Regional income convergence in Central Europe: Evidence from a pair-wise approach

***Pavel Zdrazil*[1]**

[1] *University of Pardubice, Faculty of Economics and Administration, Institute of Economic Sciences, Czech Republic, ORCID: 0000-0003-0815-404X, Pavel.Zdrazil@upce.cz.*

Abstract: *Regional disparities are usually monitored in terms of economic performance. But as pointed out by many scholars, research has to look beyond GDP, investments, unemployment, and focus also on regional inequality in measures of well-being, for example, the disposable income of households. Therefore, this article examines the income disparities among the regions of Central European countries. We apply the probabilistic definition of convergence that is tested by the time series cointegration analysis. However, in our analysis, convergence criteria are tightened to increase robustness. In particular, we propose to require meeting of both criteria, i.e., stationary and absence of unit root, instead of one for the acceptance of the cointegration condition of regional convergence. Empirical analysis shows that despite the application of stricter conditions, the hypothesis of income convergence between Central European regions in 2003–2022 cannot be rejected. In particular, we found inner-country convergence in most countries. However, the involvement of individual regions in cross-country convergence varies widely. The results suggest that convergence intensity in the easternmost and westernmost regions is weak. However, we identified a "belt of convergence" along the border of the former Iron Curtain. These findings support the hypothesis of club convergence suggested by some scholars in the region of Central and Eastern Europe. On the other hand, our results significantly challenge previous research that claimed Central European transition economies are converging, especially towards German regions. Instead, our results indicate that convergence towards German regions is weak, while convergence towards Austrian regions is much more pronounced. Finally, uncovering how regions are converging at different rates and towards different steady-states can help to optimize the allocation of EU funding.*

Keywords: *Income disparity, Central Europe, cointegration analysis, regional convergence.*

JEL Classification: *R11, D31.*

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Introduction

The examination of inequality and redistribution constitutes a pivotal discourse within the realm of regional science and policy. Mainstream research focuses on regional differences in economic performance, such as growth, investments, and employment or unemployment (Capello & Nijkamp, 2019). For many years, however, scholars have pointed out that research has to look beyond economic performance and focus on regional inequality in measures of well-being (Doyle & Stiglitz, 2014). In fact, the measure of interest for people is not GDP, but wages, salaries, taxes and subsidies, or from an economic point of view, the net disposable income of households (income; Faggian et al., 2023). There are three main reasons for this. Firstly, disposable income

is a household measure and therefore relates to the place of residence and living conditions of inhabitants (Corvers & Mayhew, 2021). Secondly, disparities in income have a detrimental effect on well-being (Nettle & Dickins, 2022). Third, income inequalities have an impact on regional economic growth, potential, and environmental aspects. (Fuka et al., 2023; Topuz, 2022).

Hajdu and Hajdu (2015) found that people in less developed Eastern European countries are more negatively affected by income inequality than people in more developed Western Europe. Therefore, the expectation of an economic boom and additional financial support that boosts income growth in regions was stimuli for eastern countries to join the European Union (EU) in 2004 (Cieslik & Turgut, 2021). In addition, the expansion of the EU towards the east in 2004 heightened the demand for a more advanced regional policy. As regional policy became more significant, there was a growing need to develop methods for assessing regional disparity, which can help validate the expenditure of funds from both the EU budget and national resources (Zdrazil & Kraftova, 2023).

Central Europe presents a significant opportunity for in-depth analysis of income disparities across regions. While there is extensive research on income disparity in general, a number of studies on the regions of Central Europe is limited (Dorjnyambuu, 2024; Kapidzic et al., 2022). Spruk (2013) argues that this is due to specificity of transition countries that provide relatively short period when convergence hypothesis could be examined. Central Europe includes both traditional (EU15) countries with rather more developed regions (Austria and Germany) and transition countries, which joined the EU in 2004 (Czechia, Hungary, Poland, Slovakia, and Slovenia). The latter countries are regarded as less developed and, therefore, eligible to gain more European funds to promote cohesion.

Following the above, the research aim of this paper is to assess the income disparities between the regions of the Central European countries. We apply the less frequently used probabilistic definition of convergence (Pesaran, 2007; Pesaran et al., 2009), which is based on a pair-wise approach to measure regional convergence in terms of the limit of expected income gaps. A high relevance of this measurement was, however, confirmed by a number of empirical studies (Arvanitopoulos et al., 2021; Drager et al., 2023; Duro et al., 2023; Ngamaba et al., 2018). As pointed by Johnson and Papageorgiou (2020) and Shibamoto et al. (2016), this kind of cointegration approach to testing the hypothesis of convergence can be described as the most comprehensive modern method with a highly informative value of its results.

