Regional Economic Convergence in Federation Contexts: A Comparative Analysis of Brazil and the European Union

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Abstract

This article examines regional economic convergence in two federal contexts: Brazil and the European Union (EU). Despite many differences, in the last decades these two economies have shown irregular economic growth and have been facing economic inequalities, launching public policies to reduce them. We analyse the tendencies of regional convergence within these economies from 2002 to 2019, focusing on sigma convergence, absolute convergence, convergence clubs and the transitional behaviour of club members. Our results show that in both cases convergence occurs, but at a slow rhythm, especially in the EU.

Keywords: Regional inequalities; Convergence analysis; Brazil; European Union

JEL classification: R10, O47, C1

1. Introduction

Regional inequalities have always been a problem and a relevant concern in economic studies from multiple perspectives. Especially in the context of federation arrangements, this question became crucial to economic dynamics and the search for regional economic convergence. This article examines the regional convergence process in two federal contexts: Brazil, a federal republic formed by 27 units and the European Union (EU), a political, economic and monetary union formed by 27 countries. Despite their marked differences, these two economies with a "federation character" have demonstrated some points in common that make their comparison rather interesting.

Historically, the economic dynamics of these two economies have shown comparable trajectories, displaying upsides and downturns, and generally following world economic trends, with a few exceptions, as the Brazilian fluctuations are more pronounced. In the early 21st century, both economies have had irregular trajectories of economic growth, alternating between periods of expansion and crisis and confirming their integration with world economic dynamics, with some differences in recent years. Moreover—and this will be the main theme of this article—these two economies have been facing significant regional inequalities within their territories and have been formulating public policies focused on reducing these inequalities. Thus, this analysis may contribute to the discussion of the tendencies of inequalities and to the evaluation of the policies implemented to deal with them.

Brazil is a country with significant wealth gaps and a demographic structure comparable to that of the EU in recent decades. Even from an administrative point of view Brazil is a federal republic with 27 units (26 states and one federal district, which are all called "states" in this article). Made up of 27 countries, the EU is an international political and economic organization of a supranational nature, but has many characteristics of a federation. These two entities govern territories targeting income equality or similarity in areas within their competence, which means aiming for some kind of convergence in income. These two apparently different situations have similarities in economic growth trends and in the policies applied by governments and regulators to reduce inequalities. In this context, the analysis of economic convergence can contribute to increasing the accuracy of the measures adopted by central and regional government bodies and the understanding of their trajectories.

Convergence analyses in federation contexts can be found in some studies, as shown in the literature review section. These studies usually focus on individual cases or search for general tendencies. The comparison of results in different contexts is less common and when it is

considered in these studies, its focus is on individual and separate processes. Differently, in this article we analyse the Brazilian and EU convergence processes in the same model and with the same parameters, increasing the originality of the study.

Considering this background, this article examines the tendencies of regional convergence in these economies, focusing on data at the state level in Brazil and at the country level in the EU in the same period (2002–2019). Using the economic convergence methodology, we investigate four elements in both economies: sigma-convergence (σ-convergence), absolute convergence, the possibility of convergence clubs and the transitional behaviour of club members. These cover different aspects of regional convergence (see, for example, Young et al., 2008). The majority of studies have stressed the importance of beta-convergence (β-convergence), as it is a sign of economies following similar paths over time. However, limiting the analysis to β-convergence alone might miss the point of economic inequality, as β-convergence does not necessarily imply σ-convergence and vice versa. Therefore, it is very useful to convey them in a single study, together with convergence club analysis, which allows for useful clustering of the regions in terms of the economic convergence rate.

The results for the two economies are analysed and compared using the same framework and parameters. The contraposition of two different economies favours revealing some aspects that individual studies do not cover. In this analysis, we identify differences and similarities regarding the level of territorial inequalities and their evolution during the period, focusing on the possibilities and characteristics of a convergence tendency.

This article is structured as follows. Section 2 explores the background of regional economic inequalities and the convergence literature in Brazil and the EU. Section 3 shows the methodology applied to the quantitative analysis and a short descriptive analysis on the collected data. The main results are presented and discussed in Section 4, while Section 5 summarizes the main findings and conclusions.

2. Background and literature review on convergence in Brazil and the EU

Convergence analysis in federation contexts has been widely discussed in the literature, mainly focusing on OECD countries, as in Van Rompuy (2021). However, considering two different federation contexts in the same study is not usual. For instance, Kessler et al. (2011), after proposing a model rooted in neoclassical assumptions, examined empirical evidence of 17

highly developed OECD countries from 1982 to 1999, and discussed the results within Canadian provinces.

However, in the case of the EU and other federation contexts, studies are scarce. We find Dow and Rodríguez-Fuentes (2020) an interesting analysis of EU countries and Spanish regions, focusing on the role of the financial sector in convergence or divergence tendencies. Furthermore, a research cooperation project on the EU and Brazil—the EU–Brazil Sector Dialogues —compares individual Brazilian countries and EU countries (Cravo et al., 2017). However, these studies usually analysed the two economies separately.

Differently, in this article we analyse these two contexts altogether, comparing the results obtained in the same model and with the same parameters. However, following the literature on convergence analysis and to better present results later on, we first discuss the studies focusing on Brazilian federation and EU contexts separately.

2.1 Regional inequalities, policies and development funds in Brazil

The level of Brazilian regional inequalities has changed over time. The economic literature usually identifies a turning point in 1970, when the historically high level of these inequalities began to decline, diminishing the gap between the richer macro-regions in the Southeast and the South on one hand and the poorer Northeast, North and Center-West on the other. However, the economic evolution, starting from 2000, shows a slowdown in this tendency in terms of regional GDP distribution and regional differences in the GDP per capita level (Diniz, 2019; Martins, 2019; Silva et al., 2016; Cardozo and Martins, 2020; Díaz-Dapena et al., 2017).

The Brazilian economy has traditionally oscillated through phases of economic growth and crisis, as well as years of rises and falls in the overall amounts of investments (Martins, 2019; Paludetto and Zanchetta Borghi, 2020; Tupy et al., 2021). Since 2003 some initiatives on regional policies have been established aiming to reduce regional inequalities. There has been a partial recovery of state activity and the launch of a new regional policy project, the National Policy of Regional Development (PNDR), inspired by EU regional policy (Cardozo and Martins, 2020). Starting in 2003 the use of constitutional funds, established in 1988 to stimulate economic activities in poorer macro-regions (i.e., in the North, Northeast and Center-West) has significantly increased. While the annual average of used resources was estimated at 3.6 billion (reais of 2010, fixed prices) in the period 1995–2002, this account almost quadrupled in the period 2003–2012, reaching 12.7 billion reais per year (Macedo et al., 2017).

