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Where is the Diffusion of Technical Progress? Economic Complexity and Industrial Employment in Brazilian Microregions¹

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Abstract This paper analyzes the productive structure of Brazilian microregions by combining indicators of economic complexity, productive specialization, and employment concentration in sectors that diffuse technical progress. Using Annual Social Information Report employment microdata and complexity indicators from the DataViva platform, it develops an employment-based typology of regional development trajectories between 2007 and 2021. The results reveal persistent spatial inequalities, with upgrading and extension trajectories concentrated in historically industrialized regions, particularly in the South and Southeast, while stagnation, contraction, and non-identified trajectories prevail in peripheral territories. The findings highlight that regional diversification and technological diffusion are strongly conditioned by prior productive capabilities and institutional arrangements. The analysis also identifies microregions with latent diversification potential through opportunity gain indicators, suggesting windows for future structural transformation. By integrating economic complexity with diffusion-based employment dynamics, the study contributes to the literature on evolutionary economic geography and offers policy-relevant insights for designing territorially differentiated development strategies in late-industrializing economies. **Keywords:** Economic complexity; Regional development; Diffusion of technical progress.

Onde se Difunde o Progresso Técnico? Complexidade Econômica e Emprego Industrial nas Microrregiões Brasileiras

Resumo Este artigo analisa a estrutura produtiva das microrregiões brasileiras combinando indicadores de complexidade econômica, especialização produtiva e concentração de empregos em setores que difundem o progresso técnico. Utilizando microdados de emprego da Relação Anual de Informações Sociais e indicadores de complexidade da plataforma DataViva, o estudo desenvolve uma tipologia baseada no emprego das trajetórias de desenvolvimento regional entre 2007 e 2021. Os resultados revelam desigualdades espaciais persistentes, com trajetórias de atualização e extensão concentradas em regiões historicamente industrializadas, particularmente no Sul e Sudeste, enquanto a estagnação, a contração e as trajetórias não identificadas prevalecem em territórios periféricos. As conclusões destacam que a diversificação regional e a difusão tecnológica são fortemente condicionadas pelas capacidades produtivas prévias e pelos arranjos institucionais. Além disso, a análise identifica microrregiões com potencial de diversificação latente por meio de indicadores de ganho de oportunidade, sugerindo janelas para futuras transformações estruturais. Ao integrar a complexidade econômica com a dinâmica do emprego baseada na difusão, o estudo contribui para a literatura sobre geografia econômica evolutiva e oferece insights relevantes para as políticas públicas para a elaboração de estratégias de desenvolvimento territorialmente diferenciadas em economias em fase de industrialização tardia. **Palavras-chave:** Complexidade econômica; Desenvolvimento regional; Difusão do progresso técnico.

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1. Introduction

In Hirschman's historical interpretation (1976), economic development is understood as a process shaped not only by income and wealth expansion but also by the distribution of these gains across society. Importantly, development unfolds unevenly across territories and social groups, reflecting structural asymmetries in productive organization and access to technological progress. From a historical perspective, productivity gains driven by technical change represented a turning point in economic thought, overcoming classical Malthusian predictions that associated population growth with inevitable limits to human sustainability. Instead, technological progress has allowed societies to expand productive capability and reorganize economic systems in ways that reshape growth trajectories and development possibilities.

One of the central mechanisms underlying economic development is the transformation and qualification of the productive structure. The expansion of productive capabilities, reflected in the diversification and sophistication of economic activities, constitutes the foundation of what has become known as economic complexity. However, the process of increasing complexity is inherently uneven, generating sectoral, regional, social, and institutional heterogeneities. In Brazil, such disparities are particularly pronounced due to the historical concentration of industrialization and technological capabilities in specific regions. As highlighted by Cano (1997), the industrialization process between 1930 and 1945 strengthened the economic centrality of São Paulo while simultaneously integrating other regions into national productive networks in an uneven and hierarchical manner.

The theory of economic complexity, developed by Hidalgo and Hausmann (2009), provides an analytical framework to understand these dynamics by linking productive diversification to the accumulation of technological and organizational capabilities. According to this perspective, the ability of countries and regions to produce sophisticated goods depends on the presence and interaction of complementary capabilities embedded in firms, institutions, and labor markets. Empirical evidence suggests that economies with diversified and less ubiquitous productive structures tend to be more resilient and capable of sustaining long-term growth. In line with this argument, Figueiredo (2004) emphasizes that technological capabilities are built through cumulative learning processes that vary across sectors and territories, reinforcing the importance of spatial heterogeneity in understanding development trajectories.

The debate on innovation further deepens this discussion by emphasizing that development is not only driven by the generation of new technologies but also by their diffusion across productive systems. Following the Schumpeterian and neo-Schumpeterian tradition, technological change is understood as a systemic and cumulative process involving firms, workers, universities, and public institutions. In this context, technological diffusion represents a continuous and adaptive process in which innovations are absorbed, adapted, and incrementally improved over time, depending on institutional arrangements and productive complementarities (Deza, 1995). For developing economies, diffusion processes often play a particularly strategic role, as technological capabilities tend to be embodied in productive activities and workforce skills rather than in frontier innovation outputs.

At the regional level, these dynamics are closely linked to the literature on endogenous development, which highlights the role of local capabilities, institutional coordination, and regional innovation systems in shaping economic growth trajectories (Amaral Filho, 2009). Regional diversification tends to occur through path-dependent processes, in which new activities emerge from the recombination of existing capabilities. However,

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the capability to diversify and upgrade productive structures varies significantly across territories, depending on factors such as knowledge spillovers, cognitive proximity between sectors, and the presence of innovation-supporting institutions. Metropolitan and industrialized regions typically benefit from dense labor markets, research institutions, and diversified productive networks, while peripheral territories face structural barriers to technological upgrading (Tödtling & Trippel, 2005).

Building on the intersection between economic complexity, technological diffusion, and regional path development, this paper proposes an original typology of regional trajectories that integrates productive specialization, changes in employment in sectors that diffuse technical progress, and variations in regional economic complexity. By adopting an employment-based perspective, the study advances existing approaches that rely primarily on patent or R&D indicators, which often underestimate technological learning processes in late-industrializing economies. This approach allows the identification of distinct regional trajectories – upgrading, extension, stagnation, contraction, and cases with no identifiable trajectory – capturing not only the persistence or transformation of productive paths but also their qualitative implications for structural change.

Previous studies have documented significant regional disparities in Brazilian technological capabilities, consistently highlighting the leadership of the Southeast, particularly São Paulo (Fornari, Gomes & Morceiro, 2014; Dias & Martinelli, 2020). This study contributes to the literature by extending the analysis to the microregional scale, exploring how economic complexity interacts with the diffusion of technical progress and productive specialization. The central hypothesis is that regions with higher economic complexity tend to exhibit greater capability to absorb and diffuse technological knowledge, fostering more dynamic and sustainable development trajectories. By doing so, the study seeks to contribute to the formulation of regional development policies that recognize territorial heterogeneity and promote structurally transformative growth.

