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# The Impact of the Economic and Social Shocks (Crises) of the 2000s on Gross Value Added in Central-Eastern Europe

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KEYWORDS

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ABSTRACT

Territorial economic and social disparities remain a major problem for the European Union today, especially in Eastern Europe. The aim of this study is to analyse the impact of the economic and social shocks of the 2000s (the economic and financial crisis of 2008-09 and the COVID-19 pandemic) on the economies of four Central Eastern European countries (Czech Republic, Slovakia, Poland, Hungary). The study presents county-level differences in gross value added with classical descriptive statistics, inequality indices, convergence analyses and spatial autocorrelation. The results show that the impact of the shocks of the 2000s varies across counties, which led to different paths of recovery. Spatial autocorrelation is significant, but patterns remain stable through the period of exogenous shocks.

## Introduction

Economic and social disparities at territorial level are a major problem in Europe today (European Parliament, 2019; Iammarino et al., 2019). No two regions have the same characteristics and starting conditions, which in the long run leads to significant disparities (Henderson & Thisse, 2004; Nemes Nagy, 1990). The European Union already mentions the importance of territorial cohesion in the preamble of the Treaty of Rome (1957), which laid the foundations for integration, and this is formally confirmed in the Single European Act of 1986, which elevates regional policy to the level of Community policy as a top priority of integration (Soós, 2020). Regions may differ not only in their initial conditions and socio-economic characteristics, but also in their short- and long-term development paths. In today's globalised world, the factors of production, information and various economic processes (e.g. working capital, trade) are spread globally, but the resulting benefits are very unequal. Local specificities are increasingly important in these rapidly changing circumstances and can contribute to improving the resilience of regions.

Like other external shocks, crises tend to have a significant impact on the development of countries and regions, and sometimes change their development paths. However, the effects can vary widely depending on the type of external shocks (economic, financial, health problems (diseases, epidemics), natural disasters, political conflicts) and the resilience of regions in such circumstances is not uniform.

The aim of the study is to analyse the impact of the economic and social shocks of the 2000s (the economic and financial crisis of 2008-2009 and the pandemic starting in 2020) on the economies of four Central and Eastern European (CEE) countries (Czech Republic, Slovakia, Poland and Hungary), based on the gross value added indicator.

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The aim is to examine whether different types of shocks have different impacts on the economies of the NUTS3 regions of the countries and to what extent the disparities within and between countries change.

## Theoretical background

The study of convergence in economic growth theories is not a recent phenomenon, one of the main goals of the EU since the beginning of integration has been the convergence of peripheral regions, a need that has been reinforced by the successive accessions (and the growing disparities that have accompanied them). Over the last decade, rapid and intense technological change and global economic integration have presented regions with new challenges. As a result, the development paths of some regions have improved, while others have failed to adapt to the new challenges. The analysis of territorial disparities is not a recent phenomenon, several researchers have already examined the positive convergence potential and catching-up potential of peripheral regions (e.g. the convergence process of nation states in Barro & Sala-i-Martin, 1992; Quah, 1996; Sala-i-Martin, 1995). In catching up, we need to distinguish between two different processes, which are positive and negative convergence (Szendi, 2016). "Catching up is positive when relatively less developed regions catch up with more developed ones, and negative when the indicators of more developed regions approach those of lagging regions" (Nagyné Molnár, 2007).

In the literature, different types of convergence analyses are used to detect trends in inequalities (e.g. sigma, beta, and gamma tests), which try to explain the development paths of given regions. Sigma convergence examines the dispersion of GDP between regions, i.e. whether the dispersion of incomes decreases over time (Kocziszky & Szendi, 2020). However, it is inherently sensitive to changes in the extreme values, for example, it also reflects the economic decline of relatively more developed regions (the negative catching-up mentioned above) as convergence. The basic idea of beta-convergence is linked to Solow's neoclassical model, which assumes that the rate of economic growth depends essentially on the growth rates of capital stock and labour (Andrei et al., 2023) and calculates with the change in average GDP relative to the base period. There are two trends in the literature on this method: absolute and conditional beta convergence. The absolute convergence theory states that less developed countries tend to grow faster in absolute terms towards a future steady state, i.e. there is a negative relationship between the initial level of development and the growth dynamics. In this theory, all regions converge to the same steady state. In contrast, conditional beta-convergence assumes that there are significant differences between regions in terms of initial conditions, available factors, and characteristics, so that there is no common steady state for each region, but each region converges towards its own development path (Eckey & Türck, 2007; Mankiw et al., 1992; Szendi, 2016). Based on the above, Quah (1996) analysed the club convergence theory in his work and found that the GDP per capita of nations does not converge towards the same steady state, but that values cluster (due to different initial conditions and differences in income distribution across economies) and convergence is observed in these clusters, which are called convergence clubs.

According to the European Commission's latest Cohesion Report, since 2000, the impact of substantial structural and territorial funding has reduced disparities between EU Member States (i.e. convergence has accelerated), but internal regional disparities between regions have increased (European Commission, 2022). In 2021, the highest GDP per capita among EU Member States was in Wolfsburg (GER) at NUTS3 region (county) level with €172,100, while the lowest was in Silistra (BG) with €4,200, a 40-fold difference (Eurostat, 2023a). The same situation within the four Visegrad countries (Czech Republic, Slovakia, Hungary, Poland) under study is as follows. The highest value is linked to Prague (CZE) with 44,300 EUR/person and the lowest to the county of Nógrád (HUN) with 6,400 EUR/person. Here the difference is 7x. This indicates a rather large disparity for the Central and Eastern European region as a whole. In NUTS3 level, the inside country differences are the highest in Poland (5.7-fold in 2020), followed by Hungary, Slovakia and the Czech Republic, with 4.59; 3.77; 3.57-fold gap respectively.