According to the quantitative analyses by Silveira-Neto and Azzoni (2011) and Resende (2014) (which focused on macro level until 2006), the benefits in terms of growth as a result of using these funds were limited. More recently, Resende et al. (2018) roughly confirmed these tendencies, emphasizing that their magnitude depends on the level/scale considered. Following a more historical and institutional approach, Macedo et al. (2017), as well as Cardozo and Martins (2020), also identified limitations in the impact of using these funds in a more recent period. On the other hand, these authors have confirmed that for a more recent period, the non-territorialized policies kept playing a relevant role, as identified by Silveira-Neto and Azzoni (2011) in the early 2000's.

Studies based on convergence analysis in Brazil began in the 1990s. The initial emphasis on absolute β-convergence gradually included conditional β-convergence, as highlighted by Ferreira (2000) and Azzoni (2001). Over time, the analyses incorporated cluster and convergence *clubs*. For instance, Silveira-Neto and Azzoni (2006), while examining data from 1985–2000 at the Brazilian states' level, identified a process of regional convergence characterized by a low coefficient and a "very sensible dynamic pattern". Considering the spatial association, the authors established two geographical clusters, echoing the historical regional divide in Brazil: the first was formed by low-income states situated in Northern and North-eastern areas, and the second by rich states in the South and Southeast. Resende (2014) analysed economic growth at the state level (and at three other more disaggregated levels) between 1991 and 2001 and recognized a process of conditional regional convergence in all space levels, although its characteristics vary across the levels, as well as the effects of public policies and infrastructures. The results indicate two different processes of convergence for two different clusters, one for rich states and another for poor states: the dispersion of income per capita decreased in the rich cluster during the period, but increased in the poor cluster (Resende, 2013). Therefore, the literature that focused on this period indicated that the speed of convergence has declined, displaying a pattern near "slow convergence" established in international and theoretical literature (Martin and Sunley, 1998).

Silveira-Neto and Azzoni (2011) identified a process of β-convergence among Brazilian states between 1995 and 2006, with a reduction of regional inequalities both in terms of GDP per capita and income. The authors added an analysis of the effects of non-spatial government policies, mainly examining the role of the minimum wage increase and the impact of the *Bolsa-família* (family grant), a programme based on cash transfer to poor households.

The results confirmed these policies as one of the drivers in this process marked by a decrease in regional inequalities, in addition to the dynamics of economic growth. Using more recent data and a multilevel approach, Díaz-Dapena et al. (2017) confirmed the presence of regional convergence at the national level between 1991 and 2010 but point out that different tendencies can be observed within the states: some of them, especially the most industrialized states situated in the Southeast, have shown internal divergent trajectories.

Although these results and conclusions unveil a non-widespread view among researchers, some tendencies may be identified based on these studies. To sum up, we can detect the following time intervals regarding the predominance of convergence tendency: 1950–1970 (oscillating), 1970–1985 (fast convergence), and 1986–1995 (slow convergence). These tendencies are compatible with other views in other contexts to evaluate regional inequalities and their indicators based on the evolution of GDP share and on the GDP per capita. However, from 1995 to 2006 there are significant differences between the results of the various studies of regional convergence, as some identify convergence while others identify divergence trends.

2.2 Regional inequalities, policies and development funds in the EU

Since the 1970s, programmes for the transfer of funds to European countries aiming at economic development have been put in place. However, there has never been clear evidence of homogeneous development of the GDP per capita as an effect of this funding strategy (Charron, 2016). Since 2002 the EU budget has increased significantly, supported by an increasingly important role of the European Central Bank since 2013. Funds devoted to regional policy (also called "cohesion policy") made up around 36% of the EU budget in the period 2007–2013, targeting the most disadvantaged European regions (Pellegrini et al., 2012). In recent years an average of about 30% of the European budget has been spent to stimulate convergence between member countries via five European structural investment funds (Von Lyncker and Thoennessen, 2017; Dall'Erba and Fang, 2017).

In this context, structural funds play a relevant role in economic dynamics, especially in the expected process of convergence across countries and regions. Evidently, even with a subnational focus, these funds affect economic convergence at the country level, as the poorest regions are predominantly in the poorest countries. Therefore, the effects of EU regional policy constitute a key question that has been examined in several studies, under a wide range of aspects and contexts (Fratesi and Wishlade, 2017).

Varblane and Vahter (2005) examined the convergence in the EU focusing on the "transitions countries", i.e. those countries that joined the EU in 2004. The authors found that unconditional or absolute β-convergence marked these countries in the period 1995–2003, when they were preparing to access the EU. More recently, several studies in the 2010s investigated club convergence in the EU at the country level, generally based on data from the last decades of the 20th century. The results of some selected studies vary concerning the number of country clubs (from 1 to 4 clubs) and the geographical pattern (West versus East; Northwest versus Southeast; core versus periphery), as shown by Von Lyncker and Thoennessen (2017).

Gräbner et al. (2020a, 2020b) argue that the initial movement towards macroeconomic convergence shown by EU countries after the adoption of the euro turned to divergent trajectories after the crisis of 2008. Largely influenced by Latin American structuralism, the authors incorporated the core–periphery approach, identifying different trajectories of countries according to their classification into four groups: core, periphery, financial hubs and catching up (Eastern Europe). The conclusion is that from 2008 onwards European integration has shaped a polarization movement through diverse "path-dependent developmental trajectories", which results in non-convergence in terms of structural change and technological capabilities (Gräbner et al., 2020a). The impact of the 2008 financial crisis is also emphasized by Botta and Tippett (2021), who identified the decline of economic growth (secular stagnation) from 2008 in Europe. However, this decline occurs largely heterogeneously between core and peripheral countries due to the technology capability gap between the core and the periphery (Alsayed et al., 2020). Moreover, demand-side factors are crucial: investment demand is positively associated with development, while fiscal cuts in the public budget (austerity measures) are negatively associated with it (Botta and Tippett, 2021).

Following the perspective of the core–periphery approach applied in the context of the EU, Simonazzi (2020) adopts a more institutional emphasis. According to the author, the current context brings new challenges to the economy that unequally affect the core countries (Central Europe) and the peripheral countries (Southern and Eastern Europe). These tendencies reinforced the unequal impact of the crisis from the 1970s and the changes in the 1980s (neoliberalization). In this view European integration has produced a divergent process that leads to different economic bases: a strong and export-oriented industrial base in the core and a less diversified industrial base in the periphery. Then the author claims for radical changes in the institutional and productive structure of the EU.

The analysis by Barbant and de Souza (2019) focused on five countries classified as "periphery" (Greece, Italy, Ireland, Portugal and Spain) and explored the difficulties faced by these countries in recovering their economies after the 2008 crisis, especially in the context of economic austerity in the EU. In this framework the only stimulus has come from external sectors, with the euro devaluation. The "institutional effects" of the EU fund allocation, expenditure and absorption lead to greater control mechanisms for those regions or countries (in the Mediterranean and Eastern Europe) that do not have the same parameters of economy of absorption as the best performing countries (in the North). This is so much so that in the post-2008 crisis the EU's financial power on national budgets and decisions at the local level has undoubtedly increased, especially in Mediterranean countries and Ireland.