1. Theoretical background

At the end of the 20th century, the assumption of a general tendency toward the convergence of national or regional economies was significantly challenged by new models based on endogenous growth factors (Barro & Sala-i-Martin, 2004; Mankiw et al., 1992). However, the new approach does not clearly state whether convergence or divergence should be a general tendency of regional development (Martin, 2001). This ambiguity of the model in a fundamental issue of disparities development led to the need of a more sophisticated analytical apparatus to measure the extent and development of spatial inequality. Johnson and Papageorgiou (2020) provide a comprehensive discussion of different concepts by which convergence can be understood, as well as methodologies that may be employed for measurement.

The new look also supposes the creation of regional disparity in economic performance, household income, employment, and education attained. In particular, the importance of inequalities in income has been pointed out (Atkinson, 2017). The empirical research concludes a negative association between income inequality and accumulation of both assets (Blanchet & Martinez-Toledano, 2023) and human capital (Mdingi & Ho, 2021), confidence in society and institutions (Rozer & Kraaykamp, 2013), social mobility (Polacko, 2021), and happiness and well-being of a population (Chen & Hsu, 2024). Conversely, income inequality demonstrates a positive correlation with crime (Itskovich & Factor, 2023), pollution (Fuka & Bata, 2024), envy (Hajdu & Hajdu, 2015), and productivity (Kanbur & Stiglitz, 2016). Finally, the real data show that decreasing of income inequality is not as often as decreasing of inequality in GDP (Ben-David & Kimhi, 2004).

Taking into account the limited number of studies that have addressed regional disparities in Central Europe, the results on

the processes of convergence or divergence in income are mixed. Based on the simple approach of beta-convergence, Crespo Cuaresma et al. (2016) found that income disparities are declining and expect this process to continue. Alcidi (2019) came to the same conclusion, however, with the question of whether the convergence process will continue. Nagy and Siljak (2022) identified income convergence between the new and old EU member states while emphasizing that notable variations exist among the new member states. Markowska et al. (2022) and Monfort (2020) developed similar conclusions, noting the different speeds of convergence. However, Cieslik and Wcislik (2020) disagree with any convergence patterns and argue that eastern regions are converging only towards France and Germany. Based on both beta- and sigma-convergence processes, Spruk (2013) confirmed the existence of catching-up processes in income. Rapacki and Prochniak (2019) argue that this is the effect of EU membership. Holobiuc (2020) agrees with this conclusion, but points out that the benefits of convergence were not equally distributed. Conversely, Borsi and Metiu (2015) argue that there is no clear evidence of real income convergence in the enlarged EU.

However, there are a number of studies that argue that the conclusions about disparities in Central Europe are very ambiguous. Matkowski et al. (2016) revealed that the convergence process is not continuous; in particular, the most intensive convergence appeared just before and after the EU enlargement in 2004. Cieslik and Turgut (2021) claim that the breakthrough comes after the new countries were admitted to the Schengen area in 2007. In contrast, numerous studies (e.g., Licchetta & Mattozzi, 2023; Nagy & Siljak, 2022) noted signs of divergence, particularly following the 2008 crisis, while the impact of EU enlargement and integration on income disparities appears to be questionable, whereas the effects on income disparities of EU enlargement and integration are spurious. Based on more comprehensive cointegration approaches, Gligoric (2014) found that convergence processes in income prevail, but these processes are not present at the whole sample, and they are not well obvious. Similar results indicating the club convergence in income have also been accessed by Monfort et al. (2013) and Duro et al. (2023). In addition, Holubiuc (2020) argues that capital cities are the winners of the convergence process in Central and Eastern Europe.

Artelaris et al. (2010) offer a different perspective when they argue that periods of convergence in regional income alternate with periods of divergence; hence, it is not easy to develop general conclusions about income disparities in Central European countries. Dogan and Saracoglu (2007) used 5 different panel root tests to investigate disparities in income, but did not confirm the income convergence hypothesis. Furthermore, many scholars conclude that regional convergence in income is more common across Central European countries, while inner-country disparities are on the rise (Kokocinska & Puziak, 2018; Zdrazil & Applova, 2016). The explanations for this are variegated; e.g., Kuttor (2009) addressed the main reasons for the polarisation of economics, especially the growth of capital city regions, and geographical advantage of western regions that are closer to the more developed markets in EU15 countries. However, Duarte et al. (2022) assume the position in global value chains also matters.