The paper is organized as follows. The next section reviews the theoretical literature on economic complexity, technological capabilities, diffusion of technical progress, and regional development. The third section presents the database and methodological strategy. The fourth section discusses the empirical results and the typology of regional trajectories. The final section concludes the study and outlines policy implications and future research avenues.

2. Literature Review

2.1 Fundamentals of Economic Complexity

In their Atlas of Economic Complexity, Hausmann and Hidalgo (2011) define it as an indicator of a society's ability to generate, absorb, and use knowledge, reflecting the diversity and sophistication of its products and the structure of its productive networks. A strategy for measuring this phenomenon must take into account important concepts such as diversity and ubiquity. The diversity of products that a country or geographical area manufactures reflects the variety of knowledge and capabilities existing in its economy. The greater the diversity, the greater the likelihood that the nation has a broad set of skills and technologies. The ubiquity of products, in turn, indicates the level of knowledge required for their production. Less ubiquitous products, manufactured by few countries, require a more specific and sophisticated set of knowledge.

The capability of a nation or even a region to produce complex goods, such as semiconductors or aircraft, reflects the existence of complex networks of individuals and organizations that possess and combine various types of specialized knowledge, codified and/or tacit learning. Less complex economies, based on products that

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require less knowledge, such as agricultural and mineral products that are minimally processed, have simpler and less diversified value chains. Regional networks and ecosystems facilitate the accumulation and transfer of knowledge, which act as repositories and disseminators of diverse learning (Hidalgo & Hausmann, 2009). Economic complexity is intrinsically linked to accumulated technological capabilities (Lall, 1992), which range from basic operational skills to advanced capabilities for radical innovation.

Hausmann and Hidalgo (2010) propose a model based on the export balance, which suggests that countries with greater productive capabilities – knowledge and skills – are able to produce a more diverse range of products. On the other hand, products that require a more specific and complex set of capabilities will be produced by fewer countries, becoming less ubiquitous – or less present and available. However, pitfalls in the process of economic diversification may arise. Countries with few capabilities will find it difficult to diversify, as the probability that a new capability will be useful to produce a new product is low in the absence of other necessary capabilities. In contrast, countries with many capabilities can combine new capabilities with existing ones, facilitating diversification.

Salles, Porto, and Rocha (2017) analyze the productive structure of the state of Minas Gerais, traditionally concentrated in low-complexity products such as iron ore and coffee, and propose a methodology to identify sectors with potential for diversification and economic sophistication. Using the Product Space approach and data from the DataViva platform, they identify two priority segments for development policies, namely biotechnological products, especially pharmaceutical chemicals for human and animal health, and mechanical-electrical industry products, such as precision instruments.

Thus, economic complexity is an important driver of economic growth. Nations identified as more complex, characterized by a diversified and sophisticated productive structure, tend to experience sustained growth rates. It should be noted that this phenomenon is not a by-product of economic prosperity, but rather a causal factor. By fostering innovation, technological advancement, and the development of a skilled workforce, economic complexity allows countries to escape low-growth traps and achieve virtuous trajectories of economic development (Hausmann et al., 2011).

2.2 Innovation and Diffusion of Technical Progress

The discussion on economic complexity naturally leads to the debate on innovation and technical progress as central drivers of economic development. Following the classical and neo-Schumpeterian tradition, technological change is understood not as an isolated outcome of individual inventors, but as a systemic and cumulative process shaped by institutional arrangements, sectoral structures, and historical trajectories. In this perspective, innovation emerges from complex interactions among firms, workers, universities, public agencies, and other social actors, rather than from linear and exogenous mechanisms (Szapiro; Matos & Cassiolato, 2021).

This approach understands innovation as a collective and cumulative phenomenon, rooted in local and national innovation systems, which can be investigated geographically. Technological capabilities – the accumulation of physical and social resources necessary to generate and manage technological change – are not given, but built through interaction between companies, universities, research centers, governments, and other social actors and institutions. Technical progress, in this context, depends on the quality of these interactions, the institutional environment, and previous technological trajectories. As Cassiolato and Lastres (2005) state, innovative performance cannot be analyzed in isolation, as it results from the articulation between agents and the way institutions shape these relationships.

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Technological diffusion plays a central role in this process, especially in peripheral economies. In the early stages, the adoption of new technologies requires specific skills and is restricted to highly qualified groups. Over time, as production becomes routine, such knowledge becomes incorporated into processes, allowing for its wider dissemination and the internalization of skills among less specialized workers. This cumulative learning, by doing, by using, by interacting, etc., forms the basis for organizational strengthening and continuous improvement of production techniques (Figueiredo, 2004).

The diffusion of technical progress, as highlighted by Lundvall and Nielsen (1999), depends on regional innovation systems that integrate universities, companies, and public policies, factors that explain the concentration of jobs in sectors that demand more skilled occupations in the South-Southeast axis (Garcia et al., 2011).

Even in companies with low and medium-low technological intensity, productivity can be boosted by knowledge spillovers from more advanced segments. The diffusion of innovation, therefore, is not limited to imitation or passive absorption, but implies organizational rearrangements, internal training, and the construction of new routines. In countries that have faced premature and incomplete industrialization, diffusion is a strategic path to technological catching-up, enabling advances even without their own technological frontier and avoiding entrapment in unsophisticated productive structures (FORNARI; GOMES; MORCEIRO, 2014).

Morceiro and Guilhoto (2019) analyze the process of Brazilian deindustrialization between 1970 and 2016 and observe less variability in sectoral intensities compared to OECD countries. They highlight, especially between 2009 and 2017, a sharp industrial downturn linked to the 2008 international financial crisis and the worsening political and institutional crises in the country. According to the authors, Brazilian deindustrialization is considered premature and concentrated in strategic sectors with greater technological content, such as those linked to science and technology and the rubber and plastic industries. This dynamic is seen as undesirable from a development perspective, as it compromises sectors with high potential for productive linkages and multiplier effects essential to economic growth.

Sectoral deindustrialization refers to the differentiated loss of participation of specific segments of the manufacturing industry in the productive structure, which in the case of developing economies such as Brazil occurs especially in more technology-intensive activities. Studies indicate that, after the country reached middle-income levels, some manufacturing sectors began to show stagnation and relative decline, a phenomenon that intensified between 2009 and 2017, amid the impacts of the 2008 international crisis and domestic political and institutional instability. Sectoral analysis reveals that this process occurs heterogeneously among industrial activities, but becomes particularly worrying when it affects strategic sectors associated with science and technology, given that industry plays a central role as an engine of economic growth and has strong knock-on and multiplier effects on other productive sectors (Fornari; Gomes & Morceiro, 2014; Morceiro & Guilhoto, 2019).

From this perspective, technical progress reinforces the central role of industry as an engine of economic development. (Diegues & Rossi, 2018). Industrial sectors with increasing returns to scale radiate productivity gains throughout the economy and expand the capability for systemic innovation. Deindustrialization, in this sense, represents not only the loss of productive complexity, but also the erosion of the conditions necessary for the generation and diffusion of technical progress. As Kaldorian interpretations indicate, recovering the industrial base also means recovering the capability to innovate and sustain regionally balanced and technologically dynamic development trajectories.

