Analysing Interregional Disparities in the EU.
An Application of Beta and Sigma Convergence

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A B S T R A C T

Implementation of regional policy has a long tradition in the European economic space. Since the beginning of European integration in the mid-20th century, a common regional policy based on cohesion, solidarity, and redistribution began to take shape. This paper is focused on the examination of the development of regional disparities in EU27 (27 European Union member states). This phenomenon is characterized by its 'inertial' nature, despite the implementation of a relatively generous system of instruments, particularly financial ones, in less developed countries and regions. However, it cannot be unequivocally proven that this is caused by inefficient, inappropriate, or misdirected redistribution within the EU27. The neoclassical concept of β-convergence and σ-convergence enables the identification of the RD's (Regional Disparities) tendency within more than 20 years. To prove the results as accurately as possible and compare the development of interregional disparities, the analysis was conducted on the crucial macroeconomic indicator "GDP" (Gross Domestic Product) expressed in PPP (Purchasing Power Parity), not only at the level of EU (European Union) member states, but also at the regional levels. The results of this research reveal that despite the long-term implementation of the common cohesion policy there is a continuous deepening of interregional disparities at all examined NUTS (Nomenclature of territorial units for statistics) levels.

1. INTRODUCTION

The initiation of the accession process for Central and Eastern European countries into the structures of the European Union at the beginning of the 21st century and their following entry into this community in 2004 (Czech Republic, Estonia, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Slovakia,

Slovenia), 2007 (Bulgaria and Romania) and 2013 (Croatia) have intensified the discussions about the effectiveness of EU (European Union) regional policy. The enlargement of the EU by 13 new member states stressed the necessity to increase the efficiency of the regional policy instruments. This pressure was primarily driven by the changes in the ratio of the volume of available financial resources and the size or the number of target areas. It was also a result of the enlargement of the interregional disparities within the community due to the accession of new regions that have been on the lower level of the economy development compared to the original members. The urgency to improve the efficiency of the EU regional policy was also indicated by many academic studies highlighting the limited or even insignificant influence of the structural funds on target regions. Boldrin et al. (2001) even concluded their research by stating that the primary purpose of EU regional policy is basically redistribution of the resources to create political balance which is the foundation of the European Union. EU regional (cohesion) policy is, after the "Common Agricultural Policy", the second most funded activity of the community, therefore, understanding its real benefits and areas for possible improvement of its effectiveness is highly desirable. This is a key reason why we will analyse economic development (convergence/divergence) of EU member states and their regions during the given period.

The main objective of this research is to determine whether the socioeconomic disparities among individual member states of the European Union persist and deepen over the long term. Our analysis deals with the development of interregional differences in all EU member states as well as their NUTS 2 and NUTS 3 level regions (as they are key objects of implementation of regional policy and its instruments – European structural and investment funds). This socioeconomic area deserves more attention, which is why we decided to process the presented analysis and its results.

Using indirect measurement methods is one of the easy ways to identify the RDs, such as scaling, scoring, and the traffic light method. These methods offer several advantages, including their clarity, ease of comparing results, the ability to incorporate additional indicators, and their capacity to consolidate multiple indicators into a single synthetic characteristic. The method of convergence is not very often used in regional statistics; it involves analyzing the direction of interregional disparities. The analysis of convergence reveals the trends in disparity development, indicating whether there is a convergence (coming closer together) or divergence (moving further apart) in the levels of the observed indicators. We will utilize this method, including its variants such as β and σ convergence analysis of gross domestic product, to confirm or reject the assumption

that despite the implementation of cohesion policy, individual member states and their regions experience divergence.

2. THEORY AND METHODOLOGY

2.1. Brief literature review

Efforts to reveal the influence of EU regional policy on economic growth and convergence have become more intense in recent times. One contributing factor to this ongoing discussion is the limitation and potential decrease in the allocation of funds aimed at fulfilling the stated objectives of this policy (particularly due to events like the United Kingdom's exit from the EU). However, it is still difficult to draw clear conclusions from these efforts. While some authors, for example Borrega et al. (2025) describe a definite positive effect of the European Structural and Investment Funds (ESIF) on economic growth, others have found weak or even no influence of this policy on economic growth and convergence. Different results can be attributed to various factors, including the low quality of data at the micro, meso, and macro levels, the absence of standardized data on fund allocation at the regional level, the inherent challenge of assessing the achievement of policy objectives from a financial perspective, and a range of methodological complexities associated with studying this problem.

Notably, more than one-third of the European Union's budget is dedicated to the field of cohesion (regional) policy through the ESIF. As outlined in Article 158 of the Treaty on European Union and the provisions of the European Community, the objective of this policy is to foster overall development within the European Union, reduce disparities in development between regions, as well as enhance economic and social cohesion. During the set period of 2007-2013, the budget allocated to regional policy amounted to €347.4 billion, while for the subsequent targeted period of 2014-2020, a total of €351.8 billion has been designated for regional policy.

According to Euractiv (2010), the key principle of EU's regional policy (also referred to as cohesion or solidarity policy) is financial solidarity aimed at supporting less developed regions and marginalised social groups. This policy plays a crucial role in sustaining regional competitiveness and significantly contributes to fostering convergence between economically disadvantaged regions and more prosperous ones. In the current period of 2021-2027, the total planned allocation within the five EU funds is of approximately €390 billion, as reported by UVP TECHNICOM (2022). Although the specific objectives may change in each programmed period, it can be generally understood that the primary underlying goal of regional policy is to reduce interregional disparities at various levels.

Interregional differences, also known as disparities, are, in real economics, a common phenomenon, but opinions on the causes, existence, justification, and elimination or equalization of disparities differ significantly across various economic theories. The term originates from the Latin word "disparitas", which denotes inequality. *"Disparity is generally understood as unevenness, variations, heterogeneity, or distinctions"* (Viturka, 2010, pp. 131-132). This term is used to address our needs and the requirements of regional economics. According to Vorauer (1997), regional disparities refer to deviations from the intended distribution of relevant characteristics in relation to different spatial reference levels, such as regional boundaries.

