Unlocking Technological Diversification: The Role of Regional and Transnational Linkages in Brazilian Regions

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Abstract

This study examined the effects of intra-regional and transnational linkages on technological diversification in Brazilian regions from 1997 to 2020, highlighting the role of stakeholder collaboration in fostering knowledge and skill development. Our findings reveal that regional linkages positively influence diversification, whereas transnational connections primarily help to preserve existing technological specialisations. These results offer valuable insights for policymakers seeking to promote innovation and diversification in emerging economies, underscoring the importance of both regional and international collaborations for technological growth.

This study investigates how intra-regional and transnational linkages affect technological diversification in Brazilian regions between 1997 and 2020. We focus on both the emergence of new technological specialisations and the persistence of existing ones. Using patent data from the Brazilian Patent Office and panel regression models with fixed effects, we examine how the structure of inter-regional and international connections relates to the dynamics of diversification. Our findings suggest that domestic regional linkages promote the entry of new specialisations, while transnational linkages are more closely associated with the retention of existing ones. These results offer insights for policymakers seeking to foster innovation in emerging economies by strengthening both regional networks and global connections.

Keywords: transnational linkages; regional linkages; complementary capabilities; regional diversification.

JEL Code: O19, O31, R11

1. INTRODUCTION

A substantial body of literature argues that regional linkages are crucial for enabling regions to access external knowledge, thereby helping them overcome the tendency to become locked into existing patterns of economic and technological activity (Ascani et al., 2020; Balland & Boschma, 2021; Hesse & Fornahl, 2020; Miguelez & Moreno, 2018; Tavassoli & Carbonara, 2014). Despite the recognised importance of regional and transnational linkages for innovation and development, their specific effects on regional diversification, both in terms of the entry of new technological specialisations and the exit of existing ones, remain poorly understood. While many studies on regional technological diversification have primarily focused on regional capabilities (Boschma et al., 2015; Boschma et al., 2022), the role of regional linkages has received comparatively less attention, with notable exceptions such as Balland and Boschma (2021), who examine European regions. Consequently, there is still limited understanding of how regional linkages influence technological diversification in terms of both the emergence and disappearance of technological specialisations. Furthermore, scholars have highlighted the lack of a systematic, widely accepted, and easy-to-apply method for identifying relevant interregional linkages, particularly in emerging economies (Iacobucci & Guzzini, 2016).

For emerging economies such as Brazil, connections with other countries can provide access to external knowledge, technologies, and markets that are not locally available, thereby helping to overcome structural weaknesses and fostering technological and economic development. However, the extent to which such connections can compensate for weak or missing capabilities within regions in emerging economies remains unclear, particularly with regard to technological diversification. Thus, it is crucial to deepen our understanding of how transnational linkages shape regional technological diversification and to develop systematic approaches for identifying and strengthening these connections. A clearer understanding of these dynamics will enable emerging economies like Brazil to strategically leverage international networks, enhance their innovation ecosystems, and foster economic growth.

This paper seeks to address this gap by investigating the effects of regional and transnational linkages on technological diversification, focusing on both the entry and exit of technological specialisations across 136 regions in Brazil between 1997 and 2020. Using patent data from the Brazilian Patent Office, we estimate two models: one assessing the probability of new technologies entering a region and another examining the likelihood of existing technologies exiting. Understanding both processes is particularly important in emerging economies, where the decline of one specialisation often precedes the rise of another, not necessarily contributing to diversification but rather resulting in technological substitution.

Our findings indicate that the emergence of new technological specialisations in Brazilian regions is more likely when they have strong connections with other domestic regions, particularly those offering complementary capabilities. In contrast, transnational linkages do not appear to influence the entry of new technologies; instead, they play a crucial role in retaining existing technological specialisations within Brazilian regions. Specifically, regions with transnational connections exhibit a lower probability of technological exit, reinforcing the stabilising effect of these linkages. Therefore, our results highlight a significant aspect of transnational linkages: although the literature often emphasises their role as sources of regional innovation, particularly in developing economies where access to new knowledge is constrained, our findings suggest that their primary function is not to drive diversification directly but rather to sustain existing specialisations, which in turn create the conditions necessary for diversification to occur.