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Fornari, Gomes, and Morceiro (2014) explain that the productivity of low and medium-low technology intensity companies is linked to two aspects. The first is linked to the innovative processes of medium-high and high technology intensity companies, and the innovative capabilities of higher intensity companies depend on links and spillovers generated by lower intensity companies. Therefore, regardless of their level (basic, intermediate, advanced), activities corroborate capabilities and generate horizontal and vertical spillovers in productive chains, with potential impacts on economic and social development. Taken together, this literature suggests that the diffusion of technical progress is a territorially embedded and sectorally differentiated process, operating through productive structures and labor markets.

2.3 Complexity and Technological Diffusion as Drivers of Regional Development

Regions have unique characteristics that influence their economic development, typically being more open than nations, with fewer barriers to the movement of goods, capital, and labor. This greater openness can facilitate economic growth, but it also exposes regions to external shocks and competition. In addition, regions often lack full sovereignty and are subject to the policies and regulations of a central government. This can limit their autonomy in decision-making and restrict their ability to implement customized development strategies. Finally, the homogeneity of regions also varies. Some regions are relatively homogeneous in terms of economic structure, cultural factors, and demographic characteristics. These differences can influence the types of policies and strategies that are most effective for regional development (Fratesi, 2024).

The concept of path dependence in economic development implies that regional diversification is influenced by existing capabilities and knowledge from the past. Regions tend to specialize in related activities, taking advantage of their strengths and local resources. Following the concept of relatedness, regional economic diversification tends to prioritize sectors that are already related to the existing productive structure. Empirical evidence shows that economic diversification tends to occur in sectors that share similar productive capabilities, as summarized by the Principle of Relatedness (Hidalgo et al., 2018). Although related diversification is a common pattern, the ability to diversify into more complex activities varies across regions. Developed regions with strong innovation capabilities may be better positioned to break through relationship constraints and pursue more ambitious diversification strategies. One of the drivers of this diversification is the presence of skilled workers (Garcia, Silva & Righi, 2011). However, for regions with limited capabilities, related diversification remains a crucial strategy for economic growth and development. Understanding these dynamics is essential for designing effective regional development policies that support diversification and promote economic complexity (Françoso et al, 2024).

Balland et al. (2019) connect the literature on smart specialization with that on diversification and economic complexity. Regions with strong innovation capabilities can explore opportunities for diversification into more complex activities, while regions with limited capabilities can focus on related diversification, leveraging their existing strengths. The relationship positively influences technological diversification, and regions specializing in complex technologies tend to grow more rapidly. Authors emphasize the importance of leveraging existing regional capabilities and suggest a balance between top-down policy orientation and bottom-up entrepreneurial discovery, and recognize the need for further research to address issues such as the role of non-technological knowledge, the balance between top-down and bottom-up approaches, and the importance of institutional governance to support smart specialization.

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Both diversification and technological diffusion are influenced by various factors, such as the presence of universities and research institutes, institutions and government agencies that foster innovation, and a skilled workforce with technical and technological knowledge. Quatraro and Scandura (2024), for instance, argue that the presence of academic inventors can influence this process by introducing new knowledge and technological capabilities to the regions in which they are located. By analyzing the relationship between academic patenting and regional diversification, their study contributes to a better understanding of the factors that shape regional innovation systems and economic development, which cuts across social, economic, and environmental issues.

Romero et al. (2021) demonstrate a positive correlation between economic complexity and economic performance, pointing out that municipalities and micro-regions with more diversified and sophisticated productive structures tend to have higher levels of GDP per capita and formal job creation. Based on employment data and replicating findings from the international literature, they conduct an empirical application for Belo Horizonte, which illustrates the practical potential of the approach by identifying sectors such as machinery, electronics, and technological services as vectors of structural transformation. By emphasizing the importance of knowledge externalities and cognitive proximity between sectors for smart diversification strategies, the paper offers analytical and operational support for the design of public policies aimed at overcoming regional development traps.

In their applied analysis, Alonso et al. (2025) demonstrate that the capability of Brazilian regions to enter, sustain, and expand activities related to the semiconductor industry is deeply conditioned by the prior structure of their technological bases, showing that processes of productive diversification occur cumulatively and depend on trajectories. Based on the framework of evolutionary economic geography, the study reveals that diversification in high-tech sectors tends to emerge in contexts where there is a high density of related knowledge, allowing for greater complexity in regional production structures. In this sense, regions with denser and more connected technological portfolios are more likely to develop new specializations, sustain innovative trajectories, and reduce risks of technological discontinuity, while regions with less cognitive proximity face structural barriers to entry into these segments.

Addressing regional development in the contemporary economies must take environmental issues into account. With regard to the recent challenges of the climate emergency and the green transition, linked to the creation of economic opportunities that guarantee human sustainability, Jakobsen et al. 2022, in a paper applied to Western Norway, highlight that the different paths of industrial transition within a region are influenced by a variety of combinations of public policies, and that regional green restructuring involves a complex set of policies implemented at different levels of governance. Even traditional sectors – or so-called brown sectors – can and should seek technical solutions to enable environmental technologies that facilitate both competitiveness and the internalization of environmental costs in the process.

Ostergaard et al. (2024) propose a typology of six green regional development trajectories – basis for the methodology proposed in the next section –, ranging from the extension of existing activities to the creation of new sectors, conditioned by the degree of prior specialization and the intensity of local economic transformations. Based on patent data, the results show that green diversification occurs in a complex and multifaceted way, depending on the interaction between organizational capabilities and systemic conditions. The relevant role of both incumbent companies, which benefit from the accumulation of knowledge and resources, and new entrants is highlighted, indicating that the transition to green technologies requires sophisticated productive and cognitive bases, as well as policies capable of stimulating the recombination of regional capabilities and increasing economic complexity.

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Desafios Regionais



Studies on economic complexity have predominantly focused on productive structure and diversification patterns, while innovation studies have tended to emphasize frontier outcomes such as patents, R&D expenditures, or firm-level innovation indicators. As a result, the mechanisms through which technical progress is absorbed, adapted, and diffused across regional labor markets, particularly in late-industrializing economies, remain insufficiently explored. Moreover, existing approaches often analyze complexity and technological change in isolation, overlooking how sectoral specialization, employment dynamics, and cumulative learning processes jointly shape regional development trajectories. This limitation is especially relevant in the Brazilian context, where technological capabilities are largely embodied in productive activities and workforce skills rather than formal innovation outputs.

This paper addresses these gaps by explicitly linking economic complexity to the diffusion of technical progress through an employment-based perspective. By combining indicators of regional economic complexity with specialization in sectors that act as technological diffusers, and by constructing a typology of regional development trajectories at the microregional level, the analysis provides a new framework for understanding how productive structure and diffusion mechanisms interact to shape uneven regional development.

3. Data and Methodology

This section outlines the databases, complexity indicators, and classification strategy used to identify regional development trajectories. Building on the gaps identified in the literature, the empirical approach combines employment-based measures of productive specialization with indicators of economic complexity to capture both the diffusion of technical progress and patterns of structural persistence and transformation across Brazilian microregions.

