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Economic convergence in the European Union at the regional level with particular attention to the impact of the COVID-19 pandemic – a spatio-temporal approach

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Abstract. The study presents an analysis of the impact of the COVID-19 pandemic on the economic convergence in the European Union (EU). It is widely known that every crisis can have a negative influence on the economic development of a country or region. This research analysed data for 233 EU regions on the NUTS-2 level in the years 2000-2020. To verify the occurrence of the convergence process, the spatio-temporal β-convergence models for pooled time series and cross-sectional data (TSCS) were estimated. Expanding the convergence models with the dummy variables characterising two critical crises in the analysed period (the global financial crisis in 2007-2009 and the start of the COVID-19 pandemic in 2020) allowed us to verify their impact on the regional convergence process in the EU. The main aim of this research is to assess the influence of presented crises on the economic convergence between EU regions. Because regions cooperate, the spatial element of the β-convergence models was also included. The additional aspect of the study is the comparison of the differences in strength of the influence of the mentioned crises on economic convergence.

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1. Introduction

The reduction of inequalities constitutes the main interest of every economy, regardless of the level of development. In the contemporary world, economic equality between regions within one country and between countries is sought. Increasingly, authors point out the importance of the spatial aspect in economic development (Barca et al., 2012). Solow started the advisement about economic convergence in his neoclassical growth theory (Solow, 1956). Based on Solow's theory, convergence relies on catching up with the more prosperous economies by the poorer ones. This type of convergence is known in the literature as β-convergence, popularised by Robert Barro and Xavier Sala-i-Martin (Barro & Sala-i-Martin, 1992).

Economic growth depends on various factors. One of them is pandemics. The negative long-run impact of the pandemic on the spreading of poverty was considered in previous studies (Gallup & Sachs, 2001; Joo et al., 2019; Brown et al., 2021; Zhang et al., 2020). It is widely known that economic growth is prolonged in areas of long-time poverty. In particular, the COVID-19 pandemic, which started in 2019, significantly influenced the living standards of the population (Kuzmenko et al., 2020; Vasilyeva et al., 2021; Matczak & Szymańska, 2022; Senetra & Szczepańska, 2022). Most of the researchers pointed out the relevance of the relationship between the COVID-19 pandemic and economic growth. Pardhan and Drydakis analysed this dependence for 38 European countries after the first wave of the pandemic (Pardhan & Drydakis, 2021). The negative impact of the COVID-19 pandemic on economic growth is indicated in other studies as well (Apergis & Apergis, 2021; Asare Vitenu-Sackey & Barfi, 2021; Soava et al., 2021; Xiang et al., 2021). In this context, the pandemic can significantly inhibit economic convergence.

In this study, the regional economic convergence across NUTS-2 European Union units was analysed. The spatial range of the research constitutes 233 regions of the European Union. The study is conducted based on data from the years 1995 and 2020. To verify whether the convergence process occurs, the β-convergence models in the absolute and conditional forms were estimated. In the considered period, two significant economic crises occurred. The first is the global financial crisis in the years 2007-2009. The second is the start of the COVID-19 pandemic at the end of 2019 (in most European countries since early 2020). In this context, the additional explanatory variables characterised by the mentioned periods, in the form of dummies, were included in the models. The main objective of the research was to assess the influence of the crises mentioned above on the economic convergence between EU regions. Additionally, the difference in the strength of this relationship between financial and pandemic crises was evaluated. Moreover, based on the existing literature review, models were enriched with the spatial factor. In the analysis, two types of connection matrices were used. The first is based on the common border criterion. The two regions are recognised as neighbours if they have a common land border. The second neighbourhood matrix was constructed based on the similarity of GDP *per capita* levels (economic distance matrix). The use of an economic neighbourhood matrix can significantly improve the quality of spatial models. Notably, including economic similarity makes the model parameters more reliable, and their interpretive values increase. In the investigation, two hypotheses were verified:

1. The COVID-19 pandemic hurt the convergence process across European Union regions, and
2. Economic similarity is more important than the geographical neighbourhood in the case of convergence across EU regions.