Within a subnational regional focus, several studies have examined the convergence of European regions at the NUTS 2 and 3 levels. For instance, analysing a sample of 208 European regions during the period 1977–2002, Bosker (2007) obtained results generally confirming the trajectory of regional convergence in all estimations. However, the rate of convergence varied depending on the type of agglomeration (within a region or between regions) and its effects on economic growth.

Del Bo et al. (2010) analysed both absolute and conditional convergence in 264 European regions (NUTS 2) during the period 1995–2006. They detected a regional absolute convergence during the period. The newer member states (i.e. those entering the EU from 2004 onwards) showed a lower speed than the EU-15 states (the so-called Eurozone member states, i.e. those who adopted the euro as their currency), but the results were not statistically significant. Moving to conditional convergence analysis, the authors confirmed the convergence in the period and highlighted the relevance of infrastructure (communications and transports) concerning economic growth and the "convergence behaviour of EU regions". Charron (2016) stresses that the distribution of funds is not only determined by the relative level of economic activity (for example, 75% of the Union's average at NUTS 2 for Objective 1). According to the author, the distribution is based on "an interaction between a region's formal institutions (the level of regional autonomy) and informal institutions (its level of quality of government)". Likewise, Fratesi and Wishlade (2017) argue that "while the eligibility criteria are explicit (…) eligible regions qualify for very different levels of funding. This results from a combination of the funding formulae and the Council negotiations, so that even within Objective 1, the aid intensity can vary significantly". As indicated by Moreno (2020), the

absorption of these funds was low in the considered period (2007–2013). Furthermore, the absorption was highly heterogeneous across the EU and even within the countries.

As Fratesi and Wishlade (2017) highlight, studies at the subnational level are increasingly moving from a global evaluation of the "total effects" of the funds to assessing the "conditional factors" of its effectiveness. This movement can be associated with the high heterogeneity of these studies and analyses (Dall'Erba and Fang, 2017). For instance, the positive effects of the funds on the economic growth of laggard regions are related to "the successful performance of rural areas close to the main urban agglomerates", in accordance with Gagliardi and Percoco's (2017) analysis at the NUTS 3 level. Likewise, these effects depend on the economic structure and size of the service sector (Percoco, 2017). Based on club convergence analysis, Von Lyncker and Thoennessen (2017) examined 194 NUTS 2 regions and established four convergence clubs, identifying geographical clusters and arguing that in the period 1980–2011 there has been a "multi-speed Europe".

The regional dynamics of economic growth are associated with credit availability. Dow and Rodríguez-Fuentes (2020) stress the role of credit in regional divergence at the subnational (Spanish regions) and international (Eurozone) levels. The authors examined the availability of credit during the business cycle in recent periods (1988–2016 for Spain and 1998–2017 for the EU). Their results showed that credit is more volatile in poorer regions/countries, assuming a procyclical behaviour: rising in the upturn, declining in recessions, and in both phases varying more intensely than in richer regions/countries. This led the authors to conclude that credit availability tends to reinforce divergent tendencies in periods of recessions, contributing to explaining the absence of real economic convergence (Dow and Rodríguez-Fuentes, 2020).

3. Materials and methods

In this article, we use economic convergence methodology to investigate four elements within Brazil and the EU: σ-convergence, absolute convergence, the possibility of convergence clubs and the transitional behaviour of club members.

σ-convergence was introduced by Barro and Sala-i-Martin (1990). In a few words, it gives a cross-sectional reduction in the variation of the GDP per capita over time (Barro and Sala-i-Martin, 2004). There are several methods to measure this σ-convergence, and we will apply the sample standard deviation, coefficient of variation and trend regression. We monitor the following value over time:

$$\sigma_t = \left[\frac{1}{n}\sum_{i=1}^{n}(y_{it} - \bar{y}_{.t})\right]^{1/2}$$

where y_{it} denotes the GDP per capita of country i at time t, $\bar{y}_{.t}$ is the mean regional or country GDP per capita at time t, and n is the number of regions or countries. If σ_t decreases, we a have σ-convergence.

β-convergence for cross-sectional data was formalized by Barro and Sala-i-Martin (2004). It regresses the annual mean growth rate of GDP per capita against the natural logarithm of the initial level of GDP per capita. Therefore, the following statistical model is suggested to measure the absolute β-convergence in a cross-section of economies for a country i:

$$log\left(\frac{y_{it}}{y_{i0}}\right) = \alpha + \beta log(y_{i0}) + \epsilon_i$$

where y_{it} is the per capita GDP at final time t, y_{i0} is the initial level of per capita GDP, (y_{it}/y_{i0}) is the growth rate, and ϵ_i is the error term, which is normally distributed with constant variance. A negative β coefficient signals the existence of convergence, and the magnitude of the β coefficient expresses the speed of convergence. Thus, the higher the absolute value of the β coefficient, the higher the speed of convergence.

β-convergence occurs if the estimated β coefficient has a negative influence on the initial level of per-capita income in a regression on growth and is statistically significant. If there exists β-convergence, it is possible to calculate the speed of convergence λ, and the corresponding "half-life" time in terms of years necessary to reach the steady state. The half-life is the time needed to reduce disparities by half (Barro and Sala-i-Martin, 2004). We can consider a standard Cobb–Douglas production function to calculate the speed of annual convergence λ, and the corresponding half-life τ:

$$\lambda = \frac{log(\beta + 1)}{t}$$

$$\tau = -\frac{log2}{log(\beta+1)}$$

where λ is the speed of convergence which measures how fast economies will converge towards the steady state, and t is the length of the period over which the growth rate is computed.

In addition, some other researchers suggested testing whether convergence occurs within groups of similar economies, a phenomenon widely referred to as "convergence clubs". There

are many proposals for detecting convergence clubs in the literature, starting from Baunol's (1986) pioneering work on the behaviour of output growth across aggregate economies. Durlauf and Johnson (1995) explored further ways to analyse cross-country growth rates via different linear models applied to economies grouped according to their initial conditions. Postiglione et al. (2013) used constrained optimization methods to detect clubs, and Royuela and Garcia (2015) considered social aspects that play a role in determining convergence clubs in the case of regional areas in Colombia. In our analysis we detected the club convergence using the method by Phillips and Sul (2007), who proposed a novel method log-*t* regression approach that allows for capturing transition dynamics and heterogeneity across regions (Gulati, 2022).

This empirical study focuses on data from the 27 EU countries and 27 Brazilian states. Data sources for our analysis were the World Bank national accounts data, the OECD national accounts data files, the Brazilian Institute of Geography and Statistics (IBGE) national account data and the Eurostat database. The considered period is the same: 2002–2019, starting in the first year of a new Brazilian series (with new methodology) and covering almost the entire period since the adoption of the euro as currency by the EU.