The diffusion of technical progress is operationalized through the identification of micro-regions with relative specialization in sectors that spill over technical progress, according to Pavitt's (1984) taxonomy as adapted by Cavalcante (2014). These sectors play a central role in processes of technological learning, acting as intermediaries between existing capabilities and emerging opportunities for productive upgrading (Hidalgo et al., 2018). Regional specialization is measured using the Revealed Comparative Advantage (RCA) indicator and its binary version, subject to a minimum employment threshold.

3.1 Data

The empirical analysis is based, in the case of the diffusion of technical progress, on microdata on employment from Brazil's Annual Social Information Report, an administrative record maintained by the Ministry of Labor that provides comprehensive coverage of the country's formal labor market. In the case of indicators of complexity, average distance, and opportunity gain, the data were accessed through the DataViva platform (Cedeplar/UFGM), which offers pre-processed statistics on employment and payroll disaggregated by sector (4-digit CNAE), occupation (4-digit CBO), and geography (558 micro-regions).

The use of employment data reflects the specific analytical requirements of research on technology diffusion in late industrializing economies. Unlike advanced economies, where innovation is predominantly captured through patents and R&D spending, technological capabilities in peripheral economies are mainly embedded in productive activities, workforce skills, and organizational practices (Lall, 1992; Figueiredo, 2004). Employment data, thus, capture the diffusion-oriented capabilities – absorption, adaptation, and incremental

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improvement of technology – that characterize technical progress in structurally heterogeneous contexts such as Brazil. Although formal employment data exclude informal activities, this approach ensures temporal consistency, sectoral accuracy, and spatial comparability across all microregions, allowing for robust identification of regional specialization patterns and structural transformations.

3.2 Complexity Indicators

DataViva, a platform developed in partnership with MIT and currently managed by Cedeplar/UFGM, offers a powerful tool for analyzing regional economic complexity in Brazil. It uses data from the Annual Social Information Report to calculate complexity indicators, such as productive density and opportunity gains, at different geographic levels. By creating alternatives to the limitations of export data, the platform provides a more accurate and detailed analysis of the Brazilian productive structure, supporting the formulation of more effective public policies for regional development, as emphasized by Freitas et al. (2023).

Regional economic complexity is measured, following Freitas et al. (2023), who adapt the reflex methodology (Hidalgo et al., 2009) to the Brazilian context using Annual Social Information Report payroll data. The RCA indicator, calculated according to Balassa (1965) and equivalent to the location quotient, identifies sectoral specializations based on payroll concentration. Regions with higher wage shares in specific sectors have a comparative advantage in these activities. Regional complexity is therefore assessed through the diversity and ubiquity of specialized sectors:

$$QL_{rs} = \frac{W_{rs}/\Sigma_s W_{rs}}{\Sigma_r W_{rs}/\Sigma_r \Sigma_s W_{rs}} \quad (1)$$

where: W_{rs} is the wage bill of occupation r in sector s ; $\Sigma_s W_{rs}$ is the total wage bill of occupation r across all sectors; $\Sigma_r W_{rs}$ is the total wage bill in sector s ; and $\Sigma_r \Sigma_s W_{rs}$ is the total wage bill across all occupations and sectors.

Based on the RCA matrix, regional diversification and product ubiquity are calculated (Freitas et al., 2019). Diversification measures sectoral variety in which a region specializes; ubiquity indicates production frequency across regions. The reflex method iterates successively between these indicators to capture interrelationships in regional productive capabilities. The ICE-R is calculated from the eigenvector associated with the second-largest eigenvalue, measuring each region's standardized distance from the complexity mean:

$$\overrightarrow{\{ICE\}_R} = \frac{\{\overrightarrow{R}\} - \langle \overrightarrow{R} \rangle}{\{dp(\overrightarrow{R})\}} \quad (2)$$

where $\langle \rangle$ denotes the mean, and dp denotes the standard deviation of $R^{\rightarrow}$; $R^{\rightarrow}$ indicates the raw value of the complexity index for region r ; $\langle R^{\rightarrow} \rangle$ is the mean of for all regions. This equation standardizes the regional economic complexity index, transforming the values into an index with a mean of zero and a standard deviation of 1.

Distance quantifies the remoteness of a product from a region's productive structure, expressing the difficulty of acquiring a comparative advantage in that product (Hausmann & Klinger, 2006). The production of different goods requires different sets of knowledge, and the proximity between these sets facilitates productive



diversification. Products that are like others already mastered require less effort to incorporate, as the necessary knowledge is partially available locally. Distance represents the amount of new knowledge that a region must assimilate to successfully produce a given good.

Operationally, distance is calculated from the sum of the proximities between a product and all products in which the region has no comparative advantage, normalized by total proximities (Hausmann & Klinger, 2007). If a region produces many products linked to product p , the distance is small (approaching zero); if it produces few, the distance is large (approaching one). At the micro-regional level, distance is calculated as the average of all products in the local economy.

In turn, Opportunity Gain quantifies the marginal contribution of a new product to productive complexity (Hausmann et al., 2011). Freitas et al. (2023) adapted this to the regional context using employment and wage data, developing the Regional Opportunity Gain indicator. This measures the average increase in complexity that a sector brings to a region, identifying which sectors open up more avenues for future diversification. Regions with greater opportunity gains have greater potential for increasing complexity through well-connected activities that serve as a stepping stone to sophisticated sectors.

Together, Distance reveals the feasibility of diversification based on existing capabilities, while Opportunity Gain assesses the strategic value for long-term structural transformation. In the analysis section, both will be relevant in evaluating micro-regions whose participation in complex and/or progress-diffusing activities is still incipient or diffuse. Although these indicators characterize the structural position and diversification potential of regions, the identification of concrete productive trajectories requires an explicit measure of regional specialization, which is presented in the following subsection.

3.3 RCA calculation

Following standard practice, a revealed comparative advantage (RCA) greater than one identifies regional specialization. To avoid excluding economically relevant activities that may not achieve full specialization, a lower threshold of $RCA \geq 0.5$ is adopted to indicate persistent productive relevance. According to Piacenti, Alves & Lima (2008), location quotients provide a measure of the relative importance of a modality or category in a region, comparing its “weight” or share in other regions. A result between 0.5 and 1.0 implies an average location of specialized jobs.

$$RCA_{p,c} = \frac{\left(\frac{X_{pc}}{X_p}\right)}{\left(\frac{X_c}{X}\right)} \quad (3)$$

where $X_{p,c}$ refers to employment in sector p in region c ; X_c denotes total employment in region c ; X_p represents total employment in sector p across the set of regions; and X indicates total employment across all sectors in the set of regions. In the next section, we present and discuss the results. Building on this measure of regional specialization, the following subsection combines RCA dynamics with changes in economic complexity and employment in technical progress – diffusing activities to construct an employment-based typology of regional development paths.

3.4 An Employment-Based Typology of Regional Path Development

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To characterize the structural trajectories of regional specialization, we classified region-sector pairs according to their initial and final RCA and changes in economic complexity and employment in sectors classified as diffusers of technical progress, in the periods 2007-2014 and 2014-2021. Based on the evolutionary economic geography literature, our classification – on upgrading, extension, contraction, and stagnation trajectories – remains parsimonious and empirically grounded. Unlike typologies based exclusively on entry and exit, this framework guides toward qualitative structural change, considering specialization, complexity dynamics, and diffusion-oriented employment together.