In the literature, many studies have considered economic convergence in Europe. Andor (2019) analysed the convergence in Western and Eastern European countries, emphasising inequalities between them. Moreover, Andor pointed out possible solutions to reduce inequalities faster. Haynes and Alemna (2023) examined the convergence between EU economies and underlined the role of the Financial Crisis and the COVID-19 Pandemic. They proved that unplanned situations and political decisions related to them favour the divergence process. In previous research, regional convergence was also analysed. Von Lyncker and Thoennessen (2017) used a panel data approach to conclude the progress of the convergence process in the EU-15 countries. Additionally, they divided NUTS-2 regions into four clusters and used the club convergence approach. The regional convergence was considered by Goecke and Hüther (2016) and Manzi et al. (2023). Manzi, with co-authors, compared the convergence process occurring between European and Brazilian regions, pointing out the similarity in their dynamics of economic growth in the analysed period.

One of the first analyses including spatial dependencies in the regional convergence models was the study conducted by Arbia and Paelinck (Arbia & Paelinck, 2003). They considered the economic convergence between 119 NUTS2 regions of the EU in the years 1980-1994. In their study, the classical and spatial β-convergence models and also the Lotka-Volterra model. In turn, Piras and Arbia (Piras and Arbia, 2007) used spatial panel data models to verify a hypothesis about the convergence process in the 125 EU-NUTS2 regions in the period 1977-2002. They conclude by discussing the significance of the dependencies between neighbours. Panel data models in the dynamic version were used by Badinger, Müller and Tondl (Badinger et al., 2004). In their research, models for spatially fitted variables were estimated as well. Considering the situation in 196 EU-NUTS2 regions, they showed that ignorance of the spatial correlation between units could lead to potentially misleading results in the economic convergence analysis. Olejnik presents the spatial approach in the regional convergence analysis (Olejnik, 2008). In turn, Rusu (Rusu, 2011) underlined the role of spatial and territorial effects in the convergence process, especially in the case of Eastern European countries. The alignment of the GDP *per capita* levels in the Visegrad Countries (at the regional level) using spatial models was concluded by Nevima and Melecky in their study (Nevima & Melecky, 2011). The investigations of the economic convergence process across the EU-NUTS2 regions in several countries using spatial econometric tools were presented in many other studies as well (Bouayad-Agha & Lionel, 2010; Simionescu, 2015; Egri & Tánczos, 2018; Siljak & Nagy, 2018; Alexa et al., 2019; Díaz Dapena et al., 2019; Kashnitsky et al., 2020; Peshev & Pirimova, 2020; Cartone et al., 2021). A few researchers conducted analyses at the NUTS-2 level within one country. For example, it is worth pointing out studies that present the verification of the convergence hypothesis in Germany (Kubis & Schneider, 2016), Turkey (Kındap & Dogan, 2019), Bulgaria (Peshev, 2022), and Ecuador (Flores-Chamba et al., 2019). Among a few studies concerning the convergence process in the EU at the NUTS-3 level, the investigation made by Postiglione and co-authors should be highlighted (Postiglione et al., 2020). Apart from estimating spatial convergence models, they also quantified the explanatory variables' average impacts (direct, indirect, and total).

2. Methodology

In the first step of the research, the long-term tendencies in the formation of the processes were investigated. For this purpose, the spatial and spatio-temporal trend models are considered. The general form of the spatial trend model is as follows (Cressie, 1993):

$$P(\boldsymbol{s}_i) = \sum_{k=0}^{p}\sum_{m=0}^{p}\theta_{km}x_i^k\, y_i^m, \qquad (1)$$

where $s_i=[x_i,y_i]$ indicates the region's location coordinates on the plane, i=1,2,…,N are indexes of spatial units, and p means the polynomial trend degree ($k+m\leq p$).

Whereas the spatio-temporal trend model can be written as:

$$P(\boldsymbol{s_i},t) = \sum_{k=0}^{p}\sum_{m=0}^{p}\sum_{l=0}^{p}\theta_{kml}x_i^k\, y_i^m t^l, \qquad (2)$$

where: s_i,i,p – as above, wherein $k+m+l\leq p$, t denotes time.