Crises can have a major impact on the development of regions, so their analysis is significant as they can have a major impact on the inequalities between them. The European Investment Bank examined the impact of the 2008-09 economic and financial crisis on territorial processes. Their analysis shows that regional economic convergence slowed down significantly in 2008-09, after nearly a decade of rapid convergence (European Investment Bank, 2012), i.e. the catching-up process was slowed down by the economic crisis. Looking at a crisis of a different nature, the OECD (2020) study finds that the COVID-19 crisis highlighted the widening of regional differences in economic growth in Europe. Palomino et al. (2020) measured the impact of policies that emphasised social distancing during the pandemics on poverty and wage inequality in Europe and found that poverty increased, and wage losses occurred during the crisis. This is why it is important to analyse the impact of different types of crises on economic development indicators.

## Methodology and data

The aim of the research is to examine patterns and trends in gross value added (GVA) as an indicator of economic development. GVA can be defined as the output (at basic prices) minus intermediate consumption (at purchaser prices), thus reflecting the level of economic growth. Indeed, value added is the difference between output and intermediate consumption (Eurostat, 2023b).

The research aims to highlight the extent to which the crises of the 2000s (external shocks) affected the development of certain regions and whether different types of crises had different effects on the level of development of regions. The territorial unit analysed will be the NUTS3 (county) level in four Central and Eastern European (CEE) countries (Czech Republic, Slovakia, Hungary, Poland). The CEEC region is relatively underdeveloped compared to the EU's northern and western member states and its catching-up is critical for the EU's complex development (Gorzelak, 2020). It is therefore important to examine how external shocks affect the convergence process of these regions. Due to the way the shocks run, the study covers several periods, firstly, the effects of the first and second waves of the 2008-09 economic and financial crisis (assuming that this was a "W" crisis as most of the literature suggests, e.g. Strauss-Khan, 2020), and secondly, the effects of the first wave of the COVID-19 pandemic in 2020[1]. The whole period under study is from 2005 to 2020, which can provide a complex overview of the processes.

The methods used in the analysis are classical descriptive statistics, different types of convergence analysis (sigma, beta and gamma) and spatial autocorrelation analysis, which examines whether neighbourhood effects are significant in the development process.

## Results

The logic of the analysis was as follows. First, I checked the distribution of gross value added data in the NUTS3 counties of the four Central and Eastern European countries under study, using basic statistical methods, and checked the changes in the values of the indicator during the crisis periods. After that I examined the inequalities between and within countries in the frames of convergence analyses to get an insight of the complex convergence processes in the region. The last step was to analyse the spatial autocorrelation between counties and the role of neighbourhood effects.

### Distribution and patterns of gross value added

Looking at the distribution of the data, there are significant west-east differences within the four countries both at the beginning and end of the period analysed, with the highest values of GVA in the Czech Republic, western Slovakia, some metropolitan areas of Poland and western Hungary, and the lowest values in eastern Slovakia, Hungary and Poland (Figure 1).

The change in the pattern shows that some areas have been able to improve significantly compared to the regional average (e.g. the regions of Sibiu, Eperjes and Banská Bystrica [SVK], Olomouc [CZE], some Polish regions such as the city region of Poznan, Warsaw Eastern Region [POL]), while others underperform compared to the base year (e.g. Karlovy Vary and Ústí nad Labem district [CZE], or, along with others, Borsod-Abaúj-Zemplén, Heves, Hajdú-Bihar or Komárom-Esztergom counties [HUN]). How-

[1] The lack of data for Polish counties does not yet allow for a second wave analysis.

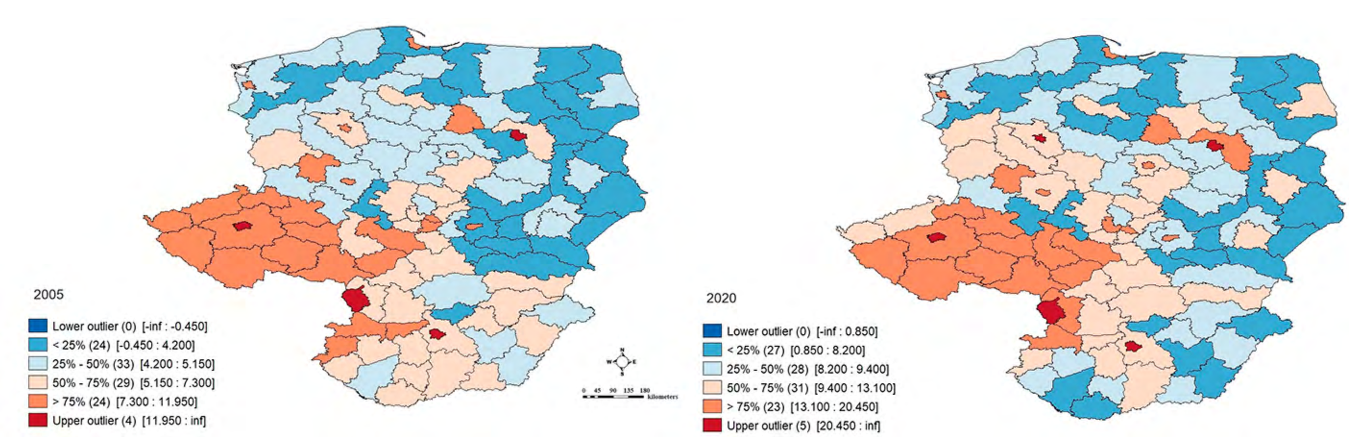


**Figure 1.** Change in specific gross value added (thousands of EUR per capita) in 2005 and 2020
*Source: Based on Eurostat data*

