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Pollution and Economic Growth: Evidence from Central and Eastern European Countries

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Abstract: We investigate the relationships between pollution and growth in eleven Central and Eastern European (CEE) countries. Aggregate results, robust to different estimators and control variables, reveal an increasing nonlinear link between GDP and CO₂ for the group of CEE countries. However, at a disaggregated, country-level, the relationship between GDP and CO₂ is characterized by much diversity among CEE countries, namely: *N*-shaped, inverted-*N*, U-shaped, inverted-U, monotonic, or no statistical link. Thus, despite an aggregated upward trend, some CEE countries managed to secure both higher GDP and lower CO₂ emissions. From a policy perspective, EU policymakers could pay more attention to these countries, and amend the current unique environmental policy to account for country-heterogeneities in order to support economic growth without damaging the environment.

Keywords: CO₂ emissions; economic growth; Central and Eastern European countries; environmental Kuznets curve.

JEL Codes: Q32, Q56, O13, P28

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I. Introduction

During the last decades, international environmental organizations increased their efforts towards finding a scenario that would ensure economic growth and minimize its negative consequences on the environment (i.e. sustainable development). At the global level, in response to the threats of climate change, the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Kyoto Protocol (1997) and the Paris Agreement (2015). While the former was focused on developed countries, the latter put more emphasis on the role of developing countries in the context of climate change.

Such global agreements are supported by more regional measures. In particular, the European Union (EU) objectives on sustainable development are part of the Europe 2020 and 2030 strategy for smart and sustainable growth. Implemented and monitored at the EU level, these climate actions aim to reduce the greenhouse gas emissions by 20% and 40%, by the end of 2020 and 2030 respectively. Furthermore, these goals are also in line with the EU 2050 low-carbon economy strategy, stressing that all sectors of the economy should contribute to the reduction of greenhouse gas emissions in order to achieve the goal of 80% reduction compared with the 1990 levels.

However, the extent to which these goals could be attained is subject to debate. For example, regarding CO₂ (which represents by far the largest share in greenhouse gas emission, namely around 75% in 2017 in EU, see Olivier et al., 2017), it is encouraging to observe that emissions in the EU decreased in 2015 with respect to 1996 by 18% in levels (by 22% per capita). Nevertheless, these numbers cover important disparities across EU, as they are driven by the strong contraction of CO₂ emissions per capita in large EU countries, such as UK (-38%), France (-24%), Italy (-20%) or Germany (-18%), while in Central and Eastern European (CEE) countries the situation is less favorable. Indeed, out of the eleven CEE countries, only six experienced negative growth rates of their CO₂ emissions per capita during 1996-2015, and in some of them this negative trend reversed in the recent period (for example in Poland in 2015 compared with 2014, see Janssens-Maenhout et al., 2017).

Motivated by the presence of such heterogeneities, the goal of this paper is to analyze the behavior of CO₂ emissions in CEE countries. Since we aim at providing insights from the perspective of fighting climate change, we link CO₂ with economic development measured by GDP (per capita). This relationship, commonly known as the Environmental Kuznets Curve (EKC) (Grossman & Krueger, 1991; Panayotou, 1993), has received a large and increasing attention in the literature. With respect to the existing studies, our analysis differs on several grounds.

First, while many contributions focus on developed countries, our analysis complements studies that look at developing or emerging countries. By focusing exclusively on CEE countries, we specifically refrain from mixing them with other EU countries (see e.g. Ozokcu & Ozdemir, 2017; Pablo-Romero & Sanchez-Braza, 2017), or other developing or emerging countries (see e.g. Atici, 2009; Iwata et al., 2011; Zaman et al., 2016), since CEE countries present particular features, as emphasized in the following.

Second, with respect to Kasman & Duman (2015) who consider new EU members and candidate countries over 1992-2010, we focus on CEE countries' particularities. Indeed, given that CEE countries experienced major imbalances at the beginning of the 1990s, we mitigate them by restricting our sample to start only in 1996. By so doing, our sample covering the 1996-2015 period is also well balanced around the mid-period of the two dates of EU enlargement with CEE countries (2004 and 2007, with Croatia joining EU in 2013). In addition, to account for the major footprint of the communist period experienced by these countries, we estimate the relationship between CO₂ and GDP conditional to a benchmark vector of two important control variable, namely energy consumption, and economic freedom. By capturing crucial features in CEE countries' dynamics during the studied period (e.g. the transition from centrally-planned to market economies), these variables may tackle an important omitted-variables bias in the identification of the CO₂-GDP link.