The remainder of the paper is structured as follows: the next section provides a concise literature review, followed by a presentation of the data and variables used in the study. We then describe patent filings with the Brazilian Patent Office (INPI) and outline the patterns of Brazilian transnational linkages. Subsequently, we present our empirical findings on the effects of regional and transnational linkages on regional diversification, considering both the entry and exit of technological specialisations in Brazil. Finally, the last section concludes the paper.

2. REGIONAL AND TRANSNATIONAL LINKAGES AND TECHNOLOGICAL DIVERSIFICATIONS

The literature on innovation frequently highlights that successful innovation processes tend to be concentrated in regions where continuous and frequent collaboration among innovation stakeholders fosters knowledge acquisition, learning, and skill development. These interconnected networks sustain regional economies' ability to generate new knowledge, thereby establishing robust regional innovation systems within national borders (Ascani et al., 2020; Audretsch & Belitski, 2020; Audretsch & Feldman, 1996; Balland & Rigby, 2017; Boschma & Frenken, 2009). A growing body of research suggests that regional linkages are crucial for accessing external knowledge, helping regions to avoid becoming locked into existing economic and technological trajectories.

Additionally, the literature on product space provides evidence that the emergence of new export products in a country is strongly influenced by national-scale capabilities rather than random events (Hidalgo et al., 2007). In this context, the institutional framework of regions, their infrastructure, and human resources all play a significant role in shaping firms' innovation efforts (Fernandes et al., 2021; Iammarino et al., 2019; Mascarini et al., 2023; Maskell & Malmberg, 1999).

Scholars have argued that regions are more likely to develop technologies related to their existing local activities because these activities offer similar capabilities. Thus, the acquisition of new skills required to develop new capabilities and update existing Scholars argue that regions are more likely to develop technologies related to their existing economic activities, as these activities provide complementary capabilities. The acquisition of new skills required for capability development and upgrading is more accessible when these skills are closely aligned with the region's current expertise (Frenken et al., 2012; Montresor & Quatraro, 2017; Rigby, 2015). By contrast, developing technologies beyond a region's existing capabilities entails significant transformation costs and carries a high risk of failure, making such diversification less likely. Empirical studies in economic geography confirm that regions tend to diversify into activities that build on their existing capabilities (Frenken et al., 2023).

Furthermore, there is broad agreement in the literature that, given the increasing complexity of technology and the challenges posed by globalised markets, regional collaboration plays a critical role in technological and regional development. Such collaboration provides access to essential and complementary knowledge that can help regions avoid stagnation and lock-in effects (Ascani et al., 2020; Balland & Boschma, 2021; De Noni et al., 2018). Indeed, collaborations and networks enable regions to draw from diverse and interconnected sources of knowledge, combining internal and external resources to foster the development of new technologies (Audretsch & Belitski, 2020; Boschma & Iammarino, 2009; Malecki, 2014; Krafft et al., 2014; Wanzenböck et al., 2024).

Thus, external linkages are widely regarded as crucial for strengthening local capabilities, preventing technological stagnation, and mitigating the risks associated with insular regional networks (Ascani et al., 2020; Balland & Boschma, 2021; De Noni et al., 2018; Santoalha & Boschma, 2021). Morrison (2023) further argues that the development of regional innovation networks is significantly shaped by sustained interactions and knowledge exchanges at both regional and transnational levels. Such interconnectedness is vital for regions to build on their existing capabilities while expanding their technological portfolios.

Despite these insights, the role of regional and transnational linkages in both the entry and exit of technological specialisations, key processes that drive regional diversification, remains underexplored. Studies on regional diversification have primarily focused on regional capabilities (Ascani et al., 2020; De Noni et al., 2017; Miguelez & Moreno, 2018; Tavassoli & Carbonara, 2014; Quatraro & Scandura, 2024), while the effects of regional and transnational linkages on the entry of new technological specialisations have received less attention, with the notable exception of Balland and Boschma (2021). Even more overlooked is the role of transnational linkages, or their absence, in influencing the exit of technological specialisations.

