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Income convergence in Central and Eastern Europe: Evidence from cross-country panel data analysis

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ABSTRACT

Recent research has suggested that unconditional convergence no longer exists. Thus, this study examined the income convergence among 11 Central and Eastern European (CEE-11) countries that joined the European Union in/after 2004 and Europe's four largest economies (Germany, France, the United Kingdom, and Italy) by using panel data from 1994 to 2019. For this purpose, it employed the beta (β) and sigma (σ) convergence approaches to analyze the dynamics of economic growth. Based on the findings, in 1996, the four largest European economies had a higher capital–labour ratio and GDP growth than CEE-11. However, by 2019, the patterns reversed. As for the regression results, there was strong evidence of unconditional β convergence between 1999 and 2019, at an annual rate of 11%, with the σ convergence and the fixed effect models further supporting income convergence. Moreover, although brief divergence occurred during various financial crises, the overall trend was a significant convergence of CEE-11 with Europe's four largest economies through higher relative GDP growth. This study contributes to the economic growth theory of income convergence across countries and highlights the importance of regional integration in enabling sustainable catch-up growth.

KEYWORDS

GDP growth, convergence, CEE-11, European countries

JEL CLASSIFICATION INDICES

O1, O4, P51

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1. INTRODUCTION

The concept of convergence is more commonly associated with economies with lower levels of per capita income (expressed in relation to their steady-state per capita income), which tend to grow faster. In recent economics literature, the questions of income convergence across regions have attracted attention. For example, previous studies have indicated that there is a debate regarding whether per capita income can continue to indefinitely grow through saving and investing in physical capital alone (Kashnitsky et al. 2020; Cartone et al. 2021; Desli – Gkoulgkoutsika 2021; Roy et al. 2021). Meanwhile, a related study argued that the growth rates of poor countries are economically greater than those of developed countries, due to the existence of diminishing returns to capital. However, unconditional divergence has not occurred for decades (Patel et al. 2021).

Kremer et al. (2022) presented mixed findings regarding unconditional and conditional convergence as well as unconditional divergence. For instance, unconditional and conditional empirical frameworks have been used to investigate the link between previous GDP and current GDP per capita. Based on the unconditional framework, the findings supported the proposition of declining disparities attributable to the preceding income levels (Barro and Sala-I-Martin 1992).

Despite the extensive literature on economic convergence across countries (Barro – Sala-i-Martin 2004; Kashnitsky et al. 2020; Cartone et al. 2021; Szczepańska-Woszczyna et al. 2022), the debate regarding global convergence remains unresolved. Thus, we examine the convergence of the Central and Eastern European (CEE-11) countries that joined the European Union (EU) in/after 2004.[1] They were most likely motivated by the four largest economies in Europe (Germany, the United Kingdom (UK), France and Italy) for two reasons. First, the CEE-11 has undergone significant economic and political transformations since the fall of socialism in the late 1980s and early 1990s. In the intervening years, many of these countries implemented market-oriented reforms, and experienced rapid economic growth. As a result, it is natural to determine whether these countries are converging with the more developed European economies.

Second, the four largest economies in Europe are important benchmarks for economic performance, since they represent a significant share of the EU's population and GDP. For instance, in 1996, Germany accounted for approximately 21% of the EU's GDP, with France at 16%, Italy at 13%, and the UK at 17%. By 2019, their shares included Germany at 21%, France at 15%, Italy at 11%, and the UK at 15%, prior to Brexit (The World Bank 2023). Hence, it is relevant to examine whether the CEE-11 is catching up with these economies, since it could have implications for their future economic prospects and integration into the broader European economy.

Considering these issues, we address two important research questions: 1) How can we quantify the degree of economic convergence or divergence in terms of the income between theCEE-11 and the four largest economies in Europe? and 2) What factors can explain the observed patterns of economic convergence or divergence between these regions? We hypothesize that the CEE-11 will grow faster than the four largest European economies.

[1]Bulgaria, Croatia, Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia.

The remainder of this study is organized as follows. The next section reviews the relevant theoretical and empirical research, while the third section explains the methodology and model specifications used in the analysis. The fourth section discusses the results of the analysis, while the final section presents the overall findings and conclusion.

2. LITERATURE REVIEW

2.1. Theoretical research

In the neoclassical growth model, income-level convergence implies the equalization of income and the tendency of poor countries' development toward rich countries. In this regard, conditional convergence occurs in poor countries that tend to grow faster than the rich ones, and the two economies converge if the growth rate of each economy declines as it approaches a steady-state income level. In fact, there has been little evidence of convergence across countries without conditioning on the determinants of this income level (Barro et al. 1991).

However, in their study on convergence for the 1960–2017 period, based on a sample of 150 countries, Kremer et al. (2022) argued that (depending on the variables and period) β convergence was negative in the early 1990s, indicating absolute convergence, while σ convergence was negative in the late 1990s. Meanwhile, although the GDP per capita of the EU-25 exhibited β convergence at purchasing power parity, it did not exist for the EU-15 and the CEE-10, confirming σ convergence for the EU-25 and the CEE-10 (Stanišić 2012). Related research has also shown that the neoclassical growth model supports β convergence when poorer countries grow faster (on average) than the richer ones, and σ convergence when the cross-sectional variance of (log) income per capita falls over time (Barro – Sala-i-Martin 1992). Additionally, β convergence corresponds to a negative slope when regressing growth on initial income levels, indicating that (on average) poorer countries are predicted to grow faster than the richer ones. As for σ convergence, previous studies found that it corresponded to the falling cross-country variance in income levels in 1980 and in early 2000 (Kremer et al. 2022; Nagy – Šiljak 2022).

According to the Solow-Swan growth model, the per capita quantities of capital (k), income (y) and consumption (c) will not increase in the-long run. This suggests that as the population grows (n), the overall capital, income and consumption levels will also grow. However, on a per capita basis, such growth remains constant. In other words, the model implies that while the total amounts of k, y and c expand with population growth, the average or per person share of these variables remains unchanged over time (Barro – Sala-i-Martin 2004).

Although the neoclassical growth model also shows diminishing returns to capital (Solow 1956; Koopmans 1963; Cass 1965), the country's per capita growth rate is contrary to its initial income level per person (Barro 1991). This hypothesis is inconsistent with the cross-country evidence from 150 countries for the 1960–2017 period, in which unconditional divergence is no longer true (Patel et al. 2021). Meanwhile, the β coefficient has been shown to be insignificantly different from zero (or even positive), indicating no unconditional convergence.

In general, an economy with initially low GDP per capita and capital per worker may experience faster growth toward a steady state, compared to an economy starting with higher income and capital per worker, due to the potential for catch-up growth and the diminishing

marginal returns to capital (Barro – Sala-i-Martin 2004). Moreover, in Panel (a) of Figure 1, the vertical line measures the distance between the gross investment per effective labour. This is represented by $sA.f(k_t)/k_t$, where s is the proportion of the output that is saved and A is the total factor productivity, capturing the efficiency with which inputs (e.g., capital and labour) are transformed into outputs. As for the depreciation rate of capital per effective labour, it is represented by $(x + n + \delta)$, where x is the growth rate of technology, n is the population growth rate (representing the rate at which the labour force is expanding), and δ is the depreciation rate of capital.

The economy at the k_o capital level is also characterized by a high growth rate and capital (which increases to reach K*), while the GDP per capita growth rate decreases due to the existence of diminishing marginal returns. In this case, the convergence is conditional, since both rich and poor countries reach the same steady state. Furthermore, the steady-state value of capital in a rich country is higher than that in a poor country, with the savings rate higher in the former than in the latter. Figure 1b illustrates a rich country with a higher initial per capita level, after which it reveals a more rapid growth. In other words, a poor country does not converge with a rich country.