2. Research methodology

To fulfil the research aim, the cointegration approach will be used to analyze the development of disparities for this study. It should be noted that this approach to testing convergence is fundamentally different from the conventional definition of convergence established by, e.g., Baumol (1986), Barro and Sala-i-Martin (2004), and Mankiw et al. (1992). The conventional approach defines convergence based on an inverse relationship between levels of income and growth (Barro, 1991), thereby indirectly deducing long-term processes in development on the basis of relations in the sample. However, the cointegration approach lies in the assessment of a time series, allowing for the direct testing of convergence hypothesis in terms of a dynamic-stochastic environment (Bernard & Durlauf, 1995; Pesaran, 2007). In fact, the cointegration approach to testing convergence is a very comprehensive modern method with a highly informative value of its results (Johnson & Papageorgiou, 2020; Shibamoto et al., 2016).

2.1 Cointegration approach to regional convergence

We follow the approach of cross-country (regional) convergence in terms of the limit

of expected income gaps (Bernard & Durlauf, 1995; Pesaran, 2007; Pesaran et al., 2009). It applies a stochastic definition to processes of economic fluctuation and convergence, and uses an econometric approach for the assessment of the development of disparities based on testing for the presence of a unit root and cointegration of time series (Arvanitopoulos et al., 2021). In their pioneering work, Bernard and Durlauf (1995) define convergence for a pair of regions as Equation (1):

$$\lim_{s\to\infty} E\left(y_{i,t+s} - y_{j,t+s} \middle| I_t\right) = 0 \tag{1}$$

where: y – log per capita income of a region; I_t – information set in time t, which contains previous and current income $y_{i,t-s}$ (for i = 1, 2, …, n at all horizons s = 0, 1, …).

This definition implies that a necessary but not sufficient condition for the convergence of regions i and j is cointegration of their income with cointegrating vector [1; −1]. However, such a condition for acceptance of convergence is very strict in assessing real data. In particular, this would indicate convergence only for economies with very similar parameters, including their long-run steady-state (Le Pen, 2011). Following the limitation but keeping the advantages of the cointegration approach to testing regional disparity, Pesaran (2007) and Pesaran et al. (2009) propose an application of the so-called probabilistic definition of convergence, see Equation (2). This definition is based on the conditional probability of the occurrence of each pair-wise income gap outside a predefined interval, i.e., that the absolute value of income gap ($y_{i,t+s} - y_{j,t+s}$) being larger than some positive constant C. Based on this approach, a pair of regions can then be classified as converging if for positive constant C a tolerance probability measure $\pi \geq 0$.

$$\Pr\left\{\left|y_{i,t+s} - y_{j,t+s}\right| < C | I_t\right\} > \pi \tag{2}$$

As is evident, Pesaran's modification does not lie in the partial evaluation of an individual time series, which was an initial stage of the Bernard-Durlauf approach. The probabilistic convergence approach lies in the analysis of the residuals of the time series expressed by their difference ($y_{i,t+s} - y_{j,t+s}$), i = 1, 2, …, n − 1, and $j = i + 1, 2, \ldots, n$. Therefore, it is always necessary to perform an individual test for each pair of regions in the sample.

Based on the results of individual tests between each pair of regions, the probabilistic approach is then based on the assessment of the ratio ($\bar{Z}_{n,t}$) between the number of pair-wise income gaps that meet the established criteria of convergence ($Z_{ij,t}$ = 1) and all sorts of pair-wise income gaps, whereas this ratio can be easily expressed by Equation (3). When applying this extension, Pesaran (2007) showed that during the application of tests with null of divergence (unit roots tests) and null of convergence (stationary tests), a low ratio ($\bar{Z}_{n,t}$) getting closer to the size of the test α, as n and $t \to \infty$, see Equation (4), can be expected in case of divergence. And vice versa, convergence can be spoken of, if $(\bar{Z}_{n,t}) > \alpha$, whereas it is getting closer to the unity, as n and $t \to \infty$, see Equation (5). These connections can be interpreted as: the higher the ratio ($\bar{Z}_{n,t}$), the more valid is the convergence process (Le Pen, 2011).

$$\bar{Z}_{n,t} = \frac{2}{n(n-1)} \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Z_{ij,t} \tag{3}$$

$$\lim_{t\to\infty} E\left(\bar{Z}_{n,t} \middle| H_0\right) = \alpha \tag{4}$$

$$\lim_{t\to\infty} E\left(\bar{Z}_{n,t} \middle| H_0\right) = 1 \tag{5}$$

The increased computational complexity caused by individual testing of each pair of regions, i.e., [$n(n-1)/2$] tests for the sample of n regions, is outweighed by the major advantages of this approach. In particular, the literature argues maintaining of a high level of information connected with high robustness of the method, namely:

i) It does not require the involvement of a benchmark entity. Therefore, the results are not compromised by choosing the wrong benchmark (Holmes et al., 2011; Le Pen, 2011).

ii) It allows testing the hypothesis for convergence/divergence in a short time series where n is great against t (Pesaran, 2007). Compared with traditional panel methods, this is a great advantage because the assessment is robust to cross-section dependence and aggregation (Pesaran et al., 2009).

iii) It overcomes the problems associated with technological progress, as it acknowledges its development both in the form of a deterministic and stochastic process, regardless of whether

it contains the component which could be described as random walk or not (Pesaran, 2007).

