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Revisiting the Environmental Kuznets Curve Hypothesis: A Case of Central Europe

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Abstract: The rapid economic growth observed in Central European countries in the last thirty years has been the result of profound political changes and economic liberalization. This growth is partly connected with reducing carbon dioxide (CO_2) emissions. However, the problem of CO_2 emissions seems to remain unresolved. The aim of this paper is to test whether the Environmental Kuznets Curve (EKC) hypothesis holds true for Central European countries in an annual sample data that covers 1995–2016 in most countries. We examine cointegration by applying the Autoregressive Distributed Lag bound testing. This is the first study examining the relationship between CO_2 emissions and economic growth in individual Central European countries from a long-run perspective, which allows the results to be compared. We confirmed the cointegration, but our estimates confirmed the EKC hypothesis only in Poland. It should also be noted that in all nine countries, energy consumption leads to increased CO_2 emissions. The long-run elasticity ranges between 1.5 in Bulgaria and 2.0 in Croatia. We observed exceptionally low long-run elasticity in Estonia (0.49). Our findings suggest that to solve the environmental degradation problem in Central Europe, it is necessary to individualize the policies implemented in the European Union.

Keywords: environmental Kuznets curve; CO_2 emissions; environmental degradation; ARDL; time series; Central Europe

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1. Introduction

The rapid economic growth observed in Central European countries in the last thirty years has been the result of profound political changes and economic liberalization. When analyzing the determinants of this growth with a long-term perspective, attention should be paid primarily to the processes of economic transformation and European integration. The economic transformation in Central European countries was initiated by social changes at the turn of the 1990s. With the change of the political system, centrally planned economies were transformed into market economies. Among other things, bureaucratic and prescriptive regulatory mechanisms were replaced with market mechanisms, and the ownership structures changed as state-owned enterprises were privatized and new private companies were set up [1].

The process of integration with Western European countries began in the early 1990s, when most countries in Central Europe signed agreements on trade and economic cooperation and other agreements establishing associations (the European agreements). Their main aim was to establish a free trade zone with European Union Member States. The trade liberalization that followed was beneficial to economic growth and contributed to reducing disparities between the East and the West [2–5]. For these reasons, our model includes the trade openness variable, which reflects the process of foreign trade liberalization. A fundamental change in the economic policy of Central European countries followed their accession to the European Union in 2004 (Romania and Bulgaria joined the EU in 2007, and Croatia in 2013). As a result, they were included in the financial assistance program under the European cohesion policy, which aims at developing the infrastructure to strengthen the cohesion of the European single market [6–8]. The rapid economic growth in Central European countries, in comparison with other European Union countries, is partly connected with reducing carbon dioxide (CO_2) emissions, which at first sight may indicate the relations described by the environmental Kuznets curve (EKC). This issue, however, requires more detailed examination.

The problem of CO_2 emissions in the European Union countries seems to remain unresolved. The European Commission has reported that if currently implemented national policies are aggregated, the EU-27 would reduce effort sharing emissions by 19% by 2030 compared to 2005. This reduction is much less than the planned 30% by the Effort Sharing Regulation [9]. However, it should be noted that CO_2 emissions have decreased in recent years. According to Eurostat, in 2019, i.e., the year before COVID-19 containment measures were widely introduced in the EU, CO_2 emissions from fossil fuel burning (mainly oil and oil products, coal, peat and natural gas) had decreased significantly by 4.3%, as compared with the previous year. The highest decreases were observed in Estonia, followed by Denmark, Greece and Slovakia, Portugal, and Spain. These decreases have been mainly driven by the power sector, where emissions fell due to coal being replaced by electricity from renewables and gas-fired power production [9]. Increases were noted in four European countries: Luxembourg, ahead of Austria, Malta, and Lithuania [10]. Despite the many efforts that were made under the European Union Emission Trading System, the need to reduce CO_2 emissions is still believed to be a constraint on economic growth, especially in relatively lower-income countries of Central Europe.

The study investigates the relationship between economic activity (growth) and CO_2 emissions. This relationship is usually formulated in terms of the environmental Kuznets curve. The EKC is a reduced form relationship between CO_2 emissions per capita and income per capita (GDP per capita). The EKC hypothesis argues that per capita emissions increase as a country develops its industries, and then they fall after this country has reached some level (the turning point) of economic development. [11]. This phenomenon has been named after Simon Kuznets, who described the relation between income inequality and economic growth as an inverted U-shaped curve [12]. In the nineties, Grossman and Krueger [13] found that a relationship between economic development and environmental degradation in North America's Free Trade Agreement countries was similar to Kuznets' inverted U-curve relationship. Thirty years later, this relationship was confirmed for Mexico and the USA by A. Miranda et al. [14]. Few researchers have examined the validity of EKC hypothesis for individual countries of Central Europe. However, there are some studies for the European Union which include the countries of Central Europe. In those cases, almost all studies tested the EKC hypothesis for a panel of the EU Member States and candidate countries. A summary of the recently published literature on the EKC in the European Union countries is tabulated in Table 1 [15–24]. Most of them, except [19], confirm the U-shaped or inverted U-shaped EKC hypothesis.

Our paper aims to verify whether the EKC hypothesis holds true for Central European countries in an annual sample data covering the period between 1995 and 2016. The Autoregressive Distributed Lag (ARDL) bound test for individual countries (time series) is used to examine the cointegration. Additionally, we apply the Johansen and Juselies cointegration approach to confirm the robustness of our results. Finally, we evaluate the existence of causality between CO_2 emissions and GDP, and determine the direction of this causality.

Table 1. Brief summary of the recently published literature on the environmental Kuznets curve in the European Union countries.

Author/s	Sample (Countries)/ and Period	Variables (Mostly Per Capita)	Results
Ali et al. [15]	33 European countries/ 1996–2017	GDP, renewable energy, energy consumption, import and export, CO_2, and urbanization.	All variables are integrated in the long run. GDP has a U-shaped and significant relationship with environmental degradation supporting the EKC hypothesis. Energy innovation has a negative and significant impact on environmental degradation.
Dogan et al. [16]	EU countries/ 1980–2014	CO_2, GDP, Industry (value added), energy structure, energy intensity, urbanization, population.	The industrial share decreases emissions through the development and absorption of energy-efficient and environmentally friendly technologies. The EKC hypothesis is confirmed.
Vasylieva et al. [17]	EU countries and Ukraine/ 2000–2016	GDP, GHG, renewable energy consumption, corruption.	The empirical results of FMOLS and DMOLS panel cointegration tests confirmed the EKC hypothesis. The increase in renewable energy led to a decline in GHG, and the rise in the control corruption index prompted a drop in GHG.
Baležentis et al. [18]	EU countries (Malta excl.); 1995–2015	GDP, GHG, biomass, other renewable energy consumption.	The models without renewable resources indicate the presence of the EKC of the GHG emission. The effect of biomass on reducing GHG emission is higher than that caused by the other renewable resources.
Bozkurt et al. [19]	selected 20 EU countries/ 1991–2013	Energy consumption, GDP, CO_2 and Kyoto dummy variable.	There is a long run cointegration relationship between CO_2, energy consumption, GDP growth, trade openness, and the Kyoto dummy variable. Energy consumption and GDP growth increase the level of CO_2 emissions, but the Kyoto dummy variable decreases CO_2 emissions in the European Union countries. The inverted U-shape EKC hypothesis is invalid.
Chen et al. [20]	16 CEE countries/ 1980–2016	CO_2, GDP, financial development index, index of globalization, energy use, renewable energy.	The EKC hypothesis is confirmed for the selected panel countries. Globalization is enhancing the environmental quality of the CEE countries.
Armeanu et al. [21]	EU countries/ 1990–2014	GDP, GHG, Emissions of Sulfur Oxides, Environmental Tax Revenues, Gross Fixed Capital Formation, and many others.	The EKC hypothesis is confirmed in sulphur oxides emissions and emissions of nonmethane volatile organic compounds.
Borozan et al. [22]	EU countries/ 2005–2016	GDP, prices of electricity and gas, taxes, education, poverty, climate conditions, recession.	The research corroborates the inverted U-shaped Residential Electricity EKC, assuming thereby at least the same level of policy efforts directed to accomplish the energy targets and household willingness to use goods in an environmentally friendly way.
Destek et al. [23,24]	10 selected CEE countries;/1991–2011	GDP, CO_2, energy consumption, urbanization, trade openness.	The EKC hypothesis is confirmed.
Marinas et al. [25]	10 EU countries from CEE;/1990–2014	GDP, renewable energy consumption.	The hypothesis of bi-directional causality between renewable energy consumption and economic growth is validated in the long run for both the whole group of analyzed countries and in the case of seven CEE states that were studied individually.