We established two analytical thresholds: (i) a minimum RCA level of 0.5 to identify regions with some selected relevance; (ii) a structural change threshold of 10% or -10% for variations in ICE and DPT. The 10% threshold follows common practice in empirical EEG studies and aims to capture significant structural variations, avoiding hypersensitivity to short-term fluctuations (Østergaard et al., 2024). These criteria result in four mutually exclusive trajectories:

- **Path extension** describes the deepening of established specializations. A region-sector pair follows this trajectory when it maintains specialization in both defined periods ($RCA_t \geq 1$ and $RCA_{t+1} \geq 1$), while experiencing substantial growth in one of the indicators, defined as greater than 10%, either in economic complexity or in jobs that diffuse technical progress. This captures structural expansion within existing productive paths, suggesting gains in local learning, absorption, and technological diffusion.
- **Path upgrading** captures a region's entry into specialization in a given activity. A region-sector pair is classified as upgrading when it moves from a previous standard of specialization to specialization ($RCA_t < 1$ and $RCA_{t+1} \geq 1$) and also avoids significant structural degradation, defined as a decline in ICE of no more than 10%. This trajectory thus covers entry into specialization, even in the absence of immediate structural improvements. It occurs in cases of relative increases in employment that disseminate technical progress while maintaining complexity levels similar to those of the initial period.
- **Path contraction** characterizes a pre-existing specialization accompanied by a deterioration of structural capabilities. The classification requires relative concentration of economic activities in both periods ($RCA_t \geq 0.5$ and $RCA_{t+1} \geq 0.5$), but there is a pronounced decline in economic complexity in the second moment, exceeding 10%. This trajectory reflects the erosion of productive capabilities without the complete exit of the activity.
- **Path stagnation** refers to the persistence of specialization without significant structural transformation. A region-sector pair follows this trajectory when it remains economically relevant in both periods ($RCA_t \geq 0.5$ and $RCA_{t+1} \geq 0.5$), showing only limited variation in economic complexity, with changes in ICE contained within $\pm 10\%$. This category represents structural stability and serves as a baseline for assessing upgrading and contraction.
- Observations that do not fit the criteria established for the four categories constitute a group of micro-regions with **no identifiable trajectory (None)**. In these situations, they comprise spaces in which the activities and/or processes associated with diffusion and complexity remain marginal or do not show substantial structural changes during the observation period.



Table 1 - Criteria of regional structural trajectories

Trajectory	RCA condition	Structural conditional
Path extension	$RCA_t \geq 1$ and $RCA_{t+1} \geq 1$	$\Delta ICE \geq 10\%$ or $\Delta DPT \geq 10$
Path upgrading	$RCA_t < 1$ and $RCA_{t+1} \geq 1$	$\Delta ICE \geq -10\%$
Path contraction	$RCA_t \geq 0.5$ and $RCA_{t+1} \geq 0.5$	$\Delta ICE < -10\%$
Path stagnation	$RCA_t \geq 0.5$ and $RCA_{t+1} \geq 0.5$	$-10\% \leq \Delta ICE \leq 10\%$

Source: Own elaboration.

In the “None” cases, the opportunity gain and average distance indicators contribute to the discussion about the alternative paths for these regions in terms of gains in productive sophistication, which will be carried out below.

4. Results and Discussion

This section is organized as follows: first, it presents general descriptive statistics for the indicators, namely RCA, ICE, opportunity gain, and average distance. Subsequently, the analysis is based on the typology presented in the previous section and discusses the literature presented previously.

4.1 Regional specialization and economic complexity

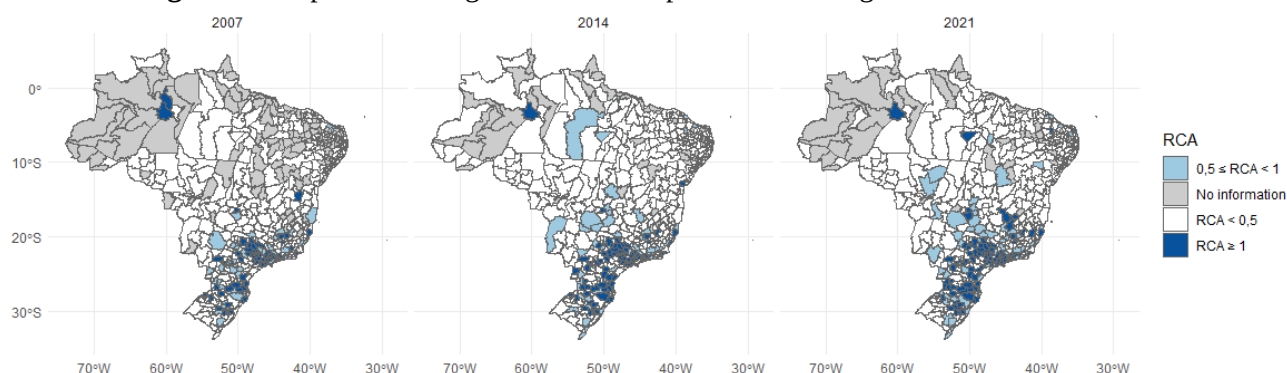
Figures 1 and 2 depict the spatial evolution of RCA in employment in sectors classified as *diffusers of technical progress* according to Pavitt’s taxonomy, alongside the ICE, for Brazilian microregions in 2007, 2014, and 2021. Together, these maps provide stylized evidence on the co-evolution of specialization and productive capabilities across space.

The RCA maps reveal a highly persistent pattern of regional specialization. In 2007, microregions with higher RCA are predominantly concentrated in the South and Southeast, reflecting the historical concentration of employment in technologically diffusive sectors. Between 2007 and 2014, changes in the spatial distribution of RCA are limited, indicating path dependence in employment-based specialization. By 2021, this pattern is preserved, with previously specialized microregions maintaining their comparative advantage and only a small number of new entries emerging in other regions of the country.

As discussed in previous sections, the concept of productive complexity is directly related to the sophistication of activities carried out in a territory. This means that regions with greater complexity not only host a greater number of productive activities, but also concentrate those that require more advanced technical skills, greater technological intensity, and greater insertion in complex production chains. Thus, the ICE-R is a measure that captures not only the quantity but, above all, the quality of local technological capabilities.