According to the economic growth theory, the average product of capital decreases with the increase in capital. For instance, this formulation involves learning by doing and spillovers. However, a poverty trap arises when the economy has an interval of diminishing average product of capital, followed by a wide range of rising average products. Meanwhile, Barro and Sala-i-Martin (2004) and Galor and Ryder (1989) argued that a poverty trap also occurs with non-constant saving rates and increasing returns. This is achieved by envisioning that a country has access to traditional as well as modern technology, and that it must pay a setup cost at every moment in time to exploit this technology. Therefore, the marginal propensity to save from output, as a function of capital per effective capital (i.e., s.f (k)/k), includes a negative slope at low levels of capital. This is followed by a wide range of variables with a positive slope, after which it declines to a negative slope at high levels of capital.

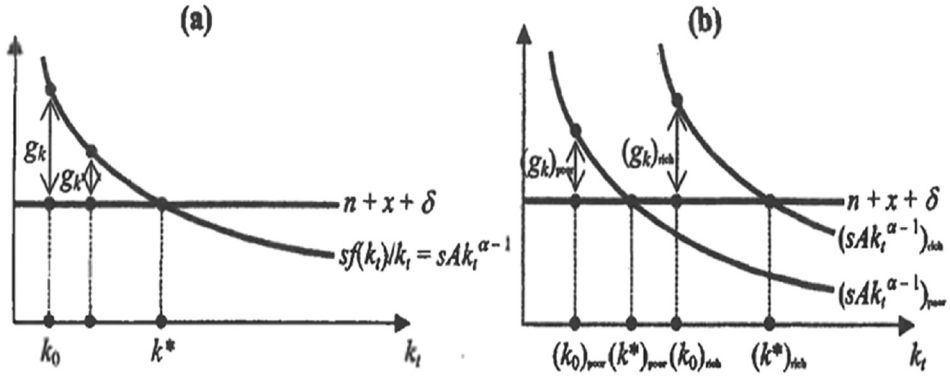

Fig. 1. Dynamics in economic growth are based on the Solow-Swan model
Source: Matkowski – Próchniak (2004: 263).

Finally, Figure 2 shows that there is a downward $s.\frac{f(k)}{k}$ at low values of k; an upward slope for an intermediate range of K; and a downward slope (or horizontal) for high values of K. There is also stability in K^*_{low} at its steady-state value, which constitutes a poverty trap for the countries that begin with K below 0 and K^*_{middle}. For the countries that begin with $k>K^*_{middle}$, it converges to K^*_{high} (with a positive long-term growth rate of k), especially if the returns to capital are constant at high values of k.

2.2. Empirical research

According to recent literature, unconditional convergence indicates that the growth rates in rich countries are no longer faster than those in poor countries (Cartone et al. 2021; Desli – Gkoulgkoutsika 2021; Kashnitsky et al. 2020; Nagy – Šiljak 2022). As poor countries continue to grow, there is a trend toward income convergence, which coincides with rapid convergence in income-related factors such as human capital, institutions, cultures and policies. However, the relationships between these factors are correlated, while economic growth appears to be less significant than previously thought, implying that these correlations may be spurious. The differences in institutions and policies remain minor, depending on the area (Kremer et al. 2022). In a related research, Kant (2019) examined 46 countries (six from South Asia and 40 from Sub-Saharan Africa) from 1951 to 2013 and found that convergence shows the "Iron law of convergence," under which 2% of the growth rate in poor countries can eliminate more than 50% of the income gap in 35 years and 90% in 115 years. The author concluded that there is a relative convergence among 28 countries, implying that the increase in poor countries' income ratios is less than that of rich countries.

The reason for the lack of convergence is because countries tend to differ in their institutions, technologies and policies. Using the same data (including whether a country was a democracy), Acemoglu and Molina (2021) found that more than 88% of the countries in their sample showed evidence of convergence, whereas Kremer et al. (2022) found no evidence of convergence.

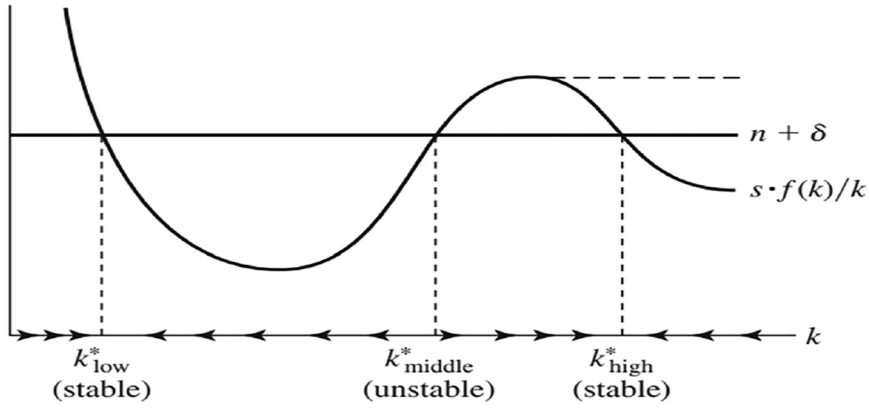

Fig. 2. Poverty trap model
Source: Barro – Sala-i-Martin (2004: 75).

Although these findings do not suggest any evidence of the relationship between democracy and growth over time, democracy has a statistically robust and significant positive economic effect on the GDP per capita (Acemoglu et al. 2019). In sum, the findings of the aforementioned literature seem to differ, even in a similar investigation with the same variables.

Since 2004, the majority of the CEE countries have joined the EU. As a result, the agenda to be a part of the EU has revived the debate on convergence. Recent studies on income convergence for the CEE countries with groups of EU countries, as well as with the EU, have been conducted. For example, regarding the real (i.e., output, productivity and income levels) and nominal convergence (i.e., monetary and price level variables such as interest rates, inflation rates and exchange rates) of 10 new EU members toward the former EU-15 during the 1993–2004 period, previous research found significant evidence of convergence in the industrial output. This indicates that there is a significant real convergence between the 10 new EU members and the largest EU economy, i.e., Germany (Kutan – Yigit 2004). However, there was no clear-cut evidence of real and nominal convergence over a longer time period (Brada et al. 2005). Using data from 1993 to 2004, Matkowski and Próchniak (2004, 2014) found a strong income convergence between the Central and Eastern European eight (CEE-8)[2] countries and the former EU members. Additionally, research on real convergence for the CEE-8 and the former EU-14 showed that there was a significant absolute and conditional convergence for various groups within the EU and the CEE-8. Specifically, there were relatively poor convergence outcomes of the EU-14 members located at the EU periphery among themselves and within the former EU countries (Allington – McCombie 2007). In their study on the convergence process of 10 new EU members and the former EU-15, Cavenaile and Dubois (2011) found that the estimated β was statistically distinct between the new CEE members and the former EU members. Holobiuc (2021) used cross-sectional regressions to determine the real convergence among the CEE countries and conducted a comparative analysis between countries and regions by using β and σ convergence. Based on the findings, there was a strong relationship between the initial level of income of the Central European countries and subsequent growth rates. Moreover, there was a reduction in income divergences between the CEE members, as exhibited by β convergence. In addition to this economic crisis, unemployment and inflation were the main factors that influenced the divergence process (Radosavljević et al. 2020). Table 1 presents an overview of this empirical literature review.

In sum, the theoretical literature has explained how economically poor countries can catch up to the richer ones, and how countries can use growth theory to guide their economic development policies. However, the empirical literature has yet to provide a clear conclusion on how developing countries can catch up to richer and more advanced ones, creating a research gap. Additionally, no unique convergence measurement has been used in the literature. For example, some studies have emphasized the importance of institutions (e.g., democracy and governance indicators) as determinants of economic convergence, while others have considered income as the primary measure of convergence. To date, no studies have included a large sample size of the CEE countries and solely focused on the four largest economies in terms of the GDP per capita to examine convergence. Moreover, there have been few analyses of the factors that determine the level of convergence by using two or more econometric approaches.

[2]Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia and Slovenia.