ever, it is also true that value added has increased in all the regions examined, so in absolute terms regional performance is improving.

The analysis of the extreme values (maximum and minimum) showed that there was no significant change between the best and worst positions, neither the economic and financial crisis nor the first wave of the pandemic had a major impact on the situation of the best and worst performing counties in the four countries. The only change is linked to the county of Nógrád (HUN), which is in the worst position since 2008, when its performance grew at a slower pace than the gross value added of the former "leader" (worst performer) Nowotarski region (Southern Poland). There was no change in the top position, with the Czech capital, Prague, having the highest per capita GVA over the whole period (Table 1).

**Table 1.** Extreme values of regional specific gross value added (EUR)

| | maximum | | minimum | |
|---|---|---|---|---|
| 2005 | Prague (CZ) | 21780.27 | Nowotarski (PL) | 3419.68 |
| 2008 | Prague (CZ) | 32439.82 | Nógrád (HU) | 4121.19 |
| 2010 | Prague (CZ) | 31467.74 | Nógrád (HU) | 3731.169 |
| 2012 | Prague (CZ) | 30754.29 | Nógrád (HU) | 3608.669 |
| 2019 | Prague (CZ) | 42523.49 | Nógrád (HU) | 5551.547 |
| 2020 | Prague (CZ) | 39878.32 | Nógrád (HU) | 5342.12 |

To explore the effects of the crises, I have created three time periods to review the impact of the different shocks on the regions. The first period runs from 2008 to 2009, covering the first wave of the economic and financial crisis ('period A'), the second from 2011 to 2012, covering the second wave of the economic and financial crisis ('period B'), and the third covers the first wave of the COVID-19 pandemic from 2019 to 2020 ('period C'). The results show that in period A there were huge declines in county-level gross value added data in almost all areas, with the Hungarian and Polish counties particularly performing extremely poor. The largest declines on the Hungarian side were in Fejér, Veszprém, Komárom-Esztergom and Győr-Moson-Sopron counties (with declines of 22.8%; 18.02%; 18.92% and 18.06% respectively), but Borsod-Abaúj-Zemplén, Békés and Vas counties also experienced specific GVA declines of more than 15%. Among the Polish counties, three regions stand out where the decline in output due to the crisis is close to or even exceeds 20%: Sieradzki (20.87%), Pulawski (19.7%) and Sosnowiecki (19.05%) in the eastern and southern counties of the country. The only area in the whole region that managed to maintain a positive trend during this period was the Bratislava district with a growth rate of 3.9% compared to 2008. The average decrease was 14.8% in Hungary, 12.26% in Poland, 8.03% in the Czech Republic and "only" 4.03% in Slovakia (thanks to the performance of the Capital Region) (Figure 2).

