI affects regional innovation in Brazil. To measure regional industrial diversification, we use the Hirschman-Herfindahl index (HHI), in which S_{ij} is the number of workers from sector i in region j, divided by the total workers of region j, and i is the number of manufacturing sectors.

$$HHI_j = \sum_{i=1}^{I} \left(S_{ij}\right)^2$$

Therefore, the HHI assumes values near 0 when employment is more equally distributed in industries and near 1 when employment is concentrated in one specific industry. Thus, the HHI is higher for specialized regions and lower for diversified regions. Using the HHI, we can assess how regional industrial structure shapes the effects of inward FDI spillovers on regional innovation.

We also used control variables associated with local innovation ecosystems, including industrial R&D and university R&D. The presence of innovation-complementary assets in the host region is an important driver of local innovation (Fu 2008). Our proxy for industrial R&D expenditures is the number of R&D researchers divided by 100 workers in a region (Kang and Dall'erba 2016; Gonçalves, de Matos, and de Araújo 2019). The proxy for university R&D is the number of scholarships granted to graduate students per 1 million inhabitants in a mesoregion, since university R&D is heavily linked to graduate programs (Araújo and Garcia 2019). We also add regional fixed effects to control for specific policies, or fiscal regimes, in Brazilian states and for any other unobserved heterogeneity. Table 1 presents descriptions of the variables. Table 2 lists the descriptive statistics, and the correlation matrix is presented in Appendix 2.

TABLE 1 ABOUT HERE

TABLE 2 ABOUT HERE

2.3 The Econometric Model

We estimate four different regional knowledge production function spatial specifications, following Zhang and Yu (2018), and use AIC and BIC (Akaike and Bayesian information criterion, respectively) as the selection criteria (see Appendix 3). The spatial error model (SEM) proved to be the best fit for the data, but there is almost no difference for a spatial autoregressive (SAR) model, which includes the spatial autocorrelation term that measures the interregional spillovers of innovation. Therefore, we use the SAR as our reference model, and our empirical model presents two specifications as follows:

$$\mathrm{PI}_{r,t} = \rho \mathrm{WPI}_{r,t-1} + \beta_1 \mathrm{FDI}_{r,t-1} + \beta_3 \mathrm{HHI}_{r,t-1} + \beta_4 \mathrm{FDI}_{r,t-1} * \mathrm{HHI}_{r,t-1} + \beta' \mathrm{X}'_{r,t-1} + \varepsilon_{r,t} \quad (1)$$

$$\mathrm{PI}_{r,t} = \beta_1 \mathrm{FDI}_{r,t-1} + \beta_3 \mathrm{HHI}_{r,t-1} + \beta_4 \mathrm{FDI}_{r,t-1} * \mathrm{HHI}_{r,t-1} + \beta' \mathrm{X}'_{r,t-1} + \mathrm{v}_{r,t} \quad (2)$$

$$\mathrm{v}_{r,t} = \lambda \mathrm{Wu}_{r,t} + \varepsilon_{r,t} \quad (3)$$

Equation (1) is the SAR specification, and Equations (2) and (3) are the SEM specifications. Both have the same parameters, and the only difference is how spatial dependence is modeled. In the models, r denotes the region, and t denotes the period. Our dependent variable is a proxy for regional innovation ($PI_{r,t}$). As is typical for innovation-led empirical models, we use independent variables with a one-period lag, since several years of innovative effort are required before a final patent is filled. $FDI_{r,t-1}$ indicates the inward FDI of period *t-1*, and the Hirschman-Herfindahl index (HHI_{t-1}) is used to assess the effect of regional industrial structure. We also include an interaction term between $FDI_{r,t-1}$ and HHI_{t-1} to analyze how the effects of inward FDI are shaped by regional industrial structure.