Third, we allow for an extended specification of the EKC, by augmenting the traditional second-order polynomial-shape between CO₂ and GDP (see e.g. Kasman & Duman, 2015) with the cube of GDP, in order to account for a potential technological effect. Combined with the use of modern estimators that, in addition to performing fairly well in small sample macroeconomic panels, appropriately account for CEE countries' heterogeneity (arising from factors influencing both CO₂ and GDP dynamics) by allowing for slope-heterogeneity (namely: the Mean Group Fully Modified Least Squared (MG-FMOLS), the Mean Group (MG), and the Augmented Mean Group (AMG) estimators), this specification allows providing new evidence on the relationship between CO₂ and GDP in CEE countries.

Finally, the related literature drawing upon panel data focuses on an aggregated link between CO₂ and GDP. However, such a relationship may ignore country-differences that seem to be at work in CEE countries, as previously emphasized. Consequently, our analysis equally provides results for the relationship between CO₂ and GDP for each of the CEE country in our sample.

Our findings are as follows. On the one hand, from an aggregated perspective, there exists an increasing nonlinear link between GDP and CO₂ for the group of CEE countries.

Specifically, the increase in CO₂ following an increase in GDP is relatively mild around a GDP level estimated at roughly 19,900 USD, but the magnitude of this effect increases as we move away from this value towards low and high GDP values. Robust across different estimators, in the presence of additional control variables, and for other measures of environmental quality, this finding suggests that much attention should be given to CEE countries from an environmental perspective, since their ongoing economic development seems to be associated with a reinforcement of CO₂ emissions on average.

On the other hand, from a disaggregated perspective, the link between GDP and CO₂ is characterized by much diversity among CEE countries. First, in Croatia, Estonia, Poland, and Slovakia the relationship is strongly nonlinear, with the existence of two GDP thresholds defining either an *N*-shaped relationship (in the former two countries) or an inverted-*N* pattern (in the latter two countries). Second, an inverted-U (U) link is found in Czech Republic, and Hungary (Bulgaria, and Latvia), associated with the existence of a maximum (minimum) level of CO₂ emissions in these countries. Third, in some countries the relationship is monotonous (increasing in Lithuania), while in Romania and Slovenia the link between GDP and CO₂ was not found to be statistically significant. From a policy perspective, these important heterogeneities (spanning from the absence of a statistical link, to the presence of multiple thresholds) should be accounted for when defining and implementing environmental policies in the CEE countries, all the more in the context of current environmental EU goals that hardly seem to incorporate country-specificities. Simple correlations—that must be taken with much caution—may suggest that the presence of a relatively important clean industry sector, along with large labor productivity and complex techniques, may support CO₂ reductions in the context of increasing GDP in our sample of CEE countries.

The paper is organized as follows. Section 2 draws upon theory to define our model, and discusses some literature. Section 3 presents the data, and the methodology. Section 4 reports the aggregate results, and explores their robustness. Section 5 provides country-level results. Finally, Section 6 discusses the policy implications of our findings, and suggests some topics for future research.

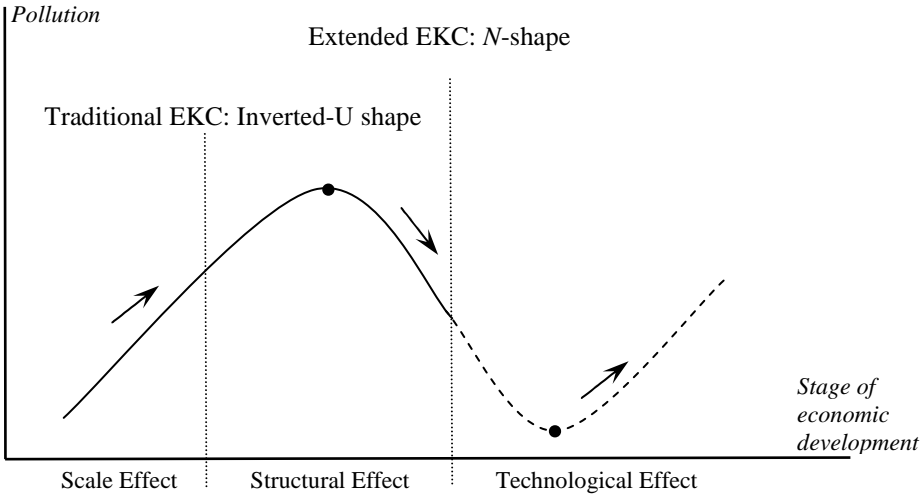
II. Theory, the model, and some related literature

