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Cross-sectional and spatial panel data analysis of territorial economic cohesion in the European Union regions based on convergence approach: From 2 to 8 per cent?

Fernando Isla-Castillo [a], Anna Garashchuk [b,*], Pablo Podadera-Rivera [c]

[a] Universidad de Málaga, Economics and Business Faculty, Applied Economics Department (Statistics and Econometrics), Economic Policy, European Union and Global Studies Research Group (SEJ 108), Spain

[b] Universidad de Málaga, Economic Structure Department, Jean Monnet Center of Excellence on European and Global Studies and Research), Economic Policy, European Union and Global Studies Research Group (SEJ 108), Universidad de Malaga, Spain

[c] Universidad de Málaga, Economics and Business Faculty, Applied Economics Department (Economic Policy), Jean Monnet 'Ad Personam, Jean Monnet Center of Excellence on European and Global Studies and Research, Economic Policy, European Union and Global Studies Research Group (SEJ 108) , Spain

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ABSTRACT

From an economic, political and social standpoint, one of the most evident and visible features of today's European Union as a supranational regional organization is its heterogeneity, where disparity seems to be the common denominator. This leads to the interest for measuring the territorial economic cohesion of the EU. From an eminently economic perspective, and working with the GDP per capita of the EU NUTS-2 regions for the period 2003–2021, this paper aims to provide evidence of a lack of territorial economic cohesion through a beta and sigma convergence methodology by applying cross-sectional and spatial panel data analysis.

The findings show that the speed of convergence depends mainly on the level of economic development, its cycles and the heterogeneity of the, which implies conditional convergence. Less developed regions show higher convergence speeds, which are also accentuated during recession periods. Greater heterogeneity among the regions also increases the convergence speed, while accentuating in the less developed regions. In general terms, the results reveal convergence speeds of the entire NUTS-2 regions between 7 and 11 per cent (much higher than 2 per cent under absolute convergence). Likewise, when considering spatial dependence, a reduction in convergence speeds between approximately 3 and 8 per cent is detected. Finally, the 29 vulnerable regions have been identified, with economic development and growth below the EU average mean, emphasizing the need to take the concerns of territorial economic cohesion into account.

1. Introduction

Within the current context of globalization, the process of building the EU requires precise, updated and appropriate knowledge of the territory to facilitate its diagnosis, as well as the adoption of political decisions, monitoring and periodic evaluation of public policies and their territorial impact. These requirements entail an instrumental challenge for the EU cohesion policy, assuming that a reduction in territorial disparities implies greater cohesion and, therefore, greater territorial balance, which in turn fosters greater economic development.

It is worth mentioning that the study and analysis of regional disparities in a certain territory, traditionally in reference to the gross domestic product per capita (GDPpc), has led to the analysis of the evolution of the reduction of such disparities, due to the need to analyse progress in terms of territorial economic convergence. Nevertheless, if we aim to determine the progress towards greater economic and social cohesion, its measurement may require the use of a broader set of indicators to assess population structure, educational levels, unemployment, living conditions, etc. Thus, for instance, Rodil et al. [1] involve factorial decomposition analyses to take into account the combination of the GDPpc indicator with productivity and employment. However, this perspective, although interesting, is beyond the scope of the present work. In this regard, when measuring the territorial economic cohesion of the EU NUTS-2 regions, in our research the GDP per capita is used as the main indicator of the development of these regions, which also summarises the evolution of the set of aforementioned indicators.

* Corresponding author.
E-mail addresses: isla@uma.es (F. Isla-Castillo), anna.garash@uma.es (A. Garashchuk), ppodadera@uma.es (P. Podadera-Rivera).

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From an economic, political and social point of view, one of the most evident and visible features of the present-day EU is precisely its heterogeneity, encompassing within its borders a whole range of socio-economic situations where disparity seems to be the common denominator. Hence, there is increasing interest in measuring territorial cohesion and regional disparities in the EU through economic convergence between its regions. The notion of territorial cohesion has been built on the pristine notion of economic and social cohesion established in the European Economic Community Treaty around "harmonious and balanced development", a kind of spatial harmony that the European Territorial Strategy, the Green Paper on Territorial Cohesion and the Lisbon Treaty itself aim for.

It is convenient, for the purposes of this work, to make a brief and clear distinction between the general concept of territorial cohesion and the concept of territorial economic cohesion. In this regard, the concept of "territorial cohesion" is above all political and multidimensional ([2–9], among others), so that it can be considered as a means to achieve competitiveness and economic growth objectives [10]. We can say that it is part of the planning and territorial ordering processes in favour of the balanced integration of the dimensions that make up the territorial system (sociocultural, economic-productive, political-institutional and physical-environmental) and socio-spatial harmony in the long term [11].

On the other hand, “economic cohesion” supposes the establishment of links between the components that allow the gearing of an economic-productive scheme, framed in the principles of environmental sustainability and good governance. Therefore, economic cohesion becomes an input for territorial cohesion [12].

Taking into account the previous premises and on the basis of a prior literature review, this paper carries out an analytical study of convergence in the NUTS-2 regions of the EU from an eminently economic perspective, using GDPpc (gross domestic product per capita in purchasing power parity) as the variable of empirical analysis. Our main objective is to provide evidence of regional disparities through a beta and sigma convergence methodology applied to the 242 cohesion regions of the EU, using panel data analysis. The research period is between 2003 and 2021 due to the availability of Eurostat data for 242 NUTS-2. The paper aims to contribute to the existing literature in the field of empirical analysis of regional economic convergence in the EU, through the traditional convergence approach (sigma and beta), applying panel data analysis and adopting a regional perspective, a level of disaggregation that, in our opinion, allows reaching more conclusive results.

Despite the wide range of studies on beta-convergence, there are important aspects that have not been sufficiently developed, such as the advantages and disadvantages of the methodologies applied, the theoretical approaches used, the different empirical results obtained without detailed justification, or the existence of different types of convergence. Also, the ongoing controversies in the use of the term "conditional" in the analysis of convergence, which can imply different steady states, factors related to steady states, or growth-determining factors should be mentioned. For example, Islam [13] identifies up to seven dichotomies regarding the convergence process. In particular, in this paper, relying on empirical evidence, we aim to clarify the advantages and disadvantages of using conventional panel data versus cross-section analysis, precisely focusing on how different convergence results can be obtained in the EU NUTS-2 regions, depending on the consideration of multiple factors such as the existence or absence of different steady states, levels of economic development, economic cycles, the 2008 financial crisis, COVID-19, and the impact of neighbouring regions under a context of territorial economic cohesion.

In line with these intentions, the article presents the following structure: the first section is the introduction; second section compiles one of the possible literature reviews on regional disparities in the EU, convergence, and spatial analysis; the third section comprises the analysis of sigma and beta convergence with static panel data and cross-sectional and spatial analysis; the fourth section describes the territorial economic convergence of the 242 EU NUTS-2 regions; the fifth section shows the observations and descriptions of data panel analysis of GDP per capita, after which we proceed with the results obtained with different methods, including the spatial analysis; and finally, the last section provides the discussion and main conclusions regarding our research.

2. Literature review

Regional disparities in GDP per capita and their evolution are topics that have been widely studied in the field of economics, especially in recent decades, and have typically been linked to concerns about the unequal development of territories[1] (regions/countries), to which considerations regarding environmental, ecological, well-being and social cohesion elements have been added [14].

Such analyses, from the neoclassical school with Solow [15,16] at the forefront to the endogenous growth school, with Romer [17,18], Lucas [19], Abramovitz [20], Rebelo [21], Barro [22], Alburquerque [23], and Vázquez Barquero [24] as the most representative authors, have attempted to explain the existence or absence of economic convergence among regions/countries (with caution regarding their interpretation depending on the periods analysed, regions sampled, geographical scale, methodologies applied, etc.), either by studying the movements of the richest regions (centre) and the poorest regions (periphery) towards the same long-term steady state (based on the existence of diminishing marginal returns to capital), in the former case; or based on technological changes, in the latter case. However, either way, both the theoretical and empirical debate[2] on regional disparities in GDP per capita has largely revolved around the different meanings of the concept of convergence, especially those of beta and sigma convergence, depending on whether the focus is on the growth rate of GDP per capita in regions with maximum and minimum starting levels to reduce the gap, in the former case, or on diminishing the level of dispersion (measured in terms of standard deviation) of the set of regions, in the latter case.

Likewise, the different results of convergence analysis have also been due to the different convergence approaches employed [25]. In this sense, contributions to the literature on economic convergence can be highlighted from two main approaches: the classical approach and a more dynamic approach, which considers distribution and temporal evolution.

Within the classical approach, mention should be made of the contributions from scholars such as Barro [22]; Barro and Sala-i-Martin [26]; Sala-i-Martin [27], who introduce the dual concept of absolute and conditioned beta convergence, as well as those of López-Bazo [28] and Villaverde [29], who discuss clear and continuous convergence

[1] Cuervo and Morales [69] highlight three major groups of contributions concerned with explaining the uneven development of territories. These groups include contributions from the stream of cumulative causation theory since the late 1950s, neoclassical theory, centre-periphery and dependency theories from the 1960s, the theory of growth poles, New Economic Geography and the convergence hypothesis, which began around 2000 and whose main representatives are Barro [70] and Sala-i-Martín [71], Keynesian "economic base" models, post-Fordist or flexible accumulation current models, to the proliferation of contributions with a more territorial focus, considering the internal capacities of territories as a fundamental element of their development (endogenous growth models), with Alburquerque, F [23]. and Vázquez Barquero [24] as the most representative authors.

[2] See Eckey and Türck [72] who provided a synthesis of studies on regional convergence in Europe. In addition to beta and sigma convergence, other methodologies are used, taking into account spatial dependence, sector type, conditional convergence, and the existence of convergence clubs, as well as the so-called Marckof chains approach (based on the computation of transition matrices), among others.