Regional controls are expressed by vector $X'_{r,t-1}$, which resumes the characteristics of the regional innovation system, and it is composed of three variables at time *t-1*: industrial R&D ($RDI_{r,t-1}$), university R&D ($RDU_{r,t-1}$) and regional fixed effects. Finally, for SAR, $\mathrm{W\,PI}_{r,t-1}$ is the spatial autoregressive term, and ρ measures the magnitude of interregional spillovers. For SEM, $v_{r,t}$ is the error term that includes the spatial error term, which includes the spatial weight matrix ($Wu_{r,t}$).

3. Results and Discussion

3.1 Econometric Analysis

To examine the relation between FDI and local industrial structure (HHI), we initially estimate four models. Model (1) is the simple model with the FDI of the previous period ($PI_{r,t}$; $FDI_{r,t-1}$) and regional fixed effects. Model (2) includes the Hirschman-Herfindahl index (HHI_{t-1}) with controls for industrial and academic R&D and population density ($RDI_{r,t-1}$; $RDU_{r,t-1}$). In Model (3), we add the spatial error term, and in Model (4), we add the spatial autocorrelation term (Table 3).

TABLE 3 ABOUT HERE

The main results demonstrate the relevance of the spatial model since the spatial coefficients of the SEM and SAR estimations are significant. The results show that inward FDI ($FDI_{r,t-1}$) has an overall positive effect on local innovation, confirming conceptual expectations and previous empirical studies (Ascani and Gagliardi 2020; Ascani, Balland, and Morrison 2020; Ning, Wang, and Li 2016; Valacchi, Doytch, and Yonzan 2021; Wang et al. 2016). Accordingly, our findings suggest that local knowledge spillovers from inward FDI are a driver that can foster local innovation, confirming H1.

Regarding regional industrial structure, the HHI coefficient is negative and significant. This finding means that as a region becomes more diversified, its innovative performance improves, while the HHI takes higher values when a region is more specialized. The coefficients for industrial R&D ($RDI_{r,t-1}$) and university R&D ($RDU_{r,t-1}$) are positive and significant, confirming that local innovation is affected by industrial and academic R&D expenditures at the regional level. Several previous empirical studies that use similar specifications show that both local industrial and academic R&D are drivers of regional innovation (Audretsch and Feldman 1996; Garcia, Araujo, and Mascarini 2013). Therefore, the results of Models (3) and (4) allow us to infer that inward FDI can generate strong local knowledge spillovers, even when controlling for other drivers of regional innovation. Finally, the spatial autoregressive coefficient estimated in Model (4) is positive, confirming previous results that indicated innovative interregional spillovers in Brazil (Araújo and Garcia 2019; Gonçalves, de Matos, and de Araújo 2019).

To analyze how regional industrial structure shapes the effects of inward FDI on local innovation, our empirical specification includes an interaction term between $FDI_{r,t-1}$ and HHI_{t-1} for both spatial specifications (Models 5 and 6, Table 3).

The results show that the interaction term is negative and significant in both specifications. Overall, the results remain the same, and the coefficient of FDI becomes significant and increases in comparison to prior specifications. The interpretation of these results is not straightforward. Similarly, since the SAR is our reference model, we need to estimate the total effects for this model; the spatial autoregressive term does not allow us to directly interpret the coefficients as partial derivatives. Hence, we calculate the direct, indirect, and total effects (Table 4). The direct and indirect effects of FDI are positive and significant, and those of the interaction term between FDI and HHI are negative and significant, implying positive and negative total effects for these variables, respectively.

TABLE 4 ABOUT HERE

The FDI total effect in Model (6) is 0.205, and the total effect of the interaction term is -0.864. The effect of inward FDI on innovation depends on the sum of the coefficients of FDI with the interaction term, multiplied by the specific HHI level. Therefore, to compare the results of the coefficients to the previous specifications, we sum these effects by multiplying the interaction term by the average value of the regions' HHI value (0.234), resulting in 0.003, which is positive, even small. A new scenario emerges after changing the HHI, as the value of the new coefficient after increasing the level of specialization by one standard deviation (+0.148) is -0.125 and that obtained after increasing the diversification level (lowering by one standard deviation) is 0.131. Thus, our empirical findings show that the inward FDI effect on innovation in diversified regions is greater than the effect in the mean region, and this effect is reduced as regional specialization increases. This result confirms H2; diversification amplifies FDI effects on local innovation.

