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Milene Simone Tessarin* & Carlos Roberto Azzoni**

* Department of Human Geography and Spatial Planning, Utrecht University, The Netherlands. E-mail: m.s.tessarin@uu.nl

** Department of Economics, University of Sao Paulo (FEA-USP), Brazil. E-mail: cazzoni@usp.br

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Abstract

This study explores the importance of labour pool and geographical concentration as essential factors that help shape pathways for innovation and influence the speed with which technological change can occur. To do so, we propose an approach based on human capital and the workers' skills that contribute to innovation. Being able to capture this broader range of professionals is crucial to assess regional innovation in Less Developed Countries, such as Brazil and other Latin American countries, as their productive structure concentrates on lower technological industries and innovative activities not centred on R&D. We created a measure of innovative potential that can be used at different levels of regional disaggregation. We analyze 374 relevant Brazilian Labour Market Areas (LMA), employing data on occupations from the Annual Report of Social Information, from 2003 to 2018. Although innovative activities are heavily concentrated in a few regions, empirical evidence suggests that a shift has occurred since the early 2000s, with lagging regions making progress faster. Nonetheless, our results show that such convergence is still slight, given the distance between the leading and lagging regions' innovative performance. Factors related to the region's previous capacities, such as the stock of workers with innovative skills, manufacturing industry share, and the number of large firms have a positive association with innovative activity in a region. Although the convergence in the innovative potential among Brazilian regions, the movement is too slow to indicate a transformation of the country as a whole to levels similar to those of developed nations.

Keywords: regional innovation, regional inequality, skills of workers, structural change.

JEL Codes: O30, O33, R11, J24, L16.

1. Introduction

An often overlooked aspect of processes around innovation, competitiveness, and capabilities building concerns the spatial context in which they occur. This study illustrates the importance of labour pool and geographical concentration as essential factors that help shape pathways for innovation and influence the speed with which technological change can occur.

Seeking to establish an association between inputs for innovative activity and regional innovative performance, we propose an approach based on human capital and the skills of workers who contribute to innovation. Human capital has a significant impact on diffusion and innovation. They are involved in interactive learning, such as learning by doing, learning by interacting, and learning by using, which increase production operations efficiency, promote cooperation between users and producers and generate incremental innovations. We aim to include workers broadly involved in innovative activities, essential for innovation in traditional industries, and complement R&D professionals in sectors with higher technological content.

Being able to capture this broader range of professionals is crucial to assess regional innovation in Less Developed Countries, such as Brazil and other Latin American countries, as their productive structure concentrates on lower technological content industries and innovative activities not centred on R&D. Human capital is one of the elements behind the concept of innovative capabilities, which involve several actors, such as universities, research centers, financing institutions, firms and workers, all acting to create and internalize knowledge to stimulate technological progress and innovation. According to Lundvall et al. (2009), innovative capabilities are needed to generate and manage technical matters and reflect on what actors know and what they can learn. In this process, the creation and accumulation of capabilities are related to the competencies of the persons involved, in the sense that capabilities are not only science-based but also experience-based learning. In this sense, local characteristics, especially the interaction of human capital in the process of knowledge accumulation, are crucial to provide a broader view of the innovative performance of developing countries.

Brazil is very heterogeneous spatially in terms of development and location of innovative activity. Although Pintec – the National Innovation Survey (IBGE, 2020) – has advanced in providing standardised and periodic data on innovative activity, it still does not allow analyses with a detailed regional disaggregation level.[1] Simões et al. (2005) used patent data, skilled

[1] Regionally, Pintec covers 15 of the 26 Federation Units in Brazil (IBGE, 2020). Those not included in the survey are located in the North and Northeast regions of the country, which invest the least in innovation.

labour, and R&D from 2000 to locate high-tech activities in Brazil. Gonçalves & Fajardo (2011) used patent data from the National Institute of Industrial Property (INPI) for 1999-2001 to verify the relationship between geographic and technological proximity as drivers of regional innovation. Sobrinho & Azzoni (2016) created a measure of the innovative potential of the Brazilian industrial sector based on workers' skills, with data from 2003 to 2012, at a granular regional level (cities and clusters).

To contribute to this literature, we created a new measure of innovative potential that can be used at different levels of regional disaggregation and with greater temporal frequency. We seek to work with the concept of innovative potential because it involves innovation inputs and not outputs. Given innovation characteristics in Latin American countries and other developing countries, traditional measures of innovation outcome – such as patents or R&D expenditures – may not accurately capture the effort involved in achieving innovation and technological change in such countries. Innovative potential includes several elements of the regional innovation system, especially the interaction between human capital, firms, and knowledge that shapes innovative capabilities.

The regional unities used in this study are Labour Market Areas (LMA), created by the Brazilian statistical office (IBGE) based on commuting to work and study. We work with 374 relevant regions spread across all states in the country. We also use data from the Annual Report of Social Information (RAIS) on occupations in the Brazilian formal labour market from 2003 to 2018. Other variables we use to assess regional innovative potential include GDP per capita, university professors in STEM fields, size of firms, and the share of manufacturing, all at the regional level not yet displayed in the literature.

The study is based on a comparative analysis between regions to identify their innovative potential. We seek to identify elements that represent innovation input and that help explain the regional innovative performance. We also seek to understand whether the dynamics of increasing spatial disparities in innovative potential – that is, the dark side of innovation – occurred in Brazil during the period covered by this study. In this sense, the role of public policy in influencing the spatial distribution of innovation is also considered in this study. Although innovative activities are heavily concentrated in a few regions, empirical evidence suggests that a shift has occurred since the early 2000s, with lagging regions making progress faster.

Nonetheless, such convergence is still slight, given the size of the discrepancies between the leading and lagging regions' innovative performance. Factors related to the previous capacities of the regions, such as the stock of workers with the necessary skills to develop innovative activity, the share of the manufacturing sector in the economy, and the presence of large firms, have a positive association with the innovative activity in the future. Thus, we can confirm that path dependence matters for innovative development.

Next, Section 2 presents the theoretical discussion on skilled workers as an input for innovation, agglomeration, diversification, and the most recent topics addressed by evolutionary economic geography. Methodology and an empirical model are specified in Section 3, and descriptive and statistical results are presented in Section 4. In the final section, we provide a conclusion and comments that can be directed to public policies.