Table 1. Summary of the empirical literature review

Authors & Year of publication	Acemoglu – Molina (2021)	Chander - Kant (2019)	Allington – McCombie (2007)	Kutan – Yigit (2004)	Cavenaile – Dubois (2011)	Holobiuc, (2021)	Estrin et al. (2001)	Kočenda (2001)	Kremer et al. (2022)	Kulhánek (2012)	Kutan – Yigit (2004)	Matkowski – Próchniak (2004, 2014)
Key notions	Cross-country income convergence patterns over the past 6 decades and investigate how GDP relates to various country characteristics.	Measuring catching-up between poor and rich country using catch-up index	Beta - convergence in transitional European economies and economic growth	Real and monetary convergence between the enlarged EU and new EU member states	Convergence process within the EU	Real convergence in CEE focused on NUTS2 statistical region	A test for convergence in transitional economies	Performance of CEE economies in terms of their convergence	Patterns of cross-country convergence	Real convergence in Central Europe	How does the income convergence refer to the tendency for poor economies to grow faster and reduce income gaps within richer countries and does cyclical convergence refer to the tendency towards similar patterns of cyclical fluctuations.	The extent of real economic convergence between CEE-8 and the old EU-12 and 15 countries.
Model type	Estimates of the causal effect of convergence using a minimalist framework by allowing heterogeneity across the country to be captured by fixed effect and IV estimates	Region level analysis using geometric means using data from the Penn World Table version 9.0.	The dynamic panel data estimators (Least squares with Dummy variables (LSDV), Instrumental variable methods (AHL, AHD), two and three Stage Least Squares (2SLS, 3SLS), exact Maximum Likelihood Estimator (MLE); GMM1 & GMM2)	A rolling cointegration approach	Panel approach	β and σ convergence	Adopt an alternative time variation model for the time-varying parameters approach.	Dynamic panel data analysis	Omitted bias formula	β and σ convergence approach: A regression equation was used to method least squares.	Panel estimation approach	β and σ convergence estimation approach

(continued)

Table 1. Continued

Authors & Year of publication	Acemoglu – Molina (2021)	Chander - Kant (2019)	Allington – McCombie (2007)	Kutan – Yigit (2004)	Cavenaile – Dubois (2011)	Holobiuc, (2021)	Estrin et al. (2001)	Kočenda (2001)	Kremer et al. (2022)	Kulhánek (2012)	Kutan – Yigit (2004)	Matkowski – Próchniak (2004, 2014)
Scope of the study	1960–2019	1951–2013	1994–2002	1980–2000	1990–2007	2000–2017	1970–1998	1991–1998	1960–2019	1995–2011	1993–2000	1995–2005
Finding	Reject the findings of Kremer et al. because of institutions and policies having the same impact across the country. Democracy as a component of the institutional variable is estimated to have a precise and significant positive impact on GDP per capita.	1) Most countries in the sample showed little or no catching-up to benchmarks over the long-term (>50 years). 2) South Asia showed slow catching-up while Sub-Saharan Africa showed overall falling behind. 3) Catching up seen in short periods (<20 years) is fragile and does not indicate long-term convergence when a longer view is taken. Inter-country income inequality persists.	The panel data estimates found a significant absolute and conditional convergence for the full sample & various clubs of the countries.	During the sample period 1980–2000, the old member states of the EU exhibited time-varying integration with the core countries.	There was a different group of convergence between the CEE countries because of heterogeneity in the EU.	β and σ estimation result shows that the poorer regions from the EU recorded higher GDP growth rates than the developed ones.	A test for the Communist bloc. There was little evidence showing communist policies ensuring convergence of per capita GDP in both regions as a whole or for local grouping. The poorest republics in the Soviet Union grew very rapidly, and under communist policies Central Europe & Balkan economies grew faster than developed economies.	There is evidence of convergence in macroeconomic fundamentals among the CEE countries in a general and higher degree of convergence which is shown in common institutional attributes and policies.	There has been unconditional convergence since 1990 and convergence since 2000. Correlated income slopes in 1990 remained largely stable and growth correlated slopes controlling income - the coefficients of growth regressions remained stable for the fundamentals of the Solow model. There are flatter correlated relationships between growth and institutional factors which are less important for economic growth.	The speed of convergence of the new EU members is greater than CEC-5 countries due to the higher initial level of GDP per capita in PPS in CEC-5 countries.	The findings show that there is evidence for convergence of income per capita between the Central, Eastern and European Union.	There was strong economic and income convergence towards the EU and the new accession countries tended to develop faster than the older members. Most CEE countries except a few Baltic states reveal good conformity of cyclical fluctuations with the euro area.

Source: Constructed by the authors.

3. DATA AND METHODOLOGY

3.1. Data type, sources and analysis

We employed panel data to investigate the economic convergence within the CEE-11 and the four largest economies in Europe over the 1994–2019 period. The data was obtained from reputable sources, such as the Penn World Table (Version 10.01), the Worldwide Governance Indicators (WGI), and the World Bank Development Index (WBDI). The selection of the CEE-11 countries was based on their income levels and the year of their accession to the EU, which occurred in/after 2004.

In this study, several indicators for income were obtained from the Penn World Table to comprehensively examine the extent of convergence, including the growth rate, the relative growth rate, the income per effective labour, the income per effective capital and the impact of total factor productivity (TFP) on convergence. Specifically, the growth rate in income per capita over time indicates whether poorer countries are catching up to richer ones (with faster growth indicating convergence), while the relative growth rate compares the growth rates of poorer and richer countries (with higher relative rates indicating convergence). Moreover, cross-country differences in human capital and physical capital are considered by income per effective labour and income per effective capital, respectively. In this case, faster increases in these measures in poorer countries indicate convergence. TFP assesses the efficacy of combining labour and capital, with the TFP growth in poorer countries indicating technological catch-up and convergence. Examining these indicators allows for the consideration of differences in labour, capital and technology, while the governance index data can be utilized to explore the influence of government indicators on cross-country convergence.

To effectively examine the data and obtain meaningful conclusions, this study employed scatter plots, β and σ convergence measures, and fixed effect estimation. These approaches enabled us to gain insights into the level and dynamics of economic convergence among the studied countries. Table 2 summarizes the measurements and data sources.

3.2. Income-convergence estimation approach

The β convergence approach was used to examine the income convergence of the CEE-11 toward the four largest economies in Europe. In this regard, the primary objective of the empirical portion of this study was to determine the value of the parameter β, which is used to calculate the rate at which the economy approaches a steady state. This convergence rate was measured by observing the decline in the growth rate as the capital stock increases. The convergence and dispersion were derived from Galton's fallacy regarding the distribution of heights in a population (e.g., Quah 1993). In this case, the β convergence estimation approach is as follows:

$$\mathrm{GDP\_g_{i,t}} = \alpha + \beta \ln\left(\mathrm{rgdpe_{i,t\_1}}\right) + \mathrm{D_{i,t}} + \mathrm{x_{ji,t}} + \varepsilon_{i,t} \quad (1)$$

where $\mathrm{GDP\_g_{i,t}}$ is the GDP growth rate for country i, $\ln(\mathrm{rgdpe_{i,t\_1}})$ is the natural logarithm of expenditure-side real GDP at chained PPPs (in US$ millions, as of 2017) for country i at time t, $\mathrm{D_{i,t}}$ is the dummy variable representing country i, $\mathrm{x_{ji,t}}$ represents the control variables, and ε is a random variable. Here, β is used to determine whether countries with a low initial GDP growth rate can catch up to the four largest European economies.