These estimations include regional fixed effects to control for differences in state policies. As Brazil has 27 states and 137 mesoregions, we can better deal with unobserved characteristics by using fixed effects at the mesoregion level. Using this approach, we estimated the SEM and SAR models, even with a relatively short panel (Models 8 and 9, Table 5).

TABLE 5 ABOUT HERE

The three main results remain similar after controlling for mesoregion fixed effects. The coefficients for the interaction term of FDI and HHI, the spatial error or autoregressive term, and the academic R&D remain significant. This result corroborates our main result, which confirms H2 and underscores the relevance of adopting the spatial model.

3.2 Robustness check

To ensure that our results are not choice-sensitive, we estimate the SEM and SAR models with alternative specifications. The first point stems from the fact that our dependent variable is defined by the domestic patenting office (Brazilian Intellectual Property Office), which can include both higher- and lower-level patents. To ensure innovation quality, we estimate new models with only higher-level patents. Following Higham, de Rassenfosse, and Jaffe (2021), we change our dependent variable for only international PCT patents; and for coinvented patents (PI Coinv) (Models 11 and 14 in Appendix 4). Overall, the results remain the same.

The second point is our variable for inward FDI, since our results could be sensitive to that variable. Thus, we estimate another model, following Valacchi et al. (2021), measuring FDI by the jobs created in each specific region (Jobs). The main results remain the same for SEM and are slightly different for SAR (Models 15 and 16 in Appendix 4). Third, we use an alternative spatial matrix specification. The results were estimated using an inverse distance spatial weight matrix. As a robustness check, we also estimated it using a Queen-contiguity matrix, and the results are quite similar (Appendix 5).

3.3 Discussion of the effects of inward FDI and the role of regional industrial structure

Our findings show that inward FDI has positive effects on regional innovation in Brazilian regions. This result is in line with the literature that notes the positive effects of inward FDI on innovation in host regions (Fu 2008; Huang, Liu, and Xu 2012; Ning, Wang, and Li 2016; Ascani, Balland, and Morrison 2020; Wang et al. 2016). We can infer that inward FDI allows the combination of new knowledge brought to the region by external investments and the extant capabilities of local actors, resulting in new knowledge combinations. Accordingly, these new combinations of knowledge can foster interactive learning in host regions, with positive effects on regional innovation. In addition, our findings allow us to conclude that the benefits of inward FDI vary according to levels of regional industrial diversification. The effect of inward FDI on regional innovation is higher for regions with diversified industrial structures. Notably, this result is robust to different variable specifications and spatial fixed effects estimations.

For diversified regions, our findings show that inward FDI is an important source of new knowledge for regions with a set of diversified and dense local capabilities. The combination of diverse and complex local knowledge with new external knowledge brought to the region through inward FDI can create new knowledge combinations that foster interactive learning and innovation. Diversified regions have better conditions for absorbing new knowledge because they cover a broader scope of technological fields and present more vertical and horizontal linkages. The diversified knowledge base in these regions proves more capable of incorporating new knowledge from several fields, fostering cross-fertilization between the new knowledge brought by FDI and local knowledge bases, stimulating regional innovation. Therefore, our findings suggest that inward FDI in diversified regions can better leverage the benefits of inward FDI for regional innovation. On the other hand, specialized regions have narrower and context-specific knowledge bases, which reduce the likelihood of taking advantage of new combinations that can be built with the new external knowledge that arrives in such regions. A more specialized knowledge base could suffer more from lock-in effects, which can result in fewer opportunities to exploit new capabilities and linkages of inward FDI. Our findings confirm these expectations, since local knowledge spillovers from inward FDI are less expressive in specialized regions than in diversified regions.