For the EU the variable of interest is the GDP per capita at US dollar constant prices, base year 2015, measured at the country level. For Brazil the variable of interest is the GDP per capita at a US dollar constant price, base year 2015, measured at the state level. They both average yearly rates considered growth rates. We use per capita values to focus on cross-unit income convergence by USD.

Tables 1A and 2A in the appendix show the average annual per capita GDP growth rate for EU countries and Brazilian states, respectively, in the period 2002–2019.

The Brazilian federal district, which hosts the capital of the country, has the highest GDP per capita increase, followed by the state of São Paulo and other states in the Southeast and the South, while the lowest per capita increases are shown by states in the North and Northeast. The growth of GDP per capita in Center-West states during the period has strengthened towards a position closer to that of the richer states, as the GDP per capita of some states even overtook the national average. This data allows the questioning of the maintenance of these funds for Center-West states, as the funds were created in a different historical context, when the per-capita GDP was lower, and the objective was to reduce inequalities. The distribution of the

GDP per capita growth for EU countries shows the highest value for Luxembourg, while the lowest growth appears that of Croatia. In the next section we present the results of our analysis.

4 Results and discussion

4.1 Checking for Brazil–EU per capita GDP dynamic similarity

In this section we present results on an exploratory analysis on the amount of similarity between Brazil and EU per-capita GDP, in order to evaluate their possible common behaviour through the years. For this task we use some visual tools from the dynamic time warping technique (DTW). DTW (Sakoe and Chiba, 1978) is a technique for finding optimal matching between the time points of two or more time series, meaning that two time series might not be seen as similar only because they have shifted each other over time. For example, if seen over time, the sine and cosine functions are shifted by $\frac{\pi}{2}$, but apart from this they have the same shape and spread over the *y* axis.

Figure 1 displays two DTW comparisons of Brazil's and the EU's GDP from 2002 to 2019. Comparisons are made for the average yearly regional/country per capita GDP and for the yearly regional/country per capita GDP variation in percentages.

<Place Figure 1 here>

The grey dashed oblique segments join the matchable points of the two series which, according to the DTW method, make the time series comparable. It can be seen that the per capita Brazilian GDP time series trend follows the EU one with a similar behaviour until 2013-2014; afterwards the EU time series increases and the Brazilian one tends to stabilize. In Figure 1b the total GDP yearly variation of the EU and Brazil are compared. Here the time series similarity is even more striking than in the case of per capita GDP. In the first two-thirds of the time series, not only is the trend very similar but also the two time series are almost coincident. After 2013–2014, the time series diverge a little, but they are still very close. All of this suggests that, overall, the two per capita GDP time series are comparable, at least in two-thirds of the considered period. Per capita GDP levels are, of course, different, but it is not the GDP levels that matter in our analysis; rather, it is the behaviour of GDP dynamics.

This analysis can be situated in the dynamics of GDP growth in the EU and Brazil. According to data from the World Bank, in this period the trajectories of economic growth in these two economies are similar and related to the world economy dynamics. In general, the crisis and recoveries have displayed a similar trajectory, although Brazilian economic growth has

oscillated more during the period: in Brazil the GDP per capita growth rates were higher than in the EU until 2013, but have been lower from 2014, marked by an economic crisis. Actually, from 2014 to 2019 the two economies have followed distinct trajectories, amplifying their difference from the world economy average: the EU attaining higher levels of GDP per capita and Brazil attaining lower levels of GDP per capita. However, the impacts of shocks and the speed of recovery are spatially differentiated (Tupy et al., 2021).

4.2 σ-convergence analysis

In this section, we present the results of an empirical investigation of the σ-convergence process of the GDP growth rates in Brazilian states and European countries. Figures 2 and 3 present boxplots of the per capita GDP dispersion for Brazilian states and EU countries. While the level of per capita GDP of both economies has slightly increased in the period, we notice that the coefficient of variation of the per capita GDP has decreased in both economies. The dispersion measures (coefficient of variation and standard deviation) are higher in EU countries, but the difference, which increased until 2013, has declined from 2014, as Brazilian coefficients of dispersion have been becoming more stable. This suggests that the downturn in Brazilian economic growth was accompanied by difficulties in reducing regional inequalities.

Table 1 provides more results from the σ-convergence analysis for Brazilian states and European countries by determining whether the cross-sectional dispersion of per capita income diminishes over time. The dispersion rate for Brazilian states is significant but very small (-0.0095). In addition, the dispersion rate for European countries is significant with a value of -0.0088, so the variation of GDP per capita for Brazilian states and EU countries decreased over time. Moreover, we can see from Figure 4 the existence of σ-convergence by evaluating the standard deviation of the time point values. Figure 5 supports the existence of σ-convergence by using the coefficient of variation and the variation rate, meaning that, during the growth process, the income levels of states/countries become more equal and the variation between their GDP levels per capita decreases. Thus, our findings on σ-convergence indicate that interregional inequality has been slowly decreasing in both Brazilian states and EU countries in a similar way.

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<Place Figure 2 here>

<Place Figure 3 here>

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4.3 Absolute convergence analysis

In this section, we present the results of an empirical investigation of the absolute convergence process of GDP growth rates in Brazilian states. Afterwards, these results are compared with the convergence of EU countries on data aggregated for the period 2002–2019. The results, as shown in Table 2, provide evidence of the existence of economic convergence among both Brazilian states and EU countries. The estimated β coefficient on the initial level of income is negative and statistically significant in all specifications.

<Place Table 2 here>

The β coefficients are negative in both models of Brazilian states and EU countries (-0.066 and -0.014, respectively). As the β coefficients are negative, on average the GDP per capita in poor states/countries grew faster than in rich states/countries in both Brazil and the EU. However, the convergence speed values for Brazil and the EU are 0.4% and 0.09%, respectively, which is very low in both cases. Although close to each other, the convergence seems to be slower in EU countries than in Brazilian states, with an average half-life value of 10 years for Brazil and 49 years for the EU to reach the steady state. In other words, the time necessary for the economies to fill half of the difference from their steady states is about 10 years for Brazil and 49 years for EU countries.

This low speed of convergence for Brazil is congruent with the long-lasting history of regional disparities in the country. Likewise, these results are in line with conclusions obtained in previous literature, which have indicated the occurrence of sigma and absolute β-convergence in the 20th century, especially in the last three decades. However, studies that incorporate the first years of the 21st century are likely to indicate a deceleration of this trend (see, among others, Azzoni, 2001; Silveira-Neto and Azzoni, 2006, 2011; Resende, 2011; Resende et al., 2016).

Results for the EU regarding absolute β-convergence are also in line with previous studies conducted at the country level (such as Młynarzewska-Borowiec, 2018; Nagy and Siljak, 2022), which identified the occurrence of both sigma and absolute β-convergence in the EU, although they are less intrusive than the 2008 crisis. Specifically for the euro area, some studies

obtained different results, stating that the tendencies of both σ and absolute β-convergence have been unstable during the time, even turning to divergence from 2008, particularly within the group of the first adopters of the euro (EA-11) (see Díaz del Hoyo, 2017; Franks et al., 2018; Coutinho and Turrini, 2020).