Table 2. Measurements and data sources

Variable	Definition and measurement	Data sources
lnrgdpe	Natural logarithmic of expenditure-side real GDP at chained PPPs (in million 2017US$)	Penn World Table version 10.01
Emp	Number of labourers engaged in production (in millions)	
Cn	Capital stocks at current purchasing power parity (PPP) in million US$.	
Delta	Average depreciation rate of capital stock	
Avh	Average annual hours worked by persons engaged	
Irr	Real internal rate of return	
Xr	Exchange rate, national currency/USD (market+estimated)	
Labsh	Share of labour compensation in GDP at current national prices	
Ctfp	TFP level at current PPPs (USA = 1)	
Pop	Population (in millions)	
csh_i	Share of gross capital formation at current PPPs	
Governance indicators	*Voice and Accountability(lnvac)*	Worldwide Governance indicators worldbank.org
	Extent to which a country's citizens can participate in selecting their government, as well as freedom of expression, freedom of association, and a free media measure of 0–5	
	lnvac = 0 indicates poor; = 5 good	
	Political Stability and Absence of Violence/Terrorism (lnPOLITY2).	
	Measures perceptions of the likelihood of political instability and/or politically motivated violence, including terrorism *(lnPOLITY2)* = 0 indicates poor; = 5 good	
	Government Effectiveness(lnGEE)	
	Refers to the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies *(lnGEE)* = 0 indicates poor; = 5 good	
	Regulatory Quality(lnRQ)	

(continued)

Table 2. Continued

Variable	Definition and measurement	Data sources
	Refers ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development *(lnRQ)* = 0 indicates poor; = 5 good	
	Rule of law(lnRL)	
	Refers to the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police and the courts, as well as the likelihood of crime and violence. *(lnRL)* = 0 indicates poor; = 5 good	
	Control of corruption (lnCC)	
	Refers extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as the "capture" of the state by elites and private interests *(lnCC)* = 0 indicates poor; = 5 good	
Lninv	Total investment (% GDP)	World Bank Development Index (World Economic Outlook database: October 2022 imf.org)
Lncpi	Natural logarithmic of consumer price index	
Lncountry_size	Land area (sq. km): Land area refers to a country's overall area, excluding inland water bodies, national claims to the continental shelf, and exclusive economic zones. In most cases, inland water bodies are defined to include significant rivers and lakes.	World Development Indicators

Source: Author's construction.

If there is no directional impact from lagged lnGDPE on GDP growth at time t, then the slope coefficient (β) in the regression is zero and the test does not register any evolutionary change. However, if the disturbances are neutralized and the variation in growth between the CEE-11 and the four largest European economies decreases over time, then the estimated β is negative and the test registers an evolutionary change, unless β is positive and the variation increases over time (e.g., Akram – Ali 2021; Kong et al. 2019).

Besides estimating income convergence, we examined the factors that influence GDP growth, since they may have varying effects on GDP in each country and produce income disparities among them. In this case, the fixed effect panel data estimation approach was used to obtain the determinants of income dispersion across the CEE-11 and the four largest European economies, since it prevents an omitted variable from changing over time and uses the fixed effect or first-differencing method, which is suitable for obtaining accurate estimation results. Meanwhile, the

fixed effect estimator is unbiased under a strict homogeneity assumption on the explanatory variables and allows for an arbitrary correlation between τ_i and the explanatory variables at any time during first differencing. According to Wooldridge (2010), any explanatory variable that is constant over time for all *i* is "swept away" by the fixed effects.

In related research, Acemoglu and Molina (2021) examined the cross-country income convergence tendencies for the 1960–2019 period in 183 countries, based on the World Development Indicators (WDI) and the Penn World Table. Specifically, they utilized institutions and policies as exogenous variables (besides the lagged year GDP per capita), with the nation-fixed effects to control for unobserved time-invariant country heterogeneity. In this case, omitting them can cause the convergence coefficients to tilt toward zero.

In the present study, the fixed effect approach was used to examine the average gross per capita income convergence of eight Southeast European economies toward the EU's average per capita income (Radosavljević et al. 2020). Thus, the structural model is as follows:

$$\mathrm{GDP\_g_{i,t}} = \beta \ln\left(\mathrm{rgdpe_{i,t\_1}}\right) + \mathrm{x_{i,t}}\varphi_1 + \mathrm{m_{i,t}}\rho + \tau_\mathrm{i} + \delta \mathrm{i, t} + \varepsilon_{\mathrm{i,t}}$$

$$\mathrm{i} = 1, 2, \ldots, \text{and t represents year}$$

where $\mathrm{GDP\_g_{i,t}}$ is the GDP growth rate for country *i*; β is the coefficient of $\ln(\mathrm{rgdpe_{i,t\_1}})$ in the real GDP at chained PPPs (in US$ millions, as of 2017) for country *i* at time t; x represents ctfp, labsh, irr, Delta, Xr, lninv, lncpi, logCAB, lncn, cn_1, lnpop, and Pop_g; and *m* represents governance indicators, such as lnvac, lnPOLITY2, lnGEE, lnRQ and lnRl. Moreover, τ_i is the unobserved fixed effect and ε is the error term.

In this study, $\varepsilon_{\mathrm{i,t}}$ was uncorrelated with each explanatory variable across all time periods and the Granger causality test was used to test the causality among the explanatory variables. Based on the findings, there was no Granger causality between the exogenous variables. In order to determine the existence of cross-sectional dependence, the residual cross-section dependency test was conducted. In this case, the null hypothesis of no cross-section dependence in residuals was rejected in all four tests, including the Breusch-Pagan LM, the Pesaran scaled LM, the bias-corrected scaled LM, and the Pesaran CD tests (see Appendix Table A1), at a significance level of 0.05. This indicates that there is evidence of cross-sectional dependence in the residuals of the fixed effect regression model. In other words, the change in one variable of an individual country can have an impact across the CEE-11 and the four largest European economies. This finding also highlights the importance of accounting for cross-sectional dependency in economic research and suggests that the use of a fixed effect regression model is appropriate for controlling the unobserved heterogeneity across countries.

4. RESULTS

4.1. Visual description

We show how smaller countries can catch up with larger economies through three visual presentations, highlighting the interplay between: 1) the GDP growth rate and the capital-labour ratio; 2) the GDP growth rate and the GDP per effective capital; and 3) the speed of convergence.

1) *The GDP growth rate and the capital-labour ratio*: In our visual description, the years 1994 and 1995 were excluded, since the former is the lagged year, and the latter is the base year for β and σ convergence and fixed effect estimations. As for 1995, we did not find any evidence of convergence or divergence.

According to the scatter plot in Figure 3, Europe's four largest economies saw strong GDP growth and capital (cn) per effective labour (emp) (i.e., the capital-labour ratio) in 1996, while the CEE countries (e.g., Latvia, Hungary, Slovakia, Romania and Croatia) had relatively low GDP growth and capital-labour ratios.

In 2019, the positive association in 1996 had shifted toward the negative. For example, in 1996, Italy, France, Germany and the UK all showed a positive link between capital per labour and the GDP growth rate. However, these countries had high capital per labour, but relatively slow GDP growth rates. This finding, which is related to convergence over the first decades of the 2000s, correlates with the transition in Southeast Europe. This was when many economies in the region experienced high growth rates (Radosavljević et al. 2020), with income convergence occurring in Northeast Asia (i.e., between China and Japan and between South Korea and Japan) (Yaya et al. 2020).

Meanwhile, countries that rapidly adopted industrial automation began to experience "soaring wages and output" in the early adoption period. However, this diminished (and even reversed) as adoption became more widespread (Acemoglu – Restrepo 2018). Thus, although Europe's four largest economies initially saw growth from capital deepening, it reached a point where additional capital investments no longer boosted productivity. This reflects how the benefits of capital investments can diminish and even turn negative as an economy reaches the frontiers of automation and capital deepening. Figure 4 presents the scatter plots (labeled "a" and "b") that demonstrate the link between the GDP growth rate and the GDP per effective capital between 1996 and 2019.

As shown in Panel a) of Figure 4, there is a negative link between GDP growth and the GDP per effective capital during the initial study period of 1996. This finding is in contrast to unconditional divergence, which has not occurred for decades (Patel et al. 2021). This negative relationship can be attributed to the phenomenon of economies of scale. Specifically, the four largest economies in Europe tend to experience higher economic initial growth, due to their capacity to produce goods and services on a large scale, contributing to enhanced productivity and economic expansion. Based on the evidence of conditional convergence in TFP growth rates across the OECD countries from 1960 to 2000, TFP convergence is driven by technology diffusion and human capital accumulation.