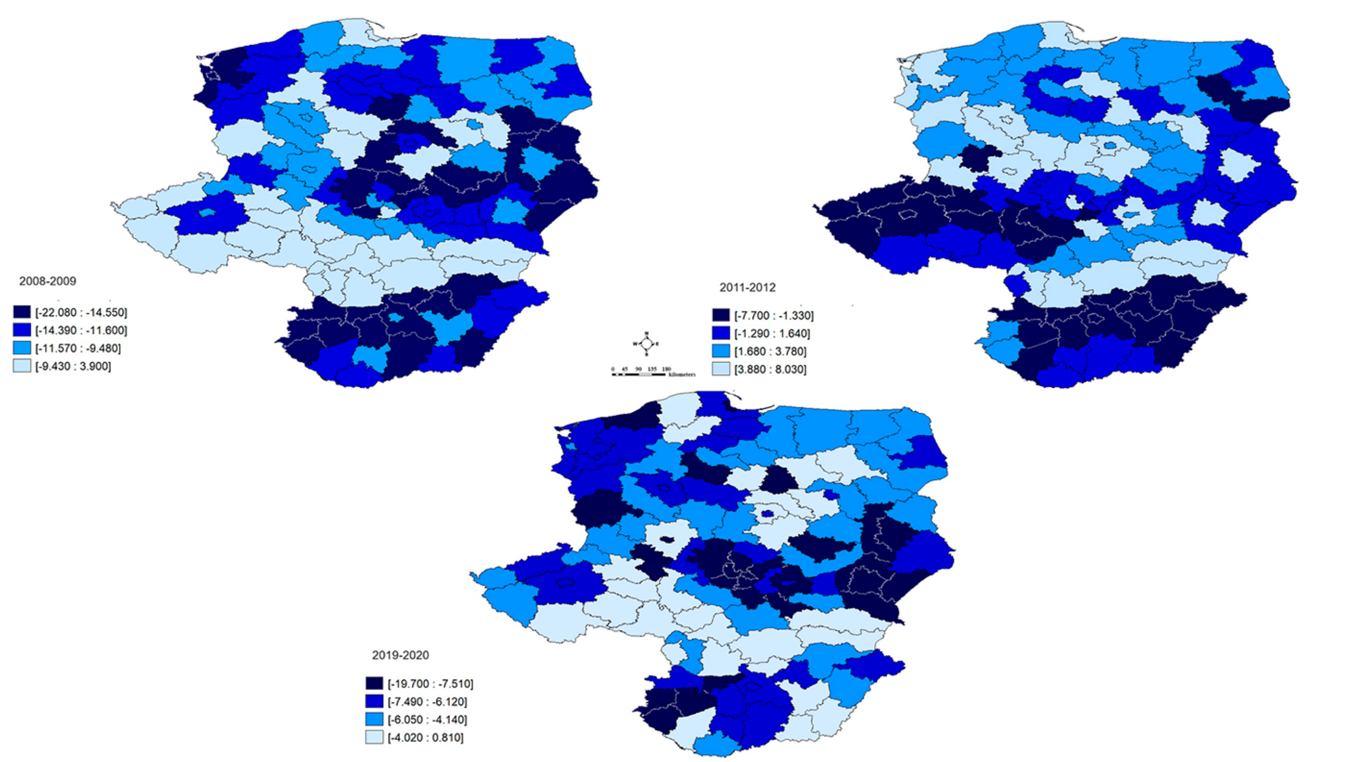


**Figure 2.** Changes in GVA due to crises

*Note: upper left – first wave of the economic and financial crisis (2008-2009); upper right – second wave of the economic and financial crisis (2011-2012); bottom – first wave of pandemics (2019-2020)*

*Source: Based on Eurostat data*

In period B, the impact of the second wave of the crisis was smaller. During this period all districts of Slovakia, except 10 counties in Poland (the remaining 63 regions) and six Hungarian counties, showed a positive trend. It was one of the highest in the city region of Wroclaw, with a maximum of over 8%. The most severe problems were in Hungary (e.g. Komárom-Esztergom, Győr-Moson-Sopron, Heves and Nógrád counties with a loss of more than 5%) and in one Czech county, Pardubice (7.7%). Period C, which quasi measures the short-term effects of the pandemic, shows a more heterogeneous picture than before. With the exception of Poland, one county in each country remained positive in the first wave (all with an increase of less than 1%; CZE: Vysocina district, HUN: Jász-Nagykun-Szolnok county, SVK: Kassa district). The largest decreases were suffered by Poland (6.75%), Hungary and the Czech Republic, with average decreases of 6.18 and 3.63% respectively. In Slovakia the figure was around 2.27%.

## Inequality indices (Hoover and Theil index)

The Hoover index is an indicator of inequality that shows "how much or what percentage of the quantity of one characteristic or socio-economic indicator needs to be reallocated in order for its spatial distribution to be equal" (Molnár, 2007). The indicator is usually interpreted in percentage form. Results close to zero imply a homogeneous distribution, i.e. the distribution of indicators is the same across territorial units, while values close to 100 indicate a completely different distribution (Nemes Nagy, 2005). It can be calculated using the following formula:

$$H = \frac{1}{2}\sum_{i=1}^{n} | x_i - f_i | \quad (1)$$

- where $\Sigma f_i$=100%, $\Sigma x_i$=100%, for the distribution of the two indicators examined.

The Hoover index as a measure of concentration shows for the four countries under study, that 18.84% of gross value added would have had to be reallocated between the NUTS 3 counties in 2005 in order to bring the distribution of value added into line with the population share of the counties, whereas by 2020 the same value had fallen slightly to 18.42%. The values suggest that the first wave of the economic and financial crisis caused the greatest increase in inequalities between areas, while the other crises caused only small changes. However, the reduction in disparities, by 0.5 percentage points, indicates positive trends (a slight convergence of the region).

A further variant of inequality indicators, the so-called Theil index, is an indicator derived from entropy, which can also be interpreted as an indicator of redundancy, measuring the disorder of the share of the indicator in the total volume of the indicator under study (Nemes Nagy, 2005). The value of this indicator ranges between zero and ∞, where zero indicates an equal distribution and higher values indicate a higher level of inequality (OECD, 2016). It therefore reaches its minimum value when all GVA values are equal and its maximum value when GVA in a region is aggregated (Major & Nemes Nagy, 1999). It can be calculated using the following formula:

$$R = \frac{1}{n}\sum_{i=1}^{n} \frac{y_i}{y} log\left(\frac{y_i}{y}\right) \quad (2)$$

- where $y_i$ specific indicator in territory $i$, while $y_i$ is the weighted average of (Nemes Nagy, 2005).

Looking at the results of the Theil index, its values show a slightly different trend from the inequality index seen previously. The value is 0.13-0.14 for the region (indicating relatively low levels of inequality and low levels of data disorder), and has increased slightly over the period under study, with only a few centuries of changes in the values due to crisis events.

## Convergence processes of gross value added in Central-Eastern Europe

Convergence analysis was used to look at the catching-up process using three methods (sigma, beta and gamma convergence analysis). The basic difference between the methods is that the sigma convergence is sensitive to outliers due to the use of the average value, and its value can also decrease if there is a decline in the value of more developed areas, so it is worth using the other two methods. Beta convergence, on the other hand, also indicates the reliability of the model with its $R^2$ value and the fit of the OLS model, while gamma convergence shows changes in the ranking of areas without being sensitive to outliers. However, it does not provide information on the internal structure of the reordering. So, there is a need for the complex application of the three methods.