Understanding regional diversification requires an examination of both the factors that drive the entry of new specialisations and those that contribute to the loss of technological activities. True diversification occurs only when regions not only gain new technological specialisations but also retain existing ones. Investigating the drivers of new technology entry helps to identify the conditions that facilitate the expansion of technological knowledge within a region. However, assessing the factors that lead to the exit of technological specialisations is equally important, as it sheds light on the challenges that may hinder diversification or lead to the erosion of critical competencies.

A comprehensive analysis of regional and transnational collaborations, considering their effect on both the entry and exit of technologies, is therefore essential for understanding the regional diversification process and formulating effective strategies to promote regional innovation and growth. This is particularly relevant in emerging economies, where regional capabilities are often limited, and new technological specialisations frequently emerge as substitutes for existing ones. By focusing on Brazil, this study contributes to a deeper understanding of the role of regional and transnational linkages in the diversification process within an emerging economy.

Specifically, this paper pursues two objectives. First, it examines the effects of regional and transnational linkages on the entry of new technological specialisations in 136 Brazilian regions between 1997 and 2020. Second, it evaluates how these same factors influence the exit of technological specialisations. By addressing both processes, this study offers a more comprehensive perspective on the role of regional linkages in shaping technological diversification in an emerging economy.

3. METHODOLOGY

3.1 DATA AND VARIABLES

We employ patent data from the Brazilian Patent Office (*INPI – National Institute of Industrial Property*), covering the period from 1997 to 2020. Following previous studies (Balland & Boschma 2021; Rigby 2015), we estimate entry and exit models to assess the probability of a region gaining or losing technological specialisation. The dependent variables capture the entry into or exit from technological specialisation within Brazilian regions[1].

To measure technological specialisation, we compute the Revealed Technological Advantage (RTA) indicator, considering all IPC codes at the technological class level, which encompasses 129 distinct patent domains. This approach is aligned with methodologies proposed by Balland & Boschma (2021), Montresor & Quatraro (2017) and Rocchetta et al. (2022). The RTA is calculated for 136 Brazilian regions, identified based on inventors' addresses, as well as for 204 countries. This enables us to determine whether a region is specialised in a given technology. A region is considered specialised in technology i ($M_{r,i}$) if it exhibits a higher relative share of patents in that technological class compared to the reference group. This is captured as a binary variable:

$$M_{r,i} = 1 \quad if \quad RTA_{r,i} = \frac{Pat_{r,i} \Big/ \sum_i Pat_{r,i}}{\sum_r Pat_{r,i} \Big/ \sum_r \sum_i Pat_{r,i}} > 1$$

A region is classified as entering a new technological specialisation if it was not specialised in $t-1$ but becomes specialised in t. Conversely, a region is considered to have exited a technological specialisation if it was specialised in $t-1$ but is no longer so in t.

Technological specialisation is assessed in four-year time windows. Given the patent data from 1997–2020, we compute specialisation for six subsequent periods: t_0 (1997–2000), t_1 (2001–2004), t_2 (2005–2008), t_3 (2009–2012), t_4 (2013–2016), and t_5 (2017–2020).

Our primary variable of interest is transnational linkages (*NTL*). We measure NTL using patent data to capture cross-border linkages through co-inventions involving inventors located both in Brazil and abroad. This follows the approach of Balland & Boschma (2021), De Noni et

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[1] We used Brazilian mesoregions correspond to the European NUTS 2 level. Brazil has 137 mesoregions; however, the Centro-Sul Cearense mesoregion (code 2306) did not have any patents during the analysis period.

al. (2017), and Le Gallo & Plunket (2020). For example, if a patent in a given technological class is co-invented by six inventors—three from region A in Brazil, one from region B in Brazil, one from the United States, and one from Canada—region A is attributed six transnational linkages, while region B is attributed two, for that technological class[2].

Our second key variable is domestic (regional) linkages (*NRL*), which capture both intra- and interregional collaborations within Brazil. These are measured by the number of co-inventions involving inventors from different Brazilian regions. Domestic linkages are crucial since regions with strong internal networks are also more likely to establish international connections[3]. Domestic linkages are crucial, as regions with robust internal networks are also more likely to establish international collaborations. Using the previous example, region A accumulates nine domestic linkages, while region B registers three in that technological class.