Vorauer further defines regional disparities as the asymmetry in spatial structure within specific regions or between regions. They become evident in varying living conditions and levels of economic development potential. Additionally, the contrast between urban and rural areas can also be understood as a form of spatial disparity (Vorauer, 1997). According to Kutscherauer et al. (2010), disparities can be characterized as variations or inequalities in specific attributes, phenomena, and processes. The identification and comparison of these disparities hold a certain rational significance (cognitive, psychological, social, economic, political etc.).

According to these authors regional disparities are discrepancies or inequalities in attributes, phenomena, or processes that exhibit distinctive spatial distribution. They can be often allocated within a defined territorial or regional structure and can be observed in at least two entities within such a territorial structure. Their causes can be diverse and result from social or natural developments, implying that the magnitude of disparities between regions changes over time. From an economic theory standpoint, it is also crucial to consider the appropriateness and effectiveness of interventions aimed at reducing regional disparities. Their existence is perceived ambiguously as it is not inherently a negative phenomenon, but rather depends on the nature, magnitude, and duration of these disparities. Due to its multidisciplinary nature, the phenomenon of regional disparities needs to be examined using a multidimensional approach. This approach involves harnessing the tools and insights from various scientific disciplines to understand the issue from different angles. Instead of solely focusing on its economic aspects, it is essential to perceive regional disparities as a complex problem encompassing social, spatial, political, administrative, institutional, environmental, and infrastructural dimensions (Gajdoš and Pašiak, 2006).

The development of regional disparities can be described through several trends. One of these trends is the tendency towards convergence, which involves reducing the level of differences and approaching a common economic level among regions within a defined group of territorial units. Convergence, in general, refers to the process of approaching a certain level or reducing the difference between values of two or more variables over time, until the difference between them approaches zero and becomes negligible. In economics, convergence is understood as *"the process of equalizing differences in various economic indicators within a group of countries, leading to a harmonization of the standard of living across individual countries"* (Barančok et al., 2006, p. 5).

According to Greene (2003), convergence occurs between time periods t and t+1 when the following condition holds for a studied economic indicator in two different economies or territories (countries, regions) x and y:

$$|x_{t+1} - y_{t+1}| < |x_t - y_t| \qquad (1)$$

The second trend is the inclination towards divergence, which involves the widening of disparities in the economic level among regions, leading to increased differences between territorial units in terms of the nature and extent of the before mentioned categories. The deepening of economic disparities can occur at various rates, but in practice, we commonly encounter progressive, degressive, or linear patterns of disparity growth. A linear growth trend of interregional disparities implies that the dynamics of disparity development should remain unchanged over time, resulting in a stable and constant disparity level. For example, if regional disparities measured on an annual basis increase at a consistent rate of 5% per year, this rate remains constant in the long term. However, such situations are rare. More often, in economic practice, we encounter disproportionate development of RD's. This means that development tendency of disparities changes over time. Progressive growth indicates an increasing dynamic trend, where the year-on-year growth rate may be exponential. On the other hand, degressive development suggests that, although interregional disparities are still growing, the rate of growth decreases in time. This indicates a declining percentage change in the development of the observed indicators on a yearly basis. The degressive trend may imply a transition towards convergence, while the progressive trend, a high likelihood of continuous growth and deepening disparities between the observed territories.

2.2. Methodology, research methods and research data

Quantifying the level of regional disparities, understanding the nature of their evolution, and obtaining precise results require knowledge and familiarity with a wide range of methods and approaches for measuring them. The utilisation of

different methods often leads to significant variations in the obtained results. As highlighted by many authors focused on the regional disparities, there is a broad spectrum of methods that can be used to express the nature of regional differences and analyse the trends in their further development. Various mathematical indexes and their variations are available, which are methodologically suitable for measuring spatial divergence and interregional disparities. The selection of the method and measurement approach depends on several factors, primarily the objective of the phenomenon under study, the precision requirements of the results, and the availability of relevant input data. The primary requirement for selecting suitable methods is the comparability of interregional disparities and their evolution over time, while incorporating the influences of financial mechanisms in the EU regional policy.

The main objective and purpose of our study is to answer the key question: Did real convergence or divergence occur among the EU27 member states during the observed period from 2000 to 2022? Our secondary goal is to explore and quantify the extent of convergence and/or divergence at the regional level of NUTS 2 and NUTS 3 in all 27 member states of the European Union. The aim is also to provide precise evidence regarding whether there has been a convergence or divergence in the economic level of member states and their regions over a period of more than two decades. Additionally, our research indirectly highlights the relevance, effectiveness, and targeting of the EU's common cohesion policy, which has been implemented for over half a century with the aim of reducing the most significant and damaging interregional disparities.

The theories of regional development are commonly categorized into the convergence and divergence concepts. The convergence approach predicts regional convergence as an outcome, while the divergence approach implies divergence rather than convergence, although this conclusion is not unequivocal and depends on various factors. Supporter of regional convergence is the neoclassical theory of (conditional) convergence, which, similarly to traditional neoclassical growth theory, assumes the convergence of disparities in regional GDP per capita. This theory has several distinctive features that set it apart from the traditional concept and hold significance for empirical research. Among the divergence theories, we mainly include the Polarization Theory, the New Economic Geography, and the Endogenous Growth Theory (Kováč et al., 2011). By nominal convergence we mean the approximation of selected macroeconomic indicators to values that would ensure macroeconomic stability in an economically integrated territory. The monitoring of uniformly determined indicators of equilibrium development is related to the examination

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of nominal convergence. Thus, the indicators can be quantified quite clearly.

Real convergence is related to issues of economic growth and the process of reducing differences in income, living standards, productivity etc. between poorer and richer economies, which occurs because of faster economic growth in poorer economies. International comparison of economies and monitoring of their development by the real convergence mostly enables long-term monitoring of GDP per capita expressed in purchasing power parity (Barančok et al., 2006).

Currently, most of the empirical studies of regional convergence are based on the neoclassical models of economic growth presented in the works of Ramsey (1928), Solow (1956), Cass (1965) and Koopmans (1963). Of these, the Solow model had a leading position until the mid-1980s. The essence of this model can be summarised in a few key points (Buček and Gerulová, 2009):

- economic growth is driven by technological progress and capital accumulation;
- technological progress is exogenous;
- the production factor is determined by the size of the population, which grows exogenously at a given rate, from which it follows that work is also exogenous;
- the capital supply is determined by investments and the investment rate is constant and exogenous, which means that output, investment, and capital supply will grow at the same long-term rate;
- factors of production are valued based on the diminishing marginal product.