A basic method of convergence analysis is sigma convergence, usually measured by trends in the coefficient of variation (CV) indicator. If the relative dispersion of gross value added relative to the average decreases over time, then the phenomenon of sigma convergence is fulfilled (Szendi, 2016). The indicator can be calculated as the ratio of the dispersion to the average value.

$$CV = \frac{st.deviation}{average} \quad (3)$$

The results show that the CV indicator vary from year to year, but when looking at the whole time span, the following can be confirmed. At the within-country level, Slovakia and Hungary showed sigma convergence, the Czech Republic showed sigma divergence, while Poland showed a slight sigma divergence or rather stagnation. At the cross-country

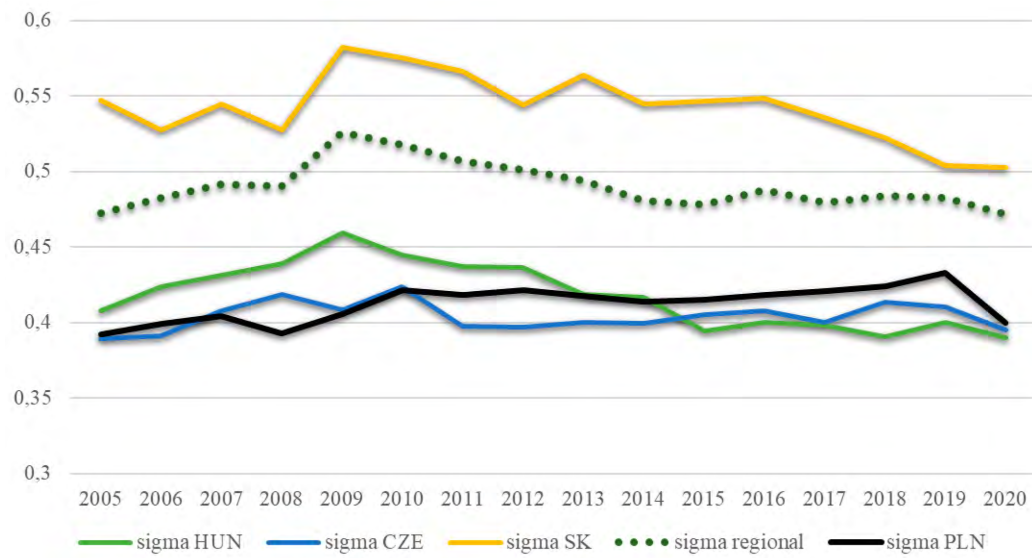


**Figure 3.** Sigma convergence within and between countries (2005-2020)
*Source: Based on Eurostat data*

level, we see sigma convergence over the whole period (Figure 3), which suggests a catching-up process between territories, but it could also be the result of uneven development (where more developed territories face more problems than less developed ones). The sigma convergence indicator is therefore adequate but does not by itself provide sufficient data to fully reveal the convergence process (Andrei et al., 2023), as it may also indicate a decline when the initially more developed areas are in a recession. Therefore, I have checked the beta and gamma convergence values.

To examine beta-convergence, we check the regression equation between the annual growth rate of GVA per capita and the GVA in the initial year. If the beta coefficient is negative and significant, then beta-convergence is satisfied (Ferkelt, 2005). In the analyses, similar to the previous study, I have reviewed the trends at both the national and regional levels, with the following results.

Beta convergence has been tested without the distorting effect of the capital regions, which has indicated a slightly stronger convergence process among the territories with $R^2$ of 5.52%.

The model results show that the linear equation explains 2.6% of the variance of the values (Table 2 and Figure 4), while the F-statistic value confirms the null hypothesis, which supports the validity of the model (significant at the 10% level). The multicollinearity condition is 4.44, which is lower than the benchmark value of the indicator, suggesting that there is no confounding degree of multicollinearity between the variables (Tóth et al., 2023). To test the normality of the residual, I used the Jarque-Bera test. The

**Table 2.** Beta convergence results of gross value added in the Visegrad countries (NUTS3)

| REGRESSION OLS METHOD | | | |
|---|---|---|---|
| | Coefficient | Std. error | Prob. |
| Constant | 4.96219 | 0.220241 | 0.00000* |
| Log of "initial year" | -0.0580751 | 0.033171 | 0.08272** |
| R-squared | | 0.026639 | |
| F-statistic | | 3.06523 | |
| Prob(F-statistic) | | 0.0827218** | |
| Multicollinearity Condition Number | | 4.448751 | |
| Jarque-Bera test | | 3.3469 | 0.18760 |
| Breusch-Pagan test | | 0.4249 | 0.51448 |
| Koenker Bassett test | | 0.4226 | 0.51562 |
| Log likelihood | | -161.468 | |
| Akaike info criterion | | 326.936 | |
| Schwarz criterion | | 332.408 | |
| half-life | 11.6 | | |