2. Theoretical discussion

2.1 Growth, innovation, and human capital

Several classical and modern theories incorporate knowledge as one factor that explains the growth of countries and regions. The Marshallian approach (Marshall, 1920) argued that spillovers of local knowledge, local labour pools, and non-tradable local inputs are central factors that promote regional agglomeration. The Jacobian tradition (Jacobs, 1969) also sees knowledge transfer in a diverse environment regarding workers and economic activities as an input for local growth. Authors of Growth Theory (Lucas, 1988; Romer, 1990) emphasise human capital in explaining economic growth. For these authors, individuals accumulate new skills and know-how that impact productivity and general human capital levels, leading to growth.

Recently, researchers in Evolutionary Economic Geography have started to argue that factors other than geographic proximity explain the growth of regions (Boschma, 2005; Neffke, Henning & Boschma, 2011; Pinheiro et al., 2022). For them, geographic proximity enhances the effects of institutional, cognitive, and structural factors in the regions. Together, the various dimensions of proximity reduce coordination costs and uncertainty and facilitate interactive learning, information and knowledge overflow, and innovation (Boschma, 2005). Thus, regions are understood in this theory as a unique repository of specific characteristics that cannot be easily reproduced elsewhere (Gertler, 2005). These particularities define development and growth trajectories.

Human capital is one of the elements that permeate all these theories. Technology is embedded in both human and physical capital (Lucas, 1988; Romer, 1990), and the interaction between them and among workers is the primary means of technology diffusion. Some studies especially reinforce the importance of professionals in the STEM fields (Science, Technology, Engineering, and Mathematics) for the firms' innovation. Graduates in the STEM fields are recognised for their technological creativity and innovation, which may generate significant benefits for firm innovation performance (Rodríguez-Pose & Lee, 2020), since these fields expose their professionals to technological developments, critical thinking, and analytical skills during the training, boosting their technical knowledge and expertise (Hsieh et al., 2022). Furthermore, STEM graduates are more likely to engage in individual patenting activities. In this sense, the stock of STEM workers has become vital for innovation and growth and a standard component of almost all innovation policies (Atkinson & Mayo, 2010).

In addition, recent evidence highlights a broader range of creative professionals with skills to identify and solve problems that also contribute to the development and diffusion of technical and organisational innovations (Rodríguez-Pose & Lee, 2020; Tessarin et al., 2020). Lundvall (1992) showed that engineers and scientists are critical in inventing and developing innovations. Additionally, some technical professionals work in the second stage of innovation, in which the innovation process and the technological adaptations are explored. For example, Schneider, et al. (2010) used the number of engineers, scientists, and managers to relate them to the product innovation of firms in Germany. Rodríguez-Pose & Lee (2020) compared the contribution of STEM professionals and creative workers (geek versus hipsters) to the innovative potential of US cities. According to Rodríguez-Pose & Lee (2020), the interdependence of these two groups, in addition to producing general innovations, increases radical innovations, particularly to the market. In the Brazilian context, Gusso (2006) and Araújo, et al. (2009) used the number of engineers, technicians, and personnel linked to R&D to measure the innovative and technological capacity of the productive sectors in Brazil, while Simões et al. (2005) evaluated mid-level (technical) and higher-level workers. These works confirm that creative and STEM occupations work together to expand the region's innovative potential.

Bell (2009) highlights that the construction of innovative capabilities is strongly linked to human capital. Although educational institutions provide the knowledge and skills needed in creative and manufacturing processes, firms are the locus where specific knowledge takes shape and turns into technological change. Firms increase workers' knowledge by transmitting productive and creative knowledge developed internally. Such development may involve acquiring new knowledge via externally trained human capital, and the combination of internal and external knowledge that results in incremental improvements and in new innovative activities.

Depending on the type of most frequent innovation in a particular industry, some professionals are more relevant than others for promoting innovation. Learning by doing and using are recognised drivers of incremental changes. Learning-by-doing, interacting and using increases efficiency in production operations and promotes interaction between users and producers (Lundvall, 1992). According to Bell (1984), the interactive learning process can occur in two ways. On the one hand, passively without significant costs, generating incremental innovations continuously; and on the other hand, in an intentional and targeted way, using an internal feedback system that involves evaluating, reviewing, interpreting and improving the experiences carried out. Radical change requires creating new knowledge that results in differentiated products and processes. In the end, product innovation, together with the accumulation of incremental innovations over the years, is responsible for a large part of the productivity growth and technological dynamism of countries.

2.2 The geography of innovation

Regions differ in their ability to accumulate knowledge, produce innovations and promote growth. One of the main theoretical arguments that explains why companies choose certain locations comes from Marshall (1920) agglomeration theory. The Marshallian or agglomeration externalities admit that firms tend to concentrate in dense urban areas to take advantage of externalities such as lower transport costs, skilled and abundant labour supply, and the existence of suppliers of specialised inputs (Caragliu et al. 2016). Firms' agglomeration of the same economic activity results in regional specialisation and produces positive externalities. Suppliers, workers, support institutions and infrastructure, focused on regional specialisation are concentrated and facilitate the exchange of information and other benefits arising from geographic proximity (Torre & Gilly, 1999; Panne, 2004).

For innovation, agglomeration and geographic proximity also have their benefits. Knowledge spillovers, especially tacit knowledge, are geographically limited since this type of knowledge is acquired through social interaction (Panne, 2004). The agglomeration facilitates the interaction between agents, the exchange of information, and knowledge spillovers, producing positive effects on the interactive learning process (Gertler, 2005).

Jacobs (1969), on the other hand, argues that knowledge can spread across complementary rather than similar industries, as ideas developed by one industry can be applied in other industries, thus generating diversification or Jacobian externalities. In this scenario, diversified rather than specialised regions stimulate the cross-fertilisation of ideas, the addition of new information and problem-solving (Jacobs, 1969), factors that drive the emergence of new types of jobs/industries (innovation, ultimately) and growth.

Several authors have investigated in depth whether agglomeration or diversification externalities are more relevant for regional innovation. Glaeser et al. (1992) argue that although most cities are specialised and generate Marshallian externalities, there are also activities outside the primary core, suggesting other externalities operating in cities. Feldman & Audretsch (1999) concluded that diversification rather than regional specialisation is the element that has promoted innovative activity in the US. But most studies (Paci & Usai, 1999; Panne, 2004; Caragliu et al., 2016; Antonelli et al., 2017) highlight that specialisation and diversification are important roles for innovation, which vary depending on the economic activity and the urban agglomeration characteristics. Regions with a greater number of high-tech industries depend more on diversification, while regions that concentrate on traditional industries depend more on agglomeration externalities to have better innovative results. Thus, agglomeration and diversification are relevant elements for promoting innovation in regions.