2) *The GDP growth rate and the GDP per effective capital*: In 2019, a positive association between GDP growth and the GDP per effective capital was observed in both the CEE-10 and the four largest economies in Europe, with the former experiencing faster growth rates than the latter (see Panel b) of Figure 4. In this regard, β and σ convergence of the GDP per capita occurred in 27 transition economies from 1990 to 2005 (Kögel 2005). The reason for this shift is that as economies evolve, they often transition from the initial stage of relying on scale-driven growth to a phase in which efficiency gains and technological advancements (e.g., increased investment in innovation, technology and human capital) lead to improved productivity (Rapacki – Próchniak 2009). Our analysis also gains strength when focusing on homogeneous groups (i.e., similar political systems, social structures and other economic

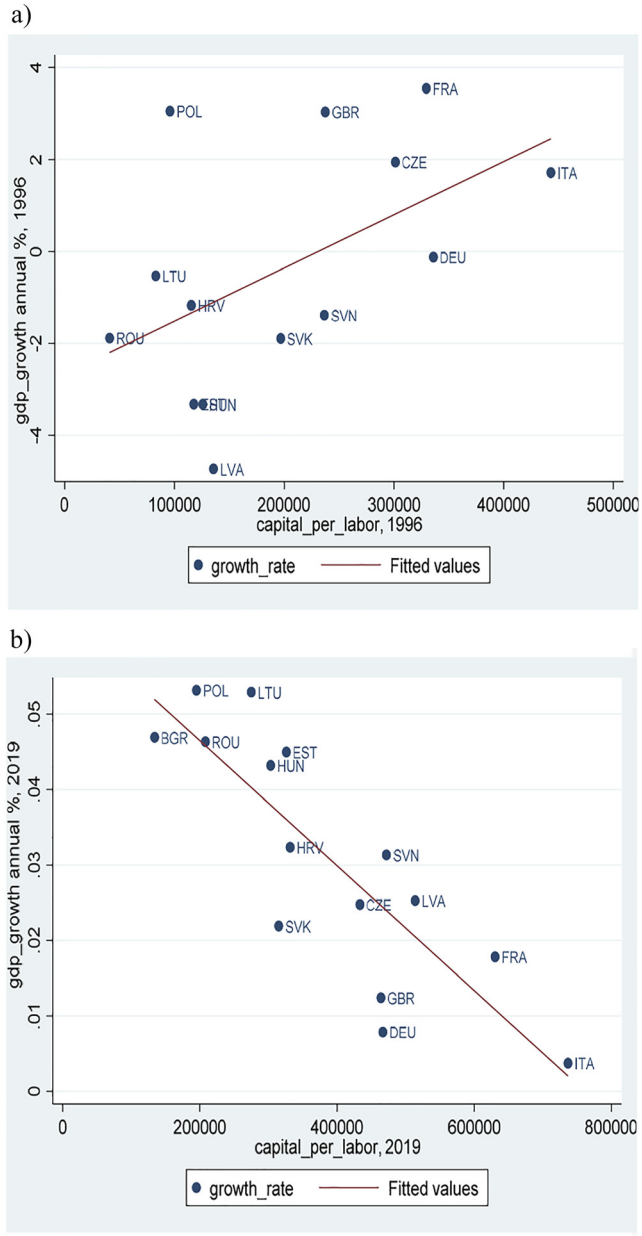

Fig. 3. The GDP growth rate and the capital-labour ratio
Source: Author's construction.

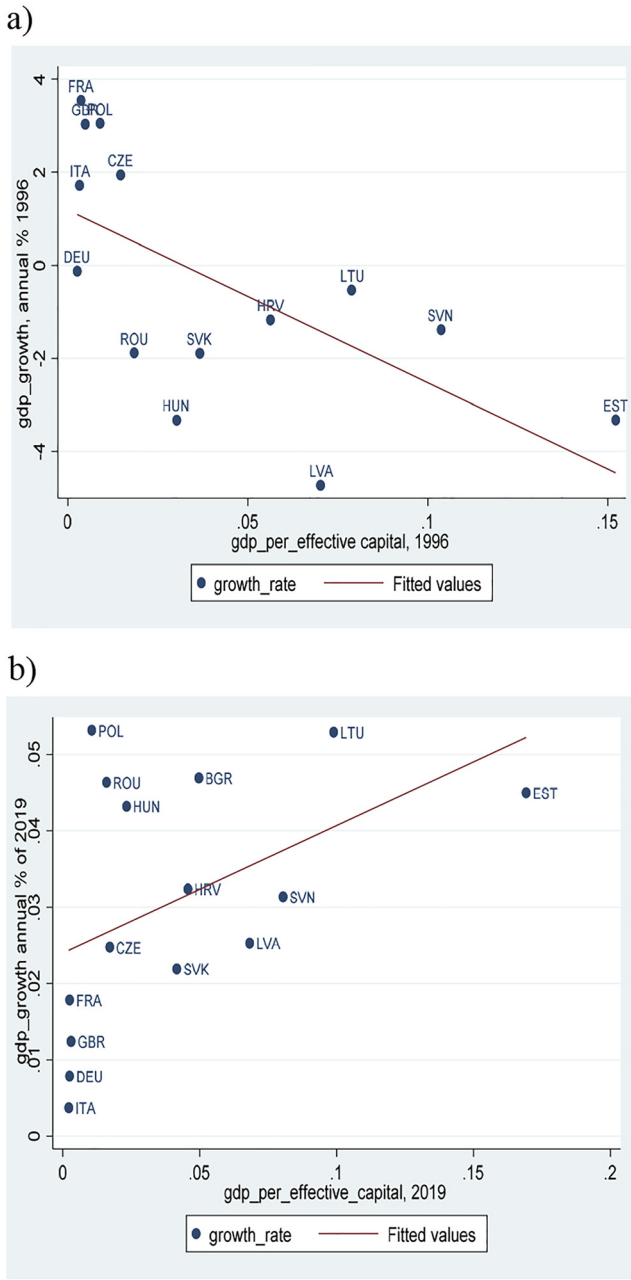

Fig. 4. The growth rate and the GDP per effective capital
Source: Author's construction, Penn World Table database (2023).

indicators), especially within the CEE and in relation to the four largest economies in Europe. This observation aligns with Acemoglu and Molina (2021), who investigated the causal effects of cross-country convergence when accounting for heterogeneity.

In sum, the observed negative correlation in 1996 highlights the trade-off between individual efficiency (the GDP per effective capital) and GDP growth. Moreover, the positive correlation in 2019 suggests a departure from the earlier dominance of economies of scale toward a more balanced and diversified growth pattern.

3) Speed of convergence: Understanding the rate at which the economies of the CEE-11 and those of the four largest European economies approach their steady state is crucial. However, this speed of convergence can vary, indicating different behaviours of the steady state.

In general, a rapid convergence suggests that the economy is approaching its steady state, whereas a slow convergence indicates that the economy is further away from its steady state. In these cases, transitional dynamics play a significant role in their growth experiences. Figure 5 illustrates the connection between the half-life (i.e., the time/year that the CEE-11 countries take for half the initial gap, after excluding the four largest European economies) and the GDP growth rate. Based on the findings, there is a negative relationship between the two aspects, indicating that higher GDP growth rates correspond to lower half-life.[3]

In sum, the CEE-11 rate of convergence toward Europe's four largest economies provides insights into how close they are to achieving steady-state levels (Alesina – Ardagna 2010; Kant 2019). Furthermore, faster convergence emphasizes the ongoing role of transition in development trajectories, while higher GDP growth appears to accelerate the pace of convergence.

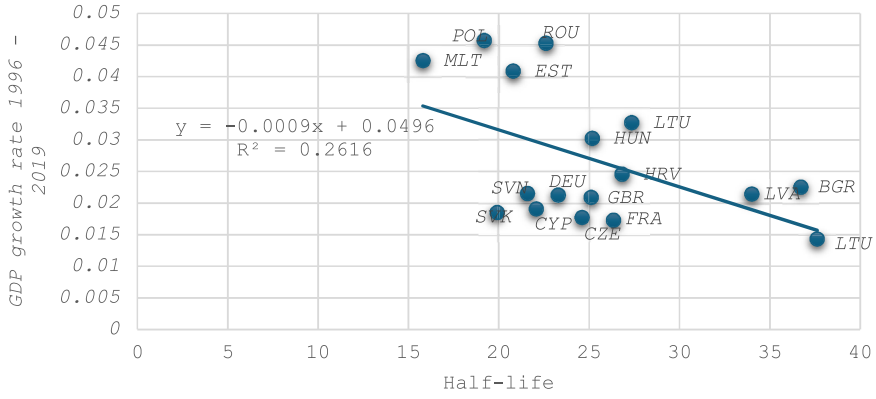

Fig. 5. Transitional dynamics
***Source*: Author's construction, Penn World Table (2023).**

[3]We define speed of convergence as the rate at which an economy approaches equilibrium. It explains and quantifies the concept of convergence's half-life. We formulate speed of convergence based on the Solow growth model (1964).