**Significant at 1%*
***Significant at 10%*

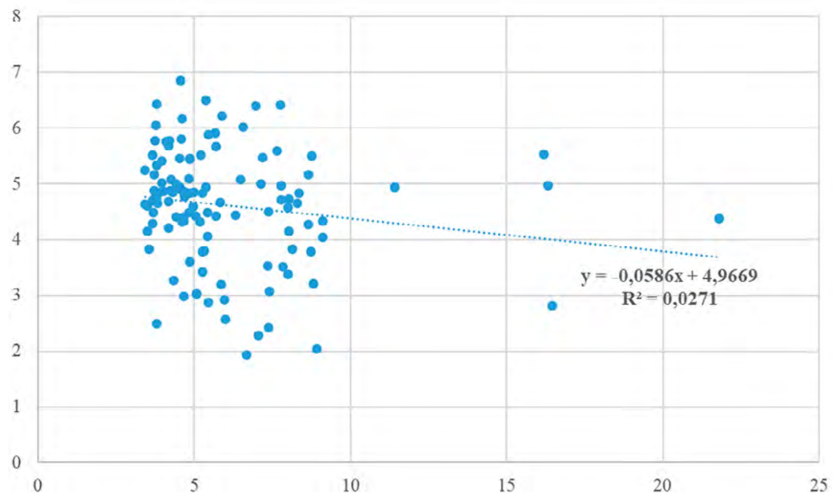


**Figure 4.** Interregional beta convergence between countries (2005-2020)
*Source: Based on Eurostat data*

associated probability value for this test is 18.76%, which indicates that we cannot reject the null hypothesis, i.e. the robustness of the data under test can be verified.

Overall, the results are uneven based on beta convergence, as shown also by the sigma. In Hungary and Slovakia there was beta convergence between counties, but the dispersion of the data is very unequal. The Czech Republic and Poland show beta divergence between 2005 and 2020. However, beta convergence has been achieved in a total of 115 NUTS3 regions in the four countries. An analysis of annual growth rates of value added shows that the Slovak and some Polish regions have grown fastest in regional terms.

A significant measure of the convergence process is the half-life, defined as the time needed for economies to complete half of the deviation from their steady state (Arbia et al., 2005). In the case of the OLS model it is 11.6 years.

The concept of gamma convergence was introduced by Boyle and McCarthy (1999) in the context of economic analysis. The index measures how the ranking of each area has changed compared to the base year:

$$\gamma = \left( \frac{var(RGDPC_{ti} + RGDPC_{t0})}{var(RGDPC_{t0} \cdot 2)} \right) \quad (4)$$

where *var* (*RGV AC*)denotes the variance of GVA per capita, while $t_i$ is the current year under consideration, $t_0$ is the base year.

The gamma convergence shows decreasing variance in all territories and scales analysed (i.e. catching up), and small ranking shifts both within and between countries (Table 3).

In the case of convergence analyses, however, it should be noted that different crisis situations and shocks may lead to different trends, as the periods A, B and C mentioned above had a major impact on the development of the regions. Looking at the periods, in terms of sigma and beta convergence, the first wave of the 2008-2009 crisis (A) resulted in greater divergence both nationally and in the wider region, with the exception of the Czech Republic, while periods B and C brought divergence and convergence. Gamma convergence is more sensitive to the crises, with all three periods showing decreasing divergences in the region as a whole. The countries, with the exception of Slovakia (where the ranking remains constant during the crisis), experienced more severe rearrangements (Hungary and Poland convergent trends, while the Czech Republic showed increasing divergences in all three periods). These results may be related to the relative position of the areas and the changes in their position, so the examination of the neighbourhood effects is significant.

**Table 3.** Beta and gamma convergence analysis of regional gross value added

| | Beta convergence | Gamma convergence |
|---|---|---|
| Hungary | y = -0.0558x + 3.3739<br>$R^2$ = 0.0649 | 2005: 2.244<br>2020: 2.215 |
| Slovakia | y = -0.0563x + 6.4319<br>$R^2$ = 0.3604 | 2005: 2.155<br>2020: 2.107 |
| Czech Republic | y = 0.0052x + 4.26<br>$R^2$ = 0.001 | 2005: 2.241<br>2020: 2.228 |
| Poland | y = 0.0024x + 4.9446<br>$R^2$ = 0,0000005 | 2005: 2.247<br>2020: 2.205 |
| Cross-country level | y = -0.0586x + 4.9669<br>$R^2$ = 0.0271 | 2005: 2.233<br>2020: 2.212 |

*Source: Based on Eurostat data*

## Spatial autocorrelation analysis

The importance of the role of space in the analysis of spatial inequalities is significant in the light of the first law of geography: “everything is related to everything else, but near things are more related than distant things” (Tobler, 1970).

Spatial autocorrelation is a method of studying spatial interactions by examining whether the spatial distribution of individual values of gross value added is random or follows some regular pattern (Dusek, 2004). Autocorrelation can be measured globally (using the Moran I index) and locally.

Moran I statistics can be used to test both global spatial autocorrelation and local spatial autocorrelation. Therefore, I tested the global autocorrelation of the value added under 999 permutations (Table 4).