Seeking to understand the factors that lead regions to follow vibrant trajectories or to be stuck in low growth trajectories, authors of evolutionary economic geography built a theoretical and empirical framework to show that history matters to point out where and how regions evolve (Neffke, Henning & Boschma, 2011; Pinheiro et al., 2022). These authors argue that externalities of diversification (composition of activities) and specialisation (size and intensity of clusters) have a fine connection since diversification does not go in any direction but to nearby areas. Diversification tends to occur more frequently for related industries, i.e. industries that share knowledge (or technologies), skills, infrastructure and similar institutions (Boschma & Frenken, 2018). Thus, industries in the regions take advantage of shared factors to diversify into nearby industries. "The more related the variety of industries is vis-à-vis the new industry, the more likely a region can be successful in that new industry. Hence, the existing set of industries conditions the likelihood of new industries emerging, and in that sense, there exists regional path dependence" (Boschma & Frenken, 2018, p. 8-9). When regional diversification moves towards unrelated industries – that is, which share few characteristics and therefore are rarer events – it means that happened an expansion of local capacities and the addition of new knowledge (Boschma & Frenken, 2018; Balland et al., 2019), the purest sense of Jacobian externalities.

In such an approach, regional development depends on the ability of regions to change paths over the time (Gertler, 2005). In this context, several dimensions of proximity are considered to explain the trajectories of regional evolution, such as technological, institutional, cognitive and social proximity (Boschma, 2005). In Brazil, Tessarin et al. (2020) showed that innovative activity is positively associated with cognitive and technological proximity among workers. Galetti, Tessarin & Morceiro (2021) also concluded that cognitive proximity between workers is correlated with diversification and the entry of new industries in Brazilian regions. The proximity between the portfolio of existing technologies in a region was also pointed out by Antonelli et al. (2017) as an element that stimulates the development of innovative activities among European regions. Other articles focused on the US regions also showed that proximity in the technological base has a positive association with patents (Kogler, Rigby & Tucker, 2013; Boschma, Balland & Kogler, 2015; Balland et al., 2019).

Therefore, evolutionary economic geography argues that the prior knowledge base and competencies established in a region will determine the future paths that the region can follow, that is, path dependence matters (Neffke, Henning & Boschma, 2011). On the one hand, regions that concentrate little diversified and little complex activities (backward regions) tend to perpetuate a trajectory of low technological dynamism for a long time. On the other hand, diversified regions with complex industries and knowledge (advanced regions) have a wider range of knowledge and technologies that can be (re)combined, resulting in innovations. Pinheiro et al. (2022) show that the process of regional industrial and technological diversification can be vigorous for advanced regions. However, the dark side of this process is that it increases spatial inequality, as lagging regions tend to have a smaller set of accumulated capabilities and complex industries to stimulate technological dynamism than advanced regions. In this sense, the gap between advanced versus lagging regions tends to increase, resulting in what has become known as the dark side of the geography of innovation (Pinheiro et al., 2022).

Literature has sought to understand the geographical unevenness of innovation. In general, innovation is even more concentrated in space than production (Pike, Rodríguez-Pose & Tomaney, 2017), as few advanced regions tend to concentrate a variety of complex industries that patent, while lagging regions specialise in less complex industries that patent little (Boschma, Balland & Kogler, 2015) when they diversify. So, the income disparities across regions are more likely to be reinforced, not reduced, according to Pinheiro et al. (2022), due to path-dependence mechanisms on regional processes of structural transformation.

Other characteristics present in the investigations on the elements that explain the regional innovation refer to the profile of the companies (mainly, activity type and size). According to Pintec (IBGE, 2020), 87.5% of private companies that implemented some type of innovation between 2015-17 are part of the manufacturing industry – this share remains relatively constant compared to previous years. Therefore, manufacturing industries tend to be largely responsible for Brazilian innovation. High-tech firms, by definition, spend more on innovative activities[2], especially R&D. On the other hand, less technologically intensive firms focus on incremental innovations and expenditures on other innovative activities (such as the acquisition of machinery and equipment with an innovative purpose or project development) (Morceiro et al., 2011; Tessarin, Suzigan & Guilhoto, 2020). This type of innovation must be taken into account because, according to OECD (2005), dissemination mechanisms and incremental changes account for most innovations carried out in developing countries.

Lastly, size also matters to innovative activity since large firms tend to spend more resources on innovation (Symeonidis, 1996). Schumpeter's theory is based on the oligopolistic entrepreneur's argument (Schumpeter, 1942) that innovation increases more than proportionately with firm size, since the costs involved in innovative activity are high and uncertain and can only be covered if the firm's sales are high. Thus, large firms have the greater financial capacity to invest in high-risk activities and be involved in more than one project simultaneously (Symeonidis, 1996). In Brazil, around 80% of expenditures made in internal R&D activities by innovative companies in 2017 correspond to companies with more than 500 employees (IBGE, 2020). Bastos & Britto (2017) indicated that larger Brazilian firms (over 500 employees) are better prepared to obtain financing and tax incentives to engage in innovative activities. In addition, the authors showed that the innovation rate among large Brazilian companies is higher than small companies. In terms of technological diversity, large firms tend to present a wide range of technological domains, producing positive effects on their innovative activity through the cross-fertilisation of ideas from different areas.

2.3 Regional innovation in Brazil

The ability to generate innovations differs between regions because it depends on unevenly distributed spatially factors, particularly with territorial dimensions and structural

[2] The traditional OECD industrial classification by technological intensity computes the total expenditure on research and development (R&D) in proportion to the sector's revenue to classify companies into four groups of technological intensity.

inequalities such as those in Brazil. Among the elements that lead to spatial inequalities, we can mention the concentration of companies, productive activity and knowledge spillovers (Audretsch & Feldman, 1996), type of sectoral regional specialisation (Glaeser et al., 1992), appropriate technological infrastructure, institutions and knowledge proximity (Boschma, 2005), scale and urban amenities (Panne, 2004), knowledge diversity (Gertler, 2005); among others. For these reasons, although we have noticed a moderate deconcentration of industrial production in recent decades and the emergence of new innovative regions, this movement is still concentrated in a few directions. This is true for Latin American countries and for regions within Brazil. Innovation indicators in Latin America are strongly led by only one country – Brazil – and show a practically null evolution over the last few decades, contrary to the trend seen in developed countries, China and India (ECLAC, 2022).

Previous studies show that the concentration of innovative activity is quite intense in Brazil, especially in the South-Southeast axis. Diniz (2002) highlighted the concentration of technological activities in the Southeast region, mainly in São Paulo State. The author pointed out that even after São Paulo lost relative importance in the distribution of productive activities between the 1970s and 1980s, the State remained in the technological leadership due to a dense and complex urban and techno-scientific network to support technological activity.