In addition, we compute complementary interregional linkages (*CIL*). Following Balland & Boschma (2021), this indicator captures capabilities absent in a given Brazilian region that may enhance the likelihood of diversification into a new technology when accessed through co-inventor linkages with other regions. The computation of *CIL* involves six steps:

1. Measuring relatedness density (RD) around technology *i* in all regions *s*, both Brazilian and foreign. First, we calculate technological relatedness between all pairs of 139 technology classes using co-occurrence analysis based on the cosine similarity index[4]. RD is then derived as the sum of relatedness between technology i and all technologies *j* in which region *r* is specialised, divided by the sum of relatedness between *i* and all technologies *j* in the dataset (136 Brazilian regions and 204 other countries). This follows methodologies from Boschma et al. (2015), Hidalgo et al. (2007), and Rigby (2015).

2. Identifying missing technologies in region *r*, defined as those for which RTA < 1, but which are related to technology *i.*

3. Identifying regions specialised (RTA > 1) in these related but missing technologies *j*.

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[2] Note that if the patent has 2 IPC classes, we count one connection for each IPC.

[3] Note that we also include domestic regional linkages from transnational patents.

[4] To do that, first, we compute the degree of relatedness between each pair of technologies for a total of 139 technology classes using co-occurrence analysis, using the cosine similarity index.

4. Summing RD scores for technology *i* across regions s (as per Step 1), conditional on those regions being specialised in technologies *j* absent in region *r*. This generates the RD added score, which measures the potential increase in RD for region *r* in technology *i*.

5. Weighting RD added by the number of co-inventor linkages between region *r* and each region *s*. The more links to regions with complementary capabilities, the more relevant these become for region *r*.

6. Summing the weighted scores from Step 5 across all regions *s* to obtain the final CIL score for region r in technology *i*.

Finally, we include time-fixed effects to account for unobserved temporal shocks.

We also include control variables. First, we included regional capabilities, proxied by relatedness density (RD), which was calculated as explained in the first step of the *CIL* indicator. Second, we incorporate Gross Domestic Product (GDP) per capita to account for the level of economic development in a region. Third, we include the natural logarithm of population size to account for variations in population across regions. Fourth, we control for technology complexity (TCI) by ranking the diversity and sophistication of the technology know-how required to introduce the technology. We include fixed effects for region-technology pairs and time-fixed effects to account for unobserved heterogeneity across region-technologies and common shocks over time.

4. THE GEOGRAPHY OF TRANSNATIONAL LINKAGES

Between 1997 and 2020, a total of 573,862 patents were filed with the Brazilian Patent Office (National Institute of Industrial Property - INPI). Of these, 24.6% (140,956) were filed exclusively by inventors based in Brazil, with the majority (105,468) consisting of non-collaborative patents submitted by a single inventor. In contrast, among the patents filed by inventors located outside Brazil, spanning 204 different countries, the majority were collaborative efforts involving multiple inventors (325,210 out of 430,915). Patents resulting from partnerships between Brazilian and foreign inventors, transnational patents, accounted for just 0.35% (1,991) of all patents filed. This highlights the fact that inventors residing outside Brazil file a significantly greater number of patents than those within the country, and collaborative efforts between domestic and foreign inventors remain relatively rare.

It is crucial to note that, despite constituting a small fraction of the patents filed with INPI, transnational patents have created 13,110 connections between Brazilian regions and other countries. Therefore, these patents can serve as a significant source of knowledge for the regions that hold them, offering crucial opportunities for knowledge acquisition, learning, and the development of new competencies, as well as for fostering new technologies. This scenario is particularly relevant in developing countries, where access to new knowledge for innovation can be limited, highlighting the substantial potential of transnational patents to drive technological diversification.

Regarding the countries with which Brazilian regions are connected, the United States ranks first (4,254 linkages), followed by Germany (2,020), France (861), Portugal (503), and Mexico (503) (see Appendix 1, Table A1).

Figure 1 illustrates the geographic distribution of transnational linkages over the entire period. As with most regional indicators in Brazil, the highest concentration of these linkages is found in the South and Southeast regions, with a few exceptions in metropolitan areas of the Northeast, North, and Midwest. Notably, during the analysed period, 50 regions did not establish any international linkages. The Metropolitana de São Paulo recorded the highest number of transnational linkages (3,109), followed by the Metropolitana do Rio de Janeiro (1,352), Campinas (1,323), and the Metropolitana de Belo Horizonte (687).