2.2 Specification of a pair-wise approach

We apply Pesaran's approach to testing convergence. A high relevance of this measurement was confirmed by a number of empirical studies (Arvanitopoulos et al., 2021; Drager et al. 2023; Duro et al., 2023; Gligoric, 2014; Holmes et al., 2011; Le Pen, 2011; Shibamoto et al., 2016). The method is complex; therefore, we will now explain the specification of all procedures in brief.

The convergence criterion of region pairs is considered the stationarity of residual (i.e., gap) series compiled of differences in the time series of these regions, or better to say, a lack of deterministic and stochastic trends in gap series. This weakens the condition of equivalence of economies significantly; however, a predicative value of test conclusions of the convergence hypothesis is not reduced (Pesaran, 2007). In fact, this concept allows the result of the income gap series to be level stationary, which is a situation where the development process will not significantly deviate from the mean, but this mean may not be 0 (Pesaran, 2007; Pesaran et al., 2009). Also, the existence of more significant differences in the structural parameters of regional economies is allowed, but only if the regions have common stochastic and deterministic trends in the development of income. The requirement for a common stochastic trend can then be described as a cointegration condition and the requirement for a common deterministic trend as a cotrending condition (Le Pen, 2011). We applied three independent tests to examine both conditions. Cross-verification, however, allows strong conclusions to be considered about the development of regional disparities.

The testing of the convergence hypothesis of household disposable income across regions starts with the Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) test (Kwiatkowski, 1992). This test works with the null hypothesis: *The series is stationary around a deterministic trend (i.e., estimated convergence)*; against the alternative hypothesis: *The series has a unit root (i.e., estimated divergence)*.

Although not rejecting the null of the KPSS test, convergence can be preliminarily estimated; our intention is to use the KPSS test as a complement to enhance the robustness of the results by subsequent application of a unit root test. Therefore, the estimation of convergence is required by both tests, i.e., with null of convergence (KPSS) and with null of divergence (generalized least squares Dickey-Fuller *t*-test; DF-GLS), for accepting the condition of convergence.

In this cross-check validation, we deviate from the usual procedure of testing convergence. In fact, previous studies (Arvanitopoulos et al., 2021; Holmes et al., 2011; Le Pen, 2011; Pesaran, 2007; Pesaran et al., 2009) usually present the application of KPSS and unit root tests as alternatives. However, they do not require reciprocal confirmation for the acceptance of the convergence condition. With our requirement for cross-check validation, we are actually able to filter out the series for which the stationary test or unit root test can fail independently. The application of both approaches thus serves as a confirmation of results and increases the robustness of testing (Kwiatkowski et al., 1992).

In the next step, we apply the unit root tests based on the Dickey-Fuller approach. In particular, we applied the generalized least squares Dickey-Fuller *t*-test (DF-GLS) defined by Elliott et al. (1996). The DF-GLS modification consists of a series transformation using generalized least squares before the application of the Dickey-Fuller *t*-test. When applying the test in accordance with Pesaran (2007), a model with an intercept and a linear deterministic trend is applied. The convergence criterion is a rejection of the null: *The series has a unit root (i.e., estimated divergence)*. In particular, rejection of null means acceptance of the alternative hypothesis: *The series has no unit root (i.e., estimated convergence)*. The DF-GLS test has substantially higher power compared to other Dickey-Fuller tests, especially when the series can be considered stationary (Zivot & Wang, 2006). In our case, this is supported by a selection of series on the basis of the application of the KPSS test.

Stationary and the absence of unit root in a series is a necessary but not sufficient condition for convergence. The approaches based on the Dickey-Fuller *t*-test may fail with respect to the issue of the identification of the deterministic trend, especially when the test data contain stochastic trend, which was clearly demonstrated by Gomez-Zaldivar and Ventosa-Santaularia (2011). Following Le Pen (2011),

the significance of the deterministic trend, which expresses a catching-up process in converging regions, is examined using a *t*-test with the null hypothesis: *There is no significant deterministic trend in a series*. However, rejection of null means acceptance of an alternative hypothesis: *There is a significant deterministic trend in a series (i.e., cotrending condition of convergence)*. Also, this is applied to the income gap series.

2.3 Data

The above methods are applied to data from the Eurostat Regional Statistics database (Eurostat, 2024). Annual data of disposable household income (in purchasing power standard, per inhabitant) are analysed. The analysis covers the 20-year series between 2003 and 2022. Considering the principles of topography, cultural and political criteria, we follow the common definition of Central Europe listed, e.g., in Encyclopaedia Britannica (2024). The reference level of research is NUTS 2 level of regions, that is, the level where the main activities of EU regional policy are carried out. Therefore, the research sample consists of: Austria (9 regions), Czechia (8), Germany (38), Hungary (8), Poland (17), Slovenia (2), and Slovakia (4).