4.4 Club convergence analysis

Club convergence theory allows for a divergence among the majority of countries or states, but for a convergence of subgroups of countries/states to multiple levels of equilibria, such as developed and developing countries, or low- and high-income growth, etc. Therefore, our adopted methodology allows us to investigate the possibility of a club convergence pattern among the countries under scrutiny. The clustering club algorithm or log-*t* test is used for this purpose, which was developed by Phillips and Sul (2007) to detect both convergence clubs and diverging regions.

The log-*t* test is applied to test the overall convergence. The results are shown in Table 3, which reports the estimated values, together with the corresponding *t*-statistics and their significance. The estimated βs are -0.638 and -0.702 for EU countries and Brazilian states, respectively, while the *t*-test suggests that the null hypothesis of overall convergence is rejected at the 1% significance level, meaning that EU countries and Brazilian states do not converge as a unique group but in subgroups or clubs, clearly according to their economic growth level.

<Place Table 3 here>

According to the log-*t* test results, we further the analysis by exploring club clustering. Clubs' convergence and convergence speed for each club of both groups are shown in Table 4. A positive estimate of β reveals the divergence process. The convergence club analysis shows that Brazilian states can be classified into three clubs with one divergent unit, as shown in Table 5. While the divergent unit is the federal district that hosts the capital of the country, the three convergent clubs consist of 7, 16 and 3 states. These three clubs confirmed the historical regional divide in Brazil between rich states in the South and Southeast (mainly in club 1) and poorer states in the North and Northeast (all in clubs 2 and 3), while two "formerly poor" states in the Center-West region are now converging in club 1.

These results are close to those obtained by several authors who focused on previous periods, as they predominantly indicate the occurrence of unconditional convergence among Brazilian

states with the establishment of two or more groups/clusters (Silveira-Neto and Azzoni, 2006, 2011; Díaz-Dapena et al. 2017).

On the other hand, among EU countries, five clubs are identified with fairly different convergence speeds, while there are no divergent countries. The five clubs have 4, 4, 3, 5 and 11 countries. The clubs might represent the very low income (club 5), low income (club 4), lower-middle income (club 3), higher-middle income (club 2) and high-income (club 1) countries.

<Place Table 4 here>

<Place Table 5 here>

Furthermore, convergence speeds clearly vary across the clubs, as the club converges faster, as indicated by the higher estimate of β. In terms of Brazilian states' clubs, the βs of clubs 1, 2 and 3 are neither negative nor greater than 2, which indicates that the states in these clubs neither diverge nor converge to the same level but converge conditionally and diverge with respect to their income levels, whereas the interpretation of convergence speed for those clubs does not apply since their βs are not statistically significant.

In terms of EU clubs, the βs of club 1, 2, 3 and 5 are negative but their t-statistics are not statistically significant, suggesting a weak convergence. For club 4, the βs are positive, indicating that countries in these clubs neither diverge nor converge. Moreover, club 1 of high-income countries seems to converge at a rate of 2.2%, and there is also slow convergence among the middle-income countries at a rate of 8.0%.

These results are in line with Monfort et al. (2013), who investigated productivity at the country level (using GDP per worker from 1980 to 2009) and identified four convergence clubs. Our results on EU conditional convergence are also in line with other recent studies, such as Młynarzewska-Borowiec (2018) and Nagy and Siljak (2022), which have identified conditional convergence in the EU.

The results for the countries are also compatible with studies with a subnational focus. For instance, Ertur et al. (2006) detected spatial convergence clubs in the estimation of growth among 138 European regions over the period 1980–1995, while Del Bo et al (2010) found signs of conditional β-convergence for the period 1995–2006. More recently, analysing the period 1980–2011, the study by Von Lyncker and Thoennessen (2017) indicated the presence of four convergence clubs in EU-15 countries.

The simultaneous decrease in absolute convergence with the occurrence of club convergence may be linked to institutional factors and macroeconomic aspects that separate core and peripheric economies, as discussed in recent studies (Gräbner et al., 2020a, 2020b; Simonazzi, 2020; Dow and Rodríguez-Fuentes, 2020; Barbant and Souza, 2019). Hence, considering together the slowdown in absolute convergence and the identification of convergence clubs in both Brazil and the EU, the results suggest a tendency towards establishing a core–periphery pattern within the two economies.

4.5 Transitional behaviour of club members

The relative transition paths for the countries in each club were obtained to examine the pattern of economic growth of a country relative to the panel average. According to theory, under the assumption of convergence for the full panel of countries, the relative transition path tends to be unique for all countries, while in the assumption of club convergence the relative transition paths of the members of each club converge to different constants. Figures 6 and 7 illustrate the relative transition paths for the different clubs, calculated as the cross-sectional average of the relative transition paths of the countries/states of each club. We can note clearly that the relative transition paths do not tend to unity since we do not have convergence for both the panels.

For the Brazilian case the plots support the existence of convergence of clubs 1, 2 and 3. It is also evident that states of each club converge to the same steady state, but the convergence between the states of clubs 1 and 3 seems to be faster than the convergence of club 2. Also, since the convergence has been taking place since the beginning of year 2002, the curves have narrowed until the end of 2019. In the EU case the plots show evidence of convergence among the first four clubs, while the last club seems to follow a different path. Likewise, the countries of each club converge to the same steady state. Moreover, the convergence between club 4 countries seems to be faster than that of other clubs. Countries in clubs 5, which are the largest, exhibit less strong convergence within their club, as indicated by relatively time-constant transition paths. Furthermore, the transition of the five clubs mostly took place at the beginning of the period and then narrowed at the end of the period.

<Place Figure 6 here>

<Place Figure 7 here>

Hence, as a whole, the results indicate a slow convergence in both economies, with the EU being slower. Additionally, a significant difference in both the convergence speed and the relative transition path between the established groups was found in the two analysed economies. These results have important policy implications for both economies.

Brazil, a country with a historically high level of regional inequalities that has declined in the last three decades of 20th century, has been experiencing difficulties keeping this rhythm. Considering the period 2002–2019, the speed of convergence is higher than in the EU, but the difference of the dispersion measures in both economies, which increased until 2013, began to fall from 2014, as a downturn marked the Brazilian economy. The insufficiency of economic resources, the macroregional character of constitutional funds and political priority disputes certainly compound obstacles to better outcomes.

The EU, which seems to devote a higher priority to regional policies in terms of economic resources, institutions and organization, has faced a slower convergence tendency. In this case the difficulties of coordinating different national governments and cultures into convergence objectives and measures are higher.

These results do not indicate that regional policies fail in achieving their goals. Actually, if these policies do not exist, inequality levels would be higher and even a slow convergence could not be reached. Thus, the results reveal the need to improve these policies by increasing economic resources and refining the accuracy of instruments and approaches.