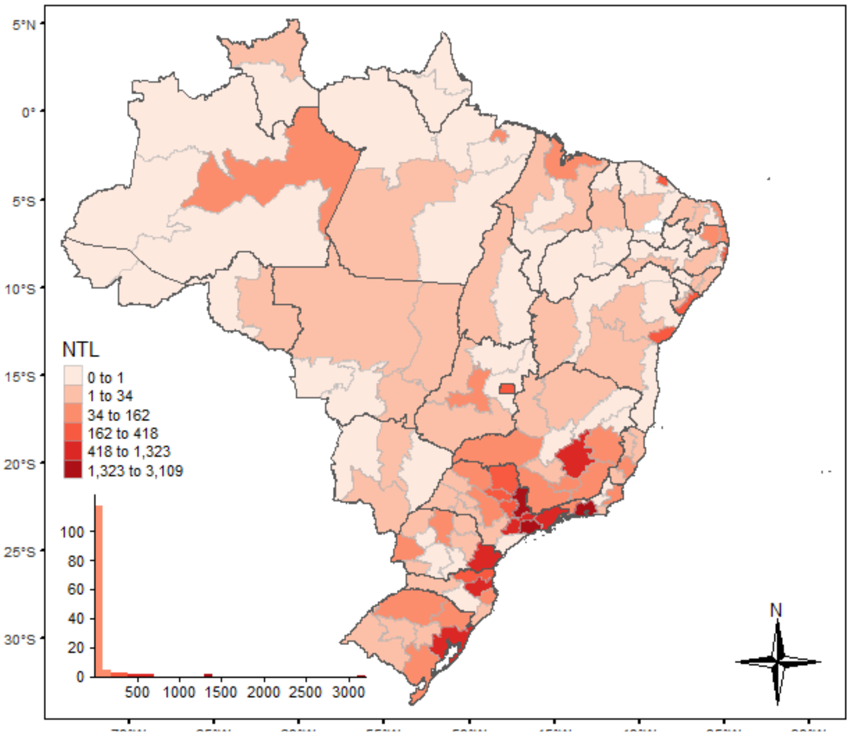

Figure 1: Geographic distribution of transnational linkages

These connections serve as vital channels for the transfer of technological knowledge, fostering innovation through collaboration and the exchange of ideas. They highlight the importance of international partnerships in knowledge transfer and innovation development. Consequently, it is expected that transnational linkages strengthen Brazil's innovation system, particularly in the regions that establish them. This study aims to examine the effects of these linkages on technological diversification, both entry and exit—across 136 Brazilian regions between 1997 and 2020.

5. MAIN RESULTS

Table 1 presents the results of the regional entry model. Regarding the control variables, all specifications indicate a positive effect of regional relatedness (RD), GDP per capita, population size, and the technology complexity index (TCI). These findings suggest that regional relatedness, economic development, agglomeration, and technological complexity increase the likelihood of new technologies entering Brazilian regions.

Table 1: Entry model

Dependent variable: Entry, or not, of a new specialisation in a technology in a region					
	(1)	(2)	(3)	(4)	(5)
Number of transnational linkages (NTL) (log)	0.205***			0.016	0.029
	(0.074)			(0.079)	(0.079)
Number of domestic (regional) linkages (NRL) (log)		0.169***		0.167***	0.044
		(0.025)		(0.026)	(0.046)
Complementarity interregional linkages (CIL) (log)			0.119***		0.095***
			(0.016)		(0.028)
Relatedness density (RD)	0.018***	0.018***	0.018***	0.018***	0.018***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
GDP per capita (log)	0.270**	0.288**	0.280**	0.288**	0.285**
	(0.137)	(0.137)	(0.136)	(0.137)	(0.136)
Population (log)	0.824**	0.781**	0.794**	0.780**	0.787**
	(0.388)	(0.388)	(0.388)	(0.388)	(0.388)
Technological Complexity Index (TCI)	0.225***	0.243***	0.242***	0.243***	0.244***
	(0.011)	(0.012)	(0.011)	(0.012)	(0.011)
Constant	-13.685***	-13.085**	-13.259***	-13.080**	-13.155***
	(5.091)	(5.090)	(5.086)	(5.090)	(5.087)
Period FE	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes
Observations	38,221	38,221	38,221	38,221	38,221
Number of IDMI	11,132	11,132	11,132	11,132	11,132
chi2	1573	1590	1611	1591	1608
ll	-15585	-15566	-15561	-15566	-15560