It can be concluded that the process of convergence in the understanding of Solow's model and the neoclassical approach to regional development, which is mainly supported by the belief that interregional differences are balanced automatically based on the movement of capital and labour, acquire certain common features. If there are regional disparities, then more developed regions accumulate capital faster, which leads to a decreasing marginal product of capital and consequently to decreasing returns on capital. Capital thus flows to regions where it is in short supply and it is subsequently appreciated. Capital is attracted by higher interest rates in peripheral regions with plenty of free labour and low wages (wage and price flexibility). In opposition, the labour force migrates from the periphery to more developed regions where wages are higher. The process of regional convergence in the level of production per capita occurs through the mechanism of equalising differences in production factors (Sloboda, 2006).

It follows that convergence in the understanding of neoclassical models occurs because of four mutually supporting processes, which are (Buček and Gerulová, 2009):

- capital accumulation and diminishing returns on capital;
  - capital mobility;
  - interregional labour mobility;
  - technology transfer.

The neoclassical approach to convergence uses and tests the so-called hypotheses of σ-convergence, ß-convergence and convergence clusters. The σ-convergence hypothesis assumes a reduction in the dispersion of real per capita income across regions over time. The ß-convergence hypothesis identifies a negative relationship between the growth rate of income per capita over time and the initial level of income per capita across regions (Soukiazis, 2000).

2.3. β-convergence

By β-convergence we mean the process when the growth rate of a poorer region is higher than the growth rate of a richer region, i.e., the poorer region "catches up" with the richer one in terms of income, or GDP per capita. It expresses the negative relationship between the growth rate of GDP per capita over time and the initial level of GDP per capita across economies. Some authors use the GDP per capita indicator in the β-convergence analysis, while others use the income per capita. Research by Abreu et al. (2005), as well as Johnson and Papageorgiou (2018) did not confirm that the use of one or the other indicator would lead to different outcome measures of convergence (Kováč et al. 2011). In our work, we will use the GDP per capita indicator available within the EUROSTAT database.

The concept of β-convergence is directly derived from neoclassical growth theory, in which one of the key assumptions is that factors of production, especially capital, are subject to the law of diminishing returns. Accordingly, the growth process should lead economies to a long-term steady state characterised by a growth rate that depends only on the (exogenous) rate of technological progress and the growth rate of the labour force. Diminishing returns suggest that the growth rate of poorer regions should be higher and GDP per capita should equal GDP per capita of richer regions (Monfort, 2008).

The methodology used to measure β-convergence was introduced by Barro and Sala-i-Martin in their work "Economic Growth and Convergence across the United States" from 1990. It was based on neoclassical models of economic growth for closed economies, as presented in the works of Ramsey (1928), Solow (1956), Cass (1965), Koopmans (1963), Von Lyncker and Thoennessen (2017), Egri and Tánczos (2025), Del Hoyo et al. (2017). According to these models, the rate of economic growth per capita tends to be inversely related to the initial level of GDP or income per capita. Specifically, if economies

are similar in terms of preferences and technology, then poorer economies (countries, regions) grow faster than richer ones. Thus, there must be some "force" that promotes the convergence of output and per capita income levels (Barro and Sala-i-Martin, 1992).

β-convergence is determined by regression analysis estimating the growth of the selected indicator (in our work GDP per capita) over a certain period as compared to the initial state of this indicator. Transient growth in the neoclassical model can be approximated by the following relation (Barro and Sala-i-Martin, 1991):

$$\log \frac{y_{it}}{y_{i,t-T}} = a - (1 - e^{-\beta}) \times [\log(y_{i,t-1}) - g(t-1)] + u_{it} \quad (2)$$

where:

$a = g + (1 - e^{-\beta}) \times \log(y^{*})$;

i – economy (region);

t – year;

$y_{i,t-T}$ – GDP per capita in region i at the end of the period T;

u_{it} – error;

y_{it} – GDP per capita in region i at the beginning of the period T;

T – observed period;

β – convergence, which indicates the rate at which economies are approaching steady state.

In equation (2), we consider the coefficient a to be a constant, i.e. the value of the steady state y* (e.g., GDP per capita) is the same for all economies that are included in the model. However, we do not know the value of the steady state, so the constant a is defined. Also, the time trend $g(t-1)$, which represents exogenous technological changes, is assumed to be the same for all economies. Element g represents the growth of the selected macroeconomic quantity in the steady state. The parameter β, which can be derived from the slope of the regression function, expresses the degree to which the regions approach the steady state. β-convergence occurs if β<0. If the dependence in the regression is significantly negative, the process of absolute convergence is proven. If, for different economies we have a non-constant coefficient a, and different steady states y*, then we are talking about conditional ß-convergence, which is minutely described in the study of Barro and Sala-i-Martin (1991) (Kováč et al. 2011).

Barro and Sala-i-Martin (1990) used as a basis for their empirical analysis equation (2) in the form given by equation (3), which can be applied to discrete time periods of the economy i and which is extended to include a random component:

$$\ln\left(\frac{y_{it}}{y_{i,t-1}}\right) = a_i - (1 - e^{-\beta}) \times [\ln(y_{i,t-1}) - x_i(t-1)] + u_{it} \quad (3)$$

where:

$$a_i = x_i + (1 - e^{-\beta}) \times \ln(\hat{y}_i^*)$$

In the case that all economies converge to the same steady state, for example achieving the same GDP per capita or the same growth rate in the long run, we say that β-convergence is absolute. Development of the disparities to the same steady state requires that economies do not differ in technology level, investment rate, savings rate, taxation rate, and other structures. It follows that unconditional (absolute) convergence occurs rather between regions of the same country that share a common degree of homogeneity, common mobility factor, similar technologies, as well as common administrative and legal system.

Absolute convergence in the understanding of the neoclassical theory assumes only a different amount of capital (Soukiazis, 2000).

It follows that the coefficient a_i in equation (3) is the same for all economies i, i.e. the value of the steady state $\hat{y}_i^*$ and the rate of technological progress x_i do not differ across economies. The time trend $x_i(t-1)$ also does not change for each i. The conditions $a_i = a$, $x_i = x$ indicate that poor economies grow unconditionally faster than rich ones when $\beta < 0$ (Barro and Sala-i-Martin, 1992).