Apart from spatial and spatio-temporal trend analysis, the spatial autocorrelation presence in the formation of processes was studied. This type of autocorrelation refers to dependence between neighbouring regions. Moran's I statistics is used the most often to test the spatial autocorrelation and takes the following form (Moran, 1948; Schabenberger & Gotway, 2005):

$$I = \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{n}w_{ij}}\cdot\frac{\sum_{i=1}^{n}\sum_{j=1}^{n}w_{ij}\,[y_i-\bar{y}][y_j-\bar{y}]}{\frac{1}{n}\sum_{i=1}^{n}[y_i-\bar{y}]^2} = \frac{n}{S_0}\cdot\frac{\boldsymbol{z}^T\boldsymbol{W}\boldsymbol{z}}{\boldsymbol{z}^T\boldsymbol{z}}, \qquad (3)$$

where y_i is the observation of the process in the i^{th} region, $\bar{y}$ denotes the average value of the process, and $\boldsymbol{W}$ is the matrix of spatial connections between units. In this research, two types of connection matrices were used: the row-standardized to unity matrix based on the common border criterion (marked as $\boldsymbol{W}$) and a matrix based on the GDP *per capita* levels similarity (marked as $\boldsymbol{D}$). Statistically significant Moran's I coefficient signalizes the presence of spatial autocorrelation.

For stationary processes (filtered out from the non-stationarity in the average), the spatio-temporal convergence models were estimated and verified. Initially, the absolute β-convergence model was discussed. The general form of the model is as follows:

$$\ln\left(\frac{GDP_{i,t}}{GDP_{i,t-1}}\right) = \beta_1\ln\left(GDP_{i,t-1}\right) + \varepsilon_{i,t}, \qquad (4)$$

where $GDP_{i,t}$ and $GDP_{i,t-1}$ are the levels of Gross Domestic Product in PPS *per capita* in the i^{th} country in time t and t-1, respectively (stationary processes), β_1 denotes the structural parameter and $\varepsilon_{i,t}$ – spatio-temporal random process. Model (2) can be written in the form of the first-order autoregressive spatio-temporal model, given as:

$$\ln(GDP_{i,t}) = (1+\beta_1)\ln(GDP_{i,t-1}) + \varepsilon_{i,t}. \quad (5)$$

Less than unity and statistically significant parameter $1+\beta_1$ points out that the convergence process occurs. Based on the model (5), the convergence characteristics such as convergence speed and half-life time can be calculated. These statistics are designated with the use of the formulas (6) and (7), respectively:

$$b = -\ln(1+\beta_1), \quad (6)$$

$$t_{hl} = \frac{\ln 2}{b}. \quad (7)$$

Next, the spatio-temporal conditional convergence models were estimated and verified. The convergence was conditioned with dummy variables characterizing periods of the financial crisis (*FC*) and COVID-19 pandemic (*COV*). Thus, a model in the form (8) was formulated:

$$\ln(GDP_{i,t}) = (1+\beta_1)\ln(GDP_{i,t-1}) + \beta_2 FC + \beta_3 COV + \eta_{i,t},$$
$$\eta_{i,t} = \lambda \sum_{j\neq i} w_{ij,t}\eta_{j,t} + \varepsilon_{i,t}. \quad (8)$$

where $GDP_{i,t}$ and $GDP_{i,t-1}$ are defined as above. Moreover, β_1,β_2,β_3 are the structural parameters of the model, and $\varepsilon_{i,t}$ is defined as above. In turn, $w_{ij,t}$ are elements of the block matrix of spatio-temporal connections, which is expressed as (Szulc and Jankiewicz, 2018):

$$\boldsymbol{W}^* = [w_{ij,t}]_{NT\times NT} = \begin{bmatrix} \boldsymbol{W_1} & \boldsymbol{0} & \cdots & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{W_2} & \cdots & \boldsymbol{0} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{0} & \boldsymbol{0} & \cdots & \boldsymbol{W_T} \end{bmatrix}, \quad (9)$$

where $\boldsymbol{W_1}=\boldsymbol{W_2}= \dots =\boldsymbol{W_T}$ indicates a standard spatial connectivity matrix, such as in (3). These matrices are the same for all years.