This result emphasizes the role of the relationship between FDI and diversity in creating positive knowledge spillovers and fostering local innovation. Our empirical results for the Brazilian context confirm findings from previous empirical studies conducted in China (Fu 2008; Wang et al. 2016). The results also show that inward FDI has a positive impact on overall regional innovation capacity. In both cases, we examine developing countries with continental dimensions, where inward FDI is regionally skewed and unevenly distributed. However, one important difference is that our results are based on a rather geographically disaggregated level, Brazilian mesoregions, whereas studies of China have focused on Chinese provinces (Wang et al. 2016).

On the other hand, our results contrast with the findings of Ning et al. (2016) in their study of China. They show that specialized industrial structures absorb FDI knowledge spillovers within cities and facilitate their dissemination to nearby cities. We can assume that the disparate findings of Ning's study of China and our research on Brazil are the result of using different geographic units. The study using Chinese cities as its unit of analysis (Ning, Wang, and Li 2016) has suggested that productive specialization can leverage the benefits of inward FDI spillovers. In contrast, studies using Brazilian regions (this research) and Chinese provinces (Wang et al. 2016) as geographical units of analysis conclude that industrial diversity can have greater effects on regional innovation.

Additionally, two other findings must be noted. First, the results from the spatial models indicate the existence of interregional knowledge spillovers in Brazilian regions, with positive impacts on innovation at the regional level. Second, our results also confirm the role of the traditional drivers of regional innovation in Brazilian regions. We find that industrial and academic R&D are relevant for regional innovation (Fritsch and Slavtchev 2010; Kang and Dall'erba 2016). The diversification of regional industrial structure also positively affects local innovation (Corsatea and Jayet 2014).

4. Final Remarks and Policy Implications

A set of studies in the economic geography literature examines the effects of inward FDI spillovers on regional economies. Most of this literature focuses on the effects of FDI spillovers on productivity growth (Moralles and Moreno 2020; Crespo and Fontoura 2007; Kim 2015; Ascani and Gagliardi 2020; Huynh et al. 2021). An increasing number of studies focus on similar effects on regional innovation (Fu 2008; Huang, Liu, and Xu 2012; Ning, Wang, and Li 2016; Ascani, Balland, and Morrison 2020; Wang et al. 2016). However, there is still a limited understanding of how regional industrial structure shapes the relation between inward FDI and regional innovation. Helping to fill this research gap, our main contribution is to present new empirical evidence for how industrial diversity shapes the effects of inward FDI knowledge spillovers on regional innovation. Accordingly, our findings show that inward FDI positively affects innovation at the regional level, since Brazilian regions receiving inward FDI have better innovative performance. In addition, the positive effects of inward FDI on local innovation are reinforced by the diversification of the local productive structure. Hence, diversified regions that receive inward FDI can better leverage the benefits of local spillovers from inward FDI.

While our empirical analysis is limited to the Brazilian context, we believe that our findings are general enough to be applied to other contexts. The presented results are highly relevant to other developing countries that similar to Brazil, receive large amounts of inward FDI, although these inflows are often regionally skewed and uneven. Our findings show that regional industrial structure shapes the effects of inward FDI spillovers. Thus, because recipient regions benefit from FDI externalities, it is necessary for a region to have local capabilities that can absorb the new knowledge brought by inward FDI. This is the case for diversified regions, where the diversity and complexity of local knowledge can amplify the effects of inward FDI spillovers, fostering the creation of new knowledge through the combination of existing knowledge and knowledge brought by inward FDI. Furthermore, the existence of high absorptive capacity in a region can amplify the effects of FDI spillovers. However, this factor extends the main findings of this paper and should be the subject of further research.

Finally, our findings have policy implications. FDI attraction policies are widely used by local governments to stimulate regional economic growth and local income generation. However, such policies must be developed while acknowledging that the benefits of local spillovers are better exploited if they are associated with the existence of a diversified local industrial structure and a set of diverse and complex capabilities. Therefore, FDI attraction policies must be associated with policies regarding the formation, consolidation, and structuring of local capacities to absorb the new knowledge brought by inward FDI, thereby combining such knowledge with local knowledge and transforming it into new knowledge and innovation.