Diniz & Gonçalves (2000) also pointed to a strong concentration of techno-scientific inputs in a few locations in the country. The authors identified that only five cities located in the Southeast concentrate 49% of researchers, 50% of national scientific articles, and 64% of international scientific articles. Such authors indicate that Brazil can be divided according to the capacity for technical-scientific development: the dynamic region includes metropolises and medium-sized cities in the Southeast and South regions; the backward region has large cities in the Northeast at a disadvantage compared to cities in the Center-South to attract and develop knowledge-intensive companies; and the empty region, specialised in the production of commodities, with low potential for technological development.

Silva e Simões (2004) crossed information from scientific publications and the number of employees in the industrial sectors. They also found a concentration of productive and scientific clusters in the Southeast region. For the authors, this region presents more significant technological opportunities concerning other country regions, which explains the maintenance of technological concentration in this country's axis. Gonçalves (2007) evaluated data on patents and technological activities and also identified the concentration of these activities in the Southeast and South regions. The author argues that the North, Northeast and vast majority of the Midwest region have low technological activity because they have few locational requirements that stimulate innovation, such as a diversified industrial base, urbanisation economies and qualified human resources.

Albuquerque et al. (2009) found that only five UF in the South and Southeast region account for 70% of GDP, 84% of patents, 79% of scientific publications and 69% of researchers in the country. This indicates that the concentration of scientific and technological results is even greater than GDP in five of the 27 UF of the country. In addition to the innovation system being spatially unequal, these authors note that it is also immature compared to the ones from advanced countries.

Rodriguez and Gonçalves (2017) investigated the regional distribution of patents in several technological domains using a regional classification by urban scale. As a result, they found that urban agglomerations in the South and Southeast (except Espírito Santo) led the hierarchy and concentration ranks in all of the 28 technological patent domains. For technological domains related to high technology, the concentration was even more evident in the urban agglomerations of São Paulo, Campinas and Rio de Janeiro. Such findings align with the literature on evolutionary economic geography, which shows that few wealthier urban areas concentrate the most complex industries in the USA (Balland & Rigby, 2017; Balland et al., 2020) and European countries (Pinheiro et al., 2022).

Sobrinho & Azzoni (2016) adopted a skills-based approach to assess the innovative potential of Brazilian regions. They calculated indexes for regions, states, and municipalities from 2003 to 2012 to show that the South and Southeast region still have the potentially most innovative industry. The authors identified 15 innovation clusters across the country. Although the concentration in the Southeast is notorious, the São Paulo cluster showed slower growth than others in the South (Curitiba-Joinville) and Northeast region (Recife e Salvador). By focusing on Brazilian microregions, Galetti, Tessarin & Morceiro (2021) also observed that microregions in the South and Southeast have a higher average skill-relatedness density than the rest of the country's microregions. This means that workers with similar skills are present in the same region, and in the end, this encourages the entry of new related firms in that region, reinforcing local specialisation and the concentration of productive and technological activity.

In general terms, what is observed in Brazil, as well as in other Latin American countries, is that efforts in science, technology and innovation do not appear sufficiently aligned with capacity-building to spread innovative potential across all regions (Badia-Miró, Nicolini & Willebald, 2020). On the one hand, public resources for innovation are mainly concentrated in universities and research centers to promote basic research. On the other hand, applied research that is led by the private sector receives a much smaller share of resources for innovation (ECLAC, 2022). As for companies, due to the lack of public resources available, many focus their innovative strategy on regions that offer more benefits and facilities in terms of infrastructure, specialized suppliers, skilled workers, etc., reinforcing the regional concentration of innovative potential.

3. Methodology

3.1 Innovative potential by regions

We take the worker-based approach to capture the innovative potential in Brazil. Workers contribute to innovative activities by applying knowledge and skills obtained through formal education and practical learning (learning by doing, learning by interacting, etc.). They also contribute to organisational change, one of the main elements of the innovative dynamic in less advanced countries (OECD, 2005), such as the Latin American countries.

A growing number of studies analyse the impact of workers' skills on the performance of firms and countries (Bacolod, Blum & Strange, 2009; Acemoglu & Autor, 2010; Neffke & Henning, 2013). Following such studies, we create a proxy for innovative potential by selecting skills linked to innovation and the subsequent occupations that perform tasks to promote innovative activities. A similar approach was proposed by Tessarin, Galetti & Morceiro (2022) to identify innovative occupations and their association with the increasing specialisation of innovative activity in Brazilian regions.

We selected Brazilian employment data from the Annual Social Security Information Report (RAIS) – from the Brazilian Labour Secretary, Ministry of Economy – which contains the number of occupations by industries and regions. This broad database provides information about 50 million workers in the nationwide formal labour market.[3]

To identify the occupations' skills content, we use a crosswalk table elaborated by Maciente (2013), who linked the North-American occupation list (O-NET) with the Brazilian occupation classification (named CBO). O-NET provides a comprehensive classification that describes occupations' attributes and required skills. With the correspondence table was possible to connect all 2,514 Brazilian occupations to 263 skills. Then, following the strategy

[3] "Formal" here refers to workers covered by social security. In Brazil, nearly 65% of all employees are formally employed in this sense (Ulyssea, 2018).

adopted by the literature, we made an accurate assessment of the skills' textual definition (Bacolod, Blum & Strange, 2009; Acemoglu & Autor, 2010; Autor & Dorn, 2013; Frey & Osborne, 2017) to sort out six skills relevant to perform innovative tasks. Applying a Principal Component Analysis (PCA) (Hair et al., 1998) we have reached an innovative skills index. Table 1 shows the skills selected and the PCA results.

Thus, all CBO occupations now have an index referring to innovative potential. We weight the number of occupations in each region by their corresponding index to obtain the innovative potential proxy for each Brazilian region. Therefore, we will call innovative jobs those with an index of innovative potential above the national average.

Table 1 – Innovative skills and PCA results

Skill name	Description	KMO
Innovation	Job requires creativity and alternative thinking to develop new ideas for and answers to work-related problems.	0.8908
Active learning	Understanding the implications of new information for both current and future problem solving and decision-making.	0.8125
Design	Knowledge of design techniques, tools, and principles involved in production of precision technical plans, blueprints, drawings, and models.	0.8219
Engineering and technology	Knowledge of the practical application of engineering science and technology. This includes applying principles, techniques, procedures, and equipment to the design and production of various goods and services.	0.7425
Technology design	Generating or adapting equipment and technology to serve user needs.	0.5303
Updating and using relevant knowledge	Keeping up-to-date technically and applying new knowledge to your job.	0.5498
	Factors resulting from PCA	**Proportion**
Factor 1	Creativity and problem solving.	0.6630
Factor 2	Technical knowledge.	0.3687

Source: Authors' elaboration, based on O-NET description.