3. Description and primary analysis of data

In this study, data characterized the Gross Domestic Product *per capita* in purchasing power standards (PPS) measured GDP in EU-NUTS2 regions were used (marked as GDP). Data come from the European Statistical Office database – EUROSTAT (https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_10r_2gdp (Accessed: 04 July 2022). Analysis was conducted with the R software (version 4.1.1).

Figure 1 presents the spatial differentiation of the GDP *per capita* in the extreme years of the research and its growth rate between 2000 and 2020. A map in part (a) shows the GDP levels in the first year of the investigation. Again, the map in part (b) presents the spatial distribution of the discussed process in 2020. In turn, in part (c), a map with the GDP growth rate is inserted. It is worth seeing the great similarity of the spatial distributions of the GDP *per capita* in both years. The central part of the European Union was dominated by regions distinguished by the highest values of the discussed process. These regions are located in Austria, Benelux countries, West Germany, and North Italy. Also, most Scandinavian regions were located in groups of units with GDP levels above the median (high and very high values). Instead, the eastern part of the Community was dominated by less-developed regions. The values of the considered process were shaped below the median value for the whole EU. The exception was region Warszawski stołeczny (PL91) in 2000, and additionally Sostinės (LT01) and București-Ilfov (RO32) in 2020. Into the same groups of values as the eastern units belonged Iberian Peninsula regions, except Madrid (ES30) and Área Metropolitana de Lisboa (PT17).

It is worth noting that a certain tendency in space is visible based on the maps of GDP spatial distribution. Therefore, spatial factors should be included in the research. In this connection, the spatial and spatio-temporal trend models in the next part of the study were concerned.

As we can see in part (c) of Figure 1, most of the eastern regions (relatively less developed) were characterised by the highest economic growth. In turn, central and western territorial units were located in the groups of countries with GDP growth below the median. Generally, regions characterised by the lowest levels of GDP *per capita* in 2000 show the highest growth rate and vice versa. Comparing the maps in parts (a) and (c), we can presume that the convergence process across EU-NUTS2 regions occurred in the period 2000-2020. The presumption is strengthened with the graph presented in Figure 2, where the negative regression line between GDP in the first year of analysis and its growth rate in the discussed period is visible.

Initially, the spatial trend models in each year of the research were estimated and verified. Only in the years 2000-2003, the second-degree spatial