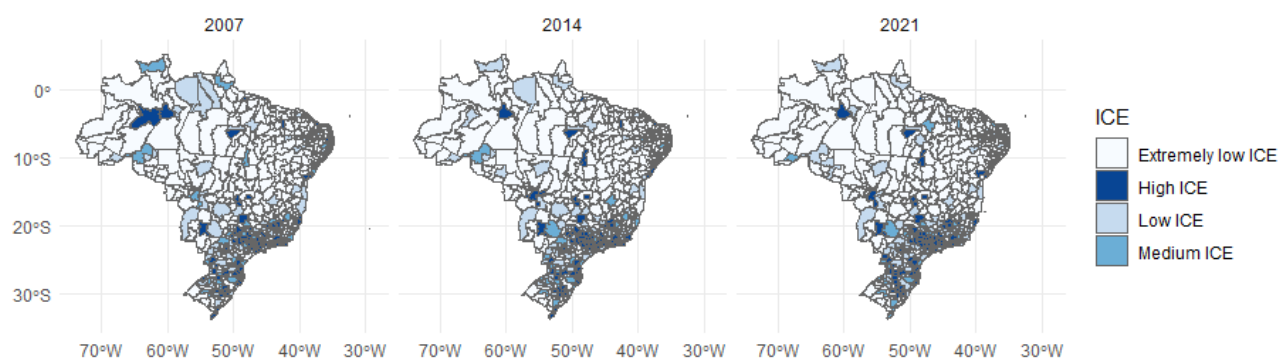
Figure 1 - Map of micro-regions with a comparative advantage in sectors with DPT Jobs



Source: Own elaboration, using Annual Social Information Report data to create the map in R. **Software:** RStudio

The ICE shows a persistent concentration of productive capabilities in a limited number of Brazilian micro-regions. In 2007, the highest ICE values were observed in São Paulo (3.97), Rio de Janeiro (3.60), Osasco (3.55), Macaé (3.39), and São José dos Campos (3.38). In 2014, the leading micro-regions were Osasco (3.73), São Paulo (3.69), Porto Alegre (3.44), Rio de Janeiro (3.28), and Curitiba (3.27), indicating continuity in the prominence of major metropolitan and industrial centers. By 2021, the ranking remained relatively stable, with São Paulo (3.79), Osasco (3.65), Rio de Janeiro (3.42), Porto Alegre (3.31), and Curitiba (3.26) presenting the highest levels of economic complexity.

Figure 2 - Map of micro-regions with economic complexity index (ICE)



Source: Own elaboration, using DataViva data to create the map in R. **Software:** RStudio

At the lower end, structural constraints also persisted over time. In 2007, the lowest ICE were recorded in Traipu (-2.10), Japurá (-2.07), Cotegipe (-1.91), Purus (-1.89), and Umbuzeiro (-1.87). In 2014, Japurá (-2.33),

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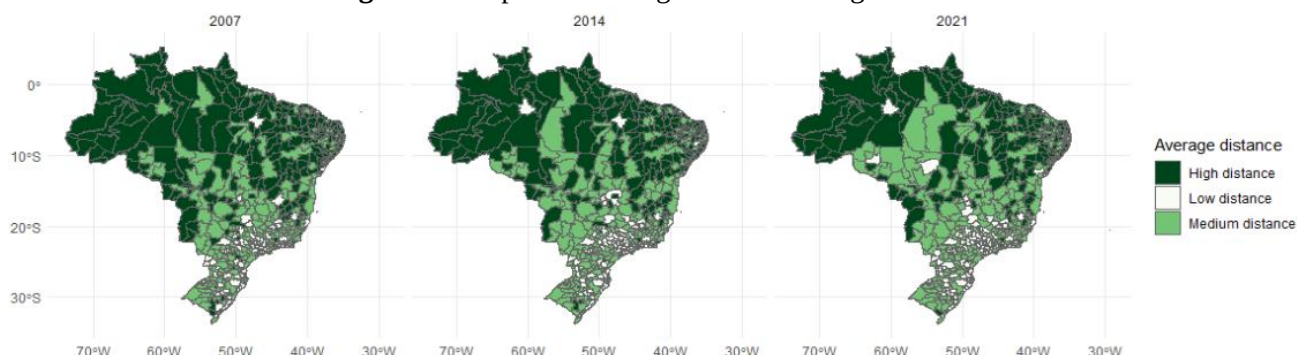
Traipu (-1.95), and Cotegipe (-1.88) remained among the least complex micro-regions. In 2021, the lowest indicators were found in Traipu (-2.37), Cotegipe (-1.95), Japurá (-2.17), Gurupi (-1.14), and Uruburetama (-0.69).

The ICE maps display greater spatial dispersion and temporal variability. Already in 2007, several microregions outside the traditional industrial core exhibit medium or high levels of economic complexity, suggesting the presence of diversified productive capabilities not yet reflected in revealed specialization. Between 2007 and 2014, variations in ICE are more widespread than variations in RCA, indicating that changes in complexity occur more frequently than changes in employment specialization. In 2021, while the South and Southeast continue to concentrate the highest ICE values, medium and high complexity clusters remain visible in other regions.

Lighter shades indicate greater potential for future gains in economic complexity. In 2007, micro-regions such as Dourados (0.23), Ourinhos (0.23), and Uberlândia (0.22) stood out for their high opportunity gains, combined with intermediate levels of distance, suggesting favorable conditions for diversification into more sophisticated activities.

In 2014, Entorno de Brasília (0.23), Ourinhos (0.23), and Caratinga (0.23) emerged as territories with the greatest potential for future gains in complexity, reflecting productive structures connected to activities capable of promoting structural transformations. In 2021, although some peripheral regions, such as Japurá (0.05), Traipu (0.04), and Litoral Ocidental Maranhense (0.05), showed positive opportunity gains, their very high distance levels indicate limited proximity to diversified productive networks, restricting their effective potential for upgrading.

Figure 3 - Map of micro-regions with average distance



Source: Own elaboration, using DataViva data to create the map in R. **Software:** RStudio

On the other hand, highly complex micro-regions, such as São Paulo, Osasco, and Porto Alegre, consistently showed negative or low opportunity gains between 2007 and 2021. This pattern suggests that, despite their current high complexity, these regions already concentrate the most sophisticated activities, reducing the marginal gains from diversification and indicating that further technological advances depend on more intensive investments in innovation and human capital.

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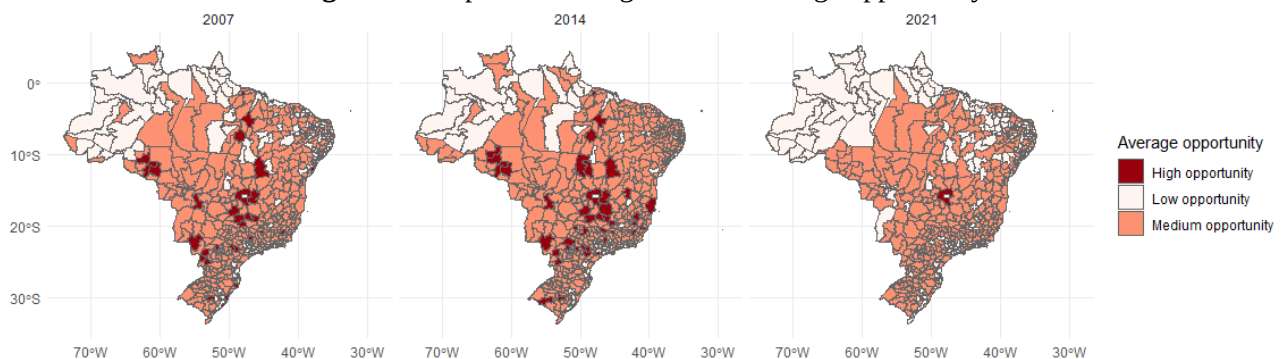


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A comparative reading of both indicators provides evidence that the accumulation of productive capabilities does not necessarily translate into immediate specialization outcomes, reinforcing the idea that economic complexity represents a latent dimension of regional development. The promotion of economic complexity requires not only sectoral diversification (Dias and Martinelli Jr., 2021), but also the articulation between technical skills (operational/intermediate) and innovation policies adapted to regional technological regimes (Fornari et al., 2014).

