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Structural breaks and regional convergence clubs in Europe

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Abstract:

This research analyses the existence of structural breaks and the composition of convergence clubs in the EU-27 using GDP per capita (PPS) over 2003–2023. To this end, the Phillips–Sul log-t approach is combined with the Bai–Perron multiple structural break test. To the best of our knowledge, this is the first EU-27 convergence club analysis at the NUTS-3 level. The results suggest that incorporating structural breaks and highly disaggregated regional data improves the understanding of European convergence dynamics and may help reduce the risk of "accidental winners" in the allocation of EU cohesion funds.

Keywords: Regional convergence; convergence clubs; structural breaks; Phillips–Sul method; NUTS-3 regions.
JEL Classification: R11; O47; C22.

Rupturas estructurales y clubes de convergencia regional en Europa

Resumen:

Esta investigación analiza la existencia de rupturas estructurales y la composición de los clubes de convergencia en la UE-27 utilizando el PIB per cápita (PPA) durante el período 2003–2023. Para ello, se combina el enfoque log-t de Phillips y Sul con la prueba de múltiples rupturas estructurales de Bai y Perron. Hasta donde alcanza nuestro conocimiento, este es el primer estudio sobre clubes de convergencia en la UE-27 a nivel NUTS-3. Los resultados sugieren que la incorporación de rupturas estructurales y de datos regionales altamente desagregados mejora la comprensión de las dinámicas de convergencia europeas y puede contribuir a reducir el riesgo de identificar «ganadores accidentales» en la asignación de los fondos de cohesión de la Unión Europea.

Palabras clave: Convergencia regional; clubes de convergencia; rupturas estructurales; método de Phillips y Sul; regiones NUTS-3.
Clasificación JEL: R11; O47; C22.

1. Introduction

The European Union represents one of the most ambitious processes of economic integration in modern history. Reducing disparities in income and living standards across regions has therefore constituted

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a central objective of the European project, as reflected in key policy documents such as the Treaty of Rome (1957), the Delors Report (1988), and the Maastricht Treaty (1992). Despite these efforts, regional convergence in the EU has not followed the neoclassical prediction of a uniform adjustment towards a common steady state (Solow, 1956; Swan, 1956). Instead, regional growth dynamics remain heterogeneous, reflecting persistent structural differences across territories (Capello et al., 2025).

In line with this, a substantial body of empirical research shows that European regions do not converge towards a single equilibrium, but rather form convergence clubs characterised by distinct long-run growth trajectories. The Phillips and Sul (2007, 2009) framework has become a standard approach to capture this heterogeneity, allowing for the identification of groups of regions that share similar growth paths over time. Empirical applications consistently identify multiple convergence regimes across European regions, typically ranging between four and six. These regimes are often structured along both geographical (north–south) and core–periphery dimensions (von Lyncker & Thoennessen, 2017; Borsi & Metiu, 2015), while their evolution appears to be strongly influenced by initial conditions, particularly income levels and human capital endowments (Bartkowska & Riedl, 2012). Additional evidence further supports the presence of persistent spatial patterns in European convergence dynamics (Cutrini & Méndez, 2023; Pintera, 2024).

However, the empirical evidence remains highly sensitive to spatial and temporal choices. As highlighted by Gagliardi and Percoco (2017), aggregated territorial levels may lead to misleading interpretations of convergence dynamics, including the identification of "false winners" and "false losers". In the European context, convergence trajectories may therefore remain obscured when analyses rely on highly aggregated territorial units such as countries or NUTS-2 regions, with direct implications for the interpretation and effectiveness of cohesion policies. Regarding the temporal dimension, the literature has shown that macroeconomic shocks can alter regional growth trajectories. For instance, in the European context the global financial crisis interrupted long-term convergence processes, particularly in Southern Europe (Camagni & Capello, 2015), and generated substantial disruptions in regional growth dynamics (Bolea et al., 2018).

Despite this evidence, few studies jointly examine the interaction between spatial scale, structural breaks, and convergence club dynamics at the NUTS-3 level. Moreover, although the role of structural breaks has been recognised, these are rarely explicitly integrated into convergence club analysis, which typically assumes time-invariant convergence dynamics. This study addresses both limitations by analysing more than 1,100 NUTS-3 regions across the EU-27 over the period 2003–2023 and by explicitly incorporating structural breaks into the empirical framework. Methodologically, it combines the Phillips and Sul (2007, 2009) convergence approach with the multiple structural break test proposed by Bai and Perron (1998, 2003), allowing for the identification of convergence regimes within structurally homogeneous subperiods. To the best of our knowledge, this study is among the first to jointly analyse convergence clubs at the NUTS-3 level for the EU-27 while explicitly accounting for structural breaks in the convergence process.