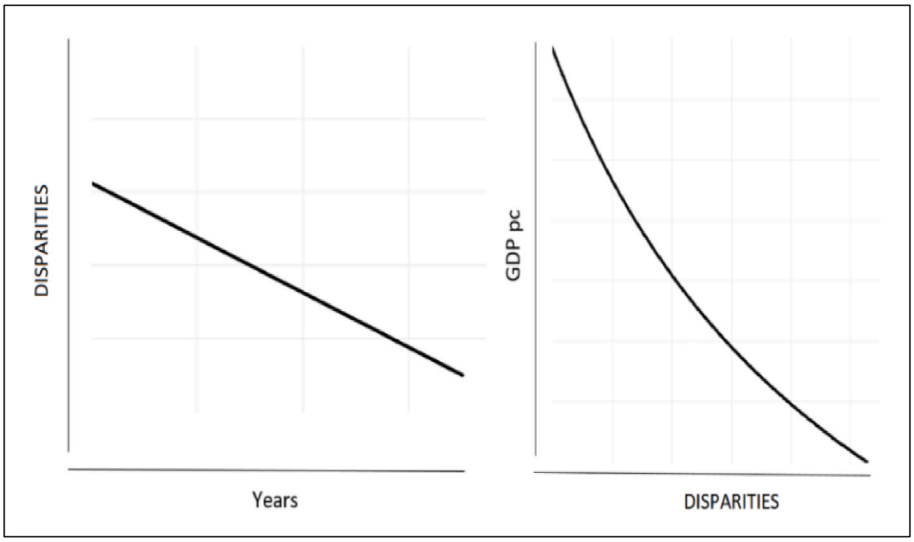

Fig. 1. Sigma convergence and territorial cohesion.
Source: Own elaboration

trends. Other notable research should include Dewhurst and Mutis [30]; Neven and Gouyette [31]; Cuadrado-Roura [32]; Armstrong [33]; Yin et al. [34]; Niebuhr and Schlitte [35]; Basile et al. [36], who analyse variations in the speed of regional convergence processes from the 1950s to the late 1990s. From the dynamic approach to disparity analysis, noteworthy contributions encompass those of López-Bazo et al. [37]; Tondl [38]; Cappelen et al. [39], which do not find clear evidence of sigma convergence in their analyses. Additionally, Rodil et al. [1] analyse the degree of regional convergence in the Eurozone (EU-12) from 1995 to 2011, employing sigma convergence tests (evolution of GDP per capita dispersion) and beta convergence (relationship between the initial level of GDP per capita of analysed regions and their rate of variation over time), yielding temporary results indicating both converging trends and weak convergence (negative slope regression line with very low quality of fit) or even diverging trends.

Furthermore, it is important to highlight other approaches to regional income analysis aimed at deriving results on development convergence. In this regard, researchers such as Bleaney and Nishiyama [40]; Ezcurra and Pascual [41]; Tselios [42], Bonesmo Fredriksen [43]; Rodríguez-Pose and Garcilazo [44]; Castells-Quintana, Ramos and Royuela [45]; Chambers and Dhongde [46], and Savoia [47], among others, all focus on measuring income inequality convergence. It is also crucial to mention that the results of convergence analyses can vary in sensitivity depending on the accessed dataset [48].

On the other hand, in the analysis of convergence, the impact of spatial influence should not be overlooked, both in terms of spatial lag and spatial error autocorrelation, expanding the traditional beta convergence model to include, through panel data models, treatment of spatial correlation among intercept terms [49–51]. Arbia et al. [52] analyse regional growth based on the effects of spatial dependence and spatial heterogeneity. Postiglione et al. [53], for example, work at NUTS-3 level of EU regions with a view to demonstrate a greater spatial interaction when analysing economic convergence. [54], Andrei et al. [55] and Chen [56] analyse in their research the possibility of measuring spatial dependence through the Moran's Index (1950) as an extension of Pearson's correlation coefficient to a spatial environment [57].

3. Convergence analysis and territorial economic cohesion

This section deals with both sigma and beta convergence analysis. In this regard, Barro and Sala-i-Martín [58] argue that sigma and beta convergence are related to each other. If there is no beta convergence (meaning the relationship is not inverse), then the dispersion of the indicator among regions continues to grow over time (sigma divergence). This is due to the fact that the poorer regions do not grow enough in terms of income, and that the richer regions do not reduce their growth, ultimately increasing the gap or inequality. However, beta convergence is a necessary, though not sufficient, condition.

3.1. Sigma convergence

As for sigma convergence, it usually means the convergence of regional economies, typically referring to the tendency for regional income levels or GDP per capita to equalize over time until they reach a "stationary" or "equilibrium" value. The literature identifies two types of convergence: beta convergence and sigma convergence. The first one establishes an inverse relationship between the growth rate and the initial level of GDP per capita,[3] while the second indicates the relationship between the dispersion of GDP per capita across regions and time.

Various measures known as static measures[4] of regional inequality are collected[5] by means of sigma convergence analysis In summary, these inequality measures are[6]: (i) Maximum/minimum ratio, (ii) Coefficient of variation, (iii) Relative mean deviation, (iv) Gini Index, (v) Atkinson Index, and (vi) Theil Index.

The dynamic analysis of the sigma convergence phenomenon is characterized by a process of reducing inequalities over time. Following the procedure described by Gomleksiz et al. (2017), the dynamic analysis of regional inequality measures leads us to formulate the following model of deterministic trend[7]:

$$I_t = \gamma_0 + \gamma_1 t + u_t \quad (1)$$

[3] To reach the "stationary" level common to all regions, regions starting with a low GDP per capita need to grow more compared to those starting with a higher GDP per capita.

[4] They are termed static because they are calculated for a specific period, typically one year.

[5] For a review of the literature on these measures, you can refer to: Jean et al., 2022, [54,73].

[6] See Dogan and Kındap [54] for further details on the measures.

[7] The evolution of time series could also have a stochastic nature [74].

where I_t is the measure of inequality. Sigma convergence implies $\gamma_1 < 0$.

Sigma convergence provides an instantaneous view of regional disparities and the dispersion of regional income. However, the measures themselves do not allow us to identify those regions/countries that are adjusting to the convergence process or undergoing a divergence process. In this regard [54], point out that sigma convergence is very useful but not sufficient to understand the convergence phenomenon.

Using the sigma convergence criterion, we can speak of territorial cohesion if the disparities among the set of regions decrease over time, thus contributing to explaining the economic development of the entire set of regions. In this regard, Garashchuk et al. [12] propose using the Gini, Atkinson, and Theil inequality measures as indicators of disparity and relate the disparities to economic development (see Fig. 1).

3.2. Beta convergence with cross-sectional analysis

The first comprehensive method for measuring beta convergence across economies was introduced by Barro and Sala-i-Martin [26,58]. For the time being, let us assume that we have observations at only two points in time: 0 and T. According to the multivariate proposal of Barro and Sala-i-Martin [59], the formulated equation will be as follows:

$$\frac{1}{T}ln\left(\frac{GDP_{iT}}{GDP_{i0}}\right) = x - \left(\frac{1-e^{-\beta T}}{T}\right)ln(GDP_{i0}) + \left(\frac{1-e^{-\beta T}}{T}\right)\ln\left(GDP_i^*\right) + u_{i0,T} \tag{2}$$

where $u_{i0,T}$ represents the effect of the error terms, between dates 0 and T; GDP_i^* is the steady-state level of GDP per capita; and x is the rate of technological progress, which we assume is the same for all economies and periods.

Observing equation (2), it is worth noting that it implies the term $\left(\frac{1-e^{-\beta T}}{T}\right)\ln\left(GDP_i^*\right)$ as an explanatory variable. Thus, not only does the growth rate of economy i depend on its initial level of GDP per capita, GDP_{i0}, but it also depends on the GDP per capita level in the steady state. Therefore, the concept of "conditional" convergence is applied, instead of “absolute” convergence: the growth rate of an economy negatively depends on its initial level of GDP after we "condition" it to its steady state.[8]

For our purposes, if we aim to estimate the convergence speed in the set of 242 NUTS-2 regions under a cross-section analysis, equation (2) can be rearranged and simply estimated by means of the following equation for the NUTS-2 regions:

$$y_i = \alpha + \gamma x_i + \gamma \ln\left(GDP_i^*\right) + u_i \tag{3}$$

where $y_i = ln\left(\frac{GDP_{i,T}}{GDP_{i,0}}\right)$, $x_i = \left(ln(GDP_{i,0}) - \frac{1}{N}\sum_{i=1}^{N} ln(GDP_{i,0})\right)$ and γ is the coefficient to be estimated for detecting the convergence.

Moreover, the coefficient α corresponds to the average growth [60] of the regions between periods 0 and T.[9]

A negative value of γ indicates convergence. A positive value indicates divergence. The convergence rate/speed (β)[10] can be calculated by using the following equality:

$$\gamma = -\left(1 - e^{-\beta T}\right) \tag{4}$$

$$\beta = -\frac{ln(1+\gamma)}{T} \tag{5}$$

In addition, half-life (τ), defined as the necessary period for half of the initial income inequalities to disappear, is another common indicator to characterize the speed of convergence. It is calculated as follows:

$$\tau = \frac{Ln(2)}{\beta} \tag{6}$$

However, in most studies, researchers choose to estimate equation (7), which represents "absolute" convergence which omits the steady states and possible spatial dependence:

$$y_i = \alpha + \gamma x_i + v_i \tag{7}$$

$$v_i = \gamma \ln\left(GDP_i^*\right) + \rho W y_i + \eta_{it} \quad |\rho| < 1$$

$$\eta_{it} = \lambda W \eta_{it} + \varepsilon_i \quad |\lambda| < 1$$

$$\mathrm{W} = \left[w_{ij}\right]_{nxn}$$

The matrix W has as many rows and columns as there are spatial units. Each element of the matrix is non-zero for pairs of regions which are neighbors. As a region cannot be its own neighbour, element $w_{ij} = 0$ for $i = j$ (Górna and Górna, 2015) [61]. The term Wy_i suggests a spatial autoregressive model (SAR) and the term $W\eta_{it}$ a spatial error model (SEM).

Even if we assume that the regions are not subject to spatial dependence ($\rho = \lambda = 0$), the problem is that to ensure the consistency of the LS estimator, and one of the following situations is required: i) consider that $GDP_i^* = GDP^*$ and ii) the steady state of each region is not related to its initial situation. The first is difficult to achieve when working with regions from different countries, and the second, if it occurs, implies a positive correlation. Admitting different steady states, the asymptotic bias when applying LS will be positive, so the convergence speeds will be biased downwards. In that case, it would be necessary to resort to a "conditional" convergence analysis, that is, to determine the convergence speed conditioned to the steady state of each region. The formulated equation will be as follows:

$$y_i = \alpha + \gamma x_i + \delta Z_i + \varepsilon_i \tag{8}$$

where Z_i collects the explanatory factors that may be related to the steady state but not to ε_i.

The analysis of conditional convergence requires substantial data on relevant variables for each region. Furthermore, the "conditions" in the convergence analysis could vary from one country to another, or in our case, from one NUTS-2 to another. For example, convergence may be hindered by structural differences in regional economies, differences in human capital, interregional taxation, the structure of interregional transfers, differences in political structure, etc. Therefore, a fruitful analysis of these "conditions" within any country or region would require a separate document, which is one reason why most empirical articles on regional convergence focus on a single country or regions within a single country.

In any case, even incorporating the variables the problem of

[8] Indeed, Barro and Sala-i-Martin [75] pointed out that beta convergence can be approached under two hypotheses: (i) absolute (unconditional) convergence and (ii) conditional convergence. The first addresses convergence under the assumption of the existence of a single steady state for all regions or countries, such that the growth of regions is solely explained by their initial endowments. The second hypothesis allows for the possibility that growth rates depend on the conditions of each economy in the region, as well as the quality of internal policies [76].

[9] By grouping the determinant variables of the "average" steady state of the set of regions or countries: the initial level of technological progress and its growth rate (Ao, x), the savings rate (s), the population growth rate (n), and the depreciation rate (δ) (see Ref. [76])..