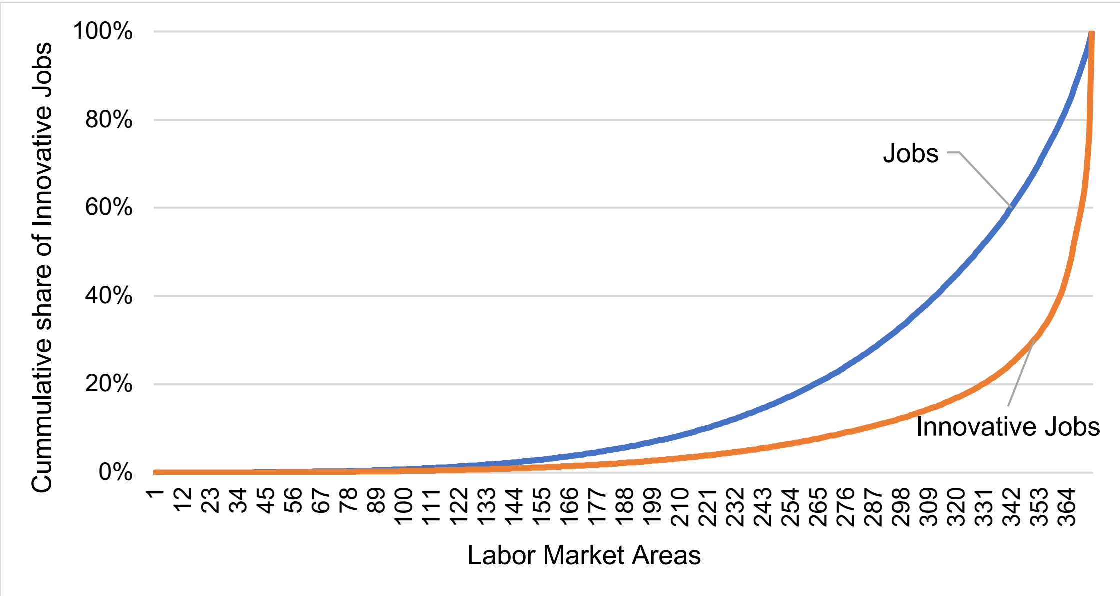
3.2 Spatial units

The regions, or spatial units, considered in the study are Labour Market Areas (LMA). The configuration of such areas is defined by the Brazilian Statistical Office (IBGE) based on commuting to work and study. To the 294 regions identified by IBGE, we added 80 urban areas that are representative in terms of the number of jobs but do not show conurbation with other cities. We ended up with 374 relevant regions, accounting for 64.2% of the national population in the 2010 census and 78% of all formal jobs in 2018. Even within this set, there is size heterogeneity, as the cumulative shares of Figure 1 indicate.

As the literature informs, agglomeration influences innovations (Paci & Usai, 1999; Panne, 2004; Gertler, 2005). Therefore, besides estimating the regression using all 374 LMAs, we restricted the estimations to LMAs with at least 500 and 1,000 innovative jobs to do alternative tests (see Table 3). The 214 LMA with 500 innovative jobs or more account for 98.5% of all innovative jobs, and the 160 LMAs with more than 1,000 innovative jobs, account for 96.5% of innovative jobs.

The lines in Figure 1 show that innovative jobs are more concentrated than overall jobs, in agreement with the literature. Only 44 regions (12% of the total) concentrate on more than 80% of innovative jobs, while 111 regions (30% of the total) concentrate on the same percentage of overall jobs.

Figure 1 - Jobs concentration across LMAs (2018)



Source: Author's elaboration based on RAIS dataset.

As the descriptive statistics show (Table 2), the indicator of the regional innovative potential shows concentration, with few areas hosting most of the innovative jobs – as the third quartile still has very few jobs (1,833 jobs in the Q3) when we compare the maximum (423,130 jobs). In terms of all jobs, concentration is also high but relatively smaller than in innovative jobs (Q3 amount has a higher proportion of jobs when compared to the maximum value of this group). We can also observe that, on average, the share of manufacturing represents around a quarter of the economic activities of the regions. For the per capita GDP the regional concentration also takes place, as well as seen for jobs.

Table 2 – Descriptive statistics

	Min	Q1	Med	Avg	Q3	Max
Innovative Jobs	0	107	503	3,881	1,833	423,130
Innovative Jobs Weighted	0	99	477	4,070	1,875	451,560
All Jobs	14	5,230	18,807	92,041	59,716	7,717,382
STEM Faculty	0	0	6	237	84	124,435
Share of Manufacturing	0,01	0,11	0,20	0,23	0,31	0,82
Per Capita GDP	1,274	9,241	15,749	19,108	25,419	135,586

Source: Author's elaboration.

3.3 Empirical test

This section investigates the trends in this concentration from 2003 to inform about possible changes in the concentration scenario. Employment data comes from RAIS dataset, per capita GDP and manufacturing share comes from IpeaData, and the STEM professors were collected from the Brazilian Higher Education Census. We regress the regional growth of innovative jobs over the period on the initial levels of this variable in each region, such as:

$$InJ_{r,t} = \alpha + \beta_1 InJ_{r,to} + \beta_2 y_{r,to} + \beta_3 EdSTEM_{r,to} + \beta_4 LgFirms_{r,to} + \beta_6 Ind_{r,to} + FE_t$$

In which:

$InJ_{r,t}$ is the share of innovative jobs in region r in year t, at the end of the period.

$InJ_{r,to}$ is the share of innovative jobs in region r at the beginning of the period. This variable represents the initial levels of innovative jobs in the regions.

$y_{r,to}$ is the per capita value of the regional GDP. It is included in the regression to represent the initial development levels of the regions. It is expected that more affluent areas are more prone to have innovative potential.

$EdSTEM_{r,to}$ is the initial number of university professors in the region in STEM areas, at both the undergraduate and graduate levels. It represents the regional capacity to produce STEM professionals.

$LgFirms_{r,to}$ is the share of firms with more than 1,000 employees in the region at the beginning of the period. The idea is to verify whether the presence of sizeable firms in the region is associated with the change in the regional share of innovative jobs.

$ShManufct_{r,to}$ is the initial share of manufacturing in the regional value-added. It informs about the sectoral composition of the regional production. It is expected that regions with larger shares of manufacturing will be related to a more intense demand for innovative jobs.