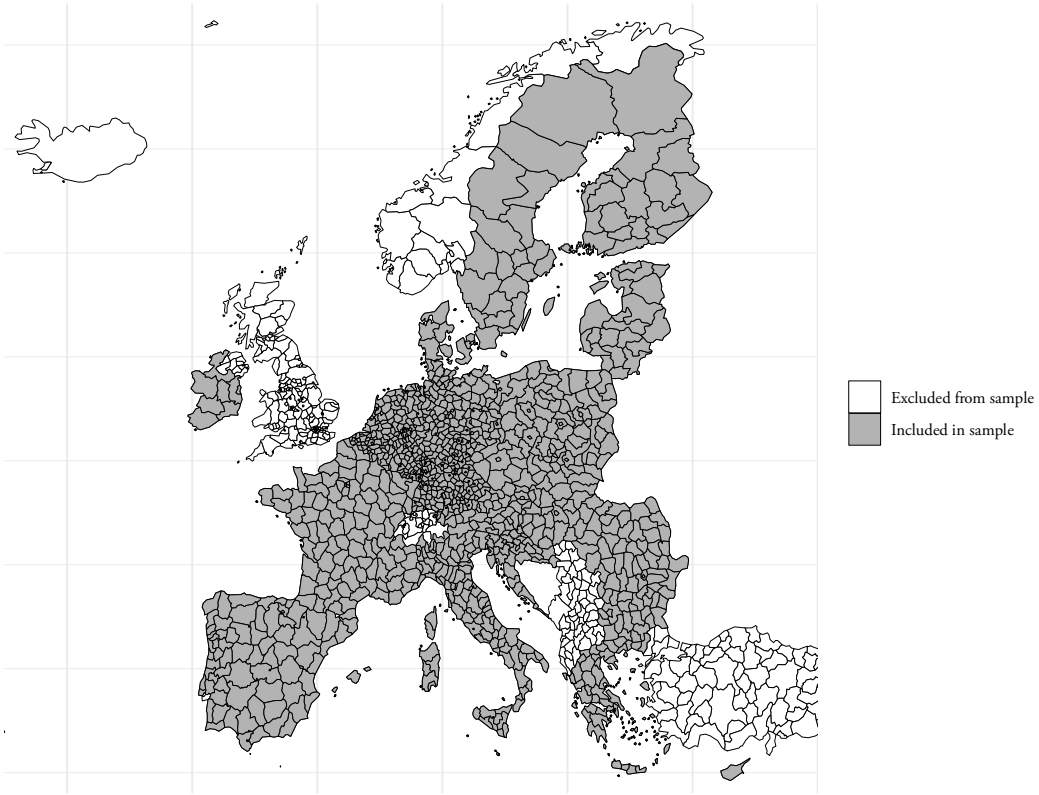
2. Methodology

Regional convergence is analysed using GDP per capita in purchasing power standards (PPS) using Eurostat data, expressed relative to the annual EU average. This indicator allows meaningful cross-regional comparisons by controlling for price level differences and is widely used in the convergence literature.

The original dataset showed a limited number of missing observations affecting GDP-PPS and population series, accounting for approximately 3.6% of total panel observations. In order to construct a balanced long-run regional dataset, missing GDP-PPS observations were reconstructed through linear interpolation within regions over time, while missing population observations were reconstructed through backward extrapolation using region-specific observed growth trends. The reconstruction procedures were implemented on an annual basis to preserve the temporal consistency of regional trajectories (see Annex A1). Robustness checks excluding reconstructed observations produced qualitatively similar convergence dynamics and broadly preserved club configurations, including the identification of the same main structural break around 2010, despite minor variations in the number of convergence clubs (Annex A2).

Following these reconstruction procedures, the final sample covers the whole EU-27 over the period 2003–2023 and includes 1,163 NUTS-3 regions (Figure 1).

FIGURE 1.
NUTS-3 regions included in the dataset



Note: The dataset also includes the islands from the EU members located outside the displayed extent.

Descriptive statistics confirm the substantial heterogeneity in income levels across European regions, with an average that ranges from 0.157 to 6.245, and with a standard deviation of 0.473.

To analyse regional convergence dynamics and identify potential convergence clubs, this study applies the methodology proposed by Phillips and Sul (2007, 2009) to our study variable. This approach has become widely used in empirical analyses of economic convergence, but also in other areas like Ecology, Energy or Finance, as it is stated by Tomal (2024). This method models regional growth dynamics through time-varying transition paths that describe how each region evolves relative to the cross-sectional average. Overall convergence is tested using the log-t regression, which evaluates whether cross-sectional dispersion declines over time. If convergence is rejected, an endogenous clustering algorithm is applied to identify convergence clubs by grouping regions that share similar transition paths.

A limitation of the Phillips and Sul approach is that it implicitly assumes stable convergence dynamics over time. However, the evolution of regional income dispersion across European NUTS-3 regions (Figure 2) shows a non-monotonic pattern consistent with major shocks such as the global financial crisis, the European sovereign debt crisis, and the COVID-19 pandemic. To account for potential structural changes, the study applies the multiple structural break test of Bai and Perron (1998, 2003), which endogenously identifies breakpoints by testing for shifts in the parameters of the time series.

FIGURE 2.
Evolution of regional income dispersion across European NUTS-3 regions (2003–2023)

Once structural breaks are detected, the Phillips–Sul convergence framework is applied separately to each regime to identify convergence clubs within each subperiod. The empirical implementation follows the procedure implemented in the R package ConvergenceClubs (Sichera and Pizzuto, 2019). Robustness checks—including the alternative merging algorithm proposed by von Lyncker and Thoennessen (2017) and the use of the AQSB estimator for the log-t regression to account for potential serial correlation and heteroskedasticity—confirm the results presented in the following section. The Bai–Perron test is implemented using the R package strucchange (Zeileis et al., 2002).