[10] For the convergence speed to be defined, it must be the case that $-1 < \gamma < 0$. If $\gamma < -1$, then there is convergence, but the steady state is not defined. This can happen when there are regions that start from a very unfavourable initial situation and also have a steady state that is much lower than the average of the set of countries or regions.

inconsistency still exists if $\rho \neq 0$. Andrei et al. [55], for example, apply a cross-sectional model with special effects applied to digitization, conditioning it on other variables such as education or gross value added per capita.

3.3. Beta convergence with panel data

There have been many attempts to estimate the convergence speed using panel data analysis by controlling for fixed effects[11]: Caselli, Esquivel, and Laffort [62], for example, applied panel data for a representative cross-section of countries, while Canova and Marcet [63] or Gömleksiz et al. [64] worked with regional data. Barro and Sala-i-Martin [59] point out that a supposed advantage of panel data analysis over cross-sections is that the steady state does not have to be kept constant, as it can be estimated for different countries or regions implicitly by applying fixed effects.

Working with panel data to investigate the convergence hypothesis, we follow Barro and Sala-i-Martin's [59] proposal for a multivariate approach, but considering all fixed effects and the presence of spatial dependence:

$$y_{i,t} = \alpha + (u_i + u_t) + \gamma x_{i,t} + \nu_{it} \tag{9}$$

$$y_{i,t} = ln(GDP_{i,t}) - ln(GDP_{i,t-k}) \; x_{i,t} = \left(ln(GDP_{i,t-k}) - \frac{1}{NxT} \sum_{i=1}^{N} \times \sum_{t=1}^{T} ln(GDP_{i,t-k}) \right)$$

$$\nu_{it} = (\rho W y_{it} + \eta_{it}) \; |\rho| < 1$$

$$\eta_{it} = \lambda W \eta_{it} + \varepsilon_{it} \; |\lambda| < 1$$

where the coefficient α, in this case, corresponds to the average growth [60] of the regions within the panel and represents a steady state and a rate of technological change for the entire set of regions in the EU. On the other hand, u_i captures all the fixed effects among regions, representing, among others, the combined effect of institutions, factor endowments and relative location, along with initial technological differences. Similarly, u_t captures the fixed effects in the time units, that is, those changes over time that remain constant among regions, such as the rate of technological change [65]. All in all, the presence of the term u_i implies admitting specific steady states for each region and, therefore, panel analysis with fixed effects entails a conditional analysis. The number of growth periods considered in the analysis is k.[12]

The literature confirms that panel analysis with fixed effects implies a higher convergence speed than the one typically obtained through cross-sectional analysis. By using fixed effects, convergence speeds in the range of 12–20 percent annually are common, much higher than the 2 % when working with cross-sections or panels without fixed effects [59]. Following the same author, a potential issue with panel use is that for it to work, many time observations need to be included to capture long-term convergence. This can only be achieved by shortening the time periods within which the growth rate is calculated, i.e., using low values of k. In other words, the dependent variable tends to be the annual growth rate or the growth rate over two to five years. The problem with such short time periods is that the growth rates tend to capture short-term adjustments around the trend rather than long-term convergences. In particular, the existence of economic cycles tends to bias the long-term estimates of convergence speeds upward during recessions and reduce speeds during economic upswings.

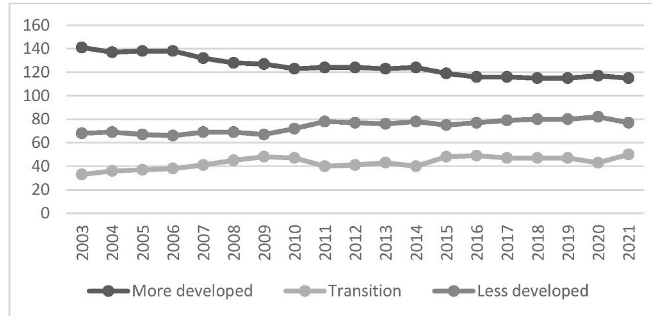

Fig. 2. Number of EU NUTS-2 according to its level of economic development. Source: Own elaboration based on data of Eurostat

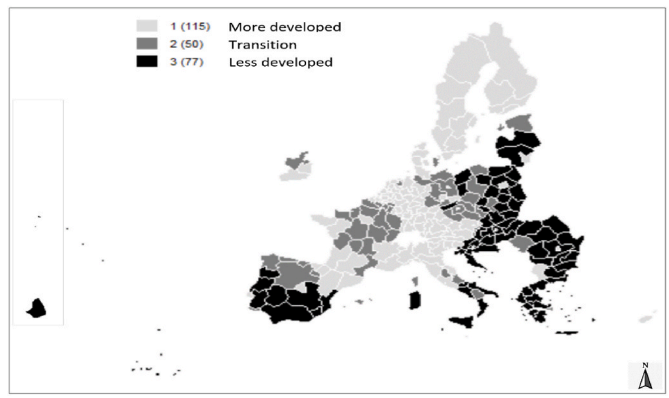

Fig. 3. Level of economic development of the EU regions (2021). Source: Own elaboration based on data of Eurostat

Moreover, a negative correlation[13] between $\boldsymbol{x}_{i,t}$ and ν_{it} would explain a negative bias in the results when omitting special dependence in the models, providing higher convergence values. To correct this bias, we consider the spatial effect by estimating the following equation:

$$y_{i,t} = \alpha + (u_i + u_t) + \gamma x_{i,t} + \rho W y_{it} + \eta_{it} \tag{10}$$

$$\eta_{it} = \lambda W \eta_{it} + \varepsilon_{it} \; |\lambda| < 1$$

Due to the endogeneity introduced by the term $Wy_{i,t}$, instrumental variables are applied using the Two-Stage Least Squares (2SLS) method using the initial situation of the regions and neighbouring regions as instruments: $x_{i,t}$ and $Wx_{i,t}$. For panel heterogeneity, fixed effects by cross-section and period are applied [66]. In this regard, the Moran's Index statistic [67] has been used to test for significant correlation between the variables or the absence of spatial correlation in the residuals ($\lambda = 0$).

From the perspective of beta convergence, the higher or lower territorial cohesion will be determined by the existence or absence of a single steady state for all regions. A single convergence rate implies higher territorial cohesion. Conversely, specific steady states or different convergence rates imply lower territorial cohesion.

The consideration of specific steady states entails a loss of territorial cohesion, even if a single convergence rate is maintained for all regions. In that case, fixed effects should be applied. However, we cannot rule

[11] The use of panel data may be justified if one wishes to control for the heterogeneity of the observed units ([66], pp. 4–7). In this case, the steady state is another source of heterogeneity. Fixed effect or random effects models are the two options for controlling for the heterogeneity that remains constant over time for each region [77]. Additionally, the fixed effects (FE) model is often applied when the differences between regions can be seen as parametric changes in the regression affecting the intercepts ([78], p. 293).

[12] The higher the value of k, the fewer the observations that are available in the panel.

[13] Such a negative correlation could be justified if cov $(x_{i,t}, \rho W y_{it}) < 0$

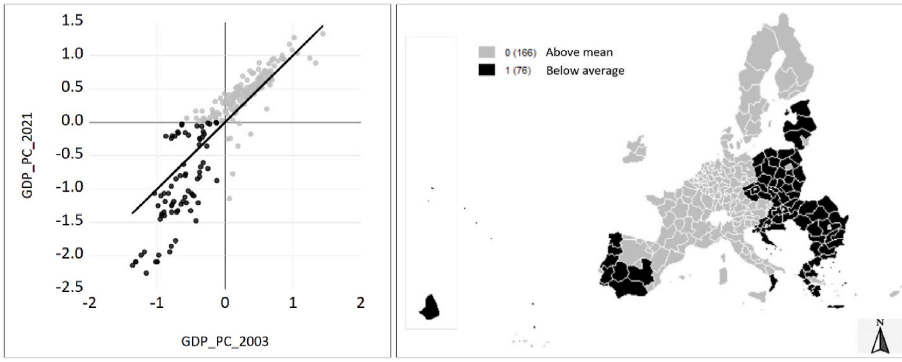

Fig. 4. Initial (2003) and final (2021) situation in panel data.
Source: Own elaboration based on data of Eurostat

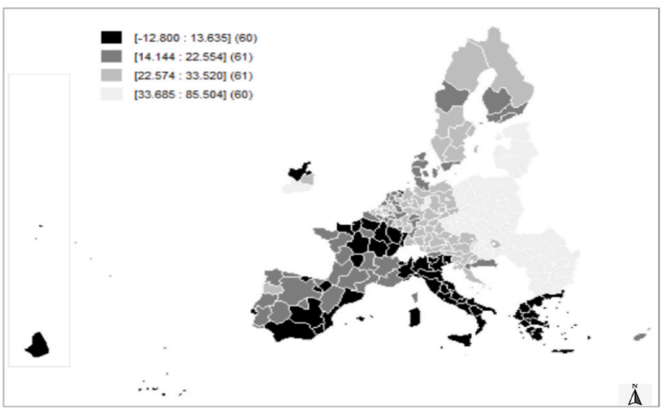

Fig. 5. Average growth rates for k = 10 of GDP (2003–2021).
Source: Own elaboration based on data of Eurostat

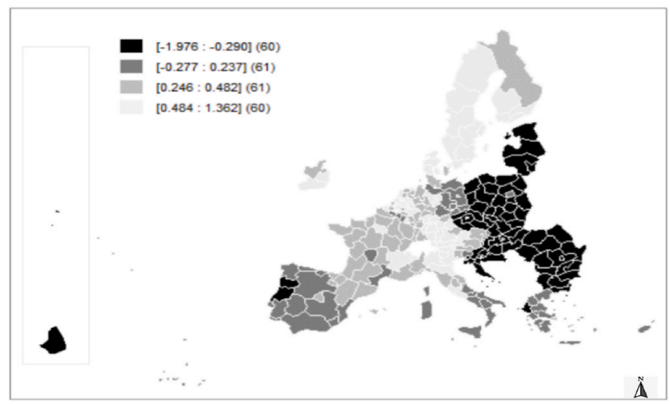

Fig. 6. Initial (t-10) mean values of GDP (2003–2021).
Source: Own elaboration based on data of Eurostat

out the existence of different convergence rates among regions, which could further reduce territorial cohesion by fragmenting regions into different groups or clusters (depending on these rates). This research aims to identify the existence of such clusters by analysing which regions may be divergent, which are more or less convergent, and whether ultimately Europe has different convergence rates based on regional levels of development. To do this using pool analysis data, we propose estimating the convergence rate from the following equation for each region with a lag k, that also allows ensuring the highest number of observations and once again represents a "conditional" convergence analysis:

$$y_{i,t} = \alpha + (u_i + u_t) + \gamma_i x_{i,t} + \nu_{it} \tag{11}$$

Considering the convergence speeds of each region $\beta_i = -\frac{ln(1+\gamma_i)}{T}$.