Figure 4 - Map of micro-regions with average opportunity



Source: Own elaboration, using DataViva data to create the map in R. **Software:** RStudio

Furthermore, as highlighted by Garcia et al. (2011) and Garcia (2017), the scarcity of technological occupations in peripheral micro-regions requires investments in technical and higher education, aligned with the needs of local technological regimes to promote interactive learning spillovers. Regional development policies should combine incentives for related diversification (Hausmann and Klinger, 2006) with the strengthening of intermediate technological capabilities (Lall, 1992), especially in micro-regions that offer high opportunity gains, as is the case with , while continuing to map the capabilities linked to sustainable development, a fundamental dimension for regional development.

4.2 Regional trajectories of specialization and economic complexity

This section presents the results and analysis based on the proposed typology that relates complexity and diffusion of technical progress. Figure 5 presents the spatial distribution of technological trajectories across Brazilian microregions between 2007 and 2014, a period marked by sustained economic growth.

In turn, Figure 6 organizes the trajectories for 2014-2021, a period in which Brazil faced a series of economic difficulties, with significant job and income losses and, specifically in 2020 and 2021, the Covid-19 pandemic – despite policies aimed at maintaining employment – had a significant impact on both the supply and demand sides.

The period between 2007 and 2014, marked by the international commodities boom and favorable demand conditions, sustained economic growth, contributed to expansion and upgrading trajectories, especially in regions with previously diversified productive structures. In contrast, the period from 2014 to 2021 was

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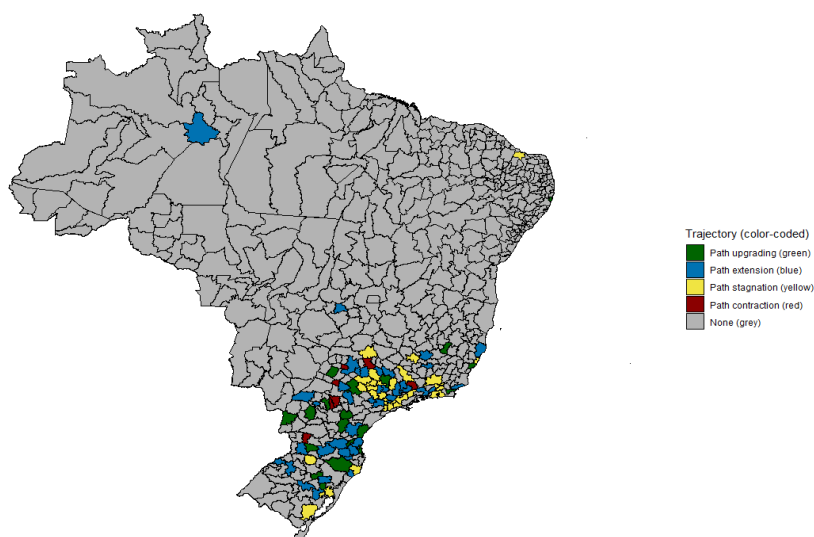
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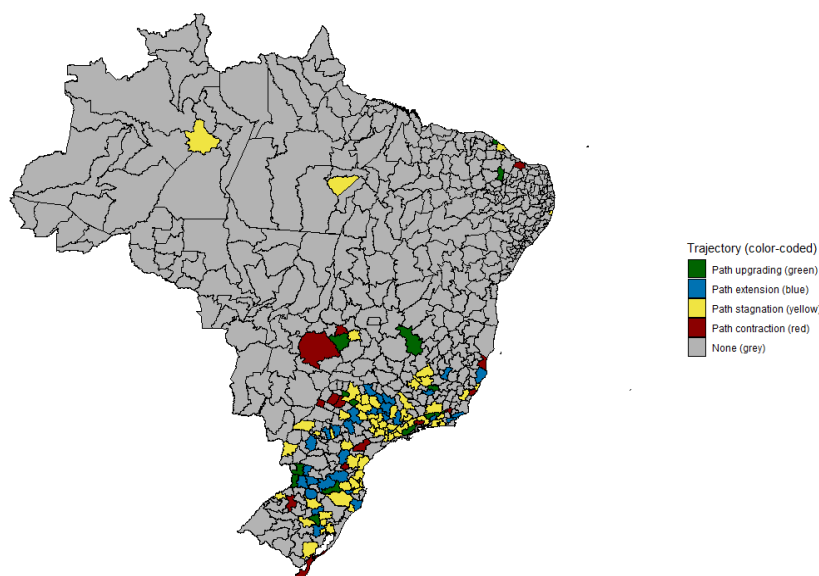
characterized by economic and fiscal crises, declining investment, and the additional shock of the COVID-19 pandemic, contexts that are associated with trajectories of stagnation and contraction.

Figure 5 - Map of regional trajectories of specialization and complexity (2007-2014)



Source: Own elaboration, using DataViva data to create the map in R. **Software:** RStudio

Figure 6 - Map of regional trajectories of specialization and complexity (2014-2021)



Source: Own elaboration, using DataViva data to create the map in R. **Software:** RStudio

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The observed patterns – in both cases – are consistent with the evolutionary economic geography literature, which emphasizes path dependence, cumulative causation, and the localized nature of capability accumulation (Boschma, 2017; Neffke, Henning & Boschma, 2011). Although regional capacities are cumulative and territorially embedded, their effective mobilization critically depends on macroeconomic stability and investment dynamics, which condition the translation of complexity and technological diffusion into structural transformation.

4.2.1 Path Upgrading

Upgrading trajectories are more prevalent in the 2007-2014 period, particularly in microregions such as Suape, Ipatinga, Araçatuba, Bauru, Londrina, Ponta Grossa, Paranaguá, Itajaí, and São Bento do Sul. In the 2014-2021 period, upgrading becomes more selective and spatially dispersed, with cases such as Pirapora, Ouro Preto, Três Rios, Barra do Piraí, Francisco Beltrão, São Miguel do Oeste, and Lajeado-Estrela, indicating that entry into new specializations under adverse macroeconomic conditions relied more strongly on localized capability recombination and pre-existing productive bases than on generalized structural expansion.

Upgrading trajectories reflect processes in which regions not only maintain their specialization in sectors that diffuse technical progress but also expand their productive base toward activities associated with higher levels of economic complexity. From the perspective of economic complexity, these regions tend to operate within dense productive networks, where the coexistence of diverse and less ubiquitous activities facilitates the recombination of capabilities and the emergence of new technological opportunities (Hausmann & Hidalgo, 2011). In evolutionary terms, upgrading trajectories illustrate successful processes of related diversification, in which regions leverage previously accumulated capabilities to enter more sophisticated sectors.