We are aware that the sample comprises diverse economies and regions differing in their size, levels of development, and sectoral structure. Nevertheless, these countries not only share a geographic position in Central Europe but also an intertwined history and substantial economic connections. This is true even for Germany, to which many of the countries under study are linked and which played a key role in their transformation. In addition, Germany is seen as the engine of the region, contributing to the growth and development of the examined countries (Andor, 2019; Polster, 2021). From this viewpoint, this results in similarities regarding anticipated growth, income, and convergence trajectories (Corvers & Mayhew, 2021; Rauhut & Humer, 2020). A variety of recent empirical research has employed a similar sample of Central Europe, incorporating both small and large, as well as more and less developed, countries and regions (e.g., Bachtrogler-Unger et al., 2023; Cieslik & Wcislik, 2020; Holubiuc, 2020; Konya, 2023; Markowska, 2022)

Furthermore, Dorjnyambuu (2024) points out that studies concerning Central and Eastern Europe are largely concentrated on a select number of countries, partially because of their heterogeneity. Therefore, several (smaller) nations of Central Europe are not well-represented in the scholarly literature. Following that Dorjnyambuu (2024) calls for further research incorporating a wider range of samples of Central European countries and regions to ensure that the development of the field does not focus disproportionately on specific nations.

The sample of 86 regions required the examination of 3,655 series compiled from log per-capita income gaps within each step of the analysis (the analysis contains 3 steps). Therefore, only the summarising results of individual steps are presented and discussed in the following sections. The logarithmic transformation of the data for testing stationary is highly desirable due to the requirement of a normal distribution of data, which resulted from a linear form of the conducted test for stationary and unit root test, as well as for one sample *t*-test (Zar, 2010). In fact, this transformation suppresses undesirable trends in the data series (Wang, 2006). Given the breadth of analysis, it is not possible to present all of the results in this paper.

3. Results and discussion

As mentioned above, a KPSS test is applied to each pair-wise income gap series. This is followed by a DF-GLS test. Applying these tests, we can evaluate the cointegration condition. Starting with the KPSS test, we found 2,751 pairs of regions ($\overline{Z}_{i,j,t}$) are not rejecting the null of stationary. Since the sample size consists of 3,655 series, the ratio of estimated convergence in the sample of all regions ($\overline{Z}_{n,t}$) is 75.3%, which largely exceeds the level of significance (α = 5%). Based on this result, the first partial assumption for the acceptance of a common stochastic trend between pairs of regions has been met by a greater number of series than it would be possible to explain by an error rate of the test procedure.

These results are further detailed in Tab. 1, which shows information in the context of the relationships between regions within and across countries. However, the matrix depicts only a share of relations that meet the criterion of convergence ($\overline{Z}_{n,t}$). Here again, the regional convergence can be preliminarily assumed as a real process, since the percentage of no rejections of null exceeds the level of significance between the regions of all countries (except Slovakia and Slovenia). The regions of Slovakia do not show a relevant number

of common stochastic trends compared to regions of Germany and Poland. Slovenia does not show a common stochastic trend between its own regions. On this aspect, however, both small countries with few regions are disadvantaged by the methodology used.

However, within the cross-check validation of testing the common stochastic trend, the test for a unit root is also applied. In contrast, the null of the DF-GLS test refers to divergence. Therefore, the rejection of null can be interpreted as an indication of convergence. The results

Tab. 1: KPSS test summary – spatial view

	Austria	Czechia	Germany	Hungary	Poland	Slovakia	Slovenia
Austria	94.4*						
Czechia	84.7*	71.4*					
Germany	40.6*	54.6*	68.1*				
Hungary	98.6*	98.4*	95.1*	75.0*			
Poland	100.0*	99.3*	100.0*	100.0*	79.4*		
Slovakia	63.9*	46.9*	2.0	87.5*	4.4	100.0*	
Slovenia	44.4*	87.5*	100.0*	100.0*	100.0*	50.0*	0.0

Note: The values refer to % $(\overline{Z}_{n,t})$ of cases with no rejection of null; * estimated convergence (significant at 0.05 significance level).

Source: own

show that 606 pairs of regions $(\overline{Z}_{i,j,t})$ are rejecting the null of unit root; therefore, the ratio of estimated convergence in the sample of all regions $(\overline{Z}_{n,t})$ is 16.6%. Furthermore, the share of regions that met the estimated convergence (α = 5%) is significant, the number is much lower compared to the previous KPSS test. As shown in Tab. 2, the regions that most frequently fulfil the condition of convergence are located in Poland and Hungary. However, in accordance with the previous KPSS testing, divergence is estimated especially for Slovenian, Slovak and German regions.