For the purpose of considering the spatial analysis, and mitigating the asymptotic bias in the convergence, the following specification has been proposed, which allows calculating region-specific convergence rates and a single spatial impact (β_i, ρ) using FE2SLS again[14]:

$$y_{i,t} = \alpha + (u_i + u_t) + \gamma_i \, x_{i,t} + \rho W y_{it} + \eta_{it} \tag{12}$$

$$\eta_{it} = \lambda W \eta_{it} + \varepsilon_{it} \; |\lambda| < 1$$

Again, the Moran's Index statistic has been used to test for significant correlation between the variables or the absence of spatial correlation in the residuals (λ = 0).

4. Data panel of GDP pc: observations and descriptive analysis

The panel data for GDP pc[15] consists of 4598 observations, distributed across 242 NUTS-2 regions and spanning 19 years (2003–2021). With respect to levels of economic development,[16] according to the official Eurostat classification, between 2003 and 2021 the number of most developed regions gradually decreased from 141 to 115, while the regions in transition and the less developed ones increased from 33 to 50 and from 68 to 77, respectively (see Fig. 2) (see Fig. 3).

Fig. 4 shows the initial and final situation of the regions in the panel with respect to the average. In the left graph, black points represent those regions that were below the average in 2003 and in 2021, while grey points represent the opposite. On the right side, a map shows the location of the regions. As can be seen, most of the regions that are below the average at the beginning and end of the period considered correspond to the currently less developed regions. However, the evolution of average growth differs.

If we calculate the average growth in the panel for long periods of 10 years, that is k = 10 (see Fig. 5), two zones of differentiated growth can be distinguished. The regions in the west and south of Europe show

[14] Identification obviously requires that the coefficients γ_i and ρ have constraints. They can be divided into common (across cross-sections and periods), cross-section-specific, and period-specific regressor parameter sets. As instruments, x_{it}, Wx_{it} can be used, which capture the initial conditions of the regions and the neighbouring regions, and the results of the indirect neighbouring regions (W^2x_{it}, W^3x_{it}), known as spillover effects [66,68].

[15] Gross domestic product per capita at current market prices by NUTS 2 regions (euros). The information used in this research is available at https://ec.europa.eu/eurostat/databrowser/view/nama_10r_2gdp__custom_11164473/default/table.

[16] The regions have been differentiated by levels of economic development according to the official EU Eurostat classification: https://ec.europa.eu/eurostat/web/regions/background.

growth rates between −12.8 % and 22.5 %, while the regions in the centre and east show much higher average growth rates, up to 85.5 % in the eastern regions.

These higher growth rates in the eastern regions are accompanied by a more unfavourable initial situation ten years ago (t-10) in these regions (see Fig. 6), which confirms the existence of a convergence process.

5. Results

This section describes the results obtained by applying different methods of analysis, such as sigma and beta convergence and a fixed effects model in panel data. Finally, the convergence speeds of the 242 EU NUTS-2 Regions were estimated during the period 2003–2021. Moreover, all these regions were clustered according to beta convergence results.

5.1. Sigma convergence and territorial economic cohesion analysis

Fig. 7(left graphs) depicts the temporal evolution of three disparity measures: maximum/minimum ratio, Gini Index (GI), and Coefficient of Variation (CV). As can be observed, the increasing trend in economic development is associated with a reduction in disparities. However, not all disparity measures follow a similar temporal evolution. Thus, only the measure based on extreme values shows a clear reduction over time, while disparities in the economic development of the 242 NUTS-2 regions and their dispersion (CV) are more influenced by economic cycles and the pandemic. Indeed, the GI inequality and the CV halted their reduction with the onset of the 2008 financial crisis. From then on, both indicators increased until the end of the crisis in 2014. Similarly, the pandemic also increased inequalities and dispersion in 2020.

Following the methodology of Garashchuk et al. [12], where levels of disparity with economic development were compared, the graphs on the right show the degree of cohesion between the disparities obtained for the 242 NUTS-2 regions and the economic development of the EU. As can be seen, cohesion measured through the coefficient of determination is much lower in terms of inequality and coefficient of variation (0.23 and 0.05 respectively) compared to the maximum/minimum ratio, where the coefficient rises to 0.76.

5.2. Beta convergence analysis with the same steady state

We begin by considering a single steady state in the set of the 242 NUTS-2 regions, only applying the least squares (LS) method.

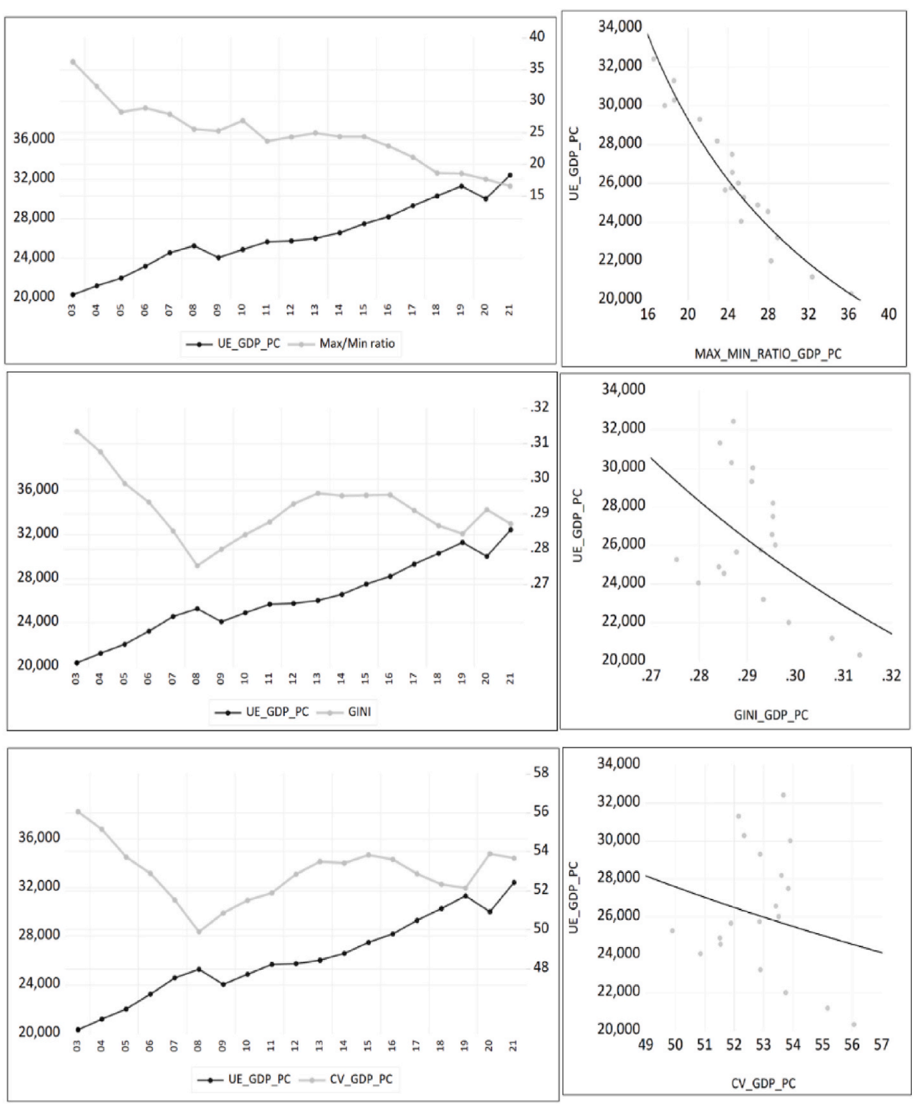

Fig. 7. Disparities in EU-242 and territorial economic cohesion.
Source: Own elaboration based on data of Eurostat

Table 1
Beta convergence (recursive estimate).

Cross-section	R^2	Alpha	Gamma	Speed (%)	Half-life (years)
2008	0.71	0.30	−0.25[a]	5.63	12.31
2009	0.68	0.24	−0.21[a]	4.01	17.30
2010	0.66	0.27	−0.22[a]	3.55	19.54
2011	0.62	0.30	−0.23[a]	3.32	20.89
2012	0.57	0.31	−0.24[a]	3.07	22.57
2013	0.55	0.31	−0.24[a]	2.80	24.80
2014	0.55	0.33	−0.25[a]	2.65	26.12
2015	0.55	0.37	−0.27[a]	2.58	26.90
2016	0.55	0.39	−0.27[a]	2.43	28.48
2017	0.57	0.43	−0.30[a]	2.53	27.37
2018	0.59	0.47	−0.32[a]	2.62	26.46
2019	0.59	0.51	−0.34[a]	2.63	26.40
2020	0.55	0.46	−0.35[a]	2.56	27.09
2021	0.58	0.55	−0.37[a]	2.58	26.89
Panel	**R^2**	**Alpha**	**Gamma**	**Speed (%)**	**Half-life (years)**
2008	0.62	0.27	−0.19[a]	4.16	16.66
2009	0.66	0.30	−0.22[a]	4.14	16.76
2010	0.67	0.33	−0.24[a]	3.98	17.40
2011	0.66	0.34	−0.25[a]	3.65	18.97
2012	0.65	0.34	−0.25[a]	3.19	21.72
2013	0.63	0.36	−0.26[a]	2.97	23.31
2014	0.61	0.37	−0.27[a]	2.80	24.75
2015	0.60	0.39	−0.27[a]	2.65	26.21
2016	0.60	0.41	−0.28[a]	2.51	27.62
2017	0.60	0.44	−0.29[a]	2.46	28.19
2018	0.60	0.48	−0.31[a]	2.46	28.15
2019	0.61	0.51	−0.33[a]	2.48	27.99
2020	0.61	0.53	−0.35[a]	2.53	27.36
2021	0.61	0.56	−0.37[a]	2.54	27.26

Note: Initial period (2003).
[a] p-value<0.01using Panel Correction Standard Errors (PCSE).
Source: Own elaboration based on data of Eurostat

Conducting a recursive estimation process starting from the initial year of 2003, Table 1 presents the different estimations of equation (7) (cross-section) and equation (9) (panel analysis with LS) from 2008 (k = 5) to 2021 (k = 18). The table includes estimations of α (average growth of the regions) and γ (convergence coefficient <0), the coefficient of determination R^2, as well as the convergence rate and the time required to halve the differences in GDP per capita from its steady state.

Fig. 8 reveals that as the temporal lag k in the growth rate increases, a gradual reduction in the convergence speed can be observed, until it stagnates around 2.5 %, with the results of the cross-section analysis and the panel analysis ultimately coinciding.[17]

The beta convergence analysis allows classifying regions into four groups or clusters (see Fig. 9): (i) "emerging" regions with low initial levels alongside high growth rates (LH), (ii) "declining" regions with initial levels above the average along with low growth rates (HL), (iii) "divergent" regions with high initial values and also high growth rates (HH), and finally (iv) "stagnant or vulnerable" regions with low initial levels and low growth rates (LL).