**Table 4.** Spatial autocorrelation diagnostics based on Moran I (2020)

| | Moran I/ Degrees of Freedom | Value | Prob |
|---|---|---|---|
| Moran's I (error) | 0.5361 | 8.7733 | 0.00000 |
| Lagrange Multiplier (lag) | 1 | 73.0781 | 0.00000 |
| Robust LM (lag) | 1 | 6.0810 | 0.01366 |
| Lagrange Multiplier (error) | 1 | 69.7115 | 0.00000 |
| Robust LM (error) | 1 | 2.7144 | 0.09945 |
| Lagrange Multiplier (SARMA) | 2 | 75.7925 | 0.00000 |

The index of global autocorrelation (0.53) indicates a moderately strong positive autocorrelation, which supports the extension of the analysis to neighbourhood effects. It also implies that gross value added in each county is positively related to its neighbours. Looking at the variation, there was no significant shift in the Moran I value over the period analysed (initial year 2005: 0.479).

Among the tools of the local spatial econometric methods, I chose the Local G* indicator, which is an indicator of the local spatial autocorrelation of each data point. The indicator is not sensitive to spatial outliers (and thus does not indicate spatial outliers, such as Local Moran I) and can be calculated using the following equation.

$$G_i^*(d) = \frac{\sum_{j=1}^{n} w_{ij} x_j}{\sum_{j=1}^{n} x_j} \quad (5)$$

where $d$ is the neighbourhood distance, and $w_{ij}$ is the weight matrix, which is a queen-contiguity neighbourhood matrix (with symmetric distribution). Positive $G_i^*$ represents the local clustering of high values (hot spots), while negative $G_i^*$ represents local clustering of low values (cold spots).

The results show that local spatial autocorrelation is significant in several areas. In general, it is true that the crises have not led to a substantial change in the distribution of clusters (Figure 5), with an overall reduction in

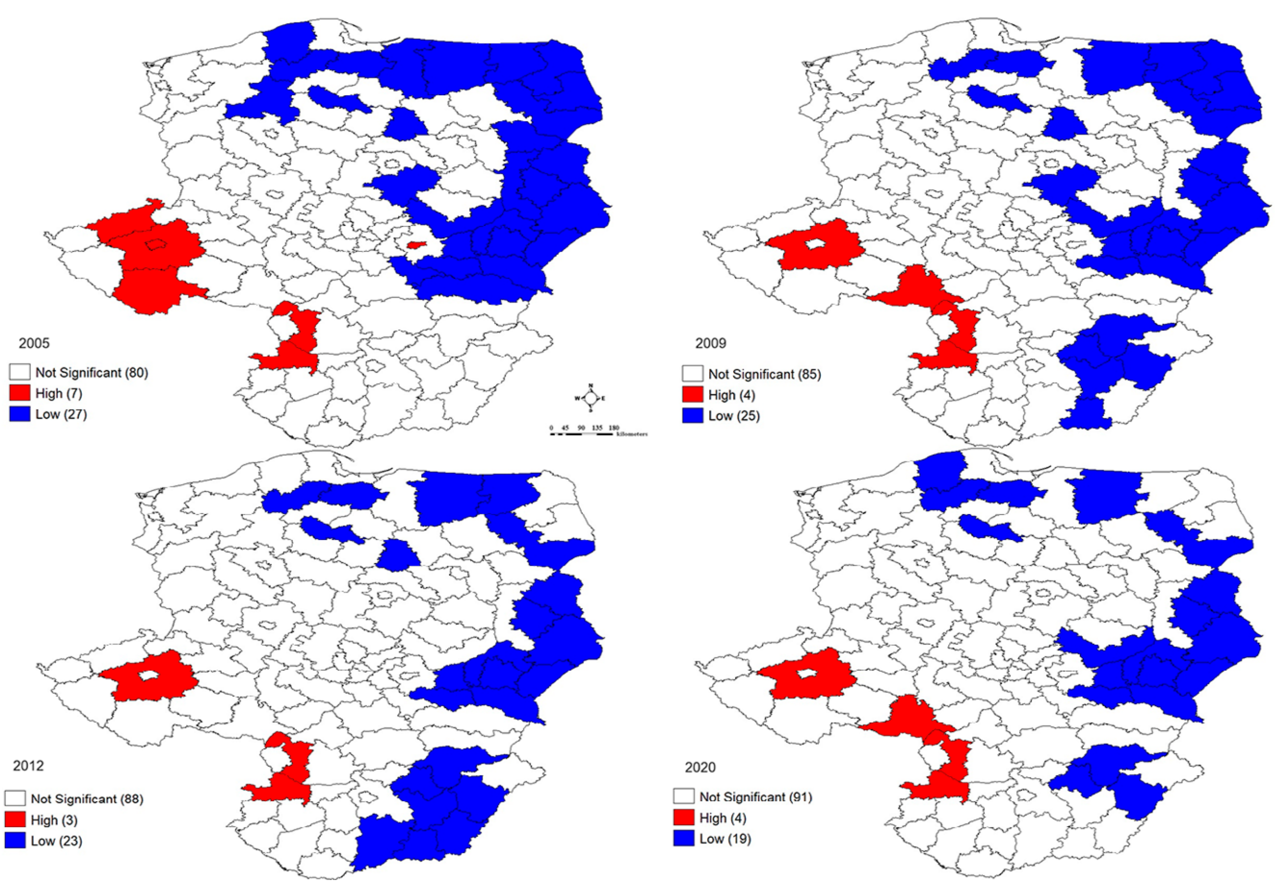


**Figure 5.** Analysis of the local spatial autocorrelation of GVA 2005, 2009, 2012, 2020
*Source: Based on Eurostat data*

the number of clusters but no significant change in the location of hot and cold spots. The following areas have been hot spots in all periods: the District of Trnava (SVK), Stredny Czechy (Central Bohemia, CZE), Győr-Moson-Sopron County (HUN). In addition to these, other Czech districts have periodically appeared as hot spots.