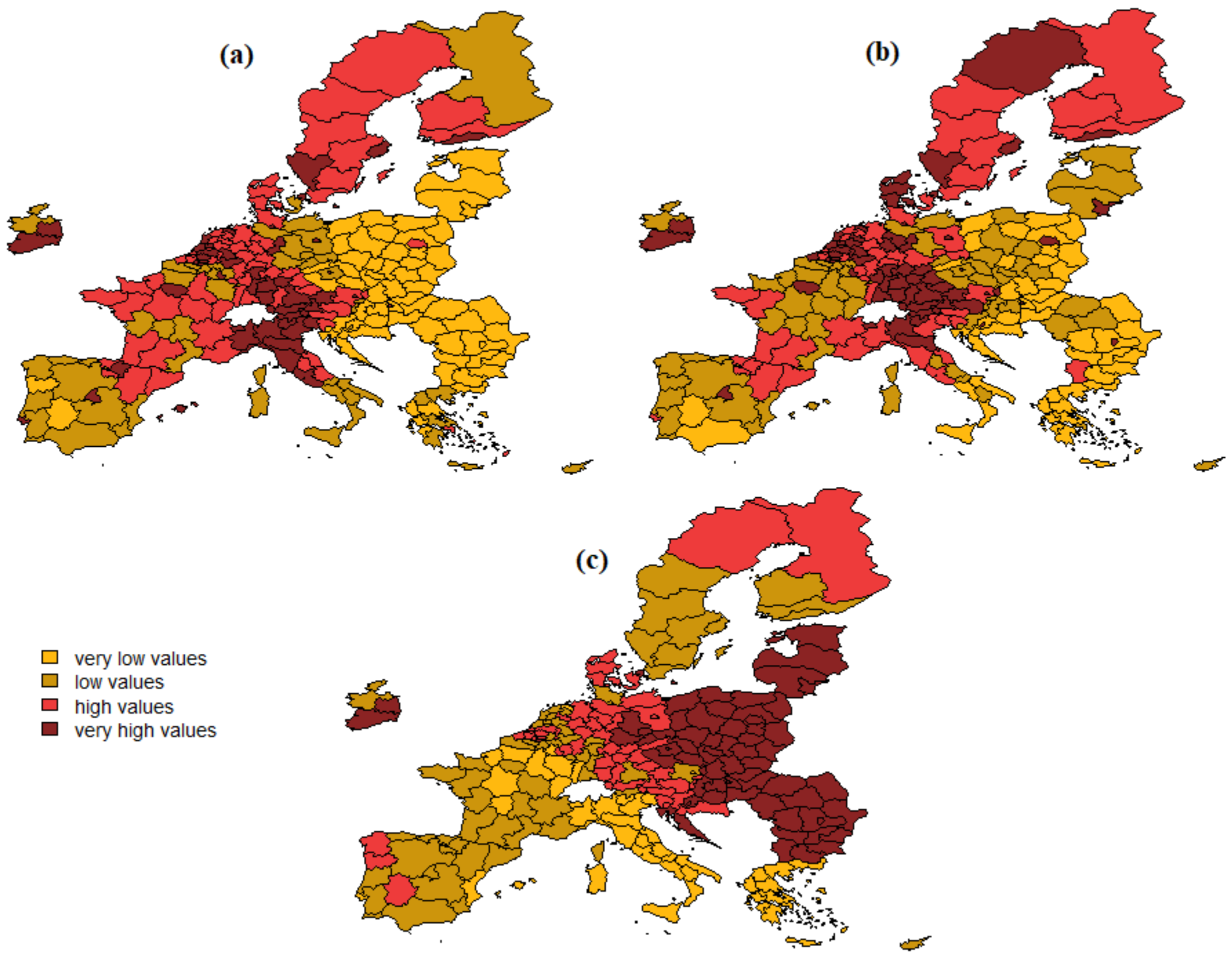

Fig. 1. Spatial distributions of GDP per capita in the years 2000 and 2020 and its growth rate in the period of 2000-2020
Source: own elaboration