Note: CEE—Central European countries, GHG—Greenhouse Gas, FMOLS—Fully Modified Ordinary Least Squares, DMOLS—Dynamic Ordinary Least Squares.

This study contributes to existing knowledge about EKC by examining a relationship between CO_2 emissions and economic growth (per capita GDP) in individual Central European countries from a long-run perspective, which allows the results to be compared. In the literature, we can find primarily studies that test the EKC hypothesis for a panel of the European Union or Central European countries. Additional novelty in our research is that in the ARDL analysis, we replace the critical values provided by Pesaran et al. [26] and Narayan [27] with the critical bounds from Kripfganz and Schneider [28,29]. We take into consideration eleven countries which joined the European Union between 2004 and 2013, namely Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia. In our model, we include trade openness and energy consumption. The importance of exports in boosting economic growth has been well demonstrated. This factor played an important role in Central European countries during the economic transition and trade liberalization process in the early nineties, whereas energy consumption, mainly from fossil fuels (i.e.,; crude oil, gas and coal) is considered to be the main cause of increasing CO_2 emissions in that region.

Section 2 of the paper describes the analyzed data and methodological framework. This is followed by the description of empirical results and discussion. Section 4 concludes with a summary.

2. Data and Methodological Framework

As stated in the introduction, the paper examines the annual data on eleven Central European countries. The time period for each country was selected depending on data availability. The annual time series data comes from the World Bank collection of development indicators, and it includes the following variables: C—CO_2 emissions per capita (in metric tons); Y—*GDP* per capita (in constant 2010 US$); E—energy use per capita (kg of oil equivalent); and T—trade openness (% of *GDP*), the sum of exports and imports of goods and services measured as a share of gross domestic product. CO_2 emissions are defined as emissions that result from cement manufacturing and fossil fuel combustion. They also include CO_2 emissions produced during consumption of gas fuels and gas flaring and liquid and solid fuels. Energy use/consumption refers to the use of primary energy before it is transformed to other end-use fuels. It is equal to domestic production plus imports and stock changes, minus exports and fuels used in international transport (World Bank Development Indicators). Trade openness can be defined as the sum of imports and exports of services and goods measured as a share of GDP (gross domestic product). In this section, we use all variables in logarithmic forms.

Following the literature on the environmental Kuznets curve, for example [30–38], we constructed a model of the long-run relationship between CO_2 emissions, economic growth, energy consumption and trade openness in logarithmic, quadratic form:

$$\ln C_t = \beta_0 + \beta_1 \ln Y_t + \beta_2 (\ln Y_t)^2 + \beta_3 \ln E_t + \beta_4 \ln T_t + \varepsilon_t \tag{1}$$

where C denotes CO_2 emissions per capita, Y—real gross domestic product per capita, E—energy use per capita, T—trade openness, and ε_t is the standard error term. All variables are in logarithmic format (ln).

According to the inverted U-shaped EKC hypothesis, the relationship requires that coefficients $\beta 1 > 0$ and $\beta 2 < 0$. If $\beta 2$ is statistically insignificant, there is a monotonic increase in the relationship between CO_2 emissions per capita and real GDP per capita. Furthermore, we expected that energy consumption causes an increase in CO_2 emissions [39,40]. It means that coefficient $\beta 3$ should be positive. Usually, the expected sign of $\beta 4$ is mixed and it depends on a country's level of economic development [34]. In the case of Central European countries, the $\beta 4$ coefficient is expected to be negative. These countries, as developed economies, have ceased to produce certain pollution-intensive goods. Moreover, technological innovations enable them to produce fewer energy- and pollution-intensive goods. The sign of $\beta 4$ is expected to be positive in developing countries with "dirty" industries [13,34,35]. We can also analyze the parameters $\beta 1$, $\beta 2$, $\beta 3$, and $\beta 4$, as the long-run elasticities of CO_2 emissions per capita, GDP per capita, squared GDP per capita, energy use and trade openness, respectively.

We examined cointegration by applying the ARDL bounds test, which recently has been used, among others, by Ozatac [41], Pal and Mitra [42], Bölük and Mert [43], Marinas et al. [25], Sharif et al. [44], Moutinho and Madaleno [45] and Zhang [46]. To confirm the robustness of our results, the Johansen approach was used. We employed the ARDL model developed by Pesaran et al. [26]. This is a standard least squares regression that incorporates the lags of the response and predictor variables as regressors. It can be employed as a cointegration test regardless of whether the variables that are considered are I(1) or I(0) or fractionally integrated. Furthermore, this approach suits our research purposes, and is preferable to other methods, providing consistent results for a small sample (as shown by the simulation results) [47].

The ARDL model representation of Equation (1) for testing the long run relation of the EKC hypothesis is formulated as follows:

$$\begin{aligned}\Delta lnC_t = \gamma_0 + \sum_{i=1}^{k} \quad & \rho_{1i}\Delta lnC_{t-i} \\ & + \sum_{i=1}^{l} \rho_{2i}\Delta lnY_{t-i} + \sum_{i=1}^{m} \rho_{3i}\Delta(lnY)^2_{t-i} \\ & + \sum_{i=1}^{n} \rho_{4i}\Delta lnE_{t-i} \\ & + \sum_{i=1}^{q} \rho_{5i}\Delta lnT_{t-i} + \alpha_1 lnC_{t-1} + \alpha_2 lnY_{t-1} + \alpha_3(lnY)^2_{t-i} + \alpha_4 lnE_{t-1} \\ & + \alpha_5 lnT_{t-1} + \mu_t\end{aligned} \tag{2}$$

where Δ denotes the difference operator; p, q, m, and n are the lag lengths; and μ_t is the serially uncorrelated error term. Pesaran et al. [47] observe that the ARDL model does not require symmetry of lag lengths where each variable can have a different number of lag terms, as it is the case in other types of cointegration tests.