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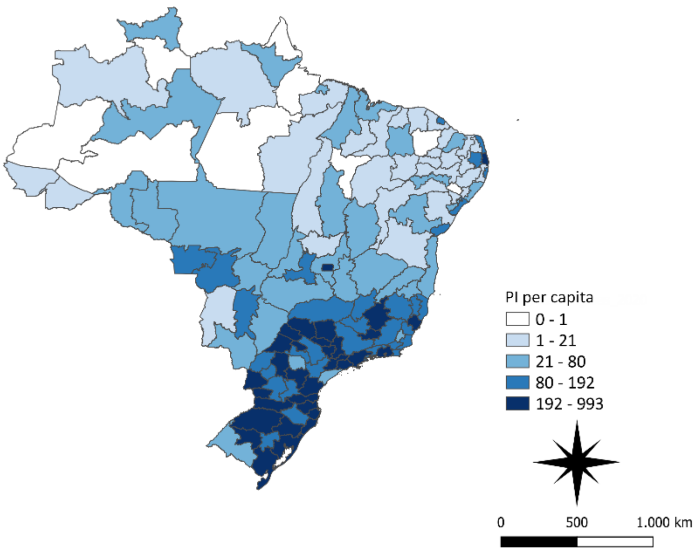
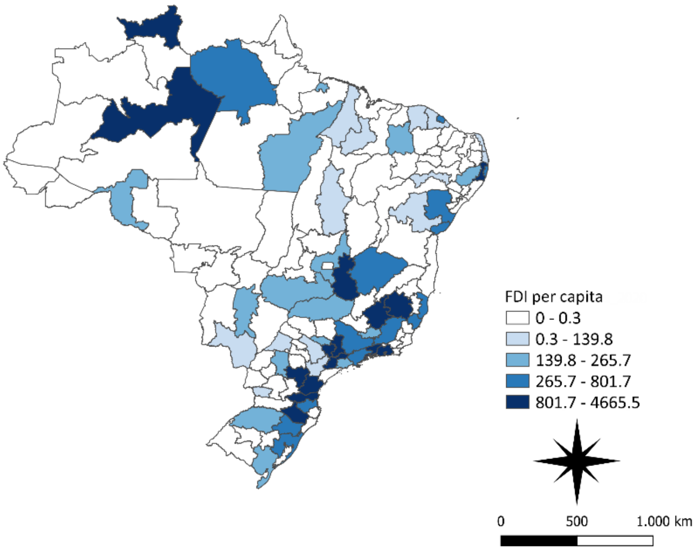
Figures and Tables

Figure 1 – Patents per 1 million inhab. by mesoregion (2006-2017)



Source: own elaboration based on BADEPI/INPI data.

Figure 2 – FDI (USD million) per 1 million inhab. by mesoregion (2003-2014)



Source: own elaboration based on fDi Markets-Financial Times database.

Table 1- Definition of the variables

Variable	Description	Source
PI	Fractional patents count per 1 million inhab.	BADEPI and IBGE
HHI	Hirschman-Herfindahl index of the meso-region employment (2 digit)	RAIS/ MTE
FDI	Announced inward FDI in millions USD per 1 million inhab.	fDI Markets
RDI	Number of R&D researchers per 100 workers in manufacturing	RAIS/ MTE
RDU	Number of graduate scholarships per 1 million inhab.	GEOCAPES and IBGE

Source: own elaboration.

Table 2 - Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
$\ln(PI_{r,t})$	685	3.369	47.669	0.000	277.787
$\ln(FDI_{r,t})$	548	1.217	2.172	0.000	8.043
$\ln(RDI_{r,t})$	548	0.498	0.306	0.060	0.888
$\ln(RDU_{r,t})$	548	172.775	355.581	0.000	2,898.405
$HHI_{r,t}$	548	0.234	0.148	0.060	0.888

Source: own elaboration.