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

Turning to our main variable of interest, the coefficient for transnational linkages (NTL) is positive and significant only when regional linkages are not controlled for (Model 1). Meanwhile, the coefficient for regional linkages (NRL) is positive and significant when interregional complementarity is not accounted for (Models 2 and 4). In contrast, the coefficient for interregional linkages (CIL) remains consistently positive and significant across all relevant specifications (Models 3 and 5).

These results suggest that connectivity with other countries may not be associated with technological diversification. Conversely, connections to other regions within Brazil appear to be positively linked to technological diversification. Furthermore, new technologies are more likely to enter a region when it is connected to other Brazilian regions that provide complementary capabilities, enhancing their relevance and increasing the likelihood of adoption.

Thus, both regional linkages and their complementarity contribute to the probability of regions developing new technological specialisations in Brazil. However, once complementarity is controlled for, the number of regional linkages alone is no longer significant. This suggests that while being connected to other regions is important, fostering connections that provide complementary capabilities is crucial for the development of new technological specialisations.

In summary, our findings highlight the key role of regional linkages within Brazil, particularly those facilitating complementary capabilities, in driving the adoption of new technologies and promoting regional diversification. In contrast, linkages with other countries appear to have a negligible effect on this process.

Our analysis also allows us to explore the potential influence of transnational linkages on regional diversification in Brazil in greater depth (Table 2). Here, we present the findings of the regional exit model. Examining the exit from technological specialisations is important because regions may not only adopt new specialisations but also abandon existing ones. In such cases, regions undergo a technological structural shift rather than a straightforward diversification process. Therefore, analysing both the entry and exit of technological specialisations is crucial to gaining a comprehensive understanding of regional diversification in Brazil.

Table 2: Exit Model

Dependent variable: Exit, or not, of a new specialisation in a technology in a region					
	(1)	(2)	(3)	(4)	(5)
Number of transnational linkages (NTL) (log)	-0.687***			-0.351***	-0.334***
	(0.098)			(0.094)	(0.093)
Number of intra- and interregional linkages (NRL) (log)		-0.376***		-0.357***	-0.306***
		(0.021)		(0.022)	(0.026)
Complementarity interregional linkages (CIL) (log)			-0.186***		-0.057***
			(0.014)		(0.017)
Relatedness density (RD)	-0.018***	-0.017***	-0.018***	-0.017***	-0.017***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
GDP per capita (log)	0.109	0.042	0.132	0.018	0.025
	(0.206)	(0.203)	(0.206)	(0.203)	(0.204)
Population (log)	-0.086	-0.090	-0.098	-0.080	-0.078
	(0.639)	(0.621)	(0.631)	(0.621)	(0.621)
Technological Complexity Index (TCI)	-0.178***	-0.297***	-0.241***	-0.302***	-0.309***
	(0.020)	(0.021)	(0.021)	(0.021)	(0.021)
Constant	1.793	1.679	2.011	1.544	1.554
	(8.391)	(8.157)	(8.294)	(8.162)	(8.164)
Period FE	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes
Observations	13,535	13,535	13,535	13,535	13,535
Number of IDMI	5,803	5,803	5,803	5,803	5,803
chi2_c	408.7	275.0	338.9	276.9	275.8
ll	-8170	-8031	-8106	-8023	-8016

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

In the regional exit model, the coefficients for transnational linkages (NTL) are significant in all cases but negative. This suggests that while transnational linkages do not influence the entry of new technologies, they reduce the likelihood of existing technologies exiting regions. In other words, connections with international actors play a vital role in maintaining the technological structure of Brazilian regions. Although these linkages may not facilitate the introduction of new technologies, they contribute to retaining existing specialisations.

Similarly, connections with other regions within Brazil are negatively associated with the loss of technological specialisations. Thus, regional linkages also reduce the likelihood of regions losing their technological specialisations. Consequently, both transnational and regional linkages play a significant role in shaping the technological structure and diversification of Brazilian regions.