2.1. Theory

The Environmental Kuznets Curve (EKC), coined by Grossman and Krueger (1991) and Panayotou (1993), assumes an inverted-U (or bell-shaped) relationship between pollution and economic development. For low economic development, the intensity of environmental

degradation is minimal. However, as the economic activity intensifies (for example, due to the industrialization process), the degree of pollution gradually increases until it reaches a maximum value. Finally, above this level of economic development, the level of pollution decreases. Grossman & Krueger (1991) explain the effect of changes in trade policy and foreign investment on pollution through three effects, namely a scale effect, a structural effect, and a technological effect, which are mostly at work at different stages of economic development.

Figure 1. Traditional EKC (Inverted-U shape) and Extended EKC (N-shape)



Subsequently, several studies, including e.g. Milimet et al. (2003), Yang et al. (2015), or Dogan & Seker (2016), explored extensions of the traditional inverted-U EKC. Specifically, it has been stressed that the relationship between pollution and economic development might be more complex, as the pattern may actually be *N*-shaped (or even inverted-*N*-shaped). In particular, the *N*-shape assumes that, as the level of economic development continues to increase, the trend in pollution may reverse and increase again. This may be because at some point economic activity is so intense that its negative impact on the environment cannot be compensated through the structural or the technological effect. Figure 1 illustrates both the traditional EKC (the continuous curve), and the extended EKC (composed of the continuous and the dotted curve).

2.2. The model

Starting from theory, we can specify the following panel model to estimate the EKC

$$CO2_{it} = \alpha_i + \beta_1 GDP_{it} + \beta_2 GDP_{it}^2 + \beta_3 GDP_{it}^3 + \phi X_{it} + \varepsilon_{it}, \tag{1}$$

which assumes a third-order polynomial in the shape of the relationship between GDP and CO_2 , with X the vector of control variables (to be discussed below), and α and ε country-fixed effects and the error term, respectively. This specification has the merit of covering a large class of EKC, beyond the inverted-U (traditional) or N -shaped (extended) EKC usually suggested by theory. Assuming such a general specification is motivated by the lack of consensus in the literature regarding the precise shape of the EKC (see the discussion in e.g. Yang et al., 2015).

2.2. Some related literature

The literature devoted to testing the empirical validity of the EKC is so large and expanding that it regularly makes the object of surveys (see e.g. Lieb, 2003; Dinda, 2004; Aslanidis, 2009; Hervieux & Mahieu, 2014). Many analyses are performed on OECD and developed countries (recent contributions include e.g. Dogan & Seker, 2016; Ben Jebli et al., 2016; Shahbaz et al., 2017; Awaworyi Churchill et al., 2018), or on samples that mix countries with different levels of economic development (see e.g. Iwata et al., 2011; Luo, 2016; Zaman et al., 2016).¹ Since we are interested in CEE countries, we review here some of the recent studies that focus on developing and/or emerging countries.

The literature devoted to these countries seems to have unveiled several types of patterns for the relationship between pollution and economic development (see Yang et al., 2015, for a very valuable state of the art of the findings of many country-, and panel- or cross-section-studies). First, using a strategy that consists of comparing long- and short-run coefficients, Narayan & Narayan (2010) conclude that in about one-third of the 43 developing countries in their sample, CO_2 emissions decreased as their income increased. Second, focusing on new EU members and candidate countries, Kasman & Duman (2015) find support for a traditional (inverted-U) EKC, a result equally emphasized in Central America by Apergis & Payne (2009), in Middle East and North African (MENA) countries by Farhani et al. (2014), in Latin America & Caribbean countries by Al-Mulali et al. (2015), in Asian countries by Apergis & Ozturk (2015), and in a larger sample of 86 developing countries by Hanifa & Gago-de-Santos (2017). Third, Ozokcu & Ozdemir (2017) highlighted an extended EKC (N -shaped) relationship between CO_2 and GDP in 52 emerging countries. Finally, in a comparison of several models in a symbolic regression framework, Yang et al. (2015) reveal