However, the steady state of the economy may depend on various factors specific to the given economy, such as the level of technology, preferences, savings rate, level of education, economic structures, or government policies. It follows that steady states will differ across economies. This fact, which corresponds to practice, results in the transition from the investigation of absolute convergence to the investigation of conditional convergence, which one occurring when economies converge to their own steady state, an aspect caused precisely by the difference in structural factors or conditions of economies. Thus, when examining convergence, these 'conditional' variables should be considered (Kováč et al., 2011).

Model (3) implies conditional β-convergence – for the given values of steady states x_i^* and $\hat{y}_i^*$, the growth rate of the economy per capita is higher, while the lower is the initial level of GDP per capita $y_{i,t-T}$.

Convergence is conditional, because $y_{i,t-T}$ enters a relationship with $\hat{y}_i^*$ and the value of $\hat{y}_i^*$ can change across economies. The coefficient β measures the pace of this conditional convergence (Barro and Sala-i-Martin, 1991).

2.4. σ-convergence

While β-convergence focuses on the possible process of 'catching-up' of rich economies by poor ones, σ-convergence refers to the reduction of disparities between economies over time. These two concepts of convergence are closely related. β-convergence is a necessary but not sufficient condition for the existence of σ-convergence. This and the number of limitations of β-convergence concept led some economists to believe that the σ-convergence concept better reflects reality, since it directly describes the distribution of income, or GDP per capita across economies without relying on an estimation of particular model (Monfort, 2008).

The most used indicators to measure σ-convergence are the standard deviation or coefficient of variation of the GDP per capita. The σ-convergence in regions occurs when the variance of the logarithms of GDP per capita decreases over time.

The basic difference between β-convergence and σ-convergence can be illustrated by their application in finding answers to two different questions. If we are interested in how quickly and to what extent the GDP per capita of a certain economy has a chance to catch up with the average GDP per capita across the economies in the sample, then β-convergence is a concept that makes sense to use. However, if we want to know how the distribution of GDP per capita behaved in the past, or how it will develop in the future, then the relevant concept is σ-convergence (Barro and Sala-i-Martin, 1991).

If we are dealing with the analysis of σ-convergence, which is another of the concepts advanced by Barro and Sala-i-Martin (1990, 1991, 1992), this occurs when the dispersion of income per capita decreases over time. σ_t^2 is the cross-sectional variance at time t of $\log y_{it}$ values across all economies. From equation (4), the variance σ_t^2 can be written in the form of a first-order differential equation:

$$\sigma_t^2 = (e^{-2\beta}) \times \sigma_{t-1}^2 + \sigma_{ut}^2 \quad (4)$$

Barro and Sala-i-Martin (1990, 1991, 1992) assume that the variance of logarithms of GDP per capita from cross-sectional data is estimated from a sufficiently large sample and corresponds to the unknown population variance. If the variance of the random component does not fluctuate over time and is denoted as σ_u^2 and the cross-sectional variance of the logarithm of GDP per capita at time t₀ is denoted as σ_t^2, then we derive the following form from equation (4):

$$\sigma_t^2 = \frac{\sigma_u^2}{1 - e^{-2\beta}} + \left(\sigma_0^2 - \frac{\sigma_u^2}{1 - e^{-2\beta}}\right) \times e^{-2\beta t} \quad (5)$$

Equation (5) indicates that the variance converges to a steady value, which we can express by the first part on the right-hand side of the equation, which increases with σ_u^2 but decreases with the convergence coefficient ß. σ_t^2 decreases (or increases) if σ_0^2 is greater (or less) than the steady state value represented by the first term on the right side of the equation. Therefore, a positive coefficient ß does not necessarily mean a decrease in σ_t^2. Thus, ß-convergence is a necessary but not sufficient condition for σ-convergence. This relation does not apply vice versa, and ß-convergence can be achieved even without σ-convergence. In other words, a negative ß coefficient means that poor regions grow faster on average than rich ones, but this does not mean absolute convergence. The concept of σ-convergence is sometimes criticised because it is more of a descriptive approach, as well as because of the presence of spatial autocorrelation that distorts the results (Rey and Dev, 2006).

2.5. Data description

According to the Eurostat, the Gross domestic product at market prices is the result of the production activity of production units in the administration of residents, created during the current accounting period. Regional gross domestic product is calculated as the sum of value added for industries in the region and product taxes less product subsidies. For international comparisons, regional gross domestic product is expressed in purchasing power parity. Purchasing power parity is calculated on the basis of prices and sales volumes of goods that are mutually comparable and representative of the countries included in the comparison. Purchasing power parity eliminates the effects of different price levels between countries. Gross domestic product cannot be confused with the household income indicator (Sloboda, 2012).

We are fully aware of the shortcomings of this indicator, such as the fact that it cannot capture processes within the grey and black economy, or the fact that it depends on prices, which can be largely distorted by the influence of bureaucracy or a lack of competition. Nevertheless, this indicator is generally accepted and considered suitable for evaluating interregional differences.

As part of the β and σ convergence analysis, we work with the GDP per capita indicator, measured by purchasing power parity in relation to the EU27 average. This methodological procedure eliminates deviations caused by different price levels in different economies. From the Eurostat database, specifically from 'General and regional statistics, regional statistics by NUTS classification, Regional economic accounts, Gross domestic product indicators', we filtered data on the above-mentioned indicator for the period from

2000 to 2022 (at the regional level NUTS 3 data are available only until 2021).

3. RESULTS AND DISCUSSION

The following calculations of β and σ convergence are based on the approach of the authors Barro and Sala-i-Martin. The basic set is the regions of the European Union at the NUTS 0, NUTS 2 and NUTS 3 levels, i.e. Member States as a whole, regions of the second and third level of the common nomenclature.