First, we checked for stationarity of each series. Only in the case of unit root can we ask whether the long-run relationship shows an inverted-U pattern of the EKC [48]. A variety of unit root tests can be used to determine the integrating properties of the variables. Here we checked the stationarity properties with the ADF unit root test.

We started the ARDL bounds test by estimating Equation (2). We computed the F-statistic and the t-statistic for the joint significance of the lagged level variables' coefficients to test the long-run relationship (cointegration) among the variables. The F-statistic and t-statistic examine the null hypothesis of no levels of relationship (cointegration) between CO_2 emissions and determinant variables: $H_0 : \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 0$, against the alternative hypothesis, which states that there exists the long-run relationship (cointegration) among the variables: $H_1 : \alpha_1 \neq \alpha_2 \neq \alpha_3 \neq \alpha_4 \neq \alpha_5 \neq 0$.

Testing for cointegration involves comparing the computed F-statistic and t-statistic with the upper and lower critical bounds. The series are cointegrated if both statistics are more extreme than critical values for I(1) variables (if p-values are less than desired level for I(1) variables). If both statistics are closer to zero than critical values for I(0) variables (if p-values are greater than desired level for I(0) variables), we cannot reject the null hypothesis. We replace the critical values provided by Pesaran et al. [26], which are near-asymptotic, and the finite-sample critical values implemented by Narayan [27] with the critical bounds from Kripfganz and Schneider [28,29]. They use response surface regressions to obtain finite-sample, asymptotic critical values, and approximate p-values, for the lower bound and upper bound of all explanatory variables (independent variables) being purely I(0) or purely I(1) (and not mutually cointegrated), respectively. The critical values from Kripfganz and Schneider are conditional on the number of explanatory variables (independent variables), their integration order, the number of short-run coefficients, and the inclusion of a time trend or an intercept [28,49].

The robustness of results was tested by applying the Johansen and Juselies cointegration approach. As a result, we obtained two statistics: trace statistics and eigenvalues. These methods are based on Johansen's maximum likelihood estimator of the parameters of a cointegrating vector error correction model (VECM) [49]. The significance of trace statistics and eigenvalues statistics demonstrates a cointegration relation among variables. For example, according to the trace statistic null hypothesis, there are r or fewer cointegrating relations. The alternative hypothesis states that there are more than r cointegrating equations that the null hypothesis assumes [50].

Finally, the stability of the ARDL model was examined with the cumulative sum of recursive residual test (CUSUM) put forward by Brown et al. [51]. It tests the assumption that after a time-series regression, the coefficients that do not interact with time are constant. The result is based on whether the time-series changes abruptly in a way that is not predicted by the model; or to use more technical terminology, it tests for structural breaks in the residuals. Additionally, we used the cumulative sum of squares of recursive residual test (CUSUMSQ). The null hypothesis that all parameters are stable cannot be rejected and the regression will be considered stable if the plots of CUSUM and CUSUMSQ statistics remain within the critical bounds.

After establishing the long-run relationship among the series, we tested the existence and direction of causality between the CO_2 emissions per capita and GDP per capita. This was done within the VECM framework (cf. [52–56]). The VECM estimate can be given as follows:

$$\begin{bmatrix} \Delta lnC_t \\ \Delta lnY_t \\ \Delta (lnY_t)^2 \\ \Delta lnE_t \\ \Delta lnT_t \end{bmatrix} = \begin{bmatrix} \varphi_1 \\ \varphi_2 \\ \varphi_3 \\ \varphi_4 \\ \varphi_5 \end{bmatrix} + \sum_{m=1}^{p-1} \begin{bmatrix} \phi_{11,m} & \phi_{12,m} & \phi_{13,m} & \phi_{14,m} & \phi_{15,m} \\ \phi_{21,m} & \phi_{22,m} & \phi_{23,m} & \phi_{24,m} & \phi_{25,m} \\ \phi_{31,m} & \phi_{32,m} & \phi_{33,m} & \phi_{34,m} & \phi_{35,m} \\ \phi_{41,m} & \phi_{42,m} & \phi_{43,m} & \phi_{44,m} & \phi_{45,m} \\ \phi_{51,m} & \phi_{52,m} & \phi_{53,m} & \phi_{54,m} & \phi_{55,m} \end{bmatrix} x \begin{bmatrix} \Delta lnC_{t-m} \\ \Delta lnY_{t-m} \\ \Delta (lnY_{t-m})^2 \\ \Delta lnE_{t-m} \\ \Delta lnT_{t-m} \end{bmatrix} + \begin{bmatrix} \varsigma_1 \\ \varsigma_2 \\ \varsigma_3 \\ \varsigma_4 \\ \varsigma_5 \end{bmatrix} x(ECT_{t-1}) + \begin{bmatrix} \mu_{1t} \\ \mu_{2t} \\ \mu_{3t} \\ \mu_{4t} \\ \mu_{5t} \end{bmatrix} \quad (3)$$

where Δ indicates the first-difference operator, p is the lags length, ECT_{t-1} the lagged error correction term; and μ denotes the random error term. Only if the error correction term is negative and highly significant is there a long-run causality from independent to dependent variables.

3. Results and Discussion

We began our analysis with examining the series stationarity. This is a prerequisite for applying the ARDL bounds testing approach to investigate a long-run relationship between the variables, and it allows us to avoid spurious results. As noted earlier, the primary assumption of the ARDL bounds testing is that variables should be stationary at the level or first difference, or that variables have a mixed order of integration such as I(0) or I(1). The stationarity was tested with the ADF test.

The results of calculations for individual countries are summarized in Appendix A in Table A1. All the variables were stationary at first difference or at the level (only lnY and lnYsq for Hungary), except for two variables: lnY and lnYsq for Slovenia. It has to be noted that the value Z(t) statistics for these variables are close to the critical value at 5%. Because of this, we assume that these variables have a weak stationarity at the first difference. Therefore, we can conclude that each country's series are integrated at I(0) or I(1).

Having established the stationarity, we could then apply the ARDL bounds testing approach to examine the cointegration for individual countries, as well as to determine whether a long-run relationship exists among the variables. We should note that the ARDL bounds test is sensitive to lag length. Using the AIC and the BIC information criteria to determine the required lag, we found that there was a problem with the ARDL bounds testing approach due to a small number of observations (there must be at least twice as many observations as coefficients). Given the small sample size, the single lag was chosen in order to minimize the loss of degrees of freedom.

We begin by applying the ARDL bounds test and present our findings in Table 2. As already mentioned, we used critical value bounds described by Kripfganz and Schneider [28,29].

Table 2. ARDL bounds cointegration test.