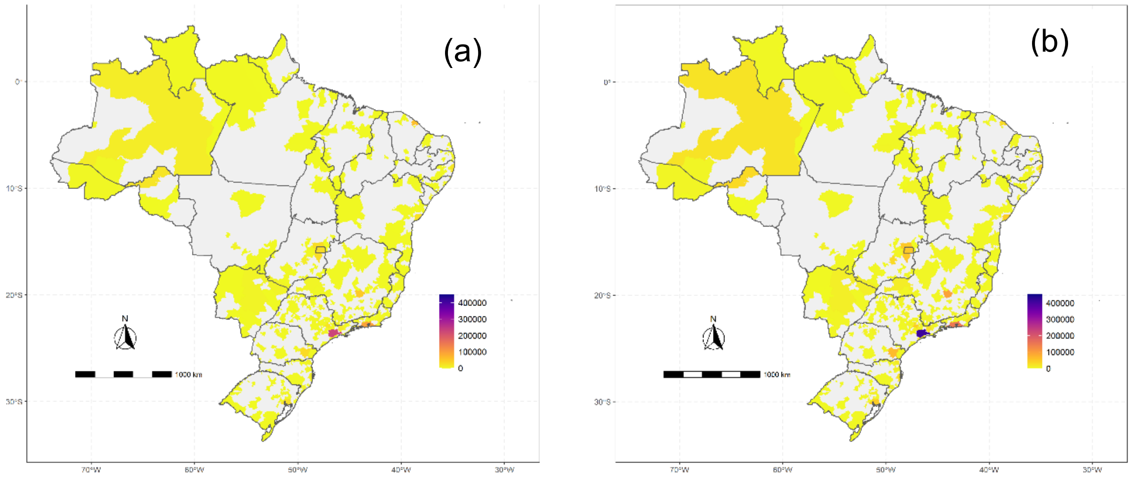
FE_t are fixed effects for each period. They capture overall macroeconomic conditions in each period.

The equation was estimated as a time panel. We defined four periods of four years and related the growth of the share of innovative jobs over each period to the respective initial value. As per data availability, the initial time is 2003 and 2018 is the last year. We have chosen four non-overlap periods to avoid possible specific time fluctuations.

4. Results

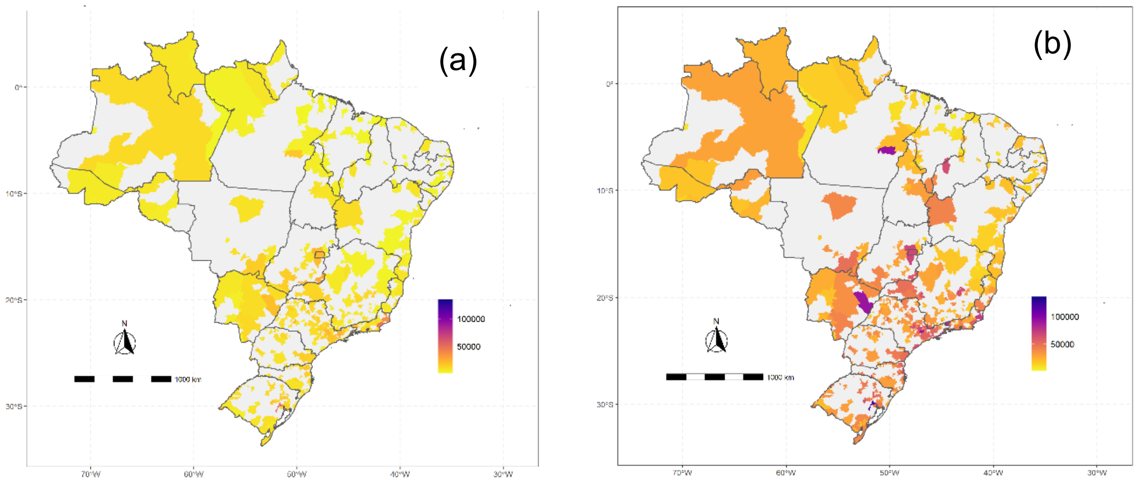
The maps below show how jobs with innovative potential are distributed across Brazilian LMAs (Figure 2), as well as GDP per capita (Figure 3), in 2003 and 2018. The most innovative regions are also those with the highest per capita income. Figures 4 and 5 allow us to make a correlation analysis of the share of innovative jobs by LMAs. The vertical axis indicates the percentage of innovative jobs in relation to all jobs, by region, in 2018, and the horizontal axis indicates the same variable in 2003. The regions above (below) the 45º dashed line showed growth (fall) in the share in 2018 compared to 2003.

Figure 2 – Innovative jobs by LMA (2003 and 2018)



Note: (a) 2003 (b) 2018. Source: Author's elaboration.

Figure 3 – Per capita GDP by LMA (2003 and 2018)

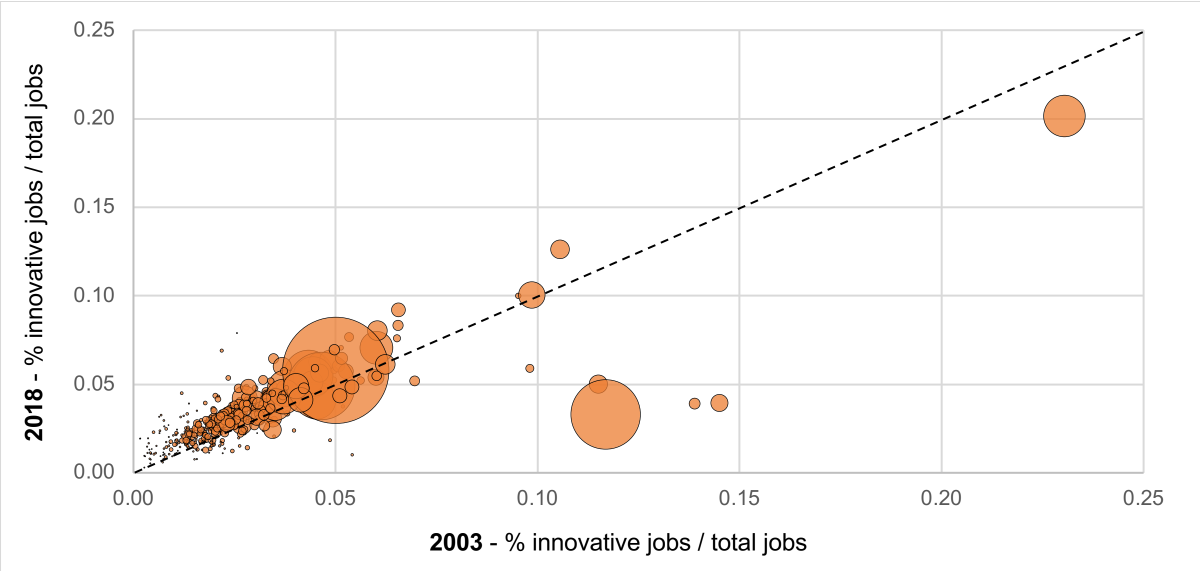


Note: (a) 2003 (b) 2018. Source: Author's elaboration.