Table 3 – Multivariate Regression Analyses. PI as dependent variable

Variables	(1) OLS	(2) OLS	(3) SEM	(4) SAR	(5) SEM	(6) SAR
$\ln(FDI_{r,t})$	0.0214* (0.0129)	0.0172 (0.0120)	0.0118 (0.00851)	0.00999 (0.00854)	0.0752*** (0.0178)	0.0603*** (0.0179)
$\ln(RDI_{r,t})$		0.289** (0.116)	0.264** (0.106)	0.219** (0.106)	0.202* (0.104)	0.166 (0.106)
$\ln(RDU_{r,t})$		0.000466*** (0.000102)	0.000397*** (6.17e-05)	0.000348*** (5.90e-05)	0.000392*** (6.09e-05)	0.000340*** (5.87e-05)
$HHI_{r,t}$		-0.848*** (0.238)	-0.698*** (0.204)	-0.635*** (0.206)	-0.636*** (0.200)	-0.587*** (0.203)
$\ln(FDI_{r,t})*HHI_{r,t}$					-0.319*** (0.0790)	-0.254*** (0.0794)
W u_t			0.824*** (0.0642)		0.836*** (0.0607)	
W $PI_{r,t}$				0.718*** (0.0686)		0.725*** (0.0681)
Constant	0.633*** (0.0279)	0.747*** (0.101)	0.721*** (0.269)	0.392 (0.275)	0.715*** (0.258)	0.386 (0.267)
Observations	548	548	548	548	548	548
Number of regions	137	137	137	137	137	137
State Fixed Effects			Yes	Yes	Yes	Yes
Mesoregion Fixed Effects			No	No	No	No
R^2	0.6339	0.7544	0.7445	0.7394	0.7589	0.7448
AIC			412.23	416.07	398.08	407.91

Source: Own elaboration

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 4 – Total Effects – SAR Model (6)

Variables	Direct	Indirect	Total
$\ln(FDI_{r,t})$	0.061***	0.144**	0.205***
	(0.018)	(0.064)	(0.077)
$\ln(RDI_{r,t})$	0.168	0.396	0.564
	(0.108)	(0.276)	(0.374)
$\ln(RDU_{r,t})$	0.0003***	0.0008***	0.001***
	(0.00006)	(0.0003)	(0.0003)
$HHI_{r,t}$	-0.599***	-1.403**	-2.002**
	(0.206)	(0.641)	(0.797)
$\ln(FDI_{r,t})*HHI_{r,t}$	-0.259***	-0.606**	-0.864**
	(0.081)	(0.282)	(0.344)

Source: Own elaboration

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 5 – Multivariate Regression Analyses. PI as dependent variable

Variables	(7) SEM	(8) SAR
$\ln(FDI_{r,t})$	0.0271 (0.0190)	0.0196 (0.0190)
$\ln(RDI_{r,t})$	-0.215 (0.136)	-0.246* (0.131)
$\ln(RDU_{r,t})$	0.000276*** (6.82e-05)	0.000266*** (6.40e-05)
$HHI_{r,t}$	-0.0139 (0.267)	-0.0442 (0.264)
$\ln(FDI_{r,t})*HHI_{r,t}$	-0.182** (0.0823)	-0.145* (0.0825)
$W\ u_t$	0.869*** (0.0549)	
$W\ PI_{r,t}$		0.840*** (0.0600)
Constant	-	-
Observations	548	548
Number of regions	137	137
State Fixed Effects	Yes	Yes
Mesoregion Fixed Effects	Yes	Yes
R^2	0.0518	0.0514
AIC	17.49	18.47

Source: Own elaboration

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Appendix 1

Table A1 – Top 10 mesoregions on inward FDI (USD million) – Brazil, 2003-2014

	Mesoregion	**FDI** (MM USD)
1	Rio de Janeiro Metro Region	19,651
2	Belo Horizonte Metro Region	6,914
3	South Rio de Janeiro State	4,910
4	Curitiba Metro Region	4,598
5	Macro Sao Paulo – Sorocaba and Jundiai	4,318
6	Manaus	4,274
7	Sao Paulo Metro Region	4,017
8	Campinas Metro Region	3,464
9	Litoral Pernambuco	2,815
10	Piracicaba Region	2,208

Source: fDi Markets-Financial Times database.