Indeed, using the average data of the 10-year growth rates (Fig. 6) and the average values of the initial values (Fig. 7), the scatter plot has been represented along with the regression line (between estimator[18]) (see Fig. 9). In this case, the convergence speed would be 2 %. On the right side of Fig. 9, the corresponding clusters are shown: 58 "emerging" regions, 121 "stagnant" regions, 29 "vulnerable" regions, and 34 "divergent" regions. The territorial cohesion based on the clusters would be

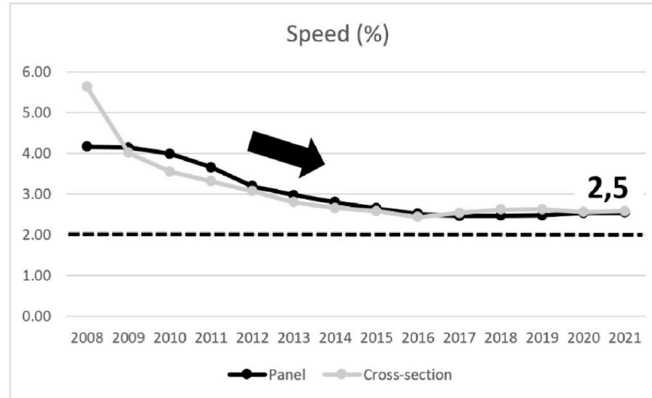

Fig. 8. Beta convergence (recursive analysis).
Source: Own elaboration based on data of Eurostat

0.74. Table 2 lists the NUTS-2 regions and the countries belonging to each cluster.

Fig. 10 presents the estimation using the between estimator and by periods, where it can be seen that less developed regions exhibit a higher slope (convergence speed) compared to more developed regions. Specifically, under the between estimator, the convergence speed in less developed regions is 4.8 % compared to 2.7 % in more developed regions (see Table 3). With the estimator by periods, the difference is more than double.[19]

5.3. *Fixed effects model in panel data: different steady state*

Each region must be conditioned to its own steady state, in addition to controlling for the rate of technological change. Using equation (9), panel analysis allows controlling for steady states that remain constant over time (one-way by cross-section) and controlling for fixed effects in regions, such as the rate of technological change (one-way by period). By controlling for fixed effects (see Table 4), the value reached by the least squares method (around 2 % in the literature) is surpassed, reaching values between 7 % and 11 % when applying one-way fixed effects by cross-section and two-way fixed effects, respectively.

The panel includes 2871 observations, which are grouped into four clusters: LH, HL, LL, and HH. Considering the convergent clusters, cohesion is 0.74, coinciding with the "between" estimator. Table 5 also includes the conditioned panel analysis for less developed and more developed regions. It can be observed that convergence speeds are higher in less developed regions when LS and one-way models are applied. More developed regions only surpass the convergence speed when controlling for fixed effects over time, including the rate of technological change, Likewise, territorial cohesion based on clusters reveals that it is higher precisely in less developed regions (0.87) than in more developed ones (0.60).

Table 5 summarises the recursive estimations controlling for fixed effects by region to measure the convergence speed based on 10-year growth rates. Starting with the one-way method, it can be observed that during the crisis period that began in 2008, the maximum speed increased from 12 % in 2009 to 21 % in 2014, before decreasing to 2.9 % during the recovery period leading up to the pre-pandemic era. Since the COVID-19 pandemic, the speed has risen again, reaching 7 %. Additionally, the speed is not defined for the years 2010 and 2011. The results become even more remarkable when controlling for all fixed effects (cross-sectional and temporal), with figures easily reaching 25 % and then stabilising around 10 % after the economic crisis of 2008. In this

[17] This estimation is biased downwards because, in fact, there are different steady states.
[18] The "between" estimator would represent a consistent estimator if steady states were not correlated with the initial situation of the regions. Otherwise, there will be a positive correlation that generates a positive bias, further reducing the estimation of the convergence speed.

[19] In any case, both estimators will be biased downwards in the presence of fixed heterogeneity in the regions (between) or over time (period).

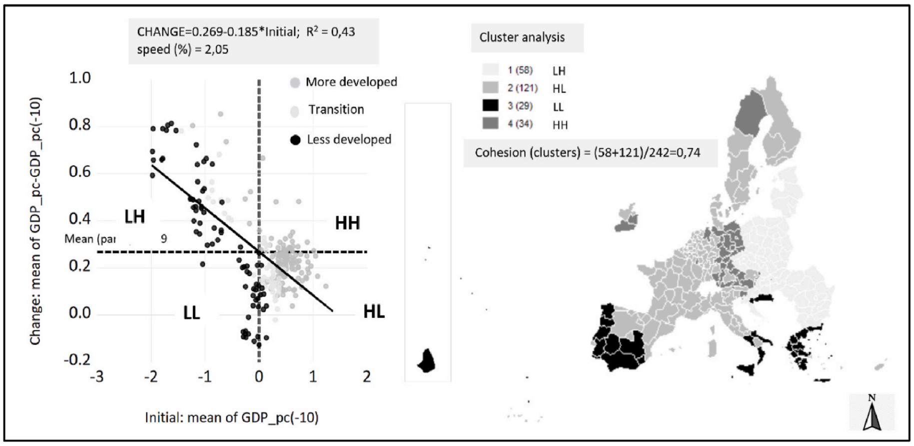

Fig. 9. Between estimator and cluster analysis: 2003–2021.
Source: Own elaboration based on data of Eurostat

Table 2
Regions NUTS-2 by cluster (between estimator: 2003–2021).

COUNTRY	NUTS2	COUNTRY	NUTS2	COUNTRY	NUTS2	COUNTRY	NUTS2
Bulgaria	6	Austria	3	Croatia	1	Austria	6
Croatia	3	Belgium	10	France	2	Belgium	1
Czech Republic	7	Cyprus	1	Greece	10	Czech Republic	1
Estonia	1	Denmark	4	Italy	4	Denmark	1
France	1	Finland	5	Portugal	6	Germany	18
Hungary	7	France	24	Spain	6	Hungary	1
Latvia	1	Germany	20	**Cluster LL**	**29**	Ireland	2
Lithuania	2	Greece	3			Luxembourg	1
Malta	1	Ireland	1			Slovakia	1
Poland	17	Italy	17			Slovenia	1
Romania	8	Nederlands	12			Sweden	1
Slovakia	3	Portugal	1			**Cluster HH**	**34**
Slovenia	1	Spain	13				
Cluster LH	**58**	Sweden	7				
		Cluster HL	**121**				

Source: Own elaboration based on data of Eurostat

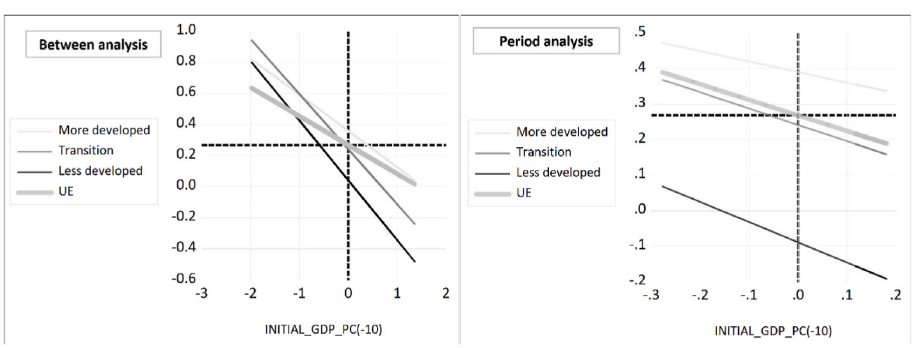

Fig. 10. Between and period estimator by development level (NUTS-2).
Source: Own elaboration based on data of Eurostat

case, the number of years where the "average" speed in the panel is not defined is higher, specifically for the period 2010–2014.

These results demonstrate that during economic downturns, inequalities are accentuated, and there is a need for greater growth to reach the specific steady state of each region, resulting in an increase in the "average" convergence speed in the panel. Controlling for fixed effects, the speed can easily reach 20 %. As a downside, this excessive increase can lead to the extreme of the speed not being defined due to the absence of an "average" steady state in the panel[20]. In the expansionary cycle starting in 2015, the convergence speed has gradually decreased, reaching 2.9 % (one-way) and 7.5 % (two-way).

[20] Indeed, if the "average" convergence speed in the panel is not defined, that is because it is not defined either for the majority of the regions.

Table 3
"Between" and "period" estimator.

	Between				Period			
	All	More	Trans.	Less	All	More	Trans.	Less
Obs	242	115	50	77	12	12	12	12
R^2	0.44	0.37	0.84	0.79	0.85	0.71	0.85	0.89
α	0.27	0.36	0.24	0.04	0.27	0.39	0.24	−0.09
p-value (α)	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
γ	−0.18	−0.23	−0.35	−0.38	−0.44	−0.30	−0.46	−0.57
p-value (β)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Speed (%)	2.05	2.65	4.36	4.84	5.76	3.51	6.13	8.40
Half-Life (years)	33.89	26.16	15.88	14.33	12.04	19.77	11.30	8.25
γ (low)	−0.21	−0.29	−0.40	−0.43	−0.57	−0.42	−0.59	−0.70
γ (high)	−0.16	−0.18	−0.31	−0.34	−0.31	−0.17	−0.33	−0.44

Source: Own elaboration based on data of Eurostat

Table 4
Panel analysis with fixed effects by NUTS-2 regions and development level.

All regions	LS	One-way (cx)	One-way (per)	Two-way
R^2	0.43	0.47	0.91	0.93
Alpha = growth rate (%)	26.85	26.85	26.85	26.85
Gamma	−0.21[a]	−0.20[a]	−0.53[a]	−0.67[a]
Speed convergence (%)	2.33	2.19	7.52	11.07
Half-Life (years)	29.80	31.65	9.22	6.26
LH	719	719	719	719
HL	1393	1393	1393	1393
LL	322	322	322	322
HH	437	437	437	437
Obs.	2871	2871	2871	2871
Cohesion (clusters)	0.74	0.74	0.74	0.74
Less developed regions	**LS**	**One-way (per)**	**One-way (cx)**	**Two-way**
R^2	0.76	0.79	0.93	0.95
Growth rate (%)	31.60	31.60	31.60	31.60
Gamma	−0.41[a]	−0.39[a]	−0.56[a]	−0.52[a]
Speed convergence (%)	5.20	4.92	8.13	7.36
Half-Life (years)	13.33	14.09	8.53	9.42
LH	366	366	366	366
HL	434	434	434	434
LL	67	67	67	67
HH	57	57	57	57
Obs.	924	924	924	924
Cohesion (clusters)	0.87	0.87	0.87	0.87
More developed regions	**LS**	**One-way (per)**	**One-way (cx)**	**Two-way**
R^2	0.37	0.39	0.83	0.89
Growth rate (%)	24.60	24.60	24.60	24.60
Gamma	−0.27[a]	−0.27[a]	−0.48[a]	−0.79[a]
Speed convergence (%)	3.14	3.10	6.51	15.70
Half-Life (years)	22.06	22.32	10.64	4.41
LH	322	322	322	322
HL	496	496	496	496
LL	306	306	306	306
HH	235	235	235	235
Obs.	1359	1359	1359	1359
Cohesion (clusters)	0.60	0.60	0.60	0.60

Note.
[a] p-value<0.01using Panel Correction Standard Errors (PCSE).
Source: Own elaboration based on data of Eurostat

Table 5
Beta convergence with fixed effects model (recursive estimates).