4.2.2 Path Extension

Between 2007 and 2014, path extension is prominent in microregions such as Manaus, Belo Horizonte, Pouso Alegre, Macaé, Sorocaba, Maringá, Curitiba, Joinville, Blumenau, Caxias do Sul, and Chapecó. In the 2014-2021 period, extension remains present in territories such as Conselheiro Lafaiete, Ipatinga, Linhares, São Carlos, Bauru, Londrina, Ponta Grossa, Chapecó, Xanxerê, Erechim, and São Jerônimo.

This pattern is closely aligned with the concept of path dependence, whereby regional diversification tends to occur within technological and sectoral domains already embedded in the local knowledge base (Boschma & Frenken, 2011). From the perspective of economic complexity, extension reflects the expansion of productive diversity without necessarily increasing the level of product sophistication, indicating that the accumulation of capabilities continues to operate but within cognitively proximate domains. At the same time, the presence of extension trajectories in regions outside the traditional industrial core, suggests that diffusion mechanisms may allow semi-peripheral territories to sustain productive diversification. This reinforces the literature on technological diffusion, which highlights the role of spillovers and cumulative learning processes in enabling incremental productivity gains even in regions with lower technological intensity (Figueiredo, 2004; Fornari et al., 2014).



4.2.3 Path Stagnation

Between 2007 and 2014, stagnation is observed in territories such as Rio de Janeiro, São Paulo, Campinas, São José dos Campos, Ribeirão Preto, Piracicaba, Porto Alegre, and Vitória. In the 2014–2021 period, it becomes even more extensive, encompassing microregions such as Belo Horizonte, Goiânia, Fortaleza, Manaus, Curitiba, Joinville, Caxias do Sul, Blumenau, and Itajaí. This outcome reflects mechanisms of technological and productive lock-in, in which the historical accumulation of capabilities becomes insufficient to sustain further structural change (Boschma, 2017).

From the complexity perspective, stagnation suggests that regional productive portfolios remain concentrated in activities with stable but not expanding capability requirements, limiting the recombination of knowledge and the emergence of new technological trajectories. Moreover, stagnation dynamics are consistent with interpretations of premature and sectorally heterogeneous deindustrialization observed in Brazil. The relative decline of strategic industrial sectors reduces the capability of manufacturing to generate spillovers and systemic innovation, thereby weakening the diffusion of technical progress across regional labor markets (Morceiro & Guilhoto, 2019; Diegues & Rossi, 2018).

4.2.4 PathContraction

Contraction trajectories are comparatively less frequent and tend to appear in intermediate and specialized microregions. Between 2007 and 2014, this pattern is observed in territories such as São Lourenço, São Joaquim da Barra, Cornélio Procópio, Assaí, and Pato Branco. In the 2014–2021 period, contraction becomes more spatially dispersed, including microregions such as Mossoró, Guarapari, Araçatuba, Birigui, Dracena, Capão Bonito, Ijuí, and Sudoeste de Goiás. These cases indicate localized declines in economic complexity despite continued specialization, suggesting processes of capability erosion and structural exhaustion. In terms of economic complexity, contraction suggests the loss of productive diversity or the displacement of activities that previously served as vectors of technological diffusion. Also, this pattern suggests the vulnerability of regions whose industrial base is concentrated in sectors exposed to international competition or technological substitution.

4.2.5 No Identified Trajectory (None)

Microregions classified as having no identifiable trajectory represent territories where the activities associated with the diffusion of technical progress and the accumulation of productive capabilities remain marginal or display limited structural change throughout the observation period. These cases reflect the structural constraints typically observed in peripheral and semi-peripheral regions, where low productive diversity and high distance from complex activities reduce the probability of successful diversification. According to the economic complexity framework, regions with limited capability portfolios face substantial barriers to entering more sophisticated sectors, as new capabilities tend to have low complementarity with existing ones (Hausmann et al., 2011).

However, the empirical evidence suggests that some of these regions exhibit latent potential for structural transformation, particularly those presenting higher opportunity gains despite elevated distance indicators. Microregions such as Uberlândia, Patos de Minas, Imperatriz, and Entorno de Brasília illustrate this intermediate

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condition, in which productive structures remain relatively constrained but maintain connections with activities capable of fostering future diversification. This reinforces the importance of targeted public policies aimed at strengthening regional innovation systems, workforce qualification, and institutional coordination, which are essential for enabling technological diffusion and overcoming regional development traps.

5. Conclusion

This paper analyzed the productive structure of Brazilian microregions by combining indicators of economic complexity, productive sophistication, and relative specialization in sectors that diffuse technical progress, using employment data from Annual Social Information Report and information from the Dataviva platform. The results reveal a uneven spatial distribution of productive capabilities across the national territory, reinforcing the persistence of historical regional asymmetries. Microregions located in the South and Southeast concentrate the highest levels of economic complexity and technological diversification, while large portions of the North and Northeast remain anchored in less sophisticated productive structures, typically associated with public services, commerce, and low technological intensity activities.

The typology of regional trajectories developed in this study provides additional evidence on the heterogeneous nature of structural change across Brazilian microregions. Upgrading trajectories are predominantly concentrated in territories with dense innovation ecosystems and diversified productive bases, confirming the role of accumulated capabilities and systemic innovation processes in enabling transitions toward more complex activities. Extension trajectories, widely observed in the historical industrial core, indicate processes of incremental diversification within cognitively proximate sectors, reflecting the persistence of path-dependent dynamics and related diversification strategies.

Stagnation trajectories highlight the structural reproduction of specialization patterns without significant increases in complexity, suggesting the presence of technological lock-in mechanisms and reinforcing evidence of sectorally heterogeneous and premature deindustrialization in Brazil. Contraction trajectories, although less frequent, signal localized erosion of productive capabilities, particularly in traditional industrial regions, indicating risks associated with technological obsolescence and the weakening of industrial spillovers. Finally, microregions classified as having no identifiable trajectory reveal territories where diffusion of technical progress remains limited, but where indicators of opportunity gain suggest latent potential for structural transformation, especially in semi-peripheral regions connected to emerging diversification opportunities.

The results corroborate the literature on economic complexity, evolutionary economic geography, and neo-Schumpeterian innovation systems by demonstrating that regional diversification is cumulative, territorially embedded, and strongly conditioned by existing productive capabilities and institutional arrangements. At the same time, the evidence reinforces the central role of industry and technological diffusion as engines of structural transformation and long-term development, particularly in late-industrializing economies characterized by uneven productive structures.

From a policy perspective, the findings suggest that regional development strategies must be calibrated to territorial specificities. Regions with consolidated productive capabilities require policies aimed at fostering technological upgrading and frontier - or radical - innovation, while semi-peripheral regions may benefit from policies that promote related diversification and strengthen regional innovation systems. In peripheral territories,

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the priority lies in expanding basic productive capabilities, workforce qualification, and institutional coordination to enable the diffusion of technical progress and reduce structural distance from complex activities.

Future research may advance this agenda by incorporating firm-level analyses and econometric approaches capable of capturing microeconomic agency, technological adoption strategies, and the role of global value chains in shaping regional diversification patterns. Additionally, further investigation into the interaction between technological diffusion, employment dynamics, and sectoral specialization may contribute to a more comprehensive understanding of structural transformation processes in developing economies.

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