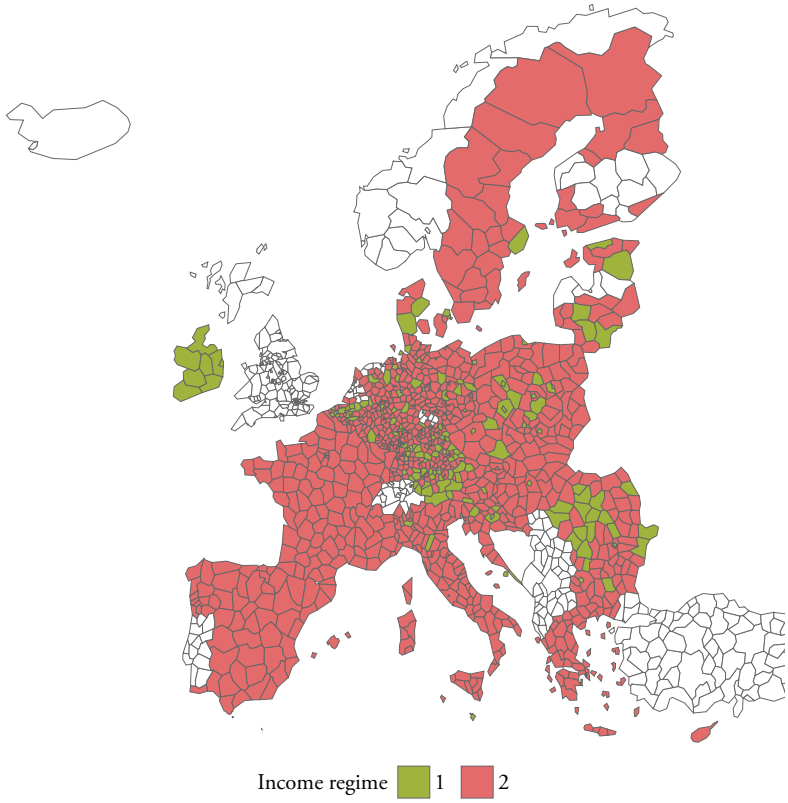
3. RESULTS

3.1. OVERALL CONVERGENCE AND CONVERGENCE CLUBS IN EUROPEAN NUTS-3 REGIONS (2003-2023)

The Phillips–Sul log-t test rejects convergence towards a common steady state for the full period (β = −0.664, t = −9.728). More specifically, two convergence clubs emerge, both displaying internal convergence: Club 1 (215 higher-income regions above the EU average; β = −0.467, t = −6.16) and Club 2 (948 lower-income regions; β = −0.275, t = −3.41) (Figure 3).

Consistent with a substantial body of empirical literature, these results support the view that European regions do not converge towards a single steady state, but instead organise into distinct convergence regimes (Bartkowska & Riedl, 2012; von Lyncker & Thoennessen, 2017; Borsi & Metiu, 2015; Cutrini & Méndez, 2023; Pintera, 2024), and extend this evidence to the NUTS-3 level for the EU-27, confirming that the absence of global convergence remains robust even when within-country heterogeneity is explicitly accounted for.

FIGURE 3.
Convergence clubs across European NUTS-3 regions (2003–2023)



Club	N regions	b (SE)	t_b	mean (2003)	mean (2023)
Club 1	215	-0.467(0.076)	-6.16	1.396	1.553
Club 2	948	-0.275(0.081)	-3.41	0.910	0.874

No divergent units were identified.