Country	Decision	Selected Model		Statistics	Kripfganz and Schneider (2018) Critical Values							
					Significance 10%		Significance 5%		Significance 1%		*p*-Value	
					I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0) Bound	I(1) Bound
Bulgaria	cointegration	Selected model	F t	22.946 *** −10.398 ***	2.728 −2.574	3.931 −3.679	3.320 −2.929	4.683 −4.096	4.742 −3.660	6.475 −4.947	0.000 0.000	0.000 0.000
Croatia	cointegration	ARDL (1 0 0 0 0)	F t	20.634 *** −5.597 ***	3.060 −2.591	4.426 −3.700	3.878 −3.013	5.515 −4.220	6.081 −3.936	8.429 −5.363	0.000 0.001	0.000 0.007
Czech Rep.	no levels relationship	ARDL (1 0 0 0 0)	F t	1.062 −1.949	2.924 −2.568	4.269 −3.679	3.664 −2.970	5.249 −4.167	5.591 −3.832	7.790 −5.216	0.605 0.254	0.855 0.589
Estonia	cointegration	ARDL (1 0 0 1 0)	F t	7.651 ** −3.866 *	2.959 −2.554	4.365 −3.674	3.742 −2.971	5.415 −4.182	5.838 −3.872	8.198 −5.286	0.003 0.010	0.013 0.077
Hungary	cointegration	ARDL (1 0 0 1 1)	F t	22.305 *** −8.906 ***	2.896 −2.567	4.226 −3.677	3.615 −2.963	5.176 −4.156	5.470 −3.808	7.614 −5.180	0.000 0.000	0.000 0.000
Latvia	cointegration	ARDL (1 1 0 0 0)	F t	24.443 *** −8.057 ***	3.088 −2.560	4.560 −3.687	3.973 −3.002	5.753 −4.233	6.455 −3.981	9.048 −5.449	0.000 0.000	0.000 0.000
Lithuania	no levels relationship	ARDL (1 1 0 0 1)	F t	2.373 −2.114	3.074 −2.576	4.493 −3.694	3.926 −3.008	5.634 −4.226	6.268 −3.959	8.738 −5.406	0.185 0.197	0.406 0.504
Poland	cointegration	ARDL (1 0 1 0 0)	F t	9.228 *** −6.077 ***	3.050 −2.542	4.548 −3.674	3.924 −2.984	5.732 −4.219	6.374 −3.959	8.998 −5.427	0.002 0.000	0.009 0.004
Romania	cointegration	ARDL (1 0 1 1 1)	F t	19.800 *** −9.231	2.896 −2.552	4.266 −3.669	3.630 −2.955	5.245 −4.157	5.548 −3.818	7.785 −5.204	0.000 0.000	0.000 0.000
Slovakia	cointegration	ARDL (1 1 0 0 1)	F t	13.175 *** −6.334 ***	2.923 −2.584	4.225 −3.687	3.644 −2.978	5.173 −4.165	5.499 −3.821	7.600 −5.188	0.000 0.000	0.001 0.001
Slovenia	cointegration	ARDL (1 0 0 0 0)	F t	14.588 *** −6.271 ***	2.924 −2.568	4.269 −3.679	3.664 −2.970	5.249 −4.167	5.591 −3.832	7.790 −5.216	0.000 0.000	0.000 0.002

Notes: The null hypothesis: no levels relationship. The selection of the model maxlags is 1. Case 3 unrestricted intercepts; no trends. ***, ** and * denote the 1%, 5% and 10% significance levels, respectively.

The results show the cointegration relationship for nine countries: Bulgaria, Croatia, Estonia, Hungary, Latvia, Poland, Romania, Slovakia, and Slovenia. As in Equation (2), the dependent variable is CO_2 emissions. The computed F and t-statistics for these nine countries are more extreme than critical values for I(1) variables (p-values < desired level for I(1) variables). We can reject the null hypothesis. By contrast, no cointegration was found in the case of the Czech Republic and Lithuania, where the computed F and t-statistics were closer to zero than critical values for I(0) variables (p-values > desired level for I(0) variables). To sum up, the results in Table 2 confirm that there is a long-run relationship (steady state equilibrium), cointegration, among the variables of the model for nine countries.

Having established that there are cointegration relations among the variables for nine countries, we estimated the long-run coefficients of equation (2) to test the inverted U-shaped EKC hypothesis. The long-run estimation results are shown in Table 3.

According to the inverted U-shaped EKC hypothesis, the relationship requires coefficients $\beta 1 > 0$ and $\beta 2 < 0$. The estimated long-run coefficients in Table 3 confirm the inverted U-shaped EKC hypothesis only in one country: Poland, where $\beta 1 > 0$ (3.39 at the 1% significance level) and $\beta 2 < 0$ (−0.19 at the 1% significance level). Although $\beta 1 > 0$ and $\beta 2 < 0$ for Croatia and Hungary, both coefficients are not significant. In the case of Slovakia and Slovenia, the coefficients are significant but $\beta 1 < 0$ and $\beta 2 > 0$, indicating that the inverted U-shaped EKC hypothesis does not hold for these countries. These coefficients denote a U-shaped growth of CO_2 emissions association [11]. The results probably indicate different economic structures and the energy sources used in individual Central European countries. For example, in Estonia, there is a dominant share of bituminous shale in the energy sector, which has been used as a common energy source since the beginning of the 20th century. In Lithuania, the last reactor of a nuclear power plant was closed in 2009. This situation radically changed the way of producing energy in this country. Poland still has problems with the excessive use of coal in energy production and a small share of renewable energies, the smallest among Central European countries: 12.2% in 2019. At the same time, the share of renewable energy in gross final energy consumption in Latvia was 41%, in Estonia 32%, and Lithuania 25,5%. Due to these differences, it is advisable to conduct in-depth research for individual countries, taking into account their specific circumstances. Interesting research in this area was carried out by Shota and Masayuki [57], taking into account the economic sectors in China. The authors investigated the relationship between China's high economic growth and environmental pollution from the agricultural and industrial sectors by estimating the EKC. They found that agricultural chemical oxygen demand and industrial wastewater depict N-shaped and reverse N-shaped Kuznets curves. Probably, models with different forms of the EKC (such as linearly-shaped, U-shaped, inverted U-shaped, N-shaped, and inverted N-shaped growth with CO_2 emissions association) should be used in the analysis of individual Central European countries.

Table 3. ARDL The Long-run coefficients *(Dependent variable = lnC* (CO_2 *emissions)*.

Country	ecm_{t-1}	β_1	β_2	β_3	β_4
Bulgaria	−0.9279025 *** (−10.40)	−7.132273 (−1.46)	0.4084599 (1.43)	1.512325 *** (22.45)	0.0763897 (0.98)
Croatia	−0.7160752 *** (−5.60)	1.207842 (0.15)	−0.0986388 (−0.22)	2.029567 *** (10.11)	0.3750321 ** (2.27)
Czech Rep.			no levels relationship		
Estonia	−0.515706 *** (−3.87)	−1.584854 (−0.65)	0.0857118 (0.66)	0.4912333 ** (2.35)	0.1529776 (1.33)
Hungary	−0.7190076 *** (−8.91)	6.922897 (1.15)	−0.3886803 (−1.21)	1.747893 *** (13.17)	−0.0756772 * (−1.82)
Latvia	−0.8154661 *** (−8.06)	−4.102585 (−1.59)	0.2141292 (1.49)	1.740268 *** (7.11)	−0.2719155 (−2.96)
Lithuania			no levels relationship		
Poland	−1.443825 *** (−6.08)	3.393525 *** (7.04)	−0.1944176 *** (−7.69)	1.054645 *** (40.71)	0.0265788 (0.93)
Romania	−0.9919402 *** (−9.23)	−3.024831 (−1.11)	0.1677077 (1.07)	1.292806 *** (19.87)	−0.1872444 *** (−3.13)
Slovakia	−0.7125795 *** (−6.33)	−9.614154 ** (−2.19)	0.5059201 ** (2.14)	1.773542 *** (4.92)	−0.124479 (−0.98)
Slovenia	−0.6979881 *** (−6.27)	−22.26621 *** (−3.38)	1.105588 *** (3.30)	1.85127 *** (7.69)	−0.1913531 (−1.54)

Notes: Numbers in parentheses represent the t-statistic. ***, **, and * denote the 1%, 5%, and 10% significance levels, respectively.