Panel (One-way)	R^2	Alpha	Gamma	Speed (%)	Half-life (years)
2008	0.90	0.27	−0.02	0.37	184.99
2009	0.94	0.30	−0.51[a]	11.94	5.80
2010	0.97	0.33	−1.03[a]	–	–
2011	0.97	0.34	−1.12[a]	–	–
2012	0.96	0.34	−0.75[a]	15.36	4.51
2013	0.98	0.36	−0.86[a]	19.92	3.48
2014	0.99	0.37	−0.91[a]	21.71	3.19
2015	0.99	0.39	−0.74[a]	11.08	6.26
2016	0.99	0.41	−0.58[a]	6.72	10.31
2017	0.99	0.44	−0.50[a]	4.95	14.01
2018	0.99	0.48	−0.47[a]	4.19	16.54
2019	0.99	0.51	−0.37[a]	2.90	23.87
2020	0.99	0.53	−0.73[a]	7.75	8.95
2021	0.99	0.56	−0.74[a]	7.55	9.18
Panel (Two-way)	**R^2**	**Alpha**	**Gamma**	**Speed (%)**	**Half-life (years)**
2008	0.93	0.27	−0.60[a]	18.50	3.75
2009	0.96	0.30	−0.66[a]	18.03	3.84
2010	0.98	0.33	−1.06[a]	–	–
2011	0.98	0.34	−1.29[a]	–	–
2012	0.97	0.34	−1.14[a]	–	–
2013	0.98	0.36	−1.06[a]	–	–
2014	0.99	0.37	−1.05[a]	–	–
2015	0.99	0.39	−0.95[a]	24.92	2.78
2016	0.99	0.41	−0.80[a]	12.26	5.65
2017	0.99	0.44	−0.77[a]	10.65	6.51
2018	0.99	0.48	−0.79[a]	10.41	6.66
2019	0.99	0.51	−0.70[a]	7.54	9.20
2020	0.99	0.53	−0.84[a]	10.88	6.37
2021	0.99	0.56	−0.88[a]	11.89	5.83

Note: speed and half-life only defined for $-1 < \gamma < 0$.
[a] p-value<0.01using Panel Correction Standard Errors (PCSE).
Source: Own elaboration based on data of Eurostat

5.4. Spatial analysis

Fig. 11 depicts the results of applying the Moran's Index to neighbouring regions (221 NUTS-2) for the year 2021, showing a clear significant correlation at 1 % between the initial values of the regions and their neighbors (0.829), between the growth rates of the regions and their neighbors (0.804), and a negative correlation between the initial values of the regions and their neighbors (−0.499). This latter negative correlation would explain the negative bias in the results when omitting special dependence in the models, providing higher convergence values.

Table 6 compiles the different estimates of the convergence rate using models (9) and (10). In order to compare the results, the estimates cover the period 2013–2021, for which the variables Wx_{it} and Wy_{it} could be calculated. As evident, under a single steady state, the POLS (Pooled Ordinary Least Squares) estimation yields a convergence rate of approximately 2 %, consistent with the findings of most cross-sectional analyses. When fixed effects are considered in the panel, for example, to control the steady states of all regions, the convergence rate ranges between 6 % (one-way) and 10 % (two-way). However, these estimates may be upwardly biased in the presence of special dependence, where the omission of the variable Wy_{it} can lead to upward biases, considering the negative correlation observed with Moran's Index.

When we consider spatial dependence, endogeneity is controlled by using x_{it} and the initial conditions of the neighbors Wx_{it} as instrumental variables (2SLS). The estimates, also controlling for fixed effects (FE2SLS), range between approximately 3 % (one-way) and 7 % (two-way). However, the presence of spatial correlation in the model errors

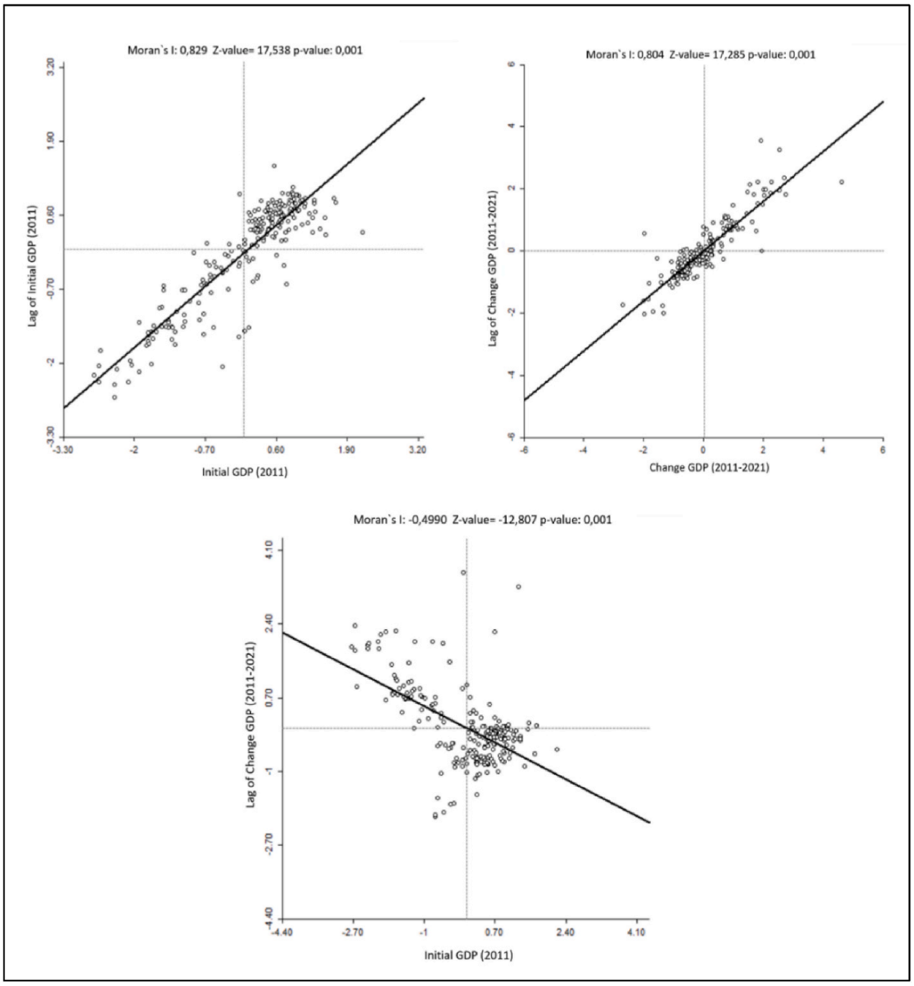

Fig. 11. Moran's Index statistics.
Source: Own elaboration based on data of Eurostat

Table 6
Estimation results models (9) and (10).

	No Spatial Model			Spatial Model	
	POLS	Fixed Effects (eq. (9))		FE2SLS (eq. (10))	
		One-way	Two-Way	One-way	Two-Way
α	0.2440***	0.2572***	0.2656***	0.0969***	0.1983***
	(0.0038)	(0.0015)	(0.0013)	(0.0093)	(0.0131)
x_{it}	−0.1711***	−0.4568***	−0.6398***	−0.2264***	−0.5184***
	(0.0052)	(0.0123)	(0.0167)	(0.0166)	(0.0265)
Wy_{it}			0.6466***	0.6466***	0.2664***
			(0.0373)	(0.0373)	(0.0523)
R^2	0.31	0.9158	0.9471	0.9463	0.9544
λ = 0 (Moran's I): 2013				−0.1390***	0.2060***
λ = 0 (Moran's I): 2017				−0.1520***	0.1730***
λ = 0 (Moran's I): 2021				0.1100***	0.5130***
Speed (%)	1.9	6.1	10.2	2.6	7.3

Notes:*,**,*** indicate significance at the 10 %, 5 % and 1 % level.
Robust standard errors are displayed in parentheses.
Instruments: x_{it} and Wx_{it}.
Source: Own elaboration based on data of Eurostat

has been detected using Moran's index, although in most cases, the levels are low.

Using equations (11) and (12), the convergence speeds of all regions have now been estimated (Table 7). In this case, the estimation using only fixed effects (equation (11)) provides a very high average convergence speed of 18.7 %, a figure that reduces to 8 % when we also consider spatial dependence to estimate the specific speeds of each region (equation (12)). As can be seen, fixed effects and instrumental variables (FE2SLS) have been applied, using x_{it}, Wx_{it} as instruments, which capture the initial conditions of the regions and neighbouring

Table 7
Estimation results models (11) and (12).

	No spatial Model	Spatial Model
	FE (eq. (11))	FE2SLS (eq. (12))
	Two-Way	Two-Way
α	0.3573*** (0.0178)	0.2163*** (0.0186)
x_{it}	−0.8459[a]	−0.5524[a]
Wy_{it}		0.5442*** (0.0523)
R^2	0.9657	0.9785
λ = 0 (Moran's I): 2013		−0.116***
λ = 0 (Moran's I): 2014		−0.209***
λ = 0 (Moran's I): 2015		−0.171***
λ = 0 (Moran's I): 2016		0.122**
λ = 0 (Moran's I): 2017		0.081*
λ = 0 (Moran's I): 2018		−0.009
λ = 0 (Moran's I): 2019		0.070*
λ = 0 (Moran's I): 2020		0.069
λ = 0 (Moran's I): 2021		−0.016
Speed (%)	18.7	8.0

Notes:*,**,*** indicate significance at the 10 %, 5 % and 1 % level.
Robust standard errors are displayed in parentheses.
Instruments: x_{it}, Wx_{it}, W^2x_{it}, W^3x_{it}.
[a] Mean of gamma coefficients.
Source: Own elaboration based on data of Eurostat

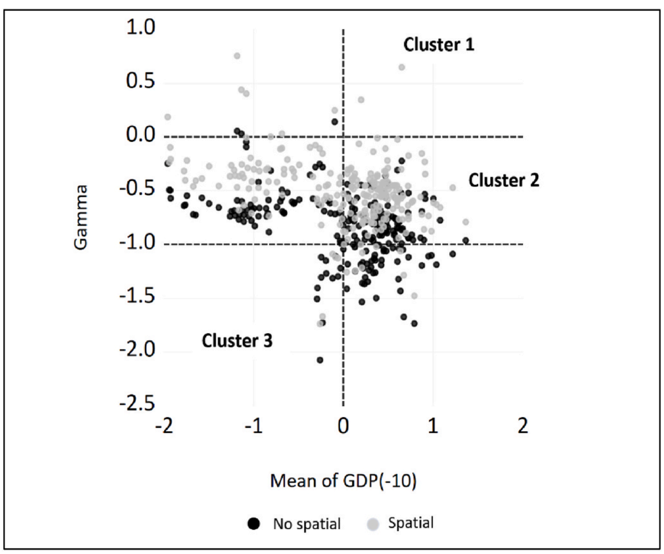

Fig. 12. Clusters by beta convergence in 242 regions NUTS-2.
Source: Own elaboration based on data of Eurostat

regions, and the results of indirect neighbouring regions [66,68] (W^2x_{it}, W^3x_{it}), known as spillover effects. The results of the average convergence speed are similar to those obtained with the panel under equation (10), confirming the robustness of the results and the method applied. In this case, applying Moran's index to the model residuals shows very low levels of spatial dependence, even an absence of dependence starting from the year 2018.