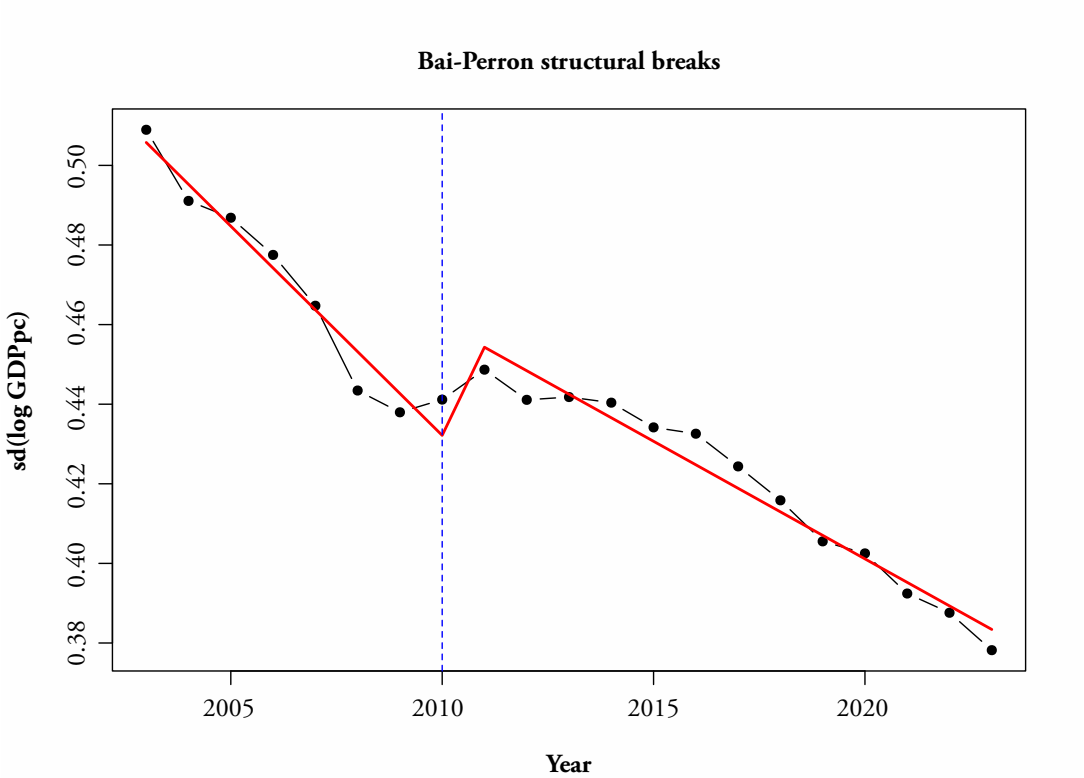
The relative transition paths reveal a persistent separation between the two groups, indicating a two-speed convergence pattern similar to that documented by Cutrini and Méndez (2023). However, while previous studies identify relatively well-defined geographical patterns—such as a North–South divide and strong country-level clustering (von Lyncker & Thoennessen, 2017), and even report "an apparent country effect, that is, regions belonging to the same country tend to cluster together" (Bartkowska & Riedl, 2012)—the spatial distribution of clubs observed for NUTS-3 regions is more complex. Entropy-based measures of the country effect (Barro et al., 1991) show that convergence regimes do not necessarily coincide with national borders: while some countries display highly concentrated club structures, others exhibit substantial internal heterogeneity. This suggests that, although core–periphery patterns remain relevant, they may oversimplify the underlying spatial structure of convergence in Europe, particularly when analysed at a more disaggregated territorial level.

3.2. Structural break detection in the convergence process

The multiple structural break test identifies three potential breakpoints in σ-convergence (2007, 2010 and 2016), indicating that regional income dispersion did not evolve uniformly over the sample

period. Following the principle of parsimony, and consistent with previous literature identifying the global financial crisis as a major turning point in European convergence dynamics (Camagni & Capello, 2015; Bolea et al., 2018), the analysis focuses on the break around 2010, which represents the most pronounced shift in the dispersion trajectory (Figure 4). In addition, implementing all detected breakpoints would generate very short subperiods, limiting the reliability of the Phillips–Sul convergence club methodology, which requires sufficiently long time series to estimate transition dynamics robustly. Alternative specifications based on the 2016 breakpoint were also explored, although they produced a substantially more fragmented convergence structure that complicated the identification of stable and economically interpretable convergence regimes.

FIGURE 4.
Bai-Perron structural break in regional income dispersion (2003-2023)



Before 2010, regional income dispersion shows a clear downward trend, indicating strong σ-convergence across European regions. After the break, dispersion follows a different dynamic, initially reflecting the impact of the global financial crisis and later a more gradual convergence process. This pattern is consistent with Licchetta and Mattozzi (2023), who find that the financial crisis had a stronger negative effect on income convergence than the COVID-19 shock in the EU and the Euro area.

For the pre-break period (2003–2010), the Phillips–Sul method identifies seven convergence clubs and two divergent regions. The distribution is highly uneven, with most NUTS-3 regions concentrated in two large clubs (Club 6: 661 regions; Club 5: 310 regions), while the remaining clubs contain fewer than 50 regions. In the post-break period (2011–2023), five convergence clubs emerge and no divergent regions are detected. The largest club (Club 4) includes 745 regions, while two others (Clubs 3 and 5) each contain 145 regions (Figure 5), consistent with previous evidence of a dominant convergence club in Europe. This comparison suggests that the number and composition of convergence clubs are not invariant over time, but instead adjust to changes in the underlying economic environment, implying that full-sample analyses may mask important internal dynamics by averaging distinct convergence regimes.