In the literature, we observed many problems with confirmation of the inverted U-shaped EKC hypothesis in European countries, for example in Dogan et al. [16] or Baležentis et al. [18], where findings partially explain the presence of the EKC with the GHG emission as an independent variable. Probably these difficulties with testing the long-run relationship result from the economic transformation in this region in the nineties. Interestingly, some empirical studies confirm an inverted U-shaped EKC in emerging countries like E7, in which economic growth is comparable to that in Central European countries [58].

As mentioned above, we expect that energy consumption leads to increasing CO_2 emissions. It means that the coefficient β3 should be positive and significant. As shown in Table 3, the coefficients are both positive and significant in all countries. The lowest values of the coefficients (elasticity) are observed in Estonia, Poland, and Romania. It means that for each 1% increase in energy consumption in these countries, the growth of CO_2 emissions is the weakest among Central European countries. However, these countries have the highest greenhouse gas emissions intensity (i.e., the ratio between emissions and GDP) out of European Union countries. The long-run elasticities in other countries range between 1.5 in Bulgaria and 2.0 in Croatia. For instance, the result for Hungary suggests that the long-run elasticity of CO_2 emissions with respect to energy use is 1.75, which indicates that for each 1% increase in per capita energy consumption, per capita CO_2 emissions go up by 1.75%. The error-correction term for Hungary is minus 0.719, which means that when per capita CO_2 emissions are above or below its equilibrium level, they adjust by nearly 72% in the first year. This adjustment is significantly fast, which supports the view that there is not much control over the growth of CO_2 emissions.

As previously stated, we observed exceptionally low long-run elasticity in Estonia (0.49), indicating that each 1% increase in per capita energy consumption increases only by 0.49% per capita CO_2 emissions. This relation probably results from the high share of renewable energy usage in gross final energy consumption. Nevertheless, it should be noted that Estonia is also one of the largest emitters of CO_2 per capita in the European Union. The differences in the long-run elasticities in Central European countries probably result from energy power production methods and resources. The set 2030 climate and energy targets oblige the European Union and national policymakers to reduce environmental degradation with energy-efficient and innovative technologies, e.g., by increasing the share of renewable energy. A recent study by Chen et al. reports that even though the use of renewable energy also degrades the environment in Central and Eastern European countries, its intensity is almost 41 times less than non-renewable energy consumption [20]. In these cases, we should assume that energy innovation helps to reduce the rate of environmental degradation.

As expected, the sign of β4 is mixed for Central European countries. However, there is a problem with the insignificance of these coefficients, except for the results in Croatia and Romania. Although these results differ from some published studies (e.g., [15]), they are consistent with those of Nepal et al.'s research [59] on the impacts of economic reforms on CO_2 emissions in East European and Central Asian transitional economies, which suggests that trade openness may not necessarily result in environmental degradation. On the other hand, Ali et al. [15] indicate that import and export are the main factors in increasing environmental degradation in 33 European countries from 1996 to 2017. Unlike our research, Ali et al. used different methods than ours: panel data methods, from which they generalized the research results.

To check the robustness of the long-run relationship, we performed the Johansen cointegration test. Due to a limited number of observations, the included maximum lag is 2. Table 4 shows the results which confirm at least one cointegration relationship among the variables in all countries.

Table 4. Johansen cointegration test results.

Country	The Trace Statistics			The Maximum Eigenvalue Statistics		
	Maximum Rank	Trace Statistics	5% Critical Value	Maximum Rank	Max Statistics	5% Critical Value
Bulgaria	2	6.5735	12.53	3	6.4521	11.44
Croatia	3	6.5735	12.53	3	6.4521	11.44
Czech Rep.	2	23.1559	24.31	1	21.0415	23.80
Estonia	2	16.7707	24.31	2	11.6739	17.89
Hungary	4	3.0253	3.84	4	3.0253	3.84
Latvia	1	32.9198	39.89	1	13.5667	23.80
Lithuania	3	8.0099	15.41	3	7.9666	14.07
Poland	1	39.8512	39.89	0	29.3755	30.04
Romania	4	2.0856	3.84	4	2.0856	3.84
Slovakia	2	19.6038	24.31	2	13.9347	17.89
Slovenia	3	7.9118	12.53	3	7.4636	11.44

Notes: Does not include a trend or a constant; an unrestricted constant is included in the model in the case of Lithuania. The maximum lag is 2. Rejection of the hypothesis at the 5% level.

Finally, the stability of model parameters was checked with the CUSUM and CUSUMSQ tests developed by Brown et al. [51]. The test results suggest the stability of the long and short run parameters, except for three countries: Croatia, Estonia, and Romania (Appendix A, Figures A1 and A2). The computing results of the cumulative sum test for parameters stability confirm our observation. The test of the null hypothesis (Ho: No structural break) for these countries shows that structural change occurred in the estimated coefficients: Croatia 1.2466**, Estonia 1.4236***, and Romania 1.1413*** (***, ** denote 1% and 5% significance levels, respectively.).

In the final part of our research, we examined the existence and direction of causality between variables within the VECM framework. Based on the EKC hypothesis, we explored the relation between per capita CO_2 emissions and per capita GDP. Firstly, we computed the results for per capita CO_2 emissions as a dependent variable, and secondly for per capita GDP. We omitted Hungary in our calculations, because the variables for this country do not have the same ordered integrations (see Appendix A, Table A1). Additionally, to simplify the calculations, we assume that the number of cointegrating equations is 1. Tables 5 and 6 report the results on the direction of long- and short-run causality between variables. The feedback relation between per capita CO_2 emissions and GDP is rare. Interestingly, these results of time series analyses do not match those from the panel data published by Ali et al. [15]. Their study of the European countries supports the hypothesis that economic growth, import, export, and energy consumption are the main factors to increase environmental degradation.

Table 5. VECM causality analysis (lnC dependent variable) vec lnC lnY lnYsq lnE lnT, trend (constant).