Figure 4 shows all LMAs, over a period of 16 years, evidencing a slight increase in the share of innovative employment in most regions - as they are located close to the dashed line. It is also evident that innovative jobs are heavily concentrated in a few LMAs, while the vast majority with a low share of innovative jobs. Furthermore, while most regions showed a small increase in their share, a few regions with a higher share of innovative jobs experienced a decline.

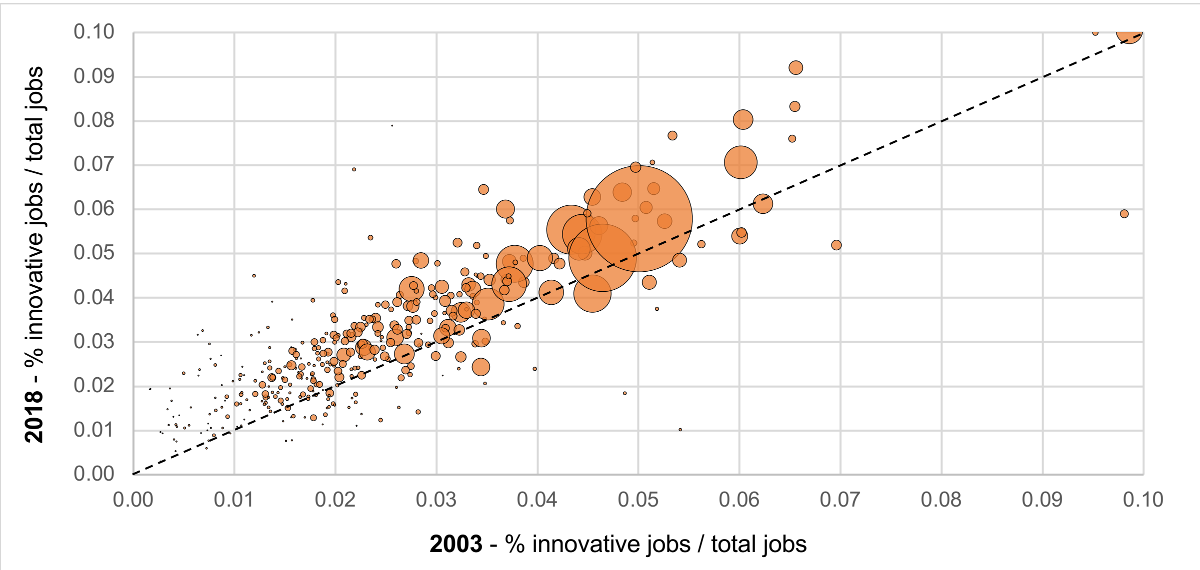
To check in detail this large set of LMAs with a low share of innovative jobs, we have considered only LMAs that have up to 10% of innovative jobs in relation to the total number of jobs (Figure 5). When we look only at this set of LMAs, it becomes clearer that small regions had a (positive) variation in the share of innovative jobs relatively greater than in large regions. As we will see below, the econometric results follow the same direction as the descriptive statistics, pointing to a relative deconcentration.

Figure 4 – Change in the share of innovative jobs by regions – All regions (2003-2018)



Source: Author's elaboration. Note: bubble size represents the number of innovative jobs by region in 2003.

Figure 5 – Change in the share of innovative jobs by regions – Selected group (2003-2018)



Source: Author's elaboration. Note: The bubble size represents the number of innovative jobs by region in 2003. Includes only regions with up to 10% of innovative jobs.

We also performed an econometric test, with results displayed in Table 3. As the negative coefficients for the initial share of innovative jobs indicate, regions with larger initial shares presented lower shares at the end of the period, and regions with small initial shares presented larger final shares. Such change suggests that convergence is taking place, as the shares of innovative jobs are becoming more similar. Although the conclusion is valid for all LMA sizes, this process is more intense in larger LMAs, as a comparison of the coefficients shows. As larger LMAs tend to be more similar, this result is expected.

As shown in Figures 2 and 3, the LMAs with the highest initial shares of innovative jobs are mostly located in the South and Southeast regions and LMAs with the smallest shares are located in the North and Northeast regions, following the pattern of the country' spatial inequality (Azzoni & Haddad, 2018; Bucciferro & Ferreira de Souza, 2020). So, rather than reinforcing spatial disparities – that is, a dark side of the geography of innovation – as preliminary evidence points to European regions (Pinheiro et al., 2022), the opposite happened in Brazil. This convergence among Brazilian are probably associated to the policies implemented by the federal government that benefited the poorest regions relative to the richest. These include a real increase in the minimum wage, the creation of universities and technical institutes in peripheral regions, the acceleration of social programs that made it possible for a large part of the population to enter education and the job market.

As for the other variables, the initial per capita income level, the initial share of manufacturing, and the initial share of large firms appeared with positive signs. This indicates that more prosperous regions, where manufacturing plays a vital role and where large firms are located, tend to present larger shares of innovative jobs at the end of the period. Such a conclusion aligns with the evolutionary economic geography argument that history (path-dependence) matters for the future trajectory (Neffke, Henning & Boschma, 2011; Pinheiro et al., 2022). In our case, the previous regional structural characteristics imply the future development of the innovative potential.

As previously indicated, the manufacturing sector performs around 70% of corporate R&D and an even higher percentage of other innovative activities in Brazil (IBGE, 2020). In addition, large companies concentrate innovative activity, according to Schumpeter (1942), especially in the manufacturing sector (Bastos & Britto, 2017). The manufacturing sector has a high capacity to promote regional development as locations where new industries are installed undergo major transformations (Greenstone, Hornbeck & Moretti, 2010; Macedo & Monasterio, 2016). However, the profound and accelerated process of deindustrialisation of the Brazilian economy (Morceiro & Guilhoto, 2022) is a worrying factor that is putting in question the ability of manufacturing to continue playing a vital role in the regional innovative potential.