5 Conclusion

A comparative analysis of Brazil and the EU, two relevant economies with federation arrangements, has revealed important results.

The DTW analysis revealed that despite marked differences between the two economies, their dynamics of economic growth in the period are comparable and similar, except for the last years of the series due to Brazil's economic crisis. The similarity in dynamics also suggests a relevant degree of integration of both economies with the world economy.

Considering these elements, we developed a convergence analysis for the Brazilian and EU economies, using the same methods and parameters. We can now summarize the four elements analysed and relate them to the background. First, the coefficient of variation, which is higher for European countries than for Brazilian states, decreased slightly in both cases. Indeed, despite some oscillation in the period, there are signs of σ-convergence within these two

economies. However, the speed of convergence is low in both cases, with that of EU countries being lower. Moreover, this speed decreased in both economies over the period. Second, we found signs of absolute convergence within the two economies analysed. In both cases the convergence also seems to be very slow, and even slower in EU countries. Third, convergence clubs are also identified in both cases, while units tend to converge within clubs, but clubs show no signs of converging with each other. In these two economies, one club is formed by the units with the highest GDP per capita and its trajectory is different from other clubs. Fourth, in both cases the relative transition path does not tend to be unique for the units of each club. This path tends to be faster in one club of each economy: poorer states in Brazil and richer countries in the EU. Overall, these results indicate a slow convergence with a marked divide into clubs with two (or more) speeds, which leads the results closer to the core–periphery approach.

Thus, by comparing these different federation contexts in the same analysis, we contrasted these two economies on both the level of regional inequalities and convergence tendencies at a common parameter, revealing both the higher level of inequalities and the lower speed of convergence for the EU. Moreover, the establishment and dynamics of convergence clubs also revealed similarities and differences between the two economies analysed, indicating the presence of core–periphery dynamics in both cases. Therefore, the results are remarkably different between groups in terms of their speeds and transitional behaviour, which means that these results are closer to core–periphery patterns and suggest relevant "inertial" obstacles to achieving convergence within the two economies.

Considering the background and growing relevance of regional development funds in both cases, these limited convergence tendencies seem to be more a result of state activity and regional policy than an automatic outcome of the market forces or economic growth as predicted by the neoclassical model. The growing use of regional development funds in Brazil and the EU (despite the limitations of the former) and the territorial impact of other public policies (which may be more in Brazil) seem to reinforce this idea.

These results also indicate the difficulties and limitations of regional policies in reversing the historical processes of regional inequalities. The two different federation contexts analysed have revealed some weaknesses. The low speed of convergence may indicate that this process can easily be interrupted, as market dynamics and innovation usually favour richer and core

states. On the other hand, if these policies did not exist, the level of inequalities would be higher and the situation would be worse.

Hence, convergence analysis results considering EU countries and Brazilian states together add new findings to the tradition of regional studies in these economies, aggregating knowledge and allowing comparative studies. These results can fruitfully be debated by incorporating other kinds of approaches, based on historical perspective, institutionally informed views and other regional inequality indexes.

In sum, our results indicate the slow tendency to reduce regional inequalities in these economies and, at the same time, the weakness and low speed of these convergence tendencies in both cases. Accordingly, the different dynamics across groups and clubs of countries or states show that the effects of regional policies are still limited and probably need to improve in dimension and focus to reach better outcomes.

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Appendix

Table A1. GDP per capita and average annual growth rate at constant price (2002–2019) – Brazilian states (Source: The World Bank)

States	GDP per capita (2002)	GDP per capita (2019)	Average annual growth rate (2002–2019 – %)
Acre	7051	7081	0.16
Amapá	8557	8266	-0.03
Amazonas	10390	10429	0.16
Pará	5716	8284	2.46
Rondônia	7265	10587	2.40
Roraima	9605	9427	0.00
Tocantins	6142	9997	3.02
Alagoas	5565	7059	1.46
Bahia	6152	7877	1.51
Ceará	5226	7157	1.93
Maranhão	3822	5497	2.28
Paraíba	5080	6760	1.77
Pernambuco	6212	8271	1.81
Piauí	3423	6443	3.93
Rio Grande do Norte	6624	8128	1.30
Sergipe	7796	7768	0.11
Espírito Santo	11767	13655	1.39
Minas Gerais	9421	12304	1.68
Rio de Janeiro	17435	18049	0.34
São Paulo	18931	20433	0.49
Paraná	12543	16297	1.63
Rio Grande do Sul	13228	16943	1.51
Santa Catarina	13728	18027	1.69
Distrito Federal	34988	36256	0.28
Goiás	10327	11879	0.91
Mato Grosso	10262	16296	3.18
Mato Grosso do Sul	10697	15376	2.31

Table A2. GDP per capita and average annual growth rate at constant price (2002–2019) – EU member countries (Source: The World Bank)

Country	GDP per capita (2002)	GDP per capita (2019)	Average annual growth rate (2002-2019 – %)
Austria	39636	46670	0.98
Belgium	36393	43071	1.00
Bulgaria	4260	8235	3.99
Croatia	9962	14068	2.10
Cyprus	23603	28211	1.12
Czech Republic	12960	20202	2.69
Denmark	49542	57553	0.90
Estonia	11417	20408	3.65
Finland	39351	46135	0.99
France	34152	38912	0.78
Germany	34883	43329	1.31
Greece	19997	19004	-0.21
Hungary	9829	15041	2.58
Ireland	44919	75143	3.27
Italy	32998	32091	-0.14
Latvia	7849	16056	4.49
Lithuania	7424	17241	5.24
Luxembourg	96270	108570	0.74
Malta	17165	27489	2.83
Netherlands	40914	48444	1.01
Poland	7607	15017	4.09
Portugal	19068	21617	0.76
Romania	5225	11222	4.68
Slovak Republic	9641	18167	3.86
Slovenia	17302	24071	2.02
Spain	25026	28102	0.71
Sweden	42377	53490	1.41

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Tables

Table 1. Trend regression to measure the σ-convergence

σ- convergence by trend regression	Brazilian states	EU countries
Intercept	19.58*** (5.44)	18.30*** (1.33)
Time	-0.0095*** (0.0027)	-0.0088 (0.0006)
R-squared	0.437	0.91
F-test	12.31***	175.52***

*Note: Standard errors in parentheses. Significant at *10%, **5%, ***1%.*

Table 2. Absolute convergence results for Brazil and the EU (beta coefficients in bold)

Absolute convergence	Brazilian states	EU countries
Intercept	0.623* (0.063)	0.165* (0.024)
Beta	**-0.066*** (0.006)	**-0.014* (**0.0024**)**
Lambda	0.0041	0. 00088
Half-life	10.15	49.2
R-squared	0.81	0.61

*Note: Standard errors in parentheses. Significant at *10%, **5%, ***1%.*

Table 3. Club convergence analysis performing a log-*t* regression test

	Brazil	Europe
Beta	-0.638* (0.0567)	-0.702* (0.0537)

*Note: Standard errors in parentheses. Significant at *10%, **5%, ***1%.* Rejection of the null hypothesis of convergence resulted significant at the 5% level.