Dependent Variable ΔlnC/Country	Type of Causality				
	Short-Run				Long-Run
	ΔlnY_{t-1}	$\Delta ln(Y_{t-1})^2$	ΔlnE_{t-1}	ΔlnT_{t-1}	ECT_{t-1}
Bulgaria	19.52732 (0.334)	−1.141072 (0.340)	0.2777692 (0.657)	0.1403034 (0.304)	0.1085911 (0.625)
Croatia	44.48498 *** (0.000)	−2.27491 *** (0.000)	−0.9074855 (0.229)	−0.1295292 (0.507)	−0.0292138 (0.889)
Czech Rep.	37.55787 ** (0.023)	−1.893389 ** (0.025)	−0.7194569 (0.186)	0.1027063 (0.530)	−0.5910012 * (0.108)
Estonia	−5.671992 (0.73)	0.2951767 (0.739)	−1.253437 (0.293)	−0.411933 (0.203)	−0.2695648 (0.760)
Latvia	10.00946 (0.623)	−0.5446163 (0.617)	1.440446 (0.205)	−0.0190665 (0.958)	0.0748077 (0.448)
Lithuania	22.12051 (0.392)	−1.186595 (0.389)	0.0164719 (0.961)	0.328258 (0.229)	0.2042606 (0.472)
Poland	−5.761343 (0.440)	0.3983925 (0.353)	−1.274876 (0.503)	−0.1517343 (0.327)	−6.922366 ** (0.018)
Romania	27.44555 *** (0.003)	−1.551871 *** (0.003)	−1.093496 * (0.060)	0.1992621 (0.125)	−0.2062757 (0.275)
Slovakia	18.29915 ** (0.021)	−0.9652483 ** (0.020)	−0.2777244 (0.610)	0.2744206 ** (0.049)	0.0435621 (0.648)
Slovenia	−21.44961 (0.583)	1.093192 (0.575)	0.2635823 (0.753)	0.1410367 (0.490)	−0.1098107 (0.154)

Notes: Numbers in parentheses represent p-value. Trend specification is constant. The selection of the model max lags is 2. ***, **, and * denote 1%, 5%, and 10% significance levels, respectively.

Table 6. VECM causality analysis (lnY dependent variable) vec lnC lnY lnYsq lnE lnT, trend (constant).

Dependent Variable ΔlnY/Country	Type of Causality				
	Short-Run				Long-Run
	ΔlnC_{t-1}	$\Delta ln(Y_{t-1})^2$	ΔlnE_{t-1}	ΔlnT_{t-1}	ECT_{t-1}
Bulgaria	0.0473663 (0.808)	0.4506616 (0.491)	0.1244479 (0.716)	−0.1061008 (0.155)	0.1046299 (0.389)
Croatia	−0.1204909 (0.783)	−0.4228583 (0.496)	0.1330792 (0.858)	0.0707448 (0.714)	0.048466 (0.815)
Czech Rep.	0.1178013 (0.697)	−0.6149802 (0.288)	−0.3170827 (0.395)	0.082952 (0.459)	−0.1769793 (0.482)
Estonia	−0.0736962 (0.891)	0.7375369 (0.137)	0.1636688 (0.806)	0.0553634 (0.760)	−1.178289 ** (0.017)
Latvia	0.1572548 (0.629)	1.002061 (0.056)	−0.0079399 (0.988)	−0.0906455 (0.606)	−0.1420247 *** (0.003)
Lithuania	−4.636562 (0.804)	0.2573678 (0.797)	−0.21239 (0.379)	0.0025929 (0.990)	−0.1481043 (0.472)
Poland	0.9298013 (0.300)	−0.1690673 (0.440)	−0.8010967 (0.411)	−0.0861874 (0.276)	−1.84046 (0.219)
Romania	0.6795092 ** (0.021)	1.465229 (0.805)	−0.0702363 (0.834)	−0.6420375 (0.086)	0.1624228 (0.183)
Slovakia	0.1481264 (0.568)	−0.5052178 * (0.105)	−0.6785857 * (0.097)	0.1931795 * (0.065)	−0.0918972 (0.199)
Slovenia	0.0536932 (0.858)	0.3428979 (0.767)	−0.709142 (0.154)	0.1019946 (0.400)	−0.0668872 (0.143)

Notes: Numbers in parentheses represent p-value. Trend specification is constant. The selection of the model maxlags is 2. ***, ** and * denote 1%, 5%, and 10% significance levels, respectively.

Table 5 shows the causal effect on CO_2 emissions. In long-run effects, the negative error correction term, which indicates convergence to long-run equilibrium, is ob-served in Croatia, the Czech Republic, Estonia, Poland, Romania, and Slovakia. The *p*-value is significant only in Poland at the 5% level and in the Czech Republic at the 10% level. In short-run effects, there is a significant causal effect from per capita GDP and per capita GDP squared to CO_2 emissions in Croatia, the Czech Republic, Roma-nia, and Slovakia. This means that strong causality occurs only in the Czech Republic. Table 6 shows the causal effect on per capita GDP. The significant negative error cor-rection term occurs only in Latvia at 1% and Estonia at 5%. In short-run effects, there is a significant causal effect from CO_2 emission to per capita GDP in Romania at the 5% level.

4. Conclusions

The article investigates the EKC hypothesis for Central European countries, on the basis of the annual sample data that covers the period between 1995 and 2016. To our knowledge, this is the first study to analyze the relationship between CO_2 emissions and economic growth in the individual countries of Central Europe from a long-term perspective. In our study, we considered eleven economies which joined the EU, namely: Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia. We examined cointegration by applying ARDL bound testing, taking into account per capita CO_2 emissions, per capita income, per capita energy consumption, and trade openness. The robustness of results was tested with the Johansen and Juselies approach. Additionally, we tested the causality between CO_2 emissions and GDP.

The empirical evidence revealed that the variables for the individual countries were integrated at I(0) or I(1). The results of ARDL bounds testing confirmed the existence of cointegration between CO_2 emissions per capita, GDP per capita, energy use per capita, and trade openness in nine countries: Bulgaria, Croatia, Estonia, Hungary, Latvia, Poland, Romania, Slovakia, and Slovenia. In all nine countries, energy consumption leads to increased CO_2 emissions. The lowest values of the elasticity are observed in Estonia, Poland, and Romania. It means that an increase in energy consumption causes the weakest growth of CO_2 emissions among Central European countries. Considering the exceptionally low long-run elasticity we observed in Estonia (0.49), this elasticity probably results from the high share of renewable energy usage in gross final energy consumption. However, Estonia is one of the largest emitters of CO_2 per capita in the European Union.

We investigated the inverted U-shaped EKC hypothesis by estimating the long-run coefficients of equation (2). Our estimates confirmed the EKC hypothesis for CO_2 emissions only in Poland, where $\beta 1 > 0$ (3.39 at the 1% significance level) and $\beta 2 < 0$ (0.19 at the 1% significance level). In the cases of Slovakia and Slovenia, the coefficients were also found to be significant but $\beta 1 < 0$ and $\beta 2 > 0$, indicating that there was a relation between growth and CO_2 emissions described by U-shaped curve. The results probably indicate different economic structures and energy sources used in individual Central European countries. Because of these differences, it is advisable to conduct in-depth research for individual countries, considering their specific circumstances. The analysis should probably test models with different forms of the EKC.

As mentioned earlier, we explored the causal relationship between the variables with the VECM. The causal long-run effect on CO_2 emissions is observed in Croatia, the Czech Republic, Estonia, Poland, Romania, and Slovakia. However, the *p*-value is significant only in two countries: in Poland at the 5% level and in the Czech Republic at the 10% level. On the other side, the causal effect on per capita GDP occurs only in Latvia at the 1% level and Estonia at the 5% level.