Additionally, the coefficients for interregional linkages with complementary capabilities are negative and significant across all specifications. This indicates that access to complementary capabilities from other regions within Brazil lowers the probability of losing technological specialisations. In other words, when regions are connected to others that provide the capabilities they lack, they are less likely to lose their existing technological specialisations.

Regarding the control variables, we find that only regional relatedness (RD) and the technology complexity index (TCI) have a negative effect on technological exit. The coefficients for GDP per capita and population size are not significant, suggesting that while regional capabilities and technological complexity reduce the likelihood of losing technological specialisations, economic development (GDP) and agglomeration (population size) do not appear to play a decisive role in this process.

6. CONCLUSIONS

This study examines the roles of regional and transnational linkages, as well as the complementarities of interregional linkages, in regional diversification within the context of an emerging economy.

Our main findings suggest that, when considering regional diversification through the entry of new technological specialisations, regional linkages within Brazil, particularly those providing complementary capabilities, positively influence the likelihood of regions diversifying, beyond the effect of regional capabilities. In other words, a new technology is more likely to enter a Brazilian region when the region is connected to others within the country, especially when these connections bring complementary capabilities that support the adoption of the new technology.

Moreover, transnational linkages do not appear to influence the entry of new technologies. Instead, they play a more significant role in retaining existing technological specialisations within Brazilian regions. A technological specialisation is less likely to disappear from a region when transnational linkages are present, even after controlling for the effects of regional linkages and complementarities. In summary, while transnational linkages may not foster the introduction of new technologies, they help preserve the technological status quo by preventing the loss of existing specialisations

Overall, our findings highlight that regional linkages within Brazil contribute both to the adoption of new technologies and to the preservation of existing technological specialisations. In contrast, transnational linkages are more relevant for maintaining existing technological specialisations rather than promoting diversification. The presence of complementary interregional linkages consistently emerges as a key driver of technological diversification, underscoring the importance of domestic collaboration in strengthening regional technological capabilities. These insights provide a deeper understanding of regional diversification dynamics in Brazil, illustrating the distinct roles played by regional and transnational linkages in this process.

From a policy perspective, our findings offer important implications. First, policymakers should encourage and strengthen interregional connections within Brazil. Promoting regional linkages, particularly those that foster complementarities, can facilitate the diffusion of new technologies, enhance innovation through the integration of diverse knowledge bases, and support joint learning. This approach can create an environment conducive to the emergence and adoption of new knowledge and practices, thereby driving technological development and regional diversification. Additionally, given that transnational linkages help maintain existing technological specialisations, policymakers should pursue strategic international collaborations that reinforce Brazil's capacity to retain critical competencies. By fostering both regional and transnational linkages, policies can not only stimulate technological and economic diversification but also build a more resilient and adaptive innovation system.

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Appendix A:

Table A1: Number of linkages that Brazil establishes with other countries

Country	Links	%
US	4,254	32
DE	2,020	15
FR	861	7
MX	503	4
PT	503	4
CA	481	4
IT	424	3
GB	406	3
ES	393	3
AR	375	3
CH	308	2
IN	214	2
SE	208	2
NL	184	1
CL	181	1
CO	153	1
AU	149	1
JP	133	1
AT	113	1
UY	110	1
DK	91	1
AE	84	1
BE	81	1
CN	71	1
CU	67	1
PL	67	1
N	65	0
IL	60	0
FI	50	0
PE	50	0
NO	44	0
RU	36	0
MG	30	0
IE	29	0
NI	26	0
VE	21	0
RS	20	0
CZ	19	0
SA	18	0
HU	16	0
SG	16	0
PY	15	0
ZA	15	0
BG	11	0
PA	11	0
PH	11	0
MZ	10	0
IR	9	0
PR	9	0
RO	9	0
EC	8	0
UA	8	0
SC	7	0
CR	6	0
TR	6	0
VN	6	0
AZ	5	0
BF	5	0
MY	5	0

AO	3	0
SR	3	0
AL	2	0
LU	2	0
NZ	2	0
BO	1	0
EE	1	0
GT	1	0
HT	1	0
KR	1	0
RE	1	0
SY	1	0
TW	1	0
Total	13,110	100