To calculate the absolute β-convergence, a regression equation was used in the form in which it was used by the authors Barro and Sala–i–Martin (1992):

$$\frac{1}{T}\ln\left(\frac{y_{iT}}{y_{io}}\right) = a + \frac{1 - e^{\beta T}}{T}\ln(y_{io}) + u_{io,T} \tag{6}$$

where the left side of the equation represents the average rate of GDP per capita growth in period o to T; a is the level of GDP per capita that is assumed to be the same for all regions. The regression coefficient of growth (β) is expressed by the formula:

$$\left(\frac{1 - e^{\beta T}}{T}\right) \tag{7}$$

at initial level of GDP per capita (y_{io}); $u_{io,T}$ represents random variable between periods o and T. To calculate the speed of convergence, we will use the relation derived by us for β:

$$\beta = \frac{\ln(1 - \beta_2 T)}{T} \tag{8}$$

3.1. Results of the analysis of beta and sigma convergence at the NUTS 0 level in the period 2000-2022

We used regression analysis as an analytical tool when determining the β_2 parameter and constructing the graph. Its results and graphical interpretation are presented in the following text (Fig. 1).

At the NUTS 0 level of the unified systematization of EU regions we included all 27 member states in the analysis, i.e. NUTS 0 territories. The graphic interpretation itself, as well as the calculated value of the trend line directive, prove the beta divergence. The higher the positive value of the direction of the trend line (the line rises steeper), the more intense the divergence and vice versa. The calculated value of the β coefficient is 0.68. Since it is a positive value, there is divergence and, therefore, the assumption of spontaneous "catching up" - convergence of economically poorer EU member states is not

fulfilled. Graphically, this is visible in the rising trend line and the slope of the line k=0.68. The higher the positive value of *β (k)*, the more intense, stronger the divergence at the level of NUTS 0 Member States. We will subsequently confront this value with the values obtained at the NUTS 2 and NUTS 3 levels.
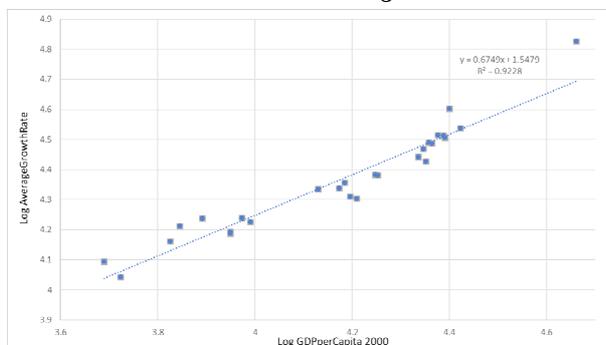

Fig. 1. Beta convergence at the NUTS 0 level (2000 - 2022) *(source: authors' own elaboration based on data from Eurostat, https://ec.europa.eu/eurostat).*

We estimated the σ-convergence by tracking the variability of regional GDP, more precisely by tracking the decreasing tendency of the standard deviation of the logarithmic values of regional GDP, which indicates a reduction of GDP differences within regions. To calculate the standard deviation, we used a relation in the form:

$$S_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n-1}} \qquad (9)$$

In the monitored period of 2000 - 2022 (limited by the availability of statistical data from Eurostat), similarly to the case of the beta convergence analysis, we recorded sigma divergence, which is demonstrated by the following graph and the direction of the straight line, with a positive value of k=0.0097. It discloses a gradual sigma divergence of all 27 EU member states in the observed 23-year period (Fig. 2).
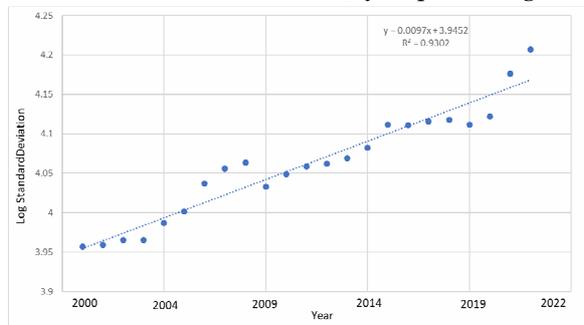

Fig. 2. Sigma convergence at the NUTS 0 level (2000 - 2022) *(source: authors' own elaboration based on data from Eurostat, https://ec.europa.eu/eurostat).*

As we already mentioned in the methodological part, β-convergence is a necessary but not a sufficient condition for σ-convergence. In the

monitored period, the dispersion of the standard deviations of GDP logarithms in the monitored set, i.e. σ-divergence, is increasing. This result can be observed in graph 2. The logarithmic value of the standard deviation continuously increases during the entire 23-year period, except for 2009, when it decreased only once, which can be explained by the impact of the economic crisis. The relationship between the results of β and σ convergence confirms that, even though the effects of regional policy and integration processes dynamised the growth of the GDP in the case of the catch-up regions compared to the developed ones, there was still a deepening of interregional disparities in all 27 EU member countries.

We carried out the analysis of beta and sigma convergence at the level of states, 27 member countries, as the cohesion policy also uses one of the five ESIF instruments - the Cohesion Fund. It supports important infrastructure projects in the field of transport and the environment. As the EU regional policy primarily focuses its interventions on the regions at NUTS 2 and NUTS 3 level regions, we make identical analysis to both mentioned regional levels in the following text.

3.2. Results of the analysis of beta and sigma convergence at the NUTS 2 level in the period 2000-2022

The results of the beta and sigma convergence analysis, which we carried out in an identical manner at the NUTS 2 regional level, concern 269 territories in all 27 Member States. From the following graph, it is possible to identify convergence/divergence just as in the case of the NUTS 0 level (Fig. 3).
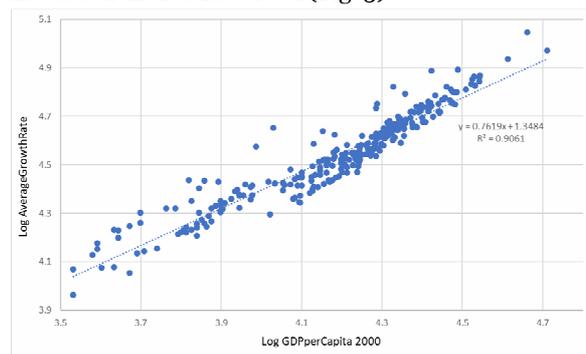

Fig. 3. Beta convergence at the NUTS 2 level (2000 - 2022) *(source: authors' own elaboration based on data from Eurostat, https://ec.europa.eu/eurostat).*