Table 4. Convergence clubs in Brazil and the EU

Clubs	Brazilian states			EU countries		
	Number of states	Beta	Convergence speed	Number of countries	Beta	Convergence speed
club1	7	1.135*(0.32)	-0.108	4	-0.085 (0.154)	0.022
club2	16	0.278 (0.21)	-0.015	4	-0.003 (0.101)	0.001
club3	3	0.533 (0.29)	-0.142	3	-0.213 (0.155)	0.080
club4				5	0.264* (0.127)	-0.047
club5				11	-0.054 (0.049)	0.005
Number of divergent units: 1				Number of divergent units: 0		

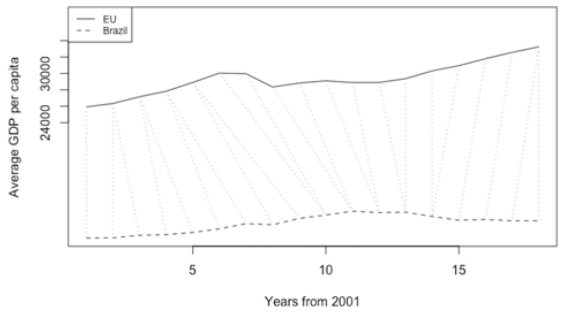
*Note: Standard errors in parentheses. Significant at *10%, **5%, ***1%.*

Table 5. States/countries for each club in Brazil and the EU

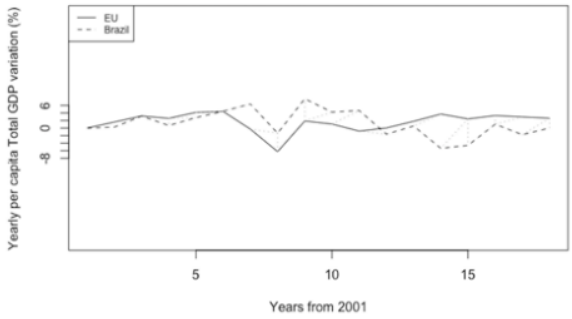
Brazilian states	Club 1	São Paulo, Rio de Janeiro, Santa Catarina, Rio Grande do Sul, Paraná, Mato Grosso, Mato Grosso do Sul.
	Club 2	Espírito Santo, Goiás, Minas Gerais, Rondônia, Amazonas, Roraima, Tocantins, Pernambuco, Bahia, Pará, Ceará, Piauí , Alagoas, Rio Grande do Norte, Amapá, Paraíba.
	Club 3	Sergipe, Acre, Maranhão
	Divergent	Distrito Federal
European countries	Club 1	Luxembourg, Sweden, Ireland, Denmark.
	Club 2	Netherlands, Austria, Germany, Malta.
	Club 3	Finland, Belgium, France.
	Club 4	Italy, Cyprus, Spain, Estonia, Lithuania.
	Club 5	Slovenia, Portugal, Czech Republic, Greece, Slovak Republic, Latvia, Hungary, Poland, Romania, Croatia, Bulgaria
	Divergent	0

Figures

Figure 1. DTW per capita GDP time series comparison between Brazil and the EU (2002–2019). (a): comparison on yearly average regional/country per capita GDP. (b): comparison on yearly regional/country per capita GDP variation. Grey dashed segments join optimal matching time points along the time series

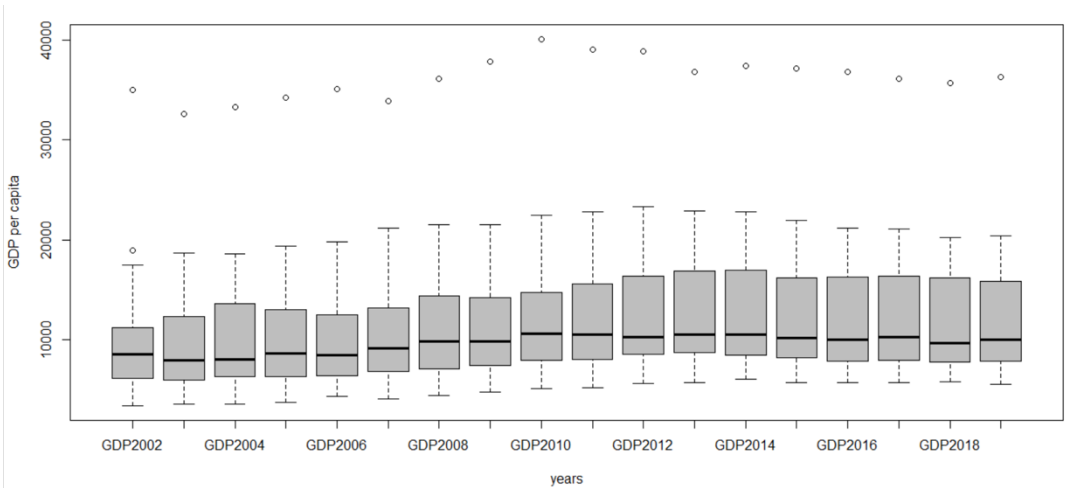


(a)



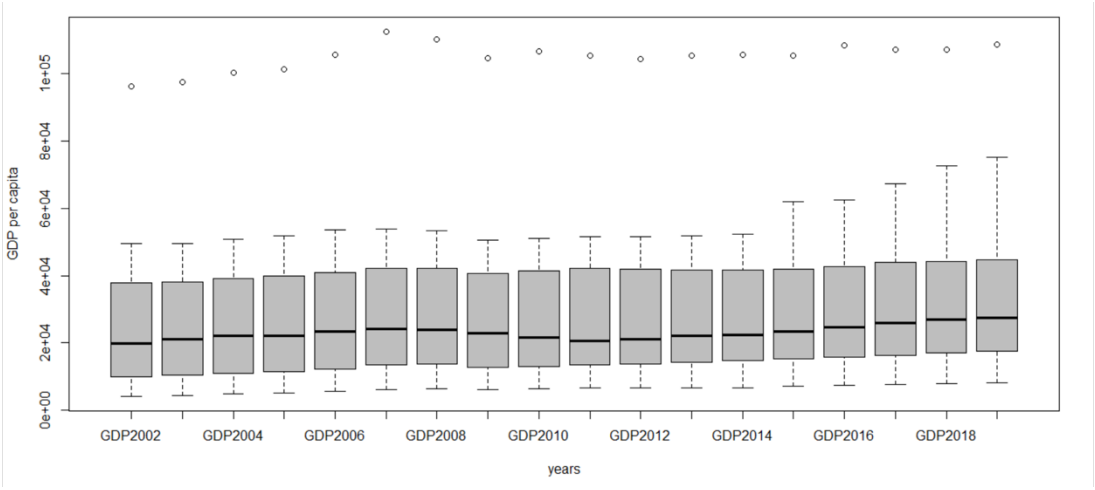
(b)

Figure 2. Dispersion of GDP per capita of Brazilian states



Note: Outlier points refer to Distrito Federal per capita GDP.