At this point, it is important to note the fundamental difference between the frequencies of acceptance of the cointegration condition between the KPSS and DF-GLS tests. This is one of the reasons why we modify Pesaran's approach and

Tab. 2: DF-GLS test summary – spatial view

	Austria	Czechia	Germany	Hungary	Poland	Slovakia	Slovenia
Austria	38.9*						
Czechia	55.6*	35.7*					
Germany	0.6	3.3	21.3*				
Hungary	20.8*	40.6*	22.7*	35.7*			
Poland	35.3*	27.9*	9.1*	21.3*	29.4*		
Slovakia	0.0	3.1	2.6	0.0	0.0	16.7*	
Slovenia	0.0	0.0	0.0	6.3*	94.1*	0.0	100.0*

Note: The values refer to % $(\overline{Z}_{n,t})$ of cases with rejection of null; * estimated convergence (significant at 0.05 significance level).

Source: own

argue that requiring both conditions ensures a higher robustness of results, as pointed out by Kwiatkowski et al. (1992). At the same time, this modification reduced the possibility of a situation where individual tests may fail to identify a deterministic trend (Gomez-Zaldivar & Ventosa-Santaularia, 2011).

After proceeding with the evaluation of common stochastic trend (cointegration condition), an analysis of the existence of a common deterministic trend (cotrending condition) follows. This issue is examined via a *t*-test, which has a null of no deterministic trend. Therefore, the rejection of null refers to acceptance of the existence of trend (i.e., cotrending condition of convergence). The results show that 2,911 pairs of regions ($\overline{Z}_{i,j,t}$) are rejecting the null of no deterministic trend, therefore the cotrending condition is met by 79.6% of the regions ($\overline{Z}_{n,t}$), which largely exceeds the level of significance (α = 5%). However, the differences between countries are interesting. In many linkages, the trend indication is 100%, while in the others, it is only around 30%. In particular, Czechia and Slovenia achieve similar results in this regard, as presented in Tab. 3.

However, the individual tests per se track only individual aspects and do not tell us much about the evolution of regional income disparities. The strength of the cointegration approach lies in linking the results of all the tests (satisfying both conditions of cointegration

Tab. 3: ***T*-test summary – spatial view**

	Austria	Czechia	Germany	Hungary	Poland	Slovakia	Slovenia
Austria	61.1*						
Czechia	100.0*	28.6*					
Germany	30.7*	100.0*	74.3*				
Hungary	88.9*	32.8*	85.9*	57.1*			
Poland	100.0*	100.0*	100.0*	91.9*	69.1*		
Slovakia	61.1*	100.0*	55.3*	75.0*	100.0*	66.7*	
Slovenia	100.0*	46.9*	100.0*	25.0*	33.8*	100.0*	100.0*

Note: The values refer to % ($\overline{Z}_{n,t}$) of cases with rejection of null; * estimated convergence (significant at 0.05 significance level).

Source: own

and cotrending); only on this basis can we make inferences about regional convergence or divergence.

Therefore, the final step in testing the hypothesis of convergence is the connection and evaluation of the results of tests that have been applied to the income gaps of the series for each pair of regions. The results of the KPSS test, also those of DF-GLS, indicate the existence of convergence process. However, the number of pairs of regions that met the convergence (cointegration) condition is lower when applying DF-GLS. If we intersect these results, we found 588 (i.e., 15.3%) pairs of regions to have a common stochastic trend (cointegration condition). However, considering also the results of *t*-test (cotrending condition), the number of pairs decreases to 496. Since the sample size consists of 3,655 series, the ratio of estimated convergence by all tests in the sample of all regions ($\overline{Z}_{n,t}$) is 13.6%. These results are further detailed in Tab. 4 that shows the context of the relationships between regions within and across countries.

In summary, we can say that ($\overline{Z}_{n,t}$) exceeds the significance level (α = 5%), and therefore we can confirm the convergence process in terms of household disposable income in Central Europe. In fact, the number of regions showing convergence could not be explained by random influences or rather by an error term of the methods applied. However, at the same time, the measured values show that, despite the confirmation of convergence, it can also be conversely considered that the differences among a number of regions are not decreasing.

Tab. 4: Income convergence in Central Europe – spatial view, final summary

	Austria	Czechia	Germany	Hungary	Poland	Slovakia	Slovenia
Austria	33.3*						
Czechia	51.4*	14.3*					
Germany	0.6	3.0	15.2*				
Hungary	20.8*	10.9*	19.7*	21.4*			
Poland	35.3*	27.9*	9.1*	21.3*	16.9*		
Slovakia	0.0	3.1	0.0	0.0	0.0	16.7*	
Slovenia	0.0	0.0	0.0	0.0	94.1*	0.0	0.0

Note: The values refer to % $(Z_{n,t})$ of cases with estimated convergence by all tests; * confirmed convergence (significant at 0.05 significance level).