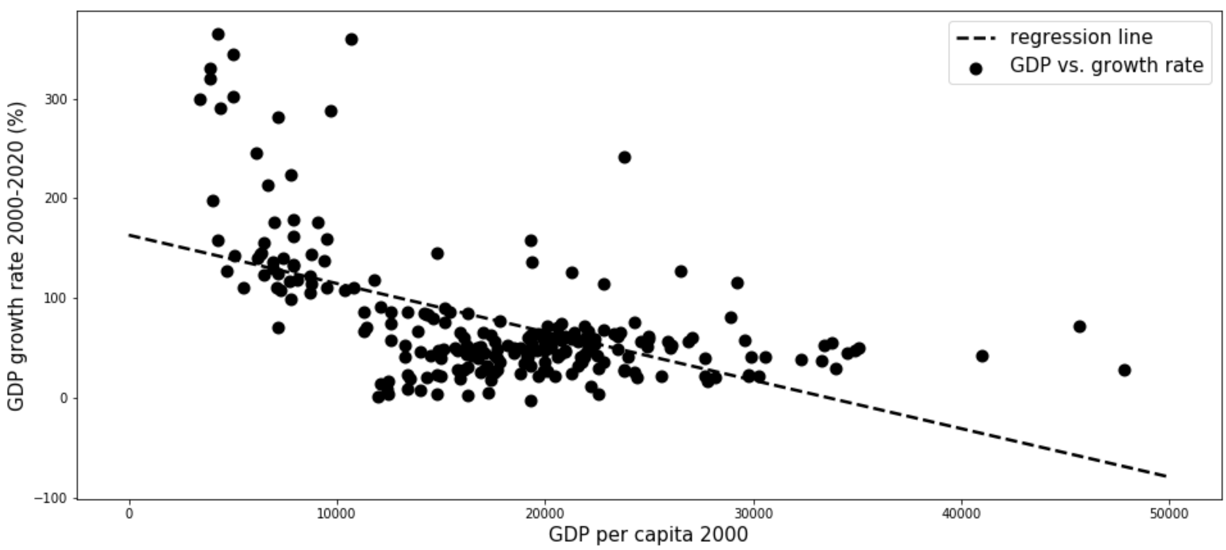

Fig. 2. The relationship between GDP per capita in 2000 and the growth rate of the GDP in the period 2000-2020
Source: own elaboration

Table 1. The results of estimation and verification of the first-degree spatio-temporal trend model

Parameter	Estimate	Standard error	t statistics	p-value
$\boldsymbol{\theta_{000}}$	8,9285	0,0437	204,1400	0,0000
$\boldsymbol{\theta_{100}}$	-0,0226	0,0006	-39,3400	0,0000
$\boldsymbol{\theta_{010}}$	0,0217	0,0009	24,3700	0,0000
$\boldsymbol{\theta_{001}}$	0,0256	0,0008	30,1400	0,0000
R^2 =0,3672				
Matrix:	***W***		***D***	
Moran's *I*	0,4964		0,5652	
p-value	0,0000		0,0000	

Source: own calculations

trend was concluded. In the remaining period, the first-degree spatial trend was noted. Moreover, the significance of the Moran's I statistics, calculated using both discussed connection matrices – ***W*** and ***D***, in the whole period was observed. Based on these observations, the first-degree spatio-temporal trend model was estimated and verified. The results are presented in Table 1.

All estimated parameters in the trend model turned out to be statistically significant, so the first-degree spatio-temporal trend in the formation of GDP *per capita* values exists. The negative estimate of parameter θ_{100} indicates an average decrease in the values of examined process in the eastern direction. In turn, a positive value of estimation of parameter θ_{010} points out the average higher economic growth level in the northern regions of the European Union. An average increase of the GDP *per capita* over time was concluded based on the positive value of the estimation of parameter θ_{001}. Both Moran's I statistics are statistically significant, too. Relatively high positive values of statistics show the relatively great similarity of the GDP *per capita* levels in neighbouring regions. Nonetheless, a higher value of the statistics for the ***D*** matrix denotes higher relevance of the economic situation similarity than the geographical neighborhood (quantified using the ***W*** matrix).

4. Empirical analysis of convergence

Initially, for the processes filtered out from the non-stationarity, the absolute β-converge model was estimated and verified. The results of this part of the investigation are presented in Table 2.

Lower than unity and statistically significant parameter $1+\beta_1$ indicates the occurrence of economic convergence across European Union regions. Based on the parameter value, it can be concluded that from one year to another, the inequalities are reduced by around 2,5%. In this connection, the time needed to reduce inequalities by half is around 30 years (t_{hl}=28,0329). Moran test results show the presence of spatial autocorrelation in the model residuals, regardless of neighbourhood matrix use, wherein higher strength of connections between the neighbouring regions is observed for the geographical neighbourhood (quantified with ***W*** matrix). Moreover, based on the LM tests results, the character of spatial dependence was appointed. Comparing the LM statistics estimates, the supremacy of the spatial error model over the spatial lag model was noticed. It means that the shocks of the random processes or processes omitted in the model from neighbouring regions are more relevant in the convergence process than shocks in their GDP *per capita* level.

Table 3 presents the results of estimation and verification of the spatial absolute and conditional β-convergence models.

Adding the spatial dependence element to the model did not change the statistical significance of the parameter $1+\beta_1$, which value shows the economic convergence between regions as well. Moreover, the parameter λ is statistically significant, too, regardless of the used connection matrix. But, it is worth noting the different impacts of the geographical and economic neighbourhood on the convergence process. The first type of spatial connection relevantly delays the convergence process. Instead, its slight acceleration is observed considering the neighbourhood resulting from the GDP *per capita* levels similarity. The time needed to reduce current inequalities by half has shortened to around 20 years.