4.2. β convergence estimation results

The presence of economic convergence or divergence can be determined by examining the sign of the coefficient for lagged real GDP at chained PPPs (in US$ millions, as of 2017) for the 1994–2019 period. However, 1994 and 1995 were excluded from the regression because the former was considered as a lagged year and the latter was removed because of collinearity. Consequently, the β regression results covering the 1996–2019 period revealed that the GDP growth rate can be the dependent variable for the observations in the sample, with lagged real lnGDP as the independent variable. As for the explanatory variables, they included: capital stock (lncn), employment (emp), population growth (pop_growth), and the capital stock depreciation rate (delta). In addition, the lagged real GDP (L. lnrgdpe) is statistically significant with a *P*-value of 0.000, while the null hypothesis of the coefficient of L.lnrgdpe is rejected, implying that lagged real GDP values can influence economic growth (Table 3).

The negative β value for the lagged real GDP implies that the CEE-11 is enjoying economic growth and catching up with the EU's four largest economies. The β value (−11.33) for the 1996–2019 period also shows that the CEE-11 is closing the income gap at a faster rate. Overall, this demonstrates the occurrence of convergence, in which the difference in GDP growth between the countries in the sample narrows over time. We assume that income growth follows a similar steady-state trajectory, resulting in an 11.3% reduction in growth difference. This finding also aligns with previous research (Rey – Montouri 1999; Holobiuc 2021; Ram 2021). Except for Croatia, Latvia and Lithuania, the lagged GDP per capita coefficient is statistically significant (implying convergence), while Estonia and Slovenia are experiencing relatively less economic growth than Bulgaria.

As for the control variable for capital stock (lncn), it is significant, indicating that a change in the capital stock of each country can affect the growth differential between the countries. However, the β coefficient for the average depreciation rate of the capital stock (σ) is positive and significant. This implies that increases in the depreciation rate of capital can lead to divergence between the CEE-11 and the four largest European economies. Meanwhile, the insignificant negative coefficient for the number of people engaged in the industry provides evidence of convergence. This finding aligns with the poverty trap, in which the marginal propensity to save from production depends on capital. Moreover, the β convergence regression results provide evidence for unconditional convergence. In sum, the empirical analysis shows that, over the sample period, the CEE-11 has been experiencing a process of unconditional convergence in GDP growth with the four largest European economies.

4.3. σ convergence estimation results

The σ-convergence regression results indicate a reduction in the variance of the lagged real GDP per capita across the CEE-11 and the four largest economies in Europe. Additionally, the positive σ coefficient implies the presence of σ convergence, signifying a tendency for the dispersion of the lagged real GDP per capita to diminish over time, while the magnitude of the coefficient (i.e., 0.945) signifies the strength of this convergence, implying that economic growth rates do not significantly change from one period to the next. This finding is consistent with those of Kant (2019) and Radosavljević et al. (2020), but contrary to the results of Akram – Ali (2021) in their assessment of per capita output convergence across 33 Indian states.

Table 3. β convergence regression results

GDP growth	Coeff.	St.Err.	*t*-value	*P*-value	95% Conf	Interval]	Sig
L.lnrgdpe	−11.333	2.225	−5.09	0	−15.708	−6.958	***
Croatia	1.759	1.939	0.91	0.365	−2.054	5.572	
Czech Republic	10.218	2.82	3.62	0	4.673	15.764	***
Estonia	−5.062	2.219	−2.28	0.023	−9.426	−0.698	**
France	36.508	7.35	4.97	0	22.053	50.963	***
Germany	41.41	9.624	4.30	0	22.484	60.336	***
Hungary	10.005	2.468	4.05	0	5.152	14.859	***
Italy	32.6	6.808	4.79	0	19.21	45.99	***
Latvia	0.172	2.745	0.06	0.95	−5.226	5.571	
Lithuania	3.404	1.965	1.73	0.084	−0.461	7.269	*
Poland	22.958	4.082	5.62	0	14.93	30.986	***
Romania	6.133	1.812	3.38	0.001	2.568	9.697	***
Slovakia	4.01	1.948	2.06	0.04	0.18	7.841	**
Slovenia	−1.064	2.332	−0.46	0.648	−5.649	3.522	
United Kingdom	37.205	7.546	4.93	0	22.364	52.045	***
Emp	−0.24	0.226	−1.06	0.29	−0.684	0.205	
Lncn	3.46	1.266	2.73	0.007	0.97	5.95	***
pop_growth	−0.551	0.932	−0.59	0.555	−2.385	1.283	
Delta	431.134	97.535	4.42	0	239.316	622.952	***
Constant	67.958	12.757	5.33	0	42.87	93.046	***
Mean dependent var		3.500	SD dependent var		4.050		
R-squared		0.152	Number of obs		375		
F-test		3.348	Prob > F		0.000		

Note: Bulgaria is the reference category. $^{***}P < 0.01$, $^{**}P < 0.05$, $^{*}P < 0.1$.
Source: Author's construction, Stata 18.

In Table 4, it is evident that several country dummies have positive and statistically significant coefficients. This indicates that the real GDP per capita in countries, such as the Czech Republic, Germany, France, Italy, Poland, Romania and the UK is higher on average than in Bulgaria, while controlling for other variables. Specifically, higher or lower real GDP per capita is observed in the Czech Republic, France, Germany, Hungary, Italy, Poland, Romania and the UK, while lower GDP is found in Estonia, Latvia and Slovenia. Conversely, Estonia, Latvia and

Table 4. σ convergence regression results

log_rgdpe	Coeff.	St.Err.	*t*-value	*P*-value	[95% Conf	Interval]	Sig
log_rgdpe. L1	0.945	0.017	55.42	0	0.912	0.979	***
Croatia	−0.004	0.01	−0.36	0.722	−0.024	0.016	
Czech Republic	0.059	0.02	2.91	0.004	0.019	0.099	***
Estonia	−0.047	0.024	−1.94	0.053	−0.095	0.001	*
France	0.169	0.054	3.11	0.002	0.062	0.276	***
Germany	0.185	0.06	3.07	0.002	0.066	0.304	***
Hungary	0.046	0.016	2.94	0.004	0.015	0.078	***
Italy	0.157	0.053	2.95	0.003	0.052	0.261	***
Latvia	−0.045	0.02	−2.30	0.022	−0.083	−0.006	**
Lithuania	−0.008	0.013	−0.66	0.509	−0.034	0.017	
Poland	0.127	0.035	3.63	0	0.058	0.196	***
Romania	0.076	0.02	3.80	0	0.037	0.116	***
Slovakia	0.015	0.01	1.57	0.118	−0.004	0.034	
Slovenia	−0.028	0.013	−2.15	0.033	−0.054	−0.002	**
United Kingdom	0.175	0.054	3.21	0.001	0.068	0.282	***
1995b	0	.	.	.	.	.	
1996	−0.017	0.012	−1.42	0.155	−0.04	0.006	
1997	−0.03	0.012	−2.53	0.012	−0.053	−0.007	**
1998	−0.005	0.012	−0.41	0.681	−0.028	0.018	
1999	−0.026	0.012	−2.19	0.029	−0.05	−0.003	**
2000	−0.002	0.012	−0.13	0.896	−0.025	0.022	
2001	−0.001	0.012	−0.10	0.919	−0.025	0.023	
2002	−0.003	0.012	−0.22	0.827	−0.027	0.022	
2003	0	0.013	−0.03	0.975	−0.025	0.024	
2004	0.013	0.013	1.02	0.31	−0.012	0.038	
2005	0.019	0.013	1.45	0.148	−0.007	0.045	
2006	0.046	0.013	3.43	0.001	0.02	0.073	***
2007	0.062	0.014	4.37	0	0.034	0.089	***
2008	0.031	0.015	2.07	0.039	0.002	0.06	**
2009	−0.058	0.015	−3.76	0	−0.089	−0.028	***
2010	0.019	0.015	1.25	0.213	−0.011	0.048	