Source: own

Since there is no known recent study that would apply a similar methodology to the regions of Central Europe, it is possible to compare our findings with the study by Le Pen (2011). In his study, the application of Pesaran's approach to 195 EU regions brought only very weak results on possible convergence processes. In general, it also identified the absence of the common stochastic trend among the regions as a major cause of violation of the convergence criterion. After all, conclusions about the rigidity of the method in the area of stationarity testing were discovered by Pesaran (2007) himself. Given these analogies, it can perhaps be assumed that our results (13.6% of confirmed convergence links) are consistent with general assumptions about the results of the applied methods and can thus be considered plausible.

Considering studies using different methodologies but focused on the same region, our results are consistent with the main findings of previous research on income convergence in Central Europe. Similarly to Crespo Cuaresma et al. (2016), Nagy and Siljak (2022), and Zdrazil and Applova (2016), we found the income convergence between regions. Kapidzic et al. (2022) argue that this is due to access to national funding and EU resources, while Nagy and Siljak (2022) claim that factors such as economic openness, inflation, and the integrity of government play a more significant role. However, Licchetta and Mattozzi (2023) point out that the process is slowing down. Further down, convergence between the own (inner-country) regions was confirmed for all countries (except Slovenia). This conclusion may be considered rather surprising, as it contradicts a number of previous studies, according to which inner-country disparities are increasing (Kokocinska & Puziak, 2018; Zdrazil & Applova, 2016). This discrepancy is likely explained by the difference in methodology, where previous studies applied different procedures and evaluated less recent data. We also found that Polish regions achieved the most convergence links, as they converged significantly with regions from all countries (except Slovakia).

However, we found that only some of the regions are engaged in the convergence process, which is similar to Markowska et al. (2022). This conclusion is evident from Fig. 1, which summarizes the intensity of convergence. This intensity is represented by the number of convergence relationships with other regions in which each region is involved (since the sample of 86 regions is examined in this study, the theoretical maximum value of intensity is 85). The intensity value for the regions with the highest numbers of convergence relationships is around 30. On the other hand, more than a third of the regions show only a low number of convergence relationships (8 or less).

Fig. 1 shows a "north-south belt" of regions that experienced convergence process more frequently. Interestingly, this belt is made up mainly of regions on the border of the former Iron Curtain. These are the regions of Austria, Czechia, Slovenia, the westernmost regions of Hungary, and the western half of Poland. Surprisingly, however, we see many white spots

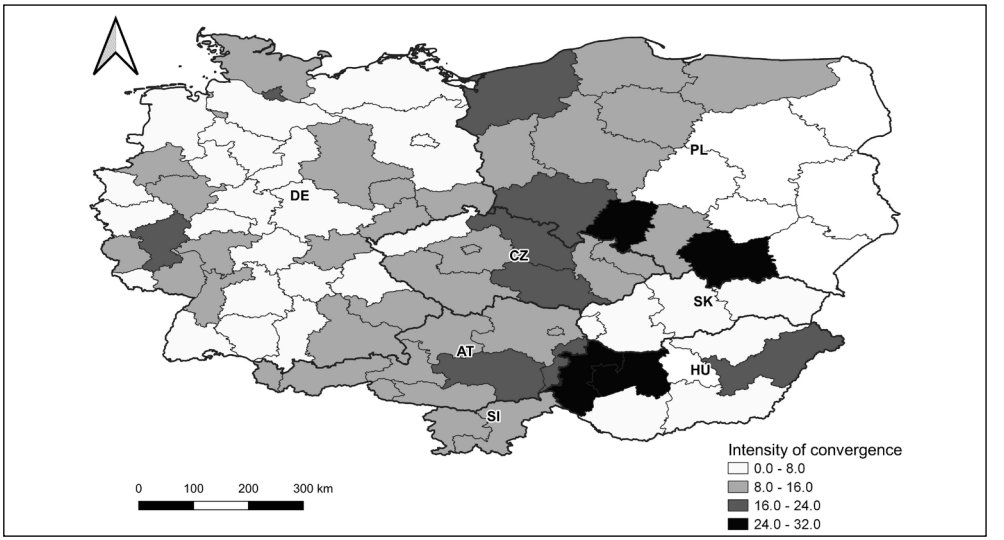

Fig. 1: Intensity of convergence in Central Europe

Source: own

(i.e., no or minimum convergence relationships) throughout Slovakia, the eastern regions of Poland, and Hungary. This observation aligns with the theoretical construct of club convergence, as explained in the literature (Basel et al., 2021; Sofi et al., 2023). Club convergence posits that clusters of regions sharing analogous characteristics or economic attributes tend to converge collectively. However, club convergence is not a rare phenomenon in Europe, since many empirical studies found some similar patterns (Drager et al., 2023; Kapidzic et al., 2022; Markowska et al., 2022).