The coefficients for the STEM faculty in the region came out positive but were not statistically different from zero. Therefore, there seems to be no association between the regional capacity to produce STEM professionals and the employment of these professionals at the local productive structure. This fact can be explained by the mobility of workers, who can move away from the regions they graduated from in search of employment with the best benefits. Thus, professionals trained in one region will not necessarily work in the same region. Lastly, many regions, especially the peripheral ones, still do not have universities.

Table 3 - Regression results

	All LMAs	InJ > 500	InJ > 1000
$ShInJ_0$	−0.1908564***	−0.2061811***	−0.2286148***
	(0.0141677)	(0.0192741)	(0.0225727)
Y_0	0.0000001***	0.0000001**	0.0000001*
	(0.00000003)	(0.00000004)	(0.00000005)
$STEMFaculty_0$	0.0000001	0.0000001	0.0000001
	(0.0000001)	(0.0000001)	(0.0000001)
$ShManuf_0$	0.0049546**	0.0066693**	0.0089107**
	(0.0020944)	(0.0033283)	(0.0042262)
$ShLargeFirms_0$	1.7145750**	2.7865740*	3,1923050
	(0.7678640)	(1,670306)	(2,074421)
# Observation.	1496	824	640
R^2	0.1138	0,1339	0,1526
Adjusted R^2	0.1090	0,1254	0,1418
Resid Std Error	0,0083	0,0097	0,0106
D of Freedom	1487	815	631

Source: Author's elaboration. Note: The dependent variable is the share of innovative jobs at the time t.

In summary, our results show that some previous local characteristics (found in the initial period) explain the future regional innovative potential (ending period). The regional convergence observed apparently has minor effects to catchup at the national level since the leader regions are too far from the other regions in terms of innovative levels. The pace of convergence should be faster to promote effective changes within the bottom group to promote the innovative success of the country as a whole.

5. Conclusion

Innovation depends on a wide range of factors. Several elements that can explain the innovative potential must be considered when analysing such a phenomenon from the regional point of view. More than innovation output, looking for the inputs and interaction among the elements which shape the regional innovative capabilities allows us to have a broader view of the innovative performance of developing countries such as those in Latin America. For this reason, many studies have sought to explore how different factors can allow better innovative performance. The Latin America context is even more intriguing, as its countries are far from the technological frontier, concentrates on less technologically intensive industries, have companies with innovative strategies focused on diffusion and count on many multinational companies in high-tech sectors – that traditionally allocate R&D activities in the host country rather than subsidiary companies in developing countries.

In terms of GDP, Latin American countries have shown a slow but robust process of regional convergence, including in the period of government-led industrialization (until mid-1970) and the liberalization time in the 1980 and 1990 decades (Badia-Miró, Nicolini & Willebald, 2020). Notwithstanding, the innovative performance has been stagnant for decades in the region. Brazil drives the innovation indicators of Latin America (62% of Latin American R&D expenditure, for example) with a reasonable distance from followers, such as Uruguay, Cuba and Argentina (ECLAC, 2022). Convergence regarding innovative performance among Latin American countries still seems a distant goal.

Brazil, in particular, has one of the most diversified production structures among its Latin American neighbours. In addition, it also has a marked regional inequality in terms of the distribution of productive activity, labour, infrastructure, and income. Such characteristics also reflect on the innovative activity, which is relatively concentrated in a few regions located in the South and Southeast regions. Our results point to some elements that explain the regions' innovative potential, such as per capita income, the degree of industrialisation, and the proportion of large companies. These factors have a positive association with the regions' innovative potential in the future, and therefore contribute to the growth of regional innovative activity.

The initial share of innovative jobs is a relevant element in our results to explain the innovative potential of the regions in the future. Regions with a higher initial share of innovative jobs tend to grow at lower rates in the future, while regions with a lower share tend to have a relatively higher growth rate. Therefore, a convergence movement of the regional innovative potential slightly reduced the deep spatial inequality. This result is quite interesting, as it goes against the grain of the initial research carried out for European regions that pointed to the dark side of the geography of innovation, that is, an even greater concentration of innovation in leading regions (with well-established technological capabilities) to the detriment of lagging ones. We believe that redistributive policies were vital for such spatial deconcentration, but the continuity of these policies ran out of steam from mid-2016 onwards.

Innovative capabilities are built little by little, and their evolution is decisive for regional innovative performance, especially for regions with less innovative potential (lagged regions). In Brazil, backward regions face major physical, social, and technological infrastructure bottlenecks. However, appropriate infrastructure is a necessary condition to attract firms from overpopulated advanced regions, which face increasing urbanisation externalities (such as diseconomies of agglomeration, pollution, congestion, rising housing prices, and price inflation for key inputs). In its turn, the enforcement and coordination of public policies are essential to provide infrastructure in such backward regions.

As manufacturing, and especially large companies, are positively associated with the regional innovative potential, the challenge is to attract them to the backward regions to maintain the convergence process and reduce the deep spatial disparities currently present. To this end, we suggest policy approaches based on the local – according to the evolutionary economic geography literature – and people-based – according to the urban economics literature. In the first case, regions with less innovative potential could explore diversification opportunities for new industries related to existing industries in the same area with greater innovative potential; thus, new industries benefited from the capabilities shared with related industries. However, related diversification towards more innovative industries is not a spontaneous process and, therefore, should be promoted by local public policies. As for the second focus, it is vital for the less advanced regions to expand and improve the education system and professional training and create mechanisms to attract and retain professionals with innovative skills. In this sense, establishing partnerships and research collaborations with excellent education and training institutions in the country and abroad is a possible path. Finally, given the advance of deindustrialisation in the South and Southeast regions, especially in industries sensitive to the high labour cost, designing policies to attract manufacturing companies to peripheral locations is another option to be explored.

Although we have identified convergence in the innovative potential of Brazilian regions, the movement is too slow to indicate a deep transformation that would raise the country as a whole to similar levels of developed nations. A strategy to bring about an unequivocal convergence between Brazilian regions depends on public policies focused on regional development projects centered on the bottom areas. Top regions have their own dynamics that feedback their innovative potential due to the offer of attractive elements for companies and workers. As most of the investments in innovation come through the public sector, it is key to direct these resources, for example, towards projects that solve local problems, to regions outside the South-Southeast axis, or to companies to diversify their innovative capabilities via the acquisition of new knowledge. Such type of policies is still rare or not robust (in terms of volume of resources and longevity), which makes structural transformation and technological change in Brazil, as well as in Latin America, unfeasible. We cannot yet say that traps such as middle income or low growth can be overcome, but it is certain that the role of public policies is crucial to achieving this objective.

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