The transparency and readability of chart 3 deteriorates slightly compared to the NUTS 0 level, which is due to the radically higher number of monitored statistical units. It is indisputable that even at the NUTS 2 level we reached the same conclusion as in the case of NUTS 0. The regions of this regional level are moving away from each other, diverging from the point of view of GDP per capita. The value of the β coefficient as well as the value of the straight-line

direction k=0.76 are higher than in the case of NUTS 0 level, which proves a more dynamic, faster deepening of interregional differences of NUTS 2 regions than at the level of the entire member states (the straight-line direction was k=0.68). The result of the sigma convergence analysis will come as no surprise (Fig. 4).
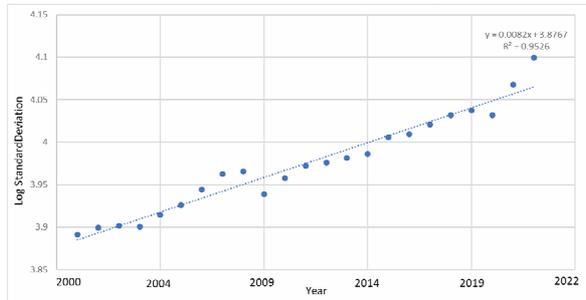

Fig. 4. Sigma convergence at the NUTS 2 level (2000 - 2022) *(source: authors' own elaboration based on data from Eurostat, https://ec.europa.eu/eurostat).*

The course of the trend line, which we have shown in figure 4, is also continuously rising, except for 2009 and 2020. The slope of the straight-line is shallower, although this indicates the deepening of interregional differences and thus sigma divergence, but at a slower pace than at the NUTS 0 level. This fact indicates a positive impact of the implementation of cohesion policy instruments precisely at the NUTS 2 level on at least slowing down the deepening of interregional disparities.

For the sake of the complexity of the beta and sigma convergence analysis, we carried out an identical procedure in the case of NUTS 3 regions as well. They are also the subject of cohesion policy and therefore financial support from the European Structural and Investment Funds.

3.3. Results of the analysis of beta and sigma convergence at the NUTS 3 level in the period 2000-2021

The results of the analysis of beta and sigma convergence at the NUTS 3 level, which we present in the following section, are predictable regarding the previous levels of the NUTS 0 and NUTS 2 regions. Again, absolute divergence can be confirmed, despite the implementation of the European Structural and Investment Funds, with approximately 2/3 priority for the lagging, least developed regions, whose GDP per capita measured in PPP reaches less than 75%, or less than 50% of the average of all EU regions.

Figure 5 represents the 1373 NUTS 3 regions of all EU member states. The value of the β coefficient as well as the value of the straight-line direction k is 0.80. Once more, it's a positive value and it rises. This situation is identical to the result of the beta convergence analysis at the NUTS 0 and NUTS 2 levels, with the difference that the straight-line rises steepest, i.e. the direction of the straight line is the highest, and

thus the dynamics of growth/deepening of interregional differences is the greatest from the point of view of GDP per capita at the NUTS 3 level in comparison to NUTS 0 and NUTS 2 level.
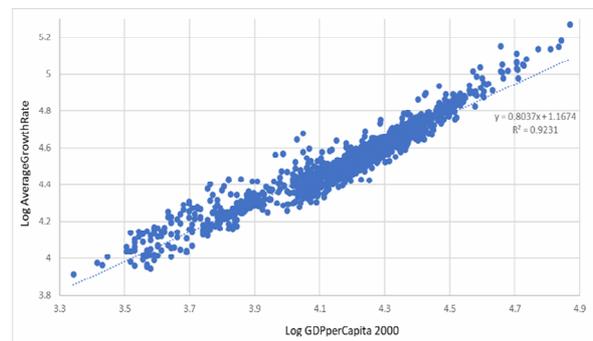

Fig. 5. Beta convergence at the NUTS 3 level (2000 - 2021) *(source: authors' own elaboration based on data from Eurostat, https://ec.europa.eu/eurostat).*

We expected the same result in the case of sigma convergence, which was confirmed just as at the NUTS 2 level. It was the continuous growth of the logarithmic value of the standard deviation, except for 2009 (economic crisis) and 2020 (COVID-19 pandemic), and therefore the total sigma divergence, i.e. deepening of the level of GDP per capita measured in PPP between 2000 and 2021 (Fig. 6).
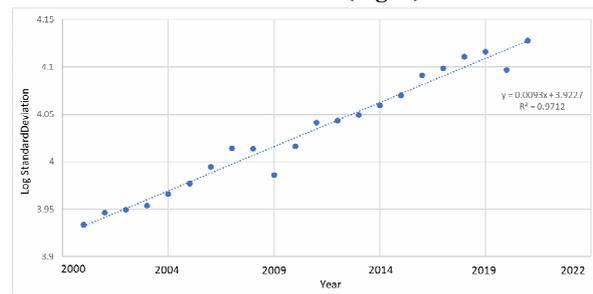

Fig. 6. Sigma convergence at the NUTS 3 level (2000 - 2021) *(source: authors' own elaboration based on data from Eurostat, https://ec.europa.eu/eurostat).*

The calculated values indicate, that strong economic or even non-economic influences, events, crises etc. "harm" more the more economically advanced entities, states, regions, but this negative impact is short-term, temporary, and its "power" fades away very quickly. Economic development will very quickly return to its usual course, in our case continuous divergence.

Regardless of the regional level of beta and sigma convergence research, we can unequivocally state that in the period of 23 years, which are available in the Eurostat database, there has been a deepening of differences between regions, despite the massive implementation of billions of euros within EU cohesion policy to its member states and regions. This negative statement, at least to some extent, improves the fact that the dynamics of the deepening (the intensity and year-on-year change) of interregional differences have remained stable, not accelerating.

3.4. Results generalisation

The results of the investigation, which we have summarized in this article, confirmed, through scientific methods, absolute beta and sigma divergence during the observed 23-year period. In practice, this means that within the EU 27, despite the implementation of the redistribution instruments of the cohesion policy, there is a deepening of interregional differences. This happens at all three analysed geographical levels – at the level of the Member States, as well as at the regional level of NUTS 2 and NUTS 3 of the common territorial systematisation.