The range of cold spots is broader: most of Eastern Poland throughout the period (e.g. Elcki, Bialski, Lubelski or Olstynski districts), the district of Eperjes at the beginning of the period, and from 2009 onwards several Hungarian counties (e.g. Borsod-Abaúj-Zemplén, Heves or Hajdú-Bihar are stable members of the group), which were also formed partly because of the crises.

The spatial autocorrelation analysis thus demonstrates that the spatial distribution of data and the role of neighbourhood effects are important for economic development, but less sensitive to external shocks. The spatial patterns are fairly stable, but the results may be modified by the addition of other areas to the study area (e.g. integration of Romania or Bulgaria). Since the spatial autocorrelation is significant, it is worth extending the results of the previous convergence study to include spatial effects, so I tested the role of neighbourhood relations in beta-convergence. This is because, if the spatial units are related, the traditional OLS regression estimation may not yield reliable results.

Two of the most common methods for econometric modelling of spatial autocorrelation are the spatial lag model and the spatial error model (Varga, 2002). Spatial lag is the weighted average of the neighbouring values of a given observation unit.

General form of the spatial autoregressive model (Gerkman & Ahlgren, 2011):

$$y = X\beta + \rho Wy + u \qquad (6)$$
$$u = \lambda Mu + \varepsilon$$

ρ and λ scalar spatial autoregressive parameters. Two special cases can occur if either ρ=0 or λ=0. If ρ=0, then the model is a spatial error model (contains a spatially lagged error term), and if λ=0 the model is a spatial lag model (contains a spatially lagged dependent variable).

The spatial error model (SEM) assumes that only the error terms in the regression are correlated, while the spatial lag model (SLM) examines how the GVA growth rate of regions depends on their own initial value added level and how this is affected by the growth rates of neighbouring regions (Andrei et al., 2023).

To select the appropriate spatial autocorrelation model, I used the classical procedure presented by Anselin (2005), which allows to decide between the SLM model and the SEM model based on Lagrange Multiplier tests. Since both the LM-Lag and LM-Error models are significant (p-value 0.0000), the robustness tests are considered. The significance of the lag model is lower among the robust tests, I decided to use it. This assumes that there is autocorrelation between different levels of the dependent variable. The results of the model are shown in Table 5.

**Table 5.** Parameters of the spatial lag model

| | Value |
|---|---|
| Mean dependent variable | 4.61368 |
| S.D. dependent variable | 1.01101 |
| Lag coefficient (Rho) | 0.746646 |
| R-squared | 0.526283 |
| Sigma-square | 0.484203 |
| S.E of regression | 0.695847 |
| Log likelihood | -129.329 |
| Akaike info criterion | 264.657 |
| Schwarz criterion | 272.866 |
| W_log annual growth rate | 0.746646 |
| | (0.0000) |
| Constant | 1.26648 |
| | (0.00032) |
| Log of "initial year" | -0.020726 |
| | (0.36701) |
| Half-life | 34.31 |

Since the analysis of $R^2$ is not relevant in spatial regression models (Anselin, 2005), I considered the values of the Log-Likelihood, the Akaike Information Criterion (AIC) and the Schwarz Criterion (SC). When comparing the Log-Likelihood values of OLS (-161.46) and SLM (-129.32), a higher value is observed for SLM. This is also supported by the Akaike Information Criterion (AIC) and the Schwarz Criterion (SC).

The model estimates the spatial autoregressive coefficient to be 0.74, which is significant at p-value (0.0000). The spatial lag model and the classical LOG model of GVA differ slightly. However, the spatial lag model suggests a slower catch-up than the OLS estimate (based on the constant and log base values), which can be underlined by the half-life values (this latter is 34.31 years by the spatial lag).

## Conclusion

The aim of the study is to test the convergence and autocorrelation of gross value added in Central-Eastern Europe. The results show that the impact of the shocks of the 2000s varies from one region to another, with some areas being able to increase their level of value added even in times of crisis. Almost all areas were deeply affected by the first wave of the economic and financial crisis, but the second wave and the first wave of the pandemic had a relatively smaller impact. In general, Hungary and Poland experienced the strongest downturns, followed by the Czech Republic and Slovakia, except in 2012 when the Czech Republic was one of the worst hits. Analyses of convergence at the intra- and inter-country level show that between 2005 and 2020, sigma convergence was mostly achieved between countries and within the four-country region, while beta convergence was achieved in Hungary, Poland and Slovakia, and in an interregional context. This indicates that the ranking of areas within countries has also changed, as evidenced by the gamma convergence of values. The difference in the results for sigma and beta convergence suggests that there has been a negative convergence process between regions over the period under study, i.e. the more developed regions have seen their indicators decline and converge with those of less developed areas. The spatial autocorrelation is significant in the area, but there is no significant change in the pattern of hot and cold spots, so the spatial patterns are not very sensitive to external shocks. The different nature of the areas and their initial conditions suggest that they have followed recovery paths from crises of different intensities. Thus, the first and second waves of the economic and financial crisis and the pandemic have had an uneven impact on the region's departments, which has further increased spatial disparities. Their convergence is best described by a spatial lag model.

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