Fig. 12 represents the parameter gamma estimations based on initial values in the panel, and identifies three groups or clusters. Cluster 1 ($\gamma > 0$) consists of divergent regions, cluster 2 ($-1<\gamma < 0$) represents convergent regions, and finally, cluster 3 ($\gamma < -1$) represents convergent regions without a defined convergence speed.

Observing Fig. 12 we can conclude that convergence speeds, when controlling for spatial dependence, are generally lower than those obtained without spatial dependence.

6. Discussion and conclusions

The literature review on territorial economic cohesion shows that both the theoretical and empirical debate regarding regional disparities in GDP per capita has largely revolved around the different meanings of the concept of convergence, especially those of beta and sigma convergence, depending on whether the focus is on the growth rate of GDP per capita in regions with maximum and minimum starting levels to reduce the gap, in the former case, or on diminishing the level of dispersion (measured in terms of standard deviation) of the set of regions, in the latter case.

On the other hand, the ability to obtain an accurate image of cohesion and its different processes is not only limited by a method, but also to a large extent by available data and indicators.

However, most studies on regional convergence have been based on an analysis of "absolute" cross-section convergence, which implies the existence of a single steady state for all regions, with convergence speed estimates biased downwards. A higher estimation of this speed has only been ensured in cases where "conditional" convergence is considered. The recourse to "absolute" convergence is mainly due to the difficulty of finding information on a common set of explanatory variables that are correlated with the different steady states for the different regions or countries. Therefore, many studies have been limited to identifying regions as homogeneous as possible, working for example with the regions of a country or with countries that share a common economic policy, such as the EU. In all these studies, the literature reports convergence speeds ranging around 2 per cent. Even so, most of the time these figures are biased downwards due to the analysis of "absolute" convergence.

This research confirms that cross-section analysis is equivalent to panel analysis by the least squares method (LS) by providing values slightly higher than 2 per cent. Working with the 242 NUTS-2 regions of the EU for the period 2003–2021, it has been shown that if we control the different steady states of each region, the convergence speed reaches 7 per cent. If we also control the rates of technological progress common to the regions, the speed increases to 11 per cent.

This "conditional" convergence analysis may vary if we also consider the levels of economic development, the existence of economic cycles, and their disruption due to possible crises or extraordinary events, such as the financial crisis of 2008 and Covid- 2019, which have significantly increased convergence speeds (within 22 % and 8 %, respectively). It is also noteworthy that if we control for technological change rates, the most developed regions show very high convergence speeds of 15 per cent compared to 7 per cent in the less developed regions, the results that would rise to 25 % and 12 % due to the financial crisis 2008 and COVID-19, respectively. In other words, the impact of the financial crisis was nearly double that of the pandemic on convergence speed.

If we also consider spatial analysis, it has been observed that convergence speeds decrease by 3 %–8 %, as neighbouring regions contribute to explaining a significant part of regional growth. In this regard, we can conclude that neighbouring regions play a critical role in explaining the region's economic performance, leading to a slower but more interconnected convergence process.

Finally, beta convergence analysis has allowed identifying the following groups of regions regardless of economic cycles: 58 low-high (emerging) regions, 121 high-low (stagnant) regions, 29 low-low (vulnerable) regions, and 34 high-high (divergent) regions. The presence of vulnerable and divergent regions is an alarming symptom of a lack of territorial cohesion that should be reported to the European Commission for further corrections of the EU cohesion policy with regard to the control and distribution of funds.

Following this line of research, and using Spatial Dynamic Panel Data, we continue to work on delving deeper into the levels of spatial dependence that regions may have on key factors such as productivity, employment, investments, and human capital, among others, not limited only to GDP per capita as in this contribution when explaining regional growth.

Conflict of interest statement

All authors declare that they have no conflicts of interest.

CRediT authorship contribution statement

Fernando Isla-Castillo: Writing – review & editing, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Anna Garashchuk:** Writing – original draft, Investigation, Conceptualization. **Pablo Podadera-Rivera:** Writing – review & editing, Supervision, Project administration, Investigation, Conceptualization.

Data availability

Data will be made available on request.

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References

[1] Rodil O, Vence X, Sánchez MC. Disparidades en la Eurozona: el debate de la convergencia regional a la luz de las asimetrías en la estructura productiva. Ekonomiaz 2014;86.
[2] Faludi A. Del desarrollo espacial europeo a la política de cohesión territorial. Estudios Regionales 2006;40(6):667–78.
[3] Faludi A. Territory: an unknown quantity in debates on territorial cohesion. Refereed article no. 51 (retrieved from, https://repository.tudelft.nl/islandora/object/uuid%3Add9603ae-2a9a-4591-b7c5-c8e3c496d5fc; 2013.
[4] Abrahams G. What "is" territorial cohesion? What does it "do"?: essentialist versus pragmatic approaches to using concepts. Eur Plann Stud 2014;22(10):2134–55.
[5] Medeiros E. Territorial cohesion: an EU concept. Eur J Sustain Dev 2016;60. retrieved from, https://journals.polito.it/index.php/EJSD/article/view/216.
[6] Podadera P, Calderón FJ. Rethinking the territorial cohesion in the EU: institutional and functional elements of the concept. E J Eur Stud 2019;10(2): 41–62.
[7] Moreno S, Polido A, Teles F, Silva P, Rodrigues C. Territorial innovation models in less developed regions in Europe: ¿the quest for a new research agenda? European Planning Studies; Abingdon Tomo 2020;28(8):1639–66.
[8] Medeiros E, Scott J, Ferreira R, Boijmans P, Verschelde N, Guillermo-Ramírez M, Gyula O, Peyrony J, Soares A. European territorial cooperation towards territorial cohesion? Reg Stud 2023. https://doi.org/10.1080/00343404.2023.2226698.
[9] Medeiros E, Zaucha J, Ciołek D. Measuring territorial cohesion trends in Europe: a correlation with EU Cohesion Policy. Eur Plann Stud 2023;31(9):1680–884. https://doi.org/10.1080/09654313.2022.2143713.
[10] Weckroth M, Moisio S. Territorial cohesion of what and why? The challenge of spatial justice for EU's cohesion policy. Soc Incl 2020;8(4):1–11. https://doi.org/10.17645/si.v8i4.3241.
[11] Cabeza I, Gutiérrez F. Cohesión territorial: de los alcances a la conceptualización. Rev Geogr Venez 2015;56(2):293–308.
[12] Garashchuk A, Isla Castillo F, Podadera Rivera P. Economic cohesion and development of the European union's regions and member states - a methodological proposal to measure and identify the degree of regional economic cohesion". Soc Econ Plann Sci 2023:101621.
[13] Islam N. What have we learnt from the convergence debate? J Econ Surv 2003;17 (3). https://doi.org/10.1111/1467-6419.00197.
[14] Podadera P. *La cohesión en el proceso de integración de la UE: de la política regional a la política de cohesión económica, social y territorial e implicaciones de política económica*. En: Molina del Pozo Martín, P.C. Derecho de la Unión Europea e Integración Regional (Liber Amicorum al Prof. Dr. Carlos Francisco Molina del Pozo). Valencia: TIRANT LO BLANCH; 2020. p. 1611–26.
[15] Solow RM. A contribution to the theory of economic growth. Q J Econ 1956;70: 65–94.
[16] Solow RM. Technical change and the aggregate production function. Rev Econ Stat 1957;39:312–20.
[17] Romer P. Increasing returns and long run growth. J Polit Econ 1986;94.
[18] Romer P. Endogenous technological change. J Polit Econ 1990;98:S71–102.
[19] Lucas RE. On the mechanics of economic development. Journal of Monetary Economies 1989;22.
[20] Abramovitz M. Thinking about growth. Cambridge: Cambridge Univ. Press; 1989.
[21] Rebelo S. Long-Run policy analysis and long run growth. J Polit Econ 1991;99: 500–21.
[22] Barro R. Economic growth in a cross section of countries. Q J Econ 1991;106: 407–43.
[23] Alburquerque F. El enfoque del desarrollo económico local. Buenos Aires: OIT; 2004.
[24] Vázquez Barquero A. In: Bosch Antoni, editor. Las nuevas fuerzas del desarrollo; 2005. Barcelona.
[25] Maza A, Villaverde J, Hierro M, Gutiérrez-Portilla P, Gutiérrez-Portilla M. Disparidades regionales en la ue-15: un enfoque de convergencia. Invest Economica 2014;73(289):35–58.
[26] Barro RJ, Sala-i-martin X. Convergence across states and regions. Brookings Pap Econ Activ 1991;1:107–82.
[27] Sala-i-martin X. La riqueza de las regiones. Evidencia y teoría sobre crecimiento regional y convergencia. Moneda Credito 1994;198:13–80.
[28] López-Bazo E. Growth and convergence across economies. The experience of the European regions. In: en Fingleton B, Eraydin A, y Paci R, editors. Regional economic growth, SMEs and the wider Europe. Ashgate; 2003. p. 49–74. Aldershot et al.
[29] Villaverde J. Regional convergence, polarisation and mobility in the European Union, 1980-1996. European Integration 2003;25:73–86.
[30] Dewhurst JHL, Mutis-Gaitan H. Varying speeds of regional GDP per capita convergence in the European Union, 1981-91. In: en Armstrong HW, y Vickerman RW, editors. Convergence and divergence among European regions. Pion Limited; 1995. p. 22–39.
[31] Neven D, Gouyette C. Regional convergence in the European community. J Common Mark Stud 1995;33(1):47–65.
[32] Cuadrado-Roura JR. Regional convergence in the European union. From hypothesis to the actual trends. Ann Reg Sci 2001;35:333–56.
[33] Armstrong HW. European union regional policy: Reconciling the convergence. In: Roura en Cuadrado, J.R. y Parellada M, editors. Regional convergence in the European union: facts, prospects and policies. Springer-Verlag; 2002. p. 231–72. Berlín et al.
[34] Yin L, Zestos GK, Michelis L. Economic convergence in the European union. J Econ Integrat 2003;18:188–213.
[35] Niebuhr A, Schlitte F. Convergence, trade and factor mobility in the European union. Implications for enlargement and regional policy. Intereconomics 2004;39: 167–76.
[36] Basile R, Nardis S, Girardi A. Regional inequalities and cohesion policiesm in the European union. 2005. camecon.com/services/europe/Downloadable%20files/isae%20paper.PDF.
[37] López-Bazo E, Vaya E, Mora A, Suriñach J. Regional economic dynamics and convergence in the European union. Ann Reg Sci 1999;33:343–70.
[38] Tondl G. *Convergence after divergence?* Regional growth in Europe. Viena: Springer; 2001.
[39] Cappelen A, Castellacci F, Fagerberg J, Verspagen B. Regional disparities in income and unemployment in Europe. In: En Fingleton B, editor. European regional growth. Springer; 2003. p. 323–50. Berlin et al.
[40] Bleaney M, Nishiyama A. Convergence in income inequality: differences between advanced and developing countries. Econ Bull 2003;4:1–10.
[41] Ezcurra R, Pascual P. Is there convergence in income inequality levels among the European regions? Appl Econ Lett 2005;12(12):763–7. https://doi.org/10.1080/13504850500245669.
[42] Tselios V. Growth and convergence in income per capita and income inequality in the regions of the EU. Spatial Econ Anal 2009;4(3):343–70. https://doi.org/10.1080/17421770903114711.
[43] Bonesmo Fredriksen K. Income inequality in the European union, OECD economics department working papers, No. 952. Paris: OECD Publishing; 2012. https://doi.org/10.1787/5k9bdt47q5zt-en.
[44] Rodríguez-Pose A, Garcilazo E. Quality of government and the returns of investment: examining the impact of cohesion expenditure in European regions. Reg Stud 2015;49(8):1274–90. https://doi.org/10.1080/00343404.2015.1007933.
[45] Castells-Quintana D, Ramos R, Royuela V. Income inequality in European Regions: recent trends and determinants. Rev Reg Res 2015;35:123–46. https://doi.org/10.1007/s10037-015-0098-4.
[46] Chambers D, Dhongde S. Convergence in income distributions: evidence from a panel of countries. Econ Modell 2016;59(C):262–70. https://doi.org/10.1016/j.econmod.2016.07.019.
[47] Savoia F. Income inequality convergence among EU regions. Soc Econ Plann Sci 2024;92:101803.
[48] Lustig N, Teles D. Inequality convergence: how sensitive are results to the choice ofdata? ECINEQ 2016. Working Paper 412: 2-41. http://www.ecineq.org/milano/WP/ECINEQ2016-412.pdf.
[49] Anselin L. Exploring spatial data with GeoDaTM: a workbook. Center for spatially integrated social science; 2005.
[50] Elhorst JP. Spatial econometrics: from cross-sectional data to spatial panels, vol. 479. Heidelberg: Springer. European Journal of Spatial Development; 2014. p. 480. Refereed article no. 51 (retrieved from, https://repository.tudelft.nl/islandora/object/uuid%3Add9603ae-2a9a-4591-b7c5-c8e3c496d5fc.
[51] Arbia G, Piras G. Convergence in per-capita GDP across European regions using panel data models extended to spatial autocorrelation effects. No 51, ISAE Working Papers from ISTAT. 2005. Available at: https://econpapers.repec.org/paper/isawpaper/51.htm.
[52] Arbia G, Basile R, Piras G. Using spatial panel data in modelling regional growth and convergence. ISAE Working Paper No. 55, Available at: SSRN: https://ssrn.com/abstract=936321; 2005. https://doi.org/10.2139/ssrn.936321.