Appendix 2

Table A2 – Correlation matrix

	$PI_{r,t}$	$\ln(FDI_{r,t})$	$\ln(RDI_{r,t})$	$\ln(RDU_{r,t})$
$\ln(FDI_{r,t})$	0.3929			
$\ln(RDI_{r,t})$	0.4865	0.4691		
$\ln(RDU_{r,t})$	0.4995	0.1660	0.2999	
$HHI_{r,t}$	-0.4026	-0.3256	-04503	-0.2531

Source: Own elaboration

Appendix 3

Table A3 – Spatial Weight Matrix: inverse of distance

Variables	(3) SEM	(4) SAR	(9) SDEM	(10) SDM
$\ln(FDI_{r,t})$	0.0118	0.00999	0.0140	0.0129
	(0.00851)	(0.00854)	(0.00866)	(0.00860)
$\ln(RDI_{r,t})$	0.264**	0.219**	0.267**	0.266**
	(0.106)	(0.106)	(0.106)	(0.105)
$\ln(RDU_{r,t})$	0.000397***	0.000348***	0.000388***	0.000391***
	(6.17e-05)	(5.90e-05)	(6.07e-05)	(6.02e-05)
$HHI_{r,t}$	-0.698***	-0.635***	-0.652***	-0.736***
	(0.204)	(0.206)	(0.217)	(0.210)
W $\ln(FDI_{r,t})$			0.0185	-0.0502
			(0.103)	(0.0803)
W $\ln(RDI_{r,t})$			-1.770	-2.460**
			(1.355)	(1.058)
W $\ln(RDU_{r,t})$			0.000401	0.000507
			(0.000722)	(0.000469)
W $HHI_{r,t}$			1.443	-1.625
			(3.541)	(2.664)
W u_t	0.824***		0.830***	
	(0.0642)		(0.0702)	
W $PI_{r,t}$		0.718***		0.730***
		(0.0686)		(0.0876)
Constant	0.721***	0.392	1.337	1.468
	(0.269)	(0.275)	(1.124)	(1.149)
Observations	548	548	548	548
Number of regions	137	137	137	137
State Fixed Effects	Yes	Yes	Yes	Yes
Mesoregion Fixed Effects	No	No	No	No
R^2	0.7445	0.7394	0.7931	0.8048
AIC	412.23	416.07	425.68	431.41

Source: Own elaboration

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1
SEM: spatial error model; SAR: spatial autoregressive model; SDEM: spatial Durbin error model; and SDM: spatial Durbin model

Appendix A4 – Robustness Check

Table A4.1 - Multivariate Regression Analyses. PI PCT as dependent variable

Variables	(11) SEM	(12) SAR
$\ln(FDI_{r,t})$	0.0503*** (0.00939)	0.0485*** (0.00931)
$\ln(RDI_{r,t})$	0.287*** (0.0473)	0.285*** (0.0468)
$\ln(RDU_{r,t})$	9.90e-05*** (2.89e-05)	9.19e-05*** (2.81e-05)
$HHI_{r,t}$	0.00135 (0.0908)	0.0153 (0.0899)
$\ln(FDI_{r,t})*HHI_{r,t}$	-0.170*** (0.0428)	-0.166*** (0.0424)
$W\ u_t$	0.546*** (0.157)	
$W\ PI\ PCT_{r,t}$		0.476*** (0.117)
Constant	-0.0553 (0.101)	-0.0773 (0.100)
Observations	548	548
Number of regions	137	137
State Fixed Effects	Yes	Yes
Mesoregion Fixed Effects	No	No
R^2	0.5685	0.5800
AIC	-391.01	-367.34