Figure 3. Dispersion of GDP per capita of EU countries



Note: Outlier points refer to Luxembourg per capita GDP.

Figure 4. Standard deviation of log per capita GDP for Brazilian states and EU member countries

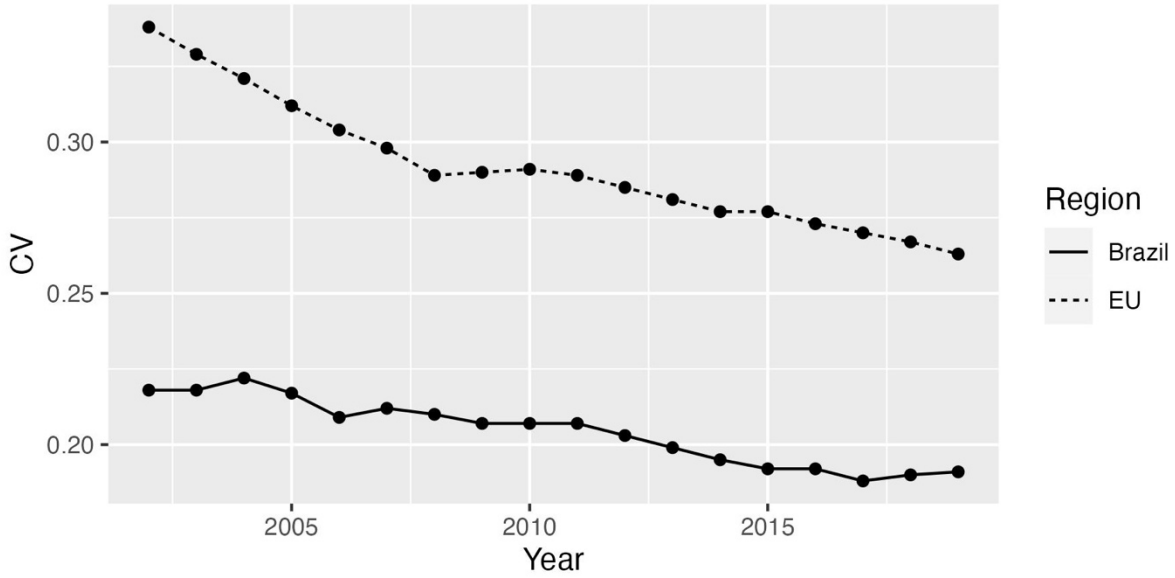


Figure 5. Coefficient of variation of the σ-convergence for Brazilian states and EU countries

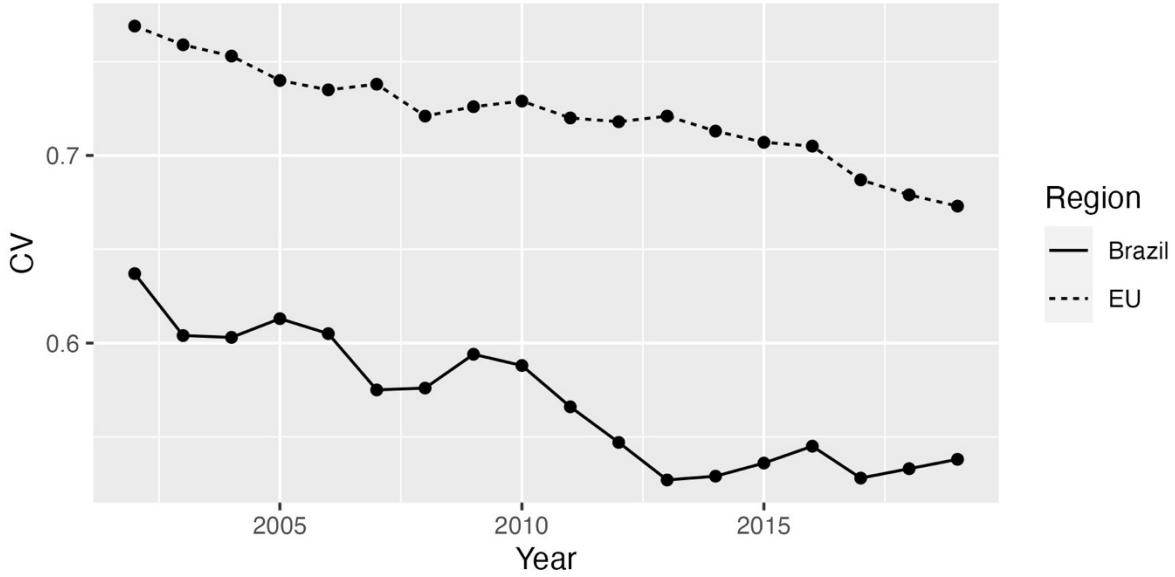


Figure 6. Relative transition paths of Brazilian states as identified by the “convergence clubs” model during 2002–2019

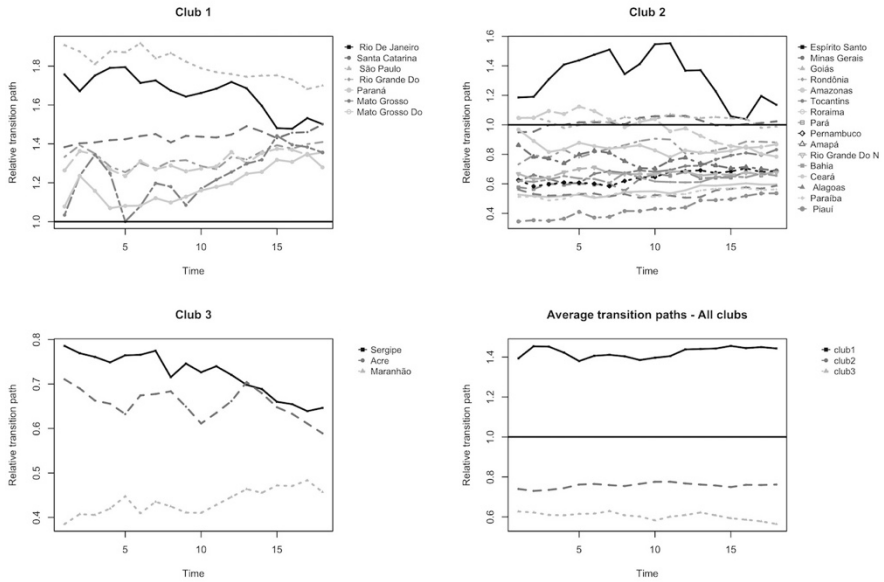


Figure 7. Relative transition paths of EU countries as identified by the “convergence clubs” model during 2002–2019