[53] Postiglione P, Cartone A, Panzera D. Economic convergence in EU NUTS 3 regions: a spatial econometric perspective. Sustainability 2020;12(17):6717.
[54] Dogan T, Kındap A. Regional economic convergence and spatial spillovers in Turkey. International Econometric Review 2019;11(1):1–23. https://doi.org/10.33818/ier.448603.
[55] Andrei JV, Chivu L, Sima V, Georgiana Gheorghe I, Nancu D, Mircea Duică M. Investigating the digital convergence in European Union: an econometric analysis of pitfalls and pivots of digital economic transformation. Economic Research-Ekonomska Istraživanja 2023;36:2. https://doi.org/10.1080/1331677X.2022.2142814.
[56] Chen Y. Spatial autocorrelation equation based on Moran's index. Sci Rep 2023;13 (1). https://doi.org/10.1038/s41598-023-45947-x. 19296–19296.
[57] Diawara N, Waller L, King R, Lorio J. Simulations of local Moran's index in a spatio-temporal setting. Commun Stat Simulat Comput 2019;48(6):1849–59. https://doi.org/10.1080/03610918.2018.1425441.
[58] Barro RJ, Sala-i-martin X. Convergence. J Polit Econ 1992;100:223–51.
[59] Barro RJ, Sala-i-martin X. Economic growth. second ed. Cambridge: The MIT Press; 2004.
[60] Darvas Z, Collin AM, Mazza J, Midoes C. Effectiveness of cohesion policy: learning from the project characteristics that produce the best results. Directorate general for internal policies. European Parliament; 2019. April.
[61] Górna J, Górna K. Analysis of convergence of European Regions with the use of composite index. Statistics in transition new series 2015;16(2):265–78.
[62] Caselli F, Esquivel G, Lefort F. Reopening the convergence debate: a new look at cross-country growth empirics. In: Working Papers Banco Central de Chile, Banco Central de Chile; 1997. p. 1–41. https://EconPapers.repec.org/RePEc:chb:bcchwp:03.
[63] Canova F, Marcet A. The poor stay poor: non-convergence across countries and regions. Unpublished. Universitat Pompeu Fabra; 1995.
[64] Gömleksiz M, Şahbaz A, Mercan B. Regional economic convergence in Turkey: does the government really matter for? Economies 2017;5(3):27. https://doi.org/10.3390/economies5030027.
[65] Yudon Y, Weeks M. Provincial income convergence in China, 1953-1997: a panel data approach. Cambridge Working Papers in Economics, Facultad de Economía, Universidad de Cambridge; 2000. https://EconPapers.repec.org/RePEc:cam:camdae:0010.
[66] Baltagi B. Econometric analysis of panel data. third ed. Chichester: John Wiley & Sons Ltd; 2005.
[67] Moran PAP. Notes on continuous stochastic phenomena. Biometrika 1950;37(1):17–23.
[68] Kelejian HH, Prucha IR. A generalized spatial two-stage least squares procedure for estimating a spatial autoregressive model with autoregressive disturbances. J R Estate Finance Econ 1998;17:99–121. https://doi.org/10.1023/A:1007707430416.
[69] Cuervo Morales MY, Morales Gutiérrez FJ. Las teorías del desarrollo y las desigualdades regionales: una revisión bibliográfica. Análisis Económico 2009;55 (XXIV).
[70] Barro R. Determinants of economic growth – a cross-country empirical study. Cambridge, Massachusetts: MIT Press; 1997.
[71] Sala-i-martin X. Apuntes de crecimiento económico. España: Antonio Bosch; 2000.
[72] Eckey HF, y Türck M. Convergence of EU-regions. A literature report. Investigaciones Regionales 2007;10:5–32.
[73] Shankar R, Shah A. Bridging the economic divide within nations: a scorecard on the performance of regional development policies in reducing regional income disparities. World Dev 2003;31(8):1421–41. https://doi.org/10.1016/S0305-750X(03)00098-6.
[74] Hill C, Griffiths W, Lim G. Principles of econometrics. fifth ed. Wiley; 2018. https://doi.org/10.1023/A:1009746629269.
[75] Barro RJ, Sala-i-martin X. Technological diffusion, convergence, and growth. J Econ Growth 1997;2:2–26s.
[76] León G. Crecimiento y convergencia económica: Una revisión para Colombia. Dimensión Empresarial 2017;11(1):61–76. https://doi.org/10.15665/rde.v11i1.161.
[77] Wooldridge JM. Econometric analysis of cross section and panel data. second ed. Cambridge: MIT Press; 2010.
[78] Greene WH. Econometric analysis. fifth ed. New Jersey: Prentice Hall; 2003.

Fernando Isla Castillo has a PhD in Business Administration and Management from the University of Malaga (1998), and is a professor at the University of Malaga, Department of Applied Economics (Statistics and Econometrics). He has taught various Econometrics subjects in Undergraduate and Postgraduate degrees. He is director of the Economic Forecast Chair at the University of Malaga (2019–), and a member of the HISPALINK-Andalusia Team that is integrated into the HISPALINK network formed by different Spanish universities dedicated to the economic forecasts of the regions in Spain (1995–). His publications and research projects cover: regional modelling, prediction and simulation techniques with econometric models, Monte Carlo simulation methods applied to econometrics, input–output tables modelling and multiplier analysis.

Anna Garashchuk, PhD Program in Economics and Business (Universidad de Málaga, Spain) is a researcher at the Jean Monnet Centre of Excellence on European and Global Studies and Research, Universidad de Málaga, Spain. She has a Master's in International Cooperation and Politics of Development. At present, she is an interim professor at the University of Malaga, Department of Applied Economics (Economic Structure). In collaboration with other researchers, she has recently published in such Journals as Humanities and Social Sciences Communications, Socio-Economic Planning Sciences, Panoeconomics, European Review, and many others.

Pablo Podadera Rivera has a PhD in Economics from the University of Malaga (1998), and a Master's Degree in European Studies (European Initiative EUROFORM), 1995. He is Professor at the University of Malaga (Department of Economic Policy of the Faculty of Economics), in which he teaches various undergraduate and graduate subjects, including 'Economics and Politics of the European Union' and 'European Union and Development'. He is Jean Monnet 'Ad Personam' Professor of European Economy and Economic Policy (2012–) and Director of the Jean Monnet Centre of Excellence (UMA-JMCE) of the University of Malaga (2017–). In addition, he is the national representative of the COST-European Cooperation in Science and Technology Program, in Action: "INTERGOVERNMENTAL COORDINATION FROM LOCAL TO EUROPEAN GOVERNANCE (IGCOORD)-CA20123 (https://igcoord.eu/); he is Director of the Research Group: Economic Policy, European Union and Global Studies (SEJ-108) (2017–), a member of ECSA-SPAIN (Spanish Association of University Professors and Researchers Specializing in European Integration) (2002–), a member of the Association for Evolutionary Economics (AFEE) (2012–), a member of the executive committee of the International Association of Applied Economics (ASEPELT) (2015–), a member of the editorial board of the magazine *Derecho y Economía de la Integración*, Juri-Dileyc, Alcalá De Henares (2015–), a member of the editorial board of the Juruá editorial house (Lisbon, Brazil) (2005-). His publications and research projects are on: local development; economy and politics of the European Union; technological innovation and territorial development; international cooperation; economic, social and territorial cohesion in the EU; EU and globalization.