(continued)

Table 4. Continued

log_rgdpe	Coeff.	St.Err.	*t*-value	*P*-value	[95% Conf	Interval]	Sig
2011	0.023	0.015	1.47	0.143	−0.008	0.053	
2012	0.002	0.016	0.12	0.905	−0.029	0.033	
2013	−0.01	0.016	−0.61	0.54	−0.041	0.022	
2014	0.004	0.016	0.22	0.827	−0.028	0.035	
2015	0.03	0.016	1.81	0.071	−0.003	0.062	*
2016	0.02	0.017	1.19	0.236	−0.013	0.053	
2017	0.038	0.017	2.19	0.029	0.004	0.071	**
2018	0.025	0.018	1.43	0.153	−0.009	0.06	
2019	0.027	0.018	1.48	0.139	−0.009	0.063	
Constant	0.647	0.189	3.41	0.001	0.274	1.02	***
Mean dependent var		12.492		SD dependent var		1.614	
R– squared		1.000		Number of obs		375	
F– test		24015.632		Prob > F		0.000	

Note: Bulgaria 1995 is the reference year; $^{***}P < 0.01$, $^{**}P < 0.05$, $^{*}P < 0.1$.
Source: Author's construction.

Slovenia have negative coefficients, suggesting that their average GDP per capita is lower than that of Bulgaria, which is the benchmark country of the fixed effects regression.

As for the year dummies, some are statistically significant, indicating that the real GDP per capita is higher or lower than the baseline year (i.e., 1995). Specifically, the GDP in 1997, 1999 and 2009 are all negative and significant, indicating that economic growth was slower than in the baseline year. Meanwhile, the coefficients for the other years, such as 1996, 1998 and 2000 to 2015, have a low magnitude and are statistically insignificant, indicating that there is no discernible difference in the growth rates relative to 1995. Moreover, the coefficient for 2009 (−0.058) is highly significant (*P*-value of <0.01), but negative. This shows that the real GDP per capita across the countries in this study significantly fell in 2009, most likely from the impact of the global financial crisis. Finally, the 2015 and 2019 coefficients of 0.03 and 0.027 are only marginally significant (*P*-value of <0.1), while the estimate is positive and the significance level is low, implying that there is no evidence of income convergence during these years.

In sum, the σ convergence regression results indicate that the CEE-11 has mainly converged to Europe's four largest economies. However, the extent of the convergence across the countries appears to vary over time. For example, the evidence of convergence exists for 1997, 1999 and 2006 (indicating a considerable and strong tendency), but from 1996 to 2000, 2010 to 2014, and 2016 to 2019 (excluding 2017), the outcome is not statistically significant, which is consistent with the results of Holobiuc (2021).

4.4. Fixed effect estimations

The structural panel data in the methodology section is checked for accuracy by using the F, LM and Hausman tests (see Appendix Table A2). As a result, the F and Hausman tests revealed that the model that determines the GDP growth rate contains an unobserved variable fixed effect. Hence, the fixed effect model was appropriate for this GDP growth rate across the CEE-11 and the four largest European countries.

In general, the natural logarithm of the GDP per capita is the dependent variable in fixed effect estimates, whereas other income and government indicators serve as explanatory variables. Among the unobserved fixed factors in the regression, there is country size (in square kilometers). For example, Alouini and Hubert (2020) analyzed the relationship between country size and economic growth by using a panel dataset of 163 countries from 1960 to 2007, and they found a significant negative correlation. As for the fixed effect regression results, they showed that all governance indicators, except the rule of law (lnRL), are statistically insignificant. Meanwhile, these variables have no individual fixed effect across the CEE-11 and the four largest European economies, indicating that they have no effect on the growth difference among these countries (Table 5).

The coefficient for lnrgdpe indicates that the GDP per capita is estimated to have a precise and significant impact on GDP growth, with a coefficient of 30.55 (SE = 6.12). This denotes that the real GDP has an individual fixed effect across the CEE-11 and the four largest European economies. Moreover, the coefficient for the share of labour compensation in the GDP (labsh), the real internal rate of return (irr), capital stocks at current PPP (lncn), the average depreciation rate of capital (delta), and the exchange rate (xr) coefficients are statistically significant, with a *P*-value of <1%. This implies that these variables exclusively have fixed effects across the countries in our sample. Meanwhile, separate tests of these variables showed a higher impact in the CEE-11 than in the four largest European economies, with an increased tendency for conditional convergence.

Another important variable is capital stock, as the major determinant of the GDP per capita across the CEE-11 and the four largest European economies. The coefficient of the natural logarithm of capital stock (lncn) −17.55 (SE = 3.87)) is statistically significant, with a *P*-value of 0.00. This is consistent with the poverty trap theory and the findings of Galor and Ryder (1989).

In sum, the relationship between GDP growth and the natural logarithm of GDP per capita (lnrgdpe) is positive and significant at the 1% level, indicating income convergence in which larger economies see slower GDP growth. Other factors in the model, such as labour share (labsh), the investment rate (irr), the depreciation rate (delta), population growth (pop_growth), political stability (lnPOLITY2), and country size, are also significant at the 1% level, with a negative association with GDP growth. This indicates that greater values of these variables correspond to slower GDP growth. Moreover, GDP growth has a positive correlation with the exchange rate (xr), which is substantial at the 5% level. In this regard, appreciating exchange rates are associated with stronger GDP growth.

4.5. Panel co-integration test

Table A3 in Appendix presents the null hypothesis of no co-integration among the panel data and the alternative hypothesis of all panels being integrated between the series of panel data by

Table 5. Fixed effect regression results

GDP_growth	Coeff.	St.Err.	*t*-value	*P*-value	95% Conf	Interval	Sig
Lnrgdpe	30.553	6.121	4.99	0	18.51	42.596	***
Ctfp	−3.4	8.396	−0.41	0.686	−19.92	13.119	
Labsh	−0.236	13.226	−5.54	0	−99.258	−47.213	***
Irr	−89.113	18.835	−4.73	0	−126.172	−52.054	***
Delta	−516.78	155.17	−3.33	0.001	−822.08	−211.48	***
Xr	0.054	0.027	1.98	0.049	0	0.109	**
Lncn	−17.554	3.872	−4.53	0	−25.172	−9.937	***
pop_growth	−1.127	1.423	−0.79	0.429	−3.926	1.672	
Lnvac	1.191	1.146	1.04	0.299	−1.063	3.446	
lnPOLITY2	−1.374	1.529	−0.90	0.37	−4.383	1.635	
GEE	−1.752	2.358	−0.74	0.458	−6.39	2.887	
lnRL	7.029	3.466	2.03	0.043	0.209	13.849	**
Lncc	−0.951	2.792	−0.34	0.734	−6.445	4.544	
country_size	−0.001	0	−3.32	0.001	−0.002	−0.001	***
Constant	139.419	29.23	4.77	0	81.908	196.929	***

Mean dependent var	3.373	SD dependent var	4.031
Overall r-squared	0.008	Number of obs.	344
F-test	6.541	Prob > F	0.000

Note: $^{***}P < 0.01$, $^{**}P < 0.05$, $^{*}P < 0.1$.
Source: Author's calculations.

using the methods of previous research (Kao 1999; Pedroni 2004). The findings show that this series is integrated, indicating that it moves in a consistent manner over time.