Undoubtedly, the variety of results shows that further research needs to be done to identify the causes of these discrepancies. In the following research, we want to use an innovative model that considers more variables, for example such as those recently used by Madaleno and Moutinho [60]. Due to the expected transformation in energy production in Central European countries, we are going to add renewable energy variable to our model, e.g., similar to the research of Soylu et al. [61]. Moreover, our findings suggest that to solve the problem of environmental degradation, it is necessary to individualize the policies that are implemented in different countries. This approach requires cooperation and flexibility when negotiating the European Union environmental policy. However, more studies on this topic need to be undertaken before applying a particular solution.

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Abbreviations

C	CO_2 emissions (metric tons per capita)
Y	Gross Domestic Product per capita (constant 2010 US$)
E	energy use (kg of oil equivalent per capita)
T	trade openness (% of GDP) the sum of exports and imports of goods and services measured as a share of gross domestic product
Ln	the natural logarithm of variable, e.g., lnC the natural logarithm of CO_2 emissions
EU	the European Union
CEE	Central and Eastern European countries
GDP	Gross Domestic Product
GHG	Greenhouse Gas
EKC	Environmental Kuznets Curve
FMOLS	Fully Modified Ordinary Least Squares
DMOLS	Dynamic Ordinary Least Squares

Appendix A

Table A1. Augmented Dickey-Fuller tests.

Country	Variable	Level Z(t)			First Difference Z(t)		
		Drift Term	Drift and Trend Terms	None	Drift Term	Drift and Trend Terms	None
Bulgaria	lnC	−1.205	−1.959	−0.975	−5.557 ***	−5.492 ***	−5.340 ***
	lnY	−0.383	−1.386	1.419	−2.465	−2.481	−2.269 **
	lnYsq	−0.350	−1.372	1.417	−2.466	−2.487	−2.261 **
	lnE	−1.636	−2.290	−0.573	−4.487 ***	−4.447 ***	−4.450 ***
	lnT	−1.391	−2.597	0.931	−5.774 ***	−5.696 ***	−5.590 ***
Croatia	lnC	−1.912	−0.970	−0.009	−2.188	−3.762 **	−2.346 **
	lnY	−1.723	−0.884	0.832	−2.377	−3.017	−2.232 **
	lnYsq	−1.716	−0.896	0.807	−2.357	−2.969	−2.211 **
	lnE	−1.640	−0.015	0.057	−1.757	−2.800	−1.994 **
	lnT	−2.009	−2.407	0.789	−4.404 ***	−4.133 **	−4.352 ***
Czech Republic	lnC	−0.488	−1.870	−1.668	−4.796 ***	−4.923 ***	−4.104 ***
	lnY	−1.133	−2.502	2.141 **	−3.306 **	−3.293 *	−1.978 **
	lnYsq	−1.082	−2.511	2.109 **	−3.288 **	−3.259 *	−1.966 **
	lnE	−1.581	−1.403	−0.346	−3.504 **	−3.741 **	−3.593 ***
	lnT	−0.433	−3.887 **	1.867 *	−4.480 ***	−4.302 **	−3.205 ***
Estonia	lnC	−2.367	−2.904	−0.136	−5.366 ***	−5.293 ***	−5.506 ***
	lnY	−1.910	−1.823	1.753 *	−3.315 **	−3.799 **	−2.337 **
	lnYsq	−1.819	−1.881	1.658 *	−3.393 **	−3.812 **	−2.392 **
	lnE	−1.528	−2.601	0.457	−4.889 ***	−4.747 ***	−4.802 ***
	lnT	−2.239	−2.559	−0.031	−3.805 ***	−3.691 **	−3.889 ***
Hungary	lnC	0.050	−1.539	−1.535	−2.906 *	−2.922	−2.636 **
	lnY	−1.025	−1.696	2.372 **	−2.416	−2.464	−1.295
	lnYsq	−0.977	−1.721	2.328 **	−2.401	−2.433	−1.289
	lnE	−1.714	−1.767	−0.053	−2.768 *	−2.706	−2.879 ***
	lnT	−2.156	−1.804	1.632 *	−3.139 **	−3.952 **	−2.385 **
Latvia	lnC	−1.899	−2.640	−0.342	−2.733 *	−2.661	−2.839 ***
	lnY	−1.693	−2.191	1.311	−3.368 **	−3.579 *	−2.379 **
	lnYsq	−1.626	−2.269	1.242	−3.447 **	−3.617 **	−2.422 **
	lnE	−0.689	−2.196	0.857	−2.331	−2.232	−2.226 **
	lnT	−0.583	−2.846	0.790	−3.024 **	−3.075	−2.848 ***
Lithuania	lnC	−2.033	−2.498	−0.103	−3.913 ***	−3.925 **	−4.048 ***
	lnY	−1.120	−1.995	2.130 **	−3.331 **	−3.353 *	−1.967 **
	lnYsq	−1.032	−2.088	2.081 **	−3.379 **	−3.363 *	−1.983 **
	lnE	−2.375	−2.324	−0.251	−3.604 **	−3.535 *	−3.730 ***
	lnT	−0.791	−3.295 *	0.907	−3.534 **	−3.576 *	−3.359 ***
Poland	lnC	−2.369	−2.331	−1.446	−2.813 *	−2.815	−2.532 **
	lnY	−0.996	−2.447	2.543 **	−3.234 **	−3.243 *	−1.191 *
	lnYsq	−0.844	−2.546	2.540 **	−3.299 **	−3.245 *	−1.127
	lnE	−2.123	−2.637	−0.516	−2.574	−2.671	−2.619 **
	lnT	−1.914	−2.964	2.964 ***	−4.409 ***	−4.813 ***	−2.551 **

Table A1. *Cont.*

Country	Variable	Level Z(t)			First Difference Z(t)		
		Drift Term	Drift and Trend Terms	None	Drift Term	Drift and Trend Terms	None
	lnC	−1.287	−2.612	−1.134	−4.270 ***	−4.186 **	−3.862 ***
	lnY	−0.548	−2.355	2.014 **	−3.736 **	−3.486 *	−2.625 **
Romania	lnYsq	−0.498	−2.335	1.993 **	−3.674 **	−3.440 *	−2.579 **
	lnE	−2.017	−2.675	−0.744	−3.718 **	−3.563 *	−3.660 ***
	lnT	−1.825	−2.808	1.633 *	−6.002 ***	−6.023 ***	−5.744 ***

Notes: All variables in logarithmic format (ln). C denotes CO_2 emissions (metric tons per capita), Y—GDP per capita (constant 2010 US$), E—energy use (kg of oil equivalent per capita), T—trade openness (% of GDP). Null Hypothesis: the variable contains a unit root. Lag length is 1 for the level and the first difference. ***, **, and * denote the 1%, 5%, and 10% significance levels, respectively.