Source: Own elaboration
Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A4.2 - Multivariate Regression Analyses. PI Coinventor as dependent variable

Variables	(13) SEM	(14) SAR
$\ln(FDI_{r,t})$	0.122*** (0.0251)	0.104*** (0.0252)
$\ln(RDI_{r,t})$	0.441*** (0.133)	0.431*** (0.135)
$\ln(RDU_{r,t})$	0.000721*** (8.56e-05)	0.000686*** (8.53e-05)
$HHI_{r,t}$	-0.686*** (0.254)	-0.679*** (0.256)
$\ln(FDI_{r,t})*HHI_{r,t}$	-0.421*** (0.113)	-0.341*** (0.114)
$W\ u_t$	0.861*** (0.0552)	
$W\ PI\ Coinventor_{r,t}$		0.693*** (0.0619)
Constant	0.387 (0.291)	0.0912 (0.294)
Observations	548	548
Number of regions	137	137
State Fixed Effects	Yes	Yes
Mesoregion Fixed Effects	No	No
R^2	0.7166	0.7230
AIC	767.75	771.03

Source: Own elaboration
Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table A4.3 - Multivariate Regression Analyses. PI as dependent variable

Variables	(15) SEM	(16) SAR
ln(FDI $Jobs_{r,t}$)	31.78 (31.50)	15.36 (31.48)
ln($RDI_{r,t}$)	0.272** (0.107)	0.220** (0.107)
ln($RDU_{r,t}$)	0.000385*** (6.11e-05)	0.000337*** (5.86e-05)
$HHI_{r,t}$	-0.668*** (0.205)	-0.615*** (0.207)
ln(FDI $Jobs_{r,t}$)*$HHI_{r,t}$	-197.6* (104.2)	-129.5 (104.3)
W u_t	0.836*** (0.0611)	
W $PI_{r,t}$		0.732*** (0.0674)
Constant	0.727*** (0.273)	0.396 (0.279)
Observations	548	548
Number of regions	137	137
State Fixed Effects	Yes	Yes
Mesoregion Fixed Effects	No	No
R^2	0.7392	0.7312
AIC	409.09	415.17

Source: Own elaboration
Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Appendix 5

Table A5 – Spatial Weight Matrix: queen contiguity

Variables	(1) SEM	(5) SAR	(9) SDEM	(13) SDM
ln($FDI_{r,t}$)	0.0128 (0.00898)	0.0140 (0.00916)	0.0184** (0.00910)	0.0172* (0.00905)
ln($RDI_{r,t}$)	0.304*** (0.109)	0.296*** (0.109)	0.324*** (0.102)	0.348*** (0.101)
ln($RDU_{r,t}$)	0.000426*** (6.26e-05)	0.000444*** (6.17e-05)	0.000392*** (5.92e-05)	0.000394*** (6.01e-05)
$HHI_{r,t}$	-0.812*** (0.208)	-0.804*** (0.212)	-0.861*** (0.211)	-0.860*** (0.203)
W ln($FDI_{r,t}$)			0.0379 (0.0262)	0.0156 (0.0228)
W ln($RDI_{r,t}$)			-0.324 (0.301)	-0.499* (0.263)
W ln($RDU_{r,t}$)			0.000233 (0.000172)	7.95e-05 (0.000156)
W $HHI_{r,t}$			-0.584 (0.713)	-0.178 (0.609)
W u_t	0.429*** (0.0683)		0.408*** (0.0682)	
W $PI_{r,t}$		0.247*** (0.0559)		0.318*** (0.0661)
Constant	0.749*** (0.261)	0.691** (0.271)	1.048*** (0.266)	1.019*** (0.270)
Observations	548	548	548	548
Number of regions	137	137	137	137
State Fixed Effects	Yes	Yes	Yes	Yes
Mesoregion Fixed Effects	No	No	No	No
R^2	0.7509	0.7422	0.8114	0.8149
AIC	464.18	479.07	462.60	472.21

Source: Own elaboration
Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1