Taking into account only transition countries, the most developed regions are included in the belt. This means that the least developed regions on the eastern border of Central Europe have not caught up with the convergence process. The benefits of EU membership, which should support convergence (Kapidzic et al., 2022; Rapacki & Prochniak, 2019), are therefore insufficiently reflected in these regions. The income in these poorest regions does not converge towards the level of their western neighbours, and hence does not create the conditions for increasing of well-being. Licchetta and Mattozzi (2023) argue this should be a result of the limited catch-up in total factor productivity growth. Prokop et al. (2021) make a similar point when they state that foreign knowledge and technology do not represent a major source of innovation and development in catching-up Central European countries. These regions cannot be considered winners of the convergence process, as described by Holobiuc (2020).

We also found that the regions of the most developed country in the sample (Germany) did not exhibit a high amount of convergence relationships. In terms of cross-country convergence, German regions converge only with some regions of Hungary and Poland. This challenges the traditional assumption that less developed regions will converge towards the more developed in terms of faster growth (Barro & Sala-i-Martin, 2004). In particular, our findings challenge the conclusions of Cieslik and Wcislik (2020), who believe that the regions of transition countries are converging towards Germany. We assume that the catching-up process in income is stronger towards the regions of Austria. In fact, Konya (2023) concludes similarly in his recent study and proposes to pay more attention to the convergence of transition countries with Austria.

The regions of the smallest countries in the sample, such as Slovenia and Slovakia, struggled to converge with the regions

of the more developed countries. Furthermore, despite witnessing income growth, the Slovak regions did not experience convergence with foreign regions. This highlights the complexities involved in achieving regional convergence, even within the context of economic integration and globalisation. This suggests that factors beyond country size, such as historical legacies, institutional frameworks, degree of globalisation, and the level of regional infrastructure, play a significant role in determining regional inequalities (Nagy & Siljak 2022). These findings correspond with the conclusions of Borsi and Metiu (2015), who argue that there is no unambiguous evidence of real income convergence in the enlarged EU. However, we can agree with the findings of Drager et al. (2023), Gligoric (2014), Kapidzic et al. (2022), and Markowska et al. (2022) that the convergence processes are valid only among some of the regions.

Conclusions

The aim of this paper was to assess the income disparities between the regions of the Central European countries. To achieve this aim, an approach based on time series cointegration analysis was used. We applied the probabilistic approach for the evaluation of disparities introduced by Pesaran, which is based on the assessment of a stochastic and a deterministic trend of time series. However, in our analysis, convergence criteria are tightened to increase robustness. In particular, we propose to require meeting both criteria, i.e., stationary and absence of unit root, instead of one for the acceptance of the cointegration condition. The significance of this modification became apparent when comparing the results of the stationarity and unit root tests.

The empirical analysis showed that despite the application of stricter conditions, the hypothesis of income convergence between Central European regions from 2003 to 2022 cannot be rejected. In particular, we found inner-country convergence in most countries. However, the involvement of individual countries in cross-country convergence varies widely. We found a “belt of convergence” made up of regions on the border of the former Iron Curtain. On the other hand, the intensity of convergence of the easternmost regions and of the westernmost regions is weak. Therefore, we assume that we can talk about confirmation of the club convergence, which has been indicated by some scholars. However, our results challenge the conclusions of previous research, according to which the transition economies of Central Europe are converging only towards the regions of Germany. Our results suggest that the convergence relationships towards the regions of Austria are more intensive.

Based on our results, it can be stated that income convergence occurs between the regions in Central Europe, suggesting that there is also a potential for a disparity decrease in standards of living and well-being of the population in the Central European regions in the future. From this conclusion, it can be inferred to a certain degree that the EU’s Cohesion Policy seems to be effective. However, this effectiveness is only partial as it is not evident in every region. The underlying question is how much it has actually impacted the developments mentioned above. We are aware that there are many factors that impact development trends and convergence trajectories, many of which are difficult to filter out. Although the research is limited by these facts, our findings provide access for better understanding of income dynamics in the Central European region. Moreover, it can also help to optimize the allocation of EU funding.

Finally, many interesting findings emerge from our analysis on regional income convergence in Central Europe, but for the discussion, we select only the most important conclusions. These results deepen the current research by showing significant differences in convergence patterns across countries. On the other hand, it also raised a number of new questions that need to be answered in further research.

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