Using the EUROSTAT application, we have generated a clear map of European countries with color-coded GDP per capita levels. These are data at the level of NUTS 2 regions from 2022. The NUTS 3 level, which represents more than 1.300 regions, would be unclear and would have been difficult to process as valid graphs. A darker green colour means a higher level of GDP per capita in a given region, while, on the contrary, the lighter the colour, even yellow, means a lower level of economic development of a given territory; countries and their regions of non-EU member states are shown in grey (Fig. 7).
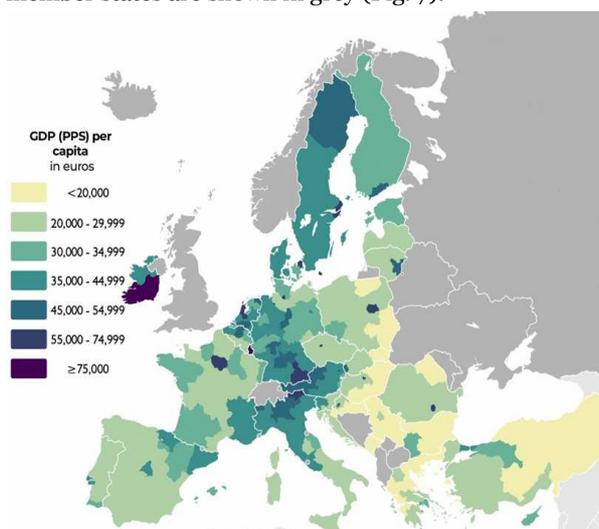

Fig. 7. GDP per capita in PPS at the NUTS 2 level (2022) *(source: authors' own elaboration based on data from Eurostat, https://ec.europa.eu/eurostat).*

We believe that such a graphic interpretation will help the reader get a better idea of the level of economic development/underdevelopment of regions in a spatial context.

The key question that initiated our research activity has a clear answer. At all monitored regional levels NUTS 0, NUTS 2 and NUTS 3, real absolute beta and sigma divergence occurs. The more developed EU member states (for example Luxembourg, Germany, France, Belgium, Netherlands, Austria, Ireland) and their regions grow faster than the less developed (for example, Slovakia, Hungary, Poland, Romania, Bulgaria and more). The rich regions are richer; the poor are

poorer. This is a relatively serious finding, since the priority of the EU cohesion policy is precisely aimed at EU lagging regions, i.e. NUTS 2 and NUTS 3 regions, whose GDP per capita measured by purchasing power parity does not exceed 75% of the EU average. According to the applicable rules of the European Commission, almost 2/3 of the resources intended for the cohesion policy go to lagging regions. Also, part of the resources from the Cohesion Fund must be included, which invests resources in the development of technical, transport, and environmental infrastructure. One of the lagging reasons of the member states and their regions is the insufficient equipment of such infrastructure (e.g., superior road network, railways, ports, airports, terminals etc.), the large extent of the aid from the Cohesion Fund ending up precisely in the least efficient regions. This should also be reflected in the regional GDP.

The rate of divergence is almost identical at all three levels examined, but the NUTS 3 regions appear to be the most problematic. During the research, we used available database of Eurostat, within which the regional GDP measured in purchasing power parity for a period of 23 years (2000 to 2022) was available at the time of processing. We consider this to be a long enough period for research and drawing conclusions. Both beta and sigma divergence are, for logical reasons, also affected by the continuing expansion of the EU in 2004 by 10 new members, as well as by 3 more full-fledged members in 2007 and 2013. Most of the regions of these new EU members were less developed from a socio-economic point of view than the average reference value of the original members until 2004. Many of their regions do not even reach 50% of the average GDP per capita in the entire EU 27 (for example, Vaslui in Romania – 29%, Yuzhen Tsentralen in Bulgaria – 41%, Voreio Aigaio in Greece – 42%, but also French Guyane – 42%). This is a challenge for the common cohesion policy, as excessive and unjustified interregional differences are a complex and multidisciplinary problem, not only for the lagging territories themselves, or for entire member countries, but also for the more developed part of the EU, primarily the 15 founding Member States excluding the United Kingdom (for example, Luxembourg, Germany, France, Belgium, Netherlands, Austria, Ireland).

4. CONCLUSIONS

The issues of assessing and quantifying interregional disparities have been a frequently discussed and economically interesting issue for several decades. The primary reason is the fact that excessive and unjustified interregional disparities are considered a complex, economic problem, but they are also a social, environmental, demographic, etc. problem. Experts agree on the essential opinion that interregional disparities are a complex and multidisciplinary

phenomenon, and at the same time they are a phenomenon that is of a long-term, persistent nature. This means that regional disparities are formed and persist for decades (centuries) and have various, not only economic, causes. For this reason, it is necessary to approach the solution of this complex problem strategically, in the long term and try to eliminate the cause(s) of the emergence of regional disparities and not only solve their consequences.

The main objective and purpose of our study is to answer the key question: Did real convergence or divergence occur among the EU27 member states during the observed period from 2000 to 2022? Our secondary goal is to explore and quantify the extent of convergence and/or divergence at the regional level of NUTS 2 and NUTS 3 in all 27 member states of the European Union. The aim is also to provide precise evidence regarding whether there has been a convergence or divergence in the economic level of member states and their regions over a period of more than two decades.

We agree with the prevailing opinion that excessive and unjustified interregional differences, i.e. the presence of lagging regions, is not only a problem of these regions, but also of both the country as a whole and regions that are more economically developed. Often, lagging regions are metaphorically compared to some kind of 'iron ball', which is attached to more developed regions (for example Eastern and Midland Ireland, Prague, Luxemburg, Brussel) as an economic but also non-economic burden. They could progress faster if they got rid of this imaginary iron ball. In principle, they have two options - to become independent and create a new state unit, or to tolerate a certain acceptable level of redistribution, to give up part of their wealth and invest it in lagging territories in the hope that they will start a multiplier effect and catch up with economic activity. The 'iron ball' will become smaller, or even cease to be a burden. Otherwise, it can pull forward the originally more developed territories.

The second aspect of interregional differences is their very nature, or character. As we outlined above, disparities are not just an economic problem. In many cases, it is precisely the non-economic issue, e.g. social, demographic or environmental. According to valid legislation, international treaties, or other global documents, every person has the right to equal treatment, to equal dignified living conditions, to a certain economic and social standard etc. Can individuals, families, or even larger groups be blamed for economically motivated mass migration? Or, on the contrary, can residents of economically 'poorer' regions be blamed for their reluctance to move to more developed areas for work? Perhaps they prefer a lower economic standard, at the price of cleaner air or water, at the price of a lower level of pollution, noise, mass consumption, agglomeration anonymity, hectic life etc.