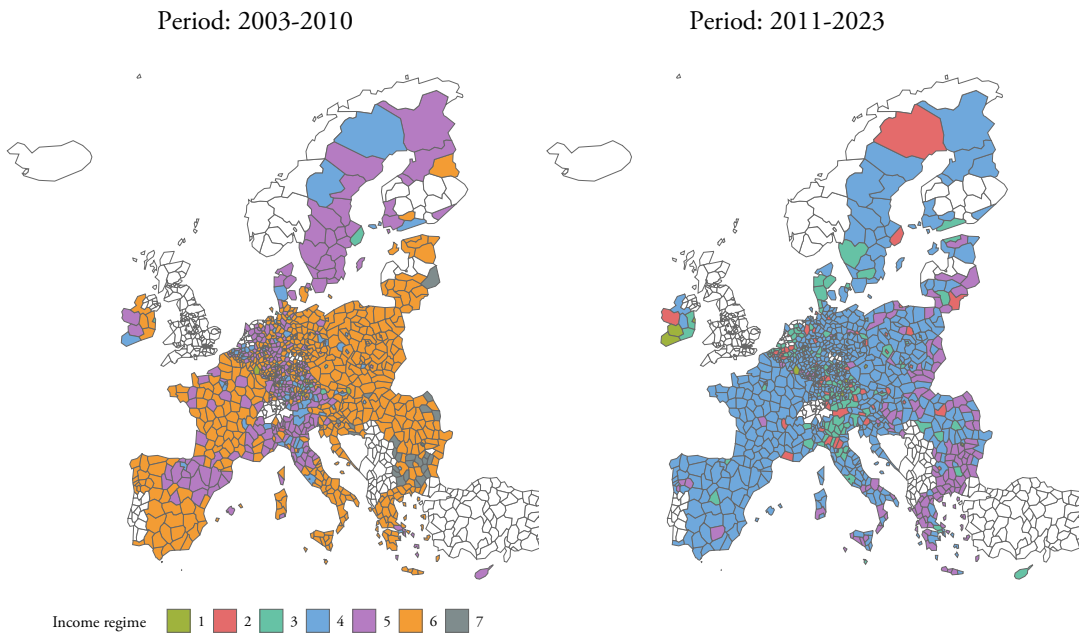
Relative transition paths (see Annex A3) indicate that clubs span a wide range of income levels and that higher-income groups continue to experience stronger gains, reinforcing persistent regional income

hierarchies. For example, in 2011–2023 the average income of the richest club rises from 2.730 to 2.905 (PPS index), whereas the lowest-income club increases only from 0.500 to 0.529.

This pattern is consistent with the literature highlighting the role of initial conditions—such as human capital and per capita income—in shaping the formation of convergence clubs among European regions (Bartkowska & Riedl, 2012; von Lyncker & Thoennessen, 2017). This interpretation is also consistent with broader regional growth literature emphasising the role of structural economic characteristics, openness, and innovation capacity in shaping long-term regional performance (Ben-David & Loewy, 1998; Sohinger, 2005).

Log-t estimates also reveal heterogeneous convergence dynamics. Although the Phillips and Sul methodology identifies groups of regions that follow similar transition paths, the associated log-t statistics do not always support the existence of convergence towards a common steady state within each group. In such cases, the identified clubs are more appropriately interpreted as groups of regions displaying similar transitional dynamics, rather than as statistically validated convergence processes.

FIGURE 5.
Spatial distribution of convergence clubs across European NUTS-3 regions before and after the structural break (2003-2010 vs. 2011-2023)



Period: 2003-2010					
Club	**N regions**	**b (SE)**	**t_b**	**mean (2003)**	**mean (2010)**
Club 1	14	-0.227 (0.225)	-1.01	2.836	3.071
Club 2	10	0.328 (0.078)	4.20	2.478	2.505
Club 3	41	-0.008 (0.189)	-0.04	1.975	1.996
Club 4	100	0.056 (0.217)	0.26	1.446	1.475
Club 5	310	-0.387 (0.235)	-1.65	1.190	1.167
Club 6	661	-0.629 (0.033)	-18.85	0.741	0.743
Club 7	25	0.236 (0.310)	0.76	0.270	0.296
Divergent	2	—	—	2.118	2.349

FIGURE 5. CONT.
Spatial distribution of convergence clubs across European NUTS-3 regions before and after the structural break (2003-2010 vs. 2011-2023)

Period: 2011-2023					
Club	**N regions**	**b (SE)**	**t_b**	**mean (2011)**	**mean (2023)**
Club 1	26	-0.398 (0.238)	-1.67	2.730	2.905
Club 2	102	0.044 (0.165)	0.27	1.675	1.655
Club 3	145	0.177 (0.218)	0.81	1.242	1.243
Club 4	745	-0.339 (0.088)	-3.87	0.897	0.888
Club 5	145	0.093 (0.084)	1.12	0.500	0.529

No divergent units were identified for this period.