Regarding the null hypothesis (H0) of no co-integration among the panel data, it implies that there is no long-term relationship or equilibrium among the variables. Meanwhile, the alternative hypothesis (Ha) suggests that all panels are co-integrated, indicating the presence of a long-term relationship or equilibrium among the variables across the series of panel data. As shown in this table, the findings of Kao (1999) and Pedroni (2004) reject the null hypothesis at the 1% level, indicating that during co-integration, the shocks to the variables are temporary and there are error correction mechanisms that bring the variables back into equilibrium over the long run. This also implies that without co-integration, the fixed effect model will be incorrectly specified, since it assumes a stable long-term relationship.

5. DISCUSSION

We used data from the Penn World Table, the WGI, the WB and the WDI to show how the CEE-11 converged with the four largest economies in Europe. The β and σ convergence methods were also used to determine the convergence. This allowed us to estimate the rate at which these parties will reach steady-state income levels. Specifically, the β-value (−11.33) and its statistically significant outcome implies that the CEE-11 tends to grow faster than the four largest European economies. This supports the notion of conditional convergence, as predicted by the neoclassical growth model. As for the σ convergence coefficient (0.94) and its statistically significant value, it shows how dispersion in the GDP per capita across the countries changed over time, which helps us further understand the decreases in dispersion between the CEE-11 and Europe's four largest economies. This decline also implies that the former is catching up to the latter, thereby supporting the existence of convergence. Moreover, the fixed effect estimation approach was applied in our analysis to determine the impact of the real GDP on the economic growth across the countries, with other variables added in the model to control for time-invariant, country-specific characteristics. This allowed us to isolate the impact of other determinants on GDP growth.

Although the basic tenants using these approaches have been elucidated in the existing literature on convergence, there are still debates on the concept of conditional convergence, after accounting for heterogeneity and non-linear relationships and considering different results. The present study also found evidence of σ convergence, with positive and statistically significant coefficients for some country dummies. This can be explained by four aspects:

- The initial conditions are the causes of the positive σ coefficients. Countries, such as Germany, France and the UK, had higher initial levels of growth because of early industrialization, allowing them to collect more physical and human capital over time. As a result, their historical advantage was reflected in their greater present income levels, in comparison to Croatia.
- Joining the EU in/after 2004 provided significant economic benefits to various countries (e.g., the Czech Republic, Poland, Romania and Hungary), including access to larger markets, funding and institutional reforms to boost productivity.
- As the CEE countries transitioned from socialist to market economies, they caught up with the Western living standards (Lopez et al. 2021). In this regard, the countries that implemented earlier reforms, such as the Czech Republic, had more years to experience economic convergence through trade and foreign direct investment spillovers within the EU (Matkowski et al. 2016).
- Industrial policies that encourage investment in manufacturing sectors benefited the countries, depending on automotive/machinery exports. For example, the Czech Republic consistently maintained greater per capita earnings than its less-industrialized rivals.

Overall, the statistically significant coefficients for the year dummies (aside from the negative signs for 1997, 1999 and 2009) can be attributed to the short-term effects of major global economic crises and the downturns that hampered growth in the CEE region. In this case, it is important to consider three major reasons. First, the 1997 Asian financial crisis affected capital flows and exports to the CEE region. Due to contagion effects, high trade-integrated economies experienced slower growth, compared to 1995 (Abiad et al. 2010). Second, the 1999

Russian crisis caused decreases in external demand, affecting the real GDP of the CEE countries (Kutan – Dibooglu 2005). Third, due to the global financial crisis, the export-oriented CEE economies experienced a significant demand shock, while declining trade and investment flows reduced growth, in comparison to the pre-crisis levels (Benecká et al. 2018). Thus, these reasons explain why the real GDP per capita growth sharply dropped, compared to the baseline year of 1995. As for the negative coefficients, they simply capture the short-term negative impacts of major global downturns on otherwise converging CEE-11 economies to Europe's four largest economies.

6. CONCLUSION

The study examined income convergence between the CEE-11 members that joined the EU in/after 2004 and the four largest European economies (Germany, France, the UK and Italy). Our motivation was the debate on the persistence of unconditional convergence. We found that unconditional divergence has not occurred for decades. Meanwhile, due to post-communism, the CEE-11 has been reforming their policies and strategies toward economic growth. Hence, we were interested to determine if they have caught up to Western Europe, which comprise the largest share of the EU's GDP and population.

Our analysis was conducted by using panel data from 1994 to 2019, with the Penn World Table, the WGI and the WBDI as the data sources. β and δ convergence techniques were also utilized to analyze the dimensions and dynamics of economic convergence across the CEE-11 and Europe's four largest economies. In this case, GDP growth was estimated according to the natural logarithm of the real GDP measured at chained PPPs. Meanwhile, fixed effect estimation was used to identify GDP growth regression, considering time-invariant country heterogeneity.

We also used visual representations of the GDP growth rate and the capital-labour ratio, the GDP growth rate and the GDP per effective capital, and the speed of convergence to show how the CEE-11's economic growth has caught up to Europe's four largest economies. Based on the findings, in 1996, the latter experienced higher capital investment and faster development than the former. However, by 2019, the patterns had flipped, with the CEE-11 growing faster and narrowing the growth disparities. Moreover, the higher GDP per worker was primarily associated with slower growth, most likely because of the scale effects that favoured larger economies. However, as the economies diversified, the 2019 graph flipped, indicating quicker growth and higher GDP per worker. Finally, the GDP growth rates, and half-life showed that faster rising economies converged at faster rates.

Our empirical analysis yielded several key findings:

- We found convincing evidence of unconditional β convergence between the CEE-11 and the four largest European economies from 1996 to 2019, using 1995 as the base year. The β coefficient of −11.33% implies that the CEE-11 is closing the income gap at an annual rate of approximately 11%.
- The σ regression coefficient was positive and statistically significant. This implies a decline in the dispersion of the GDP per capita between the CEE-11 and the four largest European economies over time, demonstrating income convergence.
- The fixed effect regressions revealed that various factors, such as the lagged GDP per capita, labour share, the investment rate, the depreciation rate, and the exchange rate showed

statistically significant individual fixed effects across nations, thus providing more support to unconditional convergence.

- In 1997, 1999 and 2009, the divergence was attributed to the short-term effects of major global economic crises, such as the 1997 Asian financial crisis, the 1999 Russian crisis, and the 2009 global financial crisis, which hampered the growth in the CEE region. However, the overall trend from 1996 to 2019 was one of significant convergence, with the CEE-11 growing faster than the four largest European economies.

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Appendix

Table A1. Cross-sectional residual dependency test

Residual Cross-Section Dependence Test			
Null hypothesis: No cross-section dependence (correlation) in residuals			
Equation: Untitled			
Periods included: 23			
Cross-sections included: 14			
Total panel (unbalanced) observations: 321			
Test employs centered correlations computed from pairwise samples			
Test	Statistic	d.f.	Prob.
Breusch-Pagan LM	217.2478	91	0.0000
Pesaran scaled LM	9.358112		0.0000
Bias-corrected scaled LM	9.039930		0.0000
Pesaran CD	−3.057500		0.0022

Source: Author's calculation.

Table A2. Summary of tests for a formulated structural model

Panel model test approach	Cross-section	Time/period	Both	Effect
F-test (H_o: No fixed effect	0.01	0.00	0.00	Fixed
LM – test (H_o: No random effect	0.00	0.000 (Hoda – King-Wu)	0.00	Random
Hausman – test - Ho: Random effect	0.00	1.00	0.00	Fixed

Source: Author's calculations.

Table A3. Panel cointegration results

Hypothesis		
H0: No cointegration	Ha: All panels are cointegrated	
	Number of panels = 15	
	Number of periods = 24	
Test approach		
Kao test for cointegration		
Modified Dickey-Fuller t	−14.7823	0.0000
Dickey-Fuller t	−11.3701	0.0000
Augmented Dickey-Fuller t	−10.1063	0.0000
Unadjusted modified Dickey-Fuller t	−17.4466	0.0000
Unadjusted Dickey-Fuller t	−11.6804	0.0000
Pedroni test for cointegration		
Modified Phillips-Perron t	1.8387	0.0330
Phillips-Perron t	−7.0204	0.0000
Augmented Dickey-Fuller t	−6.8755	0.0000

Source: Author's construction.