Negative estimates of statistically significant parameters β_2 and β_3 indicate the adverse impact of

Table 2. The results of estimation and verification of the absolute β-convergence model

Parameter	Estimate	Standard error	t statistics	p-value
$1+\beta_1$	0,9756	0,0017	576,0000	0,0000
R2=0,9861				
Matrix:	W		D	
Moran's I	0,6187		0,4592	
p-value	0,0000		0,0000	
Lagrange Multiplier tests				
Statistics	**Estimate**	**p-value**	**Estimate**	**p-value**
LM_{err}	3572,6080	0,0000	4669,0880	0,0000
LM_{lag}	22,9260	0,0000	169,9800	0,0000
RLM_{err}	3733,6020	0,0000	4537,9300	0,0000
RLM_{lag}	183,9200	0,0000	38,8230	0,0000
b	2,4726%			
t_{hl}	28,0329			

Source: own calculations

Table 3. The results of estimation and verification of the spatial absolute and conditional β-convergence models

Model	Absolute convergence		Conditional convergence	
Parameter	**SE_W**	**SE_D**	**SE_W**	**SE_D**
$1+\beta_1$	0,9960 (0,0000)	0,9643 (0,0000)	0,9973 (0,0000)	0,9658 (0,0000)
β_2	-	-	-0,0139 (0,0000)	-0,0106 (0,0028)
β_3	-	-	-0,0980 (0,0000)	-0,0633 (0,0000)
λ	0,7352 (0,0000)	0,7288 (0,0000)	0,7202 (0,0000)	0,6672 (0,0000)
Diagnostics				
Moran test	-0,0786 (0,0000)	-0,0447 (0,0000)	-0,0934 (0,0000)	-0,0387 (0,0000)
AIC	-19414,0000	-18379,0000	-19808,0000	-18466,0000
Log-lik	9709,8060	9192,5030	9909,1450	9237,8610
b	0,4001%	3,6346%	0,2730%	3,4823%
thl	173,2525	19,0706	253,8886	19,9047

Source: own calculations

the financial crisis and COVID-19 pandemic on the GDP *per capita* level, respectively. It is worth noting the higher strength of the influence of the pandemic than the financial crisis, even its shorter duration (referring to the analysed period). Moreover, the speed of convergence (b) turned out to be slightly lower than in the absolute convergence models. This means that taking into account periods of crises, the process of equalizing GDP levels slows down.

A disadvantage of estimated models is the spatial autocorrelation in their residuals. But the significance of the relatively low value of the Moran's I statistics results from the size of the research sample. In the light of the Akaike criterion and Logarithm of likelihood values, the superiority of the models estimated using the ***W*** matrix was noted, but statistical differences between models for both types of regional connections are small.

5. Conclusion

Regional convergence is a very important issue in economic analyses. The occurrence of convergence in the European Union across NUTS2 regions was confirmed more than once. In this study, the economic convergence in the EU-NUTS2 regions between 2000 and 2020 was discussed and positively verified. Nevertheless, few studies have considered the impact of the COVID-19 pandemic on the alignment of GDP levels. The extension of β-convergence models with the variables characterising crisis periods allowed us to confirm the negative influence of, among others, the COVID-19 pandemic on regional economic convergence. Moreover, the negative impact of the financial crisis on the convergence process was noted. However, the influence of financial disasters was weaker than that of the COVID-19 pandemic. Hence, recovery from the crisis in 2020 may take longer than recovery from the financial crash.

Estimated spatial convergence models showed the different effects of shocks occurring in the geographical and economic neighbours. The convergence process slows down in the first case, but in the second, it speeds up.

In further research, the division of EU-NUTS2 regions into smaller groups and the estimation of club-convergence models are worth considering. The premise of this division can be a different impact of the COVID-19 pandemic, depending on the region's character and wealth. Tourist regions or less-developed regions are potentially more affected by the pandemic.

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