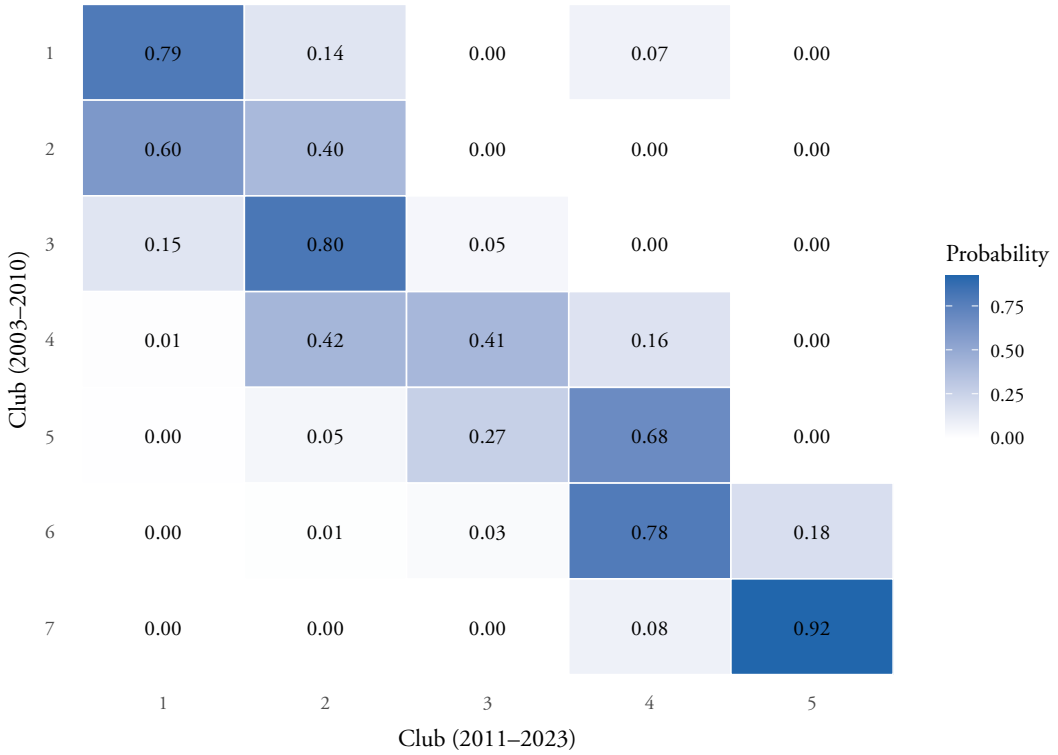
From a qualitative perspective, the spatial distribution of convergence clubs in the post-break period (2011–2023) points to a more nuanced and hierarchical structure of convergence regimes across European NUTS-3 regions. In particular, the largest convergence club (Club 4) includes territories from both traditionally high-income economies (such as Germany, France, the Netherlands, and Austria) and lower-income or catching-up countries (such as Poland, Romania, and Portugal). This composition suggests the existence of a broadly shared intermediate steady state, rather than convergence towards a single high-income equilibrium.

At the upper end of the distribution, smaller and more selective convergence clubs (Clubs 1–3) are disproportionately composed of regions located in highly developed economies, particularly in Central and Northern Europe. This configuration is consistent with previous evidence linking higher-income regions to more diversified economic structures, stronger institutional environments, higher levels of human capital, and greater innovation capacity (Hospers, 2003). In spatial terms, these clubs also exhibit a marked concentration in major metropolitan regions, which are often surrounded by neighbouring territories belonging to lower-income clubs, suggesting the presence of persistent spatial gradients in regional development (Pintera, 2024; Bartkowska & Riedl, 2012).

At the lower end, a more clearly defined peripheral convergence club (Club 5) emerges, with a strong concentration of regions from Southern and Eastern Europe, particularly Greece and Bulgaria, but also including regions from Romania, Hungary, and parts of Italy and Spain. This spatial configuration is consistent with previous findings documenting a North–South gradient in regional income levels and the presence of geographically clustered convergence regimes (von Lyncker & Thoennessen, 2017). These regions are typically associated with lower productivity levels, weaker innovation capacity, and less diversified economic structures. Additionally, in some cases, they may also exhibit a stronger reliance on service-based activities—such as tourism—which some strands of the literature associate with more volatile growth trajectories and potentially lower productivity gains under conditions of high sectoral dependence (Haller et al., 2020; Radić-Matošević et al., 2021; Bimonte et al., 2026). However, this interpretation should be treated with caution, as these factors are not directly modelled in the present analysis.

Finally, entropy-based measures highlight substantial cross-country differences in the internal structure of convergence regimes. Countries such as Germany, the Netherlands, Belgium, Ireland and Austria display strong internal heterogeneity, whereas Finland, Spain, Portugal and largely France exhibit more homogeneous structures, with most regions concentrated in a dominant club. These patterns are consistent with the transition analysis (Figure 6), which points to a high persistence of regional convergence regimes: most regions remain within adjacent income groups across the two sub-periods, while the reduction from seven to five clubs mainly reflects consolidation among intermediate regimes rather than substantial mobility.

FIGURE 6.
Transition probability matrix between convergence clubs



Taken together, these results suggest that the structural break around 2010 is associated with a reorganisation of convergence regimes in Europe, reflected in a reduction in the number of clubs and a consolidation of intermediate growth groups, while regional income hierarchies remain largely persistent. A decline in the number of clubs should therefore not necessarily be interpreted as evidence of stronger convergence, but rather as a reduction in the number of steady states shaping regional growth dynamics, and points to potential limitations in the capacity of cohesion policies to effectively reduce regional disparities in a context characterised by persistent structural heterogeneity.

4. DISCUSSION AND CONCLUSIONS

This study combines the Phillips–Sul convergence framework (Phillips and Sul, 2007, 2009) with the Bai–Perron structural break test (Bai and Perron, 1998, 2003) to analyse the evolution of convergence clubs across more than 1,100 EU-27 NUTS-3 regions over 2003–2023. To the best of our knowledge, it provides among the first convergence club analyses for the entire EU at this spatial scale, while also explicitly accounting for structural instability in regional growth dynamics, thereby contributing to both the empirical and methodological literature on regional convergence.