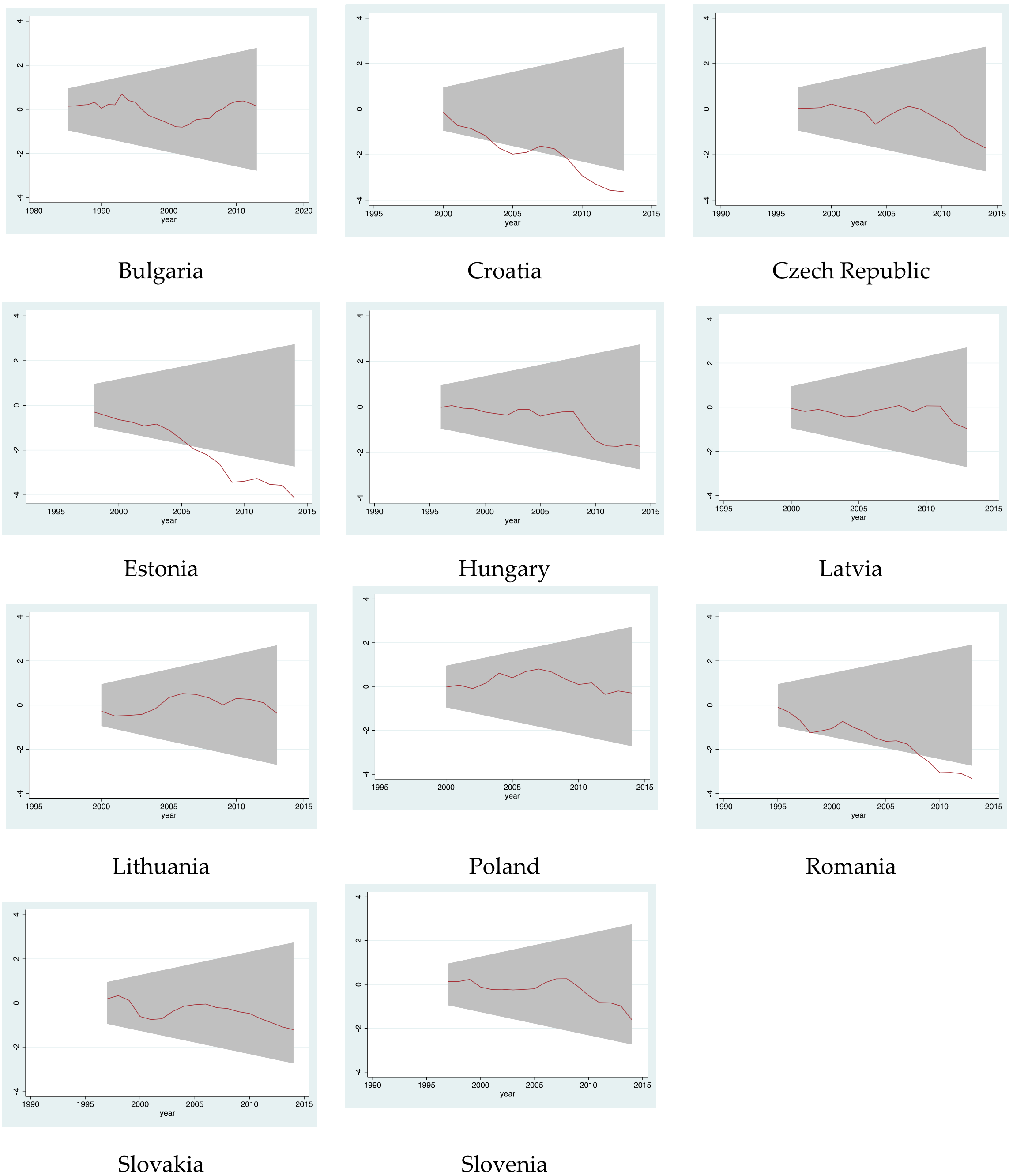

Figure A1. The cumulative sum test (CUSUM) Note: Recursive CUSUM plot of lnC with 95% confidence bands around the null.

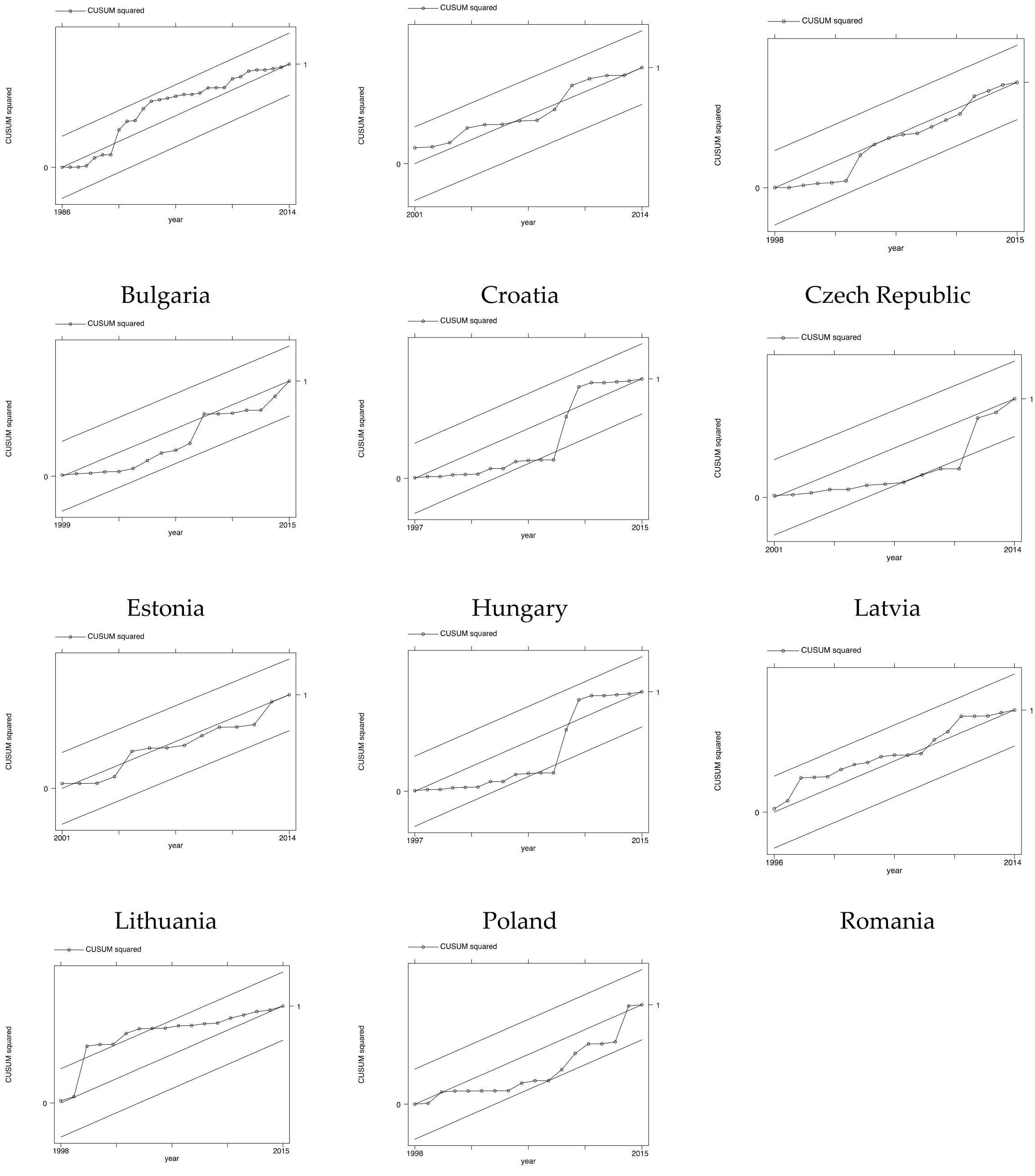

Figure A2. The cumulative sum of squares test (CUSUMSQ) Note: The straight lines represent critical bounds at the 5% significance level.

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