Regional policy also offers possible solutions in this case. It is possible to choose a 'people for work' or 'work for people' approach. The former motivates human capital to reallocate for higher disposable income to more developed areas, while the latter encourages capital providers to allocate it to underdeveloped regions, economically less attractive but with possible investment incentives. Both approaches to interventions are not ideal and are not always effective.

As we mentioned in the theoretical and methodological part, excessive RDs are a comprehensive problem, as well as the problems of the regional policy implementation. Since hundreds of billions of euros are involved, it is extremely important to pay adequate attention to this area. These are interventions by the public sector, the public governments of the member states and the "joint EU government". Public sector interventions carry certain risks unknown to the private sector. In addition, the economic reality is highly uncertain and difficult to predict. An effectively and successfully implemented tool in country (region) X may or may not work equally successfully and effectively in country (region) Y. We do not dare to prove that the common regional policy does not work, that it is ineffective and unaddressed. It is possible that without it, disparities between countries and their regions could grow even faster. However, we cannot demonstrate this.

We recommend to the public authorities to stop focusing primarily on the only authoritative macroeconomic aggregate - the gross domestic product. The focus of individual ESIFs and their support of projects are extremely heterogeneous - from investments in local, regional and national to transnational, European infrastructure, human resources, use of local potential, environmental activities, rural support, agriculture, fishing and aquaculture, and innovations etc. We do not consider it correct to generalize all these heterogeneous activities into GDP. The investments from ESIF are tied to the level of GDP, which has its own economic logic and rationality, but at the same time, it is a significant distortion of economic reality. It is an indisputable quantitative and qualitative benefit for the public, or at least for selected groups of the population, if we use specific European resources to reconstruct a destroyed road, build a new school, hospital, or reduce the energy consumption of public buildings. Clearly, it is beneficial to build new or repair old railway lines, increase the comfort and safety of travel, bring better and faster transport connections within regions and also among them. Renovate the square, build public water supply, sewerage, civil infrastructure, and many others. At the same time, we should note that many of these investments will be manifested quantitatively by increasing the regional GDP. Simultaneously, apparently no one will object to the fact that these are

useful and quality-of-life-increasing investments for the population, the private and public sector, so they are welcome and desirable.

Regional policy, as well as other common policies within the EU, are based on the principle of solidarity and sharing. The public sector will always need to apply this principle, which is based on redistribution of financial sources. Redistribution in regional policy involves the transfer of financial sources from the more developed member states (for example, Luxembourg, Germany, France, Belgium, Netherlands, Austria, Ireland) and their regions to the benefit of the less developed regions, lagging ones. In practice, this is reflected in the annual "membership" fees of each member state to the common budget, while, at the same time, each country draws some part of the resources from this budget. We distinguish two categories of countries, the so-called absolute payers (net contributors – for example Germany, France, Belgium, Luxemburg, Netherlands etc.), who pay more into the budget than they take from it, and absolute beneficiaries (net beneficiaries – Poland, Hungary, Malta, Cyprus, Romania, Bulgaria, Lithuania, Latvia, Estonia), who get more than they pay. As long as the rate of redistribution is adequate and does not cause demotivation, it is economically rational and desirable. However, if its rate exceeds the tolerable limit, it has a demotivating effect. Not only for absolute payers, who may decide they no longer want to pay (e.g., probably the United Kingdom), but it may also disincentivise absolute beneficiaries, who simply rely on their advantageous financial position while trying to maintain that status. Excessive redistribution causes more problems than beneficial effects. This is certainly a situation that no EU member state wants.

Finally, we would like to draw the readers' attention to several potentially real economic and non-economic influences, facts, and aspects that can "shuffle the cards", i.e. fundamentally influence the desired convergence or undesirable divergence, or their dynamics and pace. Since the EU is a relatively large market with millions of inhabitants - heterogeneous consumers, a market spread over a vast geographically heterogeneous area (climate, geographical location, dependence on energy, agriculture, industry, tourism etc.), current challenges and threats, or those that potentially come into consideration in the future, can fundamentally affect the divergence or convergence of EU member states and their regions, as well as their corresponding speed and dynamics. We are primarily referring to the "green and digital transformation", challenges in the energy sector, related geopolitical relations, competitive pressures from Asia (especially China, where issues of carbon footprint or sustainable development are far from being as prominent as in the EU), potential economic threats coming from the USA, especially with regard to Donald Trump's protectionist policy and disunity, even conflict within the EU itself (a

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certain resistance or different positions, e.g. in Hungary, Slovakia), extremism (military, political, human), the war conflict in Ukraine, which has had and may still have strong political, economic, social, environmental, but also other impacts, taking place in the immediate vicinity of the eastern external border of the EU and NATO (North Atlantic Treaty Organization) (in 2025 we are witnessing "accidental" penetrations of military equipment into airspace, e.g. in Poland) and many others. All of the above, as well as many other influences, can significantly affect the socio-economic development in the entire EU as such, but also in its individual parts, which is related to the geographical heterogeneity, or different vulnerability of some regions. However, certain influences, on the contrary, can contribute to the dynamics of growth and development of economically "stronger" member states and/or their regions, which will result in a higher dynamic of divergence and, thus, the lagging behind of economically poorer regions of the EU.

We are aware that research into interregional differences is extremely demanding, complex and requires an interdisciplinary approach. We are also aware that such research can be carried out using various quantitative and qualitative methods. As we have stated in the text itself, the methods we used yielded results that we consider to be correct under the given conditions. However, we do not exclude that the use of other methods and procedures could yield similar but also different results. As we are aware of the limits of our approach and its outputs, we can imagine other possibilities in the future to evaluate and quantify interregional differences in a more complex, exact, multidisciplinary and therefore objective manner. However, this is demanding not only in terms of methodological approach, but also in terms of source data and their correct use. The effort to examine interregional differences as objectively as possible is desirable, especially because in the so-called Billions of euros are dedicated to cohesion and regional policy and they need to be implemented as effectively as possible and in the interest of achieving the set goals.

5. ACKNOWLEDGEMENTS

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