Our results confirm the absence of global convergence in Europe and the presence of multiple convergence clubs, in line with a broad body of empirical evidence. However, they also refine existing findings by showing that convergence patterns become significantly more complex when analysed at a more disaggregated territorial level. In particular, the NUTS-3 perspective reveals substantial within-country heterogeneity and more fragmented spatial configurations than those typically identified at the NUTS-2 level.

The results extend the literature by demonstrating that convergence club structures across European NUTS-3 regions are time-varying and influenced by major macroeconomic shocks, consistent with previous literature (Phillips and Sul, 2009; Martin, 2012; Tomal, 2024). Accounting for the structural break associated with the global financial crisis reveals evidence of a reorganisation of convergence regimes, with seven clubs and two divergent regions in the pre-crisis period and five clubs thereafter. By contrast, analyses based on full sample periods identify only two clubs, suggesting that standard approaches may mask important internal dynamics by averaging distinct convergence regimes. These findings also highlight the importance of distinguishing between similarities in transitional dynamics and statistically validated convergence processes in contexts characterised by heterogeneous regional trajectories.

From a structural perspective, the qualitative interpretation of convergence clubs suggests that long-run growth trajectories are closely linked to regional characteristics such as urbanisation, sectoral composition and institutional capacity, in line with previous studies (e.g., von Lyncker & Thoennessen, 2017; Cutrini and Méndez, 2023). In particular, higher-income clubs tend to be associated with capital and metropolitan regions, characterised by more diversified economic structures, whereas lower-income clubs are more concentrated in peripheral regions with weaker productivity dynamics and greater dependence on less knowledge-intensive sectors.

These findings have important implications for cohesion policy. The presence of substantial within-country heterogeneity suggests that reliance on the NUTS-2 framework may lead to suboptimal targeting of European cohesion funds, potentially generating "accidental winners" and "false losers" in the allocation process (Gagliardi and Percoco, 2017). By contrast, evidence at the NUTS-3 level, as presented in this study, provides a more nuanced understanding of regional disparities and may contribute to the design of more effective and territorially targeted policy interventions. Future research could build upon these findings by explicitly modelling the causal mechanisms underlying convergence club formation and their evolution over time, particularly regarding the role of institutional quality, sectoral specialisation, innovation capacity, and exposure to macroeconomic shocks.

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Annex

A1. Treatment of Missing Observations and Construction of the Regional Database

The limited number of missing observations in the original Eurostat database affecting GDP expressed in purchasing power standards (PPS) and population series were reconstructed using interpolation and extrapolation procedures applied separately to each variable.

First, missing GDP-PPS observations for region i in year t, denoted as $y_{i,t}$ were completed through linear interpolation between between two observed years t_0 and t_1, according to:

$$\hat{y}_{i,t} = y_{i,t0} + \frac{t-t_0}{t_1-t_0}(y_{i,t1} - y_{i,t0}),$$

$$\text{for all } (\mathrm{t0} < \mathrm{t} < \mathrm{t1}).$$

Second, missing population observations for region i, denoted as $Pop_{i,t}$ were reconstructed through backward extrapolation using region-specific average logarithmic growth rates estimated from the observed data (g_i):

$$g_i = mean(\frac{\Delta ln(Pop_i)}{\Delta t})$$

$$\widehat{Pop}_{i,t-1} = (\frac{Pop_t}{e^{g_i}})$$

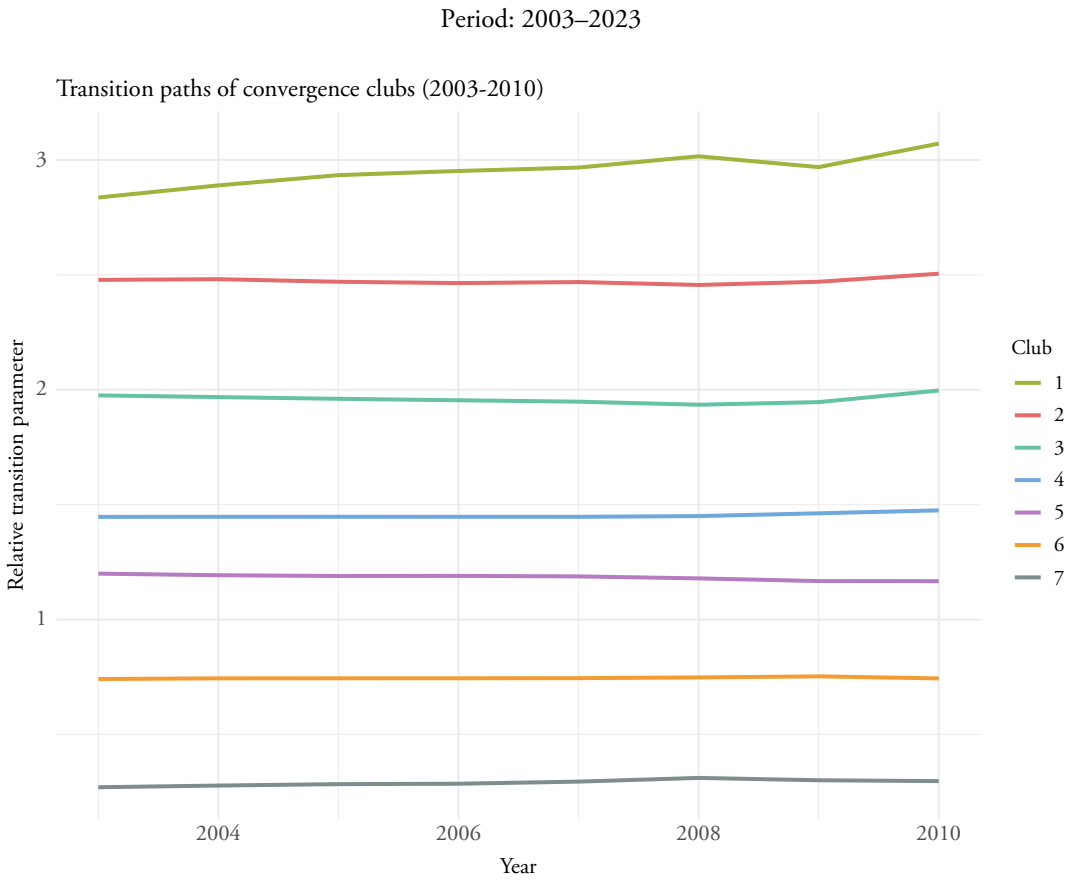
This procedure preserves the observed long-run demographic trend of each region while avoiding abrupt discontinuities in the reconstructed series. Missing regional GDPpc PPS was subsequently computed as $y^*_{i,t}/Pop^*_{i,t}$, where $*$ denotes the final reconstructed series.

A2. Robustness check.

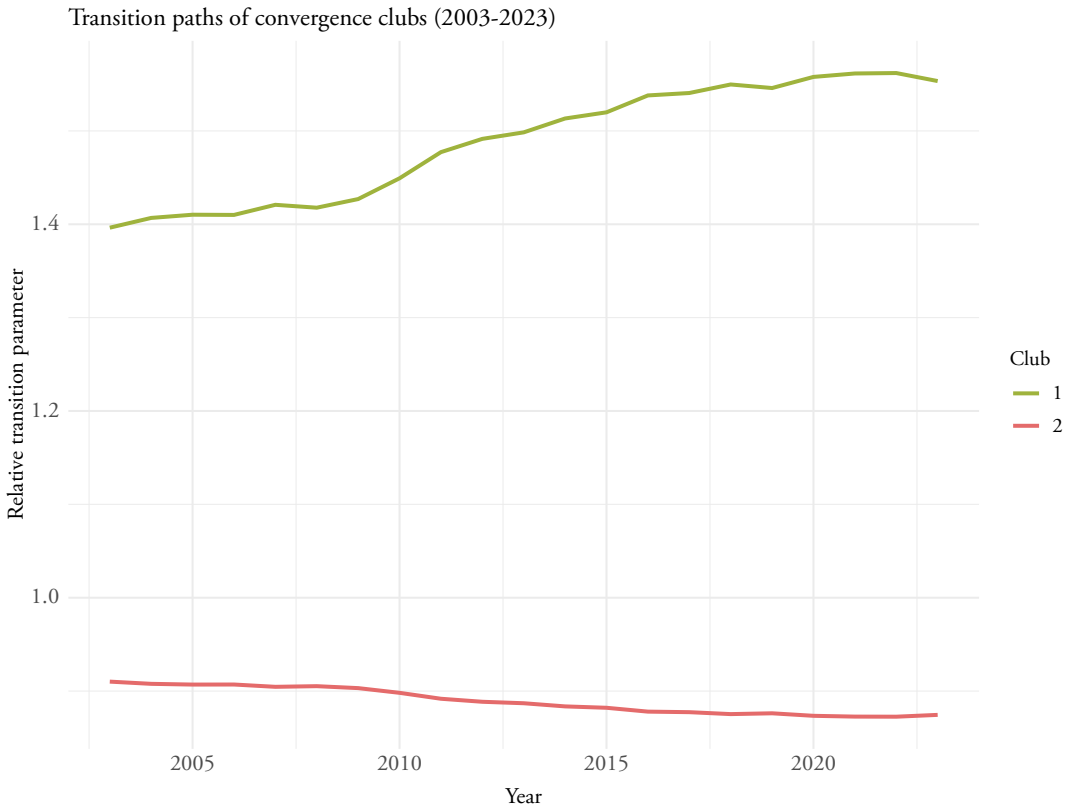
	Baseline sample	Robustness sample (no reconstruction)
NUTS-3 regions	1,163	1,055
Observations	24,423	23,533
Period covered	2003–2023	2003–2023
Main structural break identified	2010	2010
Number of clubs (2003–2023)	2	3
Divergent units (2003–2023)	0	0
Number of clubs (2003–2010)	7	7
Divergent units (2003–2010)	2	0
Number of clubs (2011–2023)	5	6
Divergent units (2011–2023)	0	0

Notes: The robustness sample excludes all regional observations affected by interpolation or extrapolation procedures. Club convergence estimations were replicated following the same Phillips and Sul (2007) methodology applied in the baseline specification.

A3. Relative transition paths of convergence clubs.



Period: 2003–2010



Period: 2011–2023