¹ Alternatively, some studies are conducted at a sub-national level; for example, Hamit-Hagggar (2012) looks at Canadian industrial sectors, Apergis et al. (2017) consider the US states, and Wang et al. (2017) focus on the Chinese provinces.

that the shape of the relationship between CO₂ and GDP may be monotonically increasing, inverted-U, or inverted-N in their sample of 38 developing countries. This lack of consensus in the relationship between CO₂ and GDP in developing countries calls for a careful analysis of the specificities of CEE countries.

III. Data, modeling considerations, and methodology

3.1. Data

We perform our analysis on eleven CEE countries that joined the EU from 2004 onwards, namely Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia. To abstract from the important imbalances experienced by these countries following the end of the Cold War, we restrict our data to the period 1996-2015. Since there are no missing data, our yearly panel is balanced and contains a total of 220 observations.

Our main variables are *CO₂*, defined as the log of CO₂ emissions per capita from fossil fuel use and industrial processes, and *GDP*, defined as the log of GDP per capita based on purchasing power parity in constant 2011 prices. In addition, as previously emphasized, when estimating the relationship between GDP and CO₂ in CEE countries, we must account for the major footprint of the communist period experienced by these countries. To do so, we include in the vector *X* of control variables (see equation (1) above) two variables that may appropriately capture for the large economic and institutional changes that took place in these countries during the period we analyze, namely: *ENG*, defined as the log of gross inland energy consumption per capita, and *ECFR*, defined as the log of the index of economic freedom of Heritage Foundation. Tables A1-2 in the Supplementary Material present the variables, and descriptive statistics.

Descriptive statistics reveal that CO₂ emissions per capita present a downward trend in six out of the eleven countries in our sample. Bearing in mind the communist past of these countries, firms in the industrial sector (one of the most important pillars of the economy) were large state-owned companies operating in heavy-polluting industries. After the collapse of the communist regime, many of these companies have been dissolved or privatized over the years, contributing to the decline in energy CO₂ emissions.

Regarding GDP per capita, all countries display an upward trend, with a particularly large increase in the Baltic countries. Their accelerated economic growth was driven by the development of their financial system, large commercial flows, and fiscal systems attracting foreign direct investments (IMF, 2014). From a broader perspective, all countries benefited

from a convergence period characterized by high and sustained economic growth rates, particularly in the early 2000s (see e.g. IMF, 2016).

3.2. Modeling considerations

When estimating the relationship between GDP and CO₂, we have to keep in mind the different dynamics experienced by the CEE countries of our sample, particularly regarding CO₂. Consequently, we further investigate several properties of the data used in our analysis.

3.2.1. Cross-section dependence, and heterogeneity

The cross-section dependence in our sample is related to the fact that CO₂ emissions in one country could depend on CO₂ emissions in other countries, and also with potential common dynamics of GDP, given that these countries were a part of a common (closed) system until 1990. To test for cross-sectional dependence we use four tests, namely: Baltagi et al. (2012) Bias-Corrected (BC) scaled LM, Pesaran (2004) CD, Pesaran (2004) scaled LM, and Breusch-Pagan (1980) LM. The statistics of these tests are provided in Table 1, and show that the null hypothesis of cross-sectional independence is strongly rejected in all cases in favor of the presence of cross-sectional dependence.

Table 1. Cross-sectional dependence analysis

| Test/Variable | CO ₂ | GDP | ENG | ECFR |
|-------------------|---------------------|----------------------|---------------------|---------------------|
| BC scaled LM | 24.01*** (0.00) | 91.91*** (0.00) | 20.05*** (0.00) | 37.39*** (0.00) |
| Pesaran CD | 6.30*** (0.00) | 31.95*** (0.00) | 12.28*** (0.00) | 20.00*** (0.00) |
| Pesaran scaled LM | 24.30*** (0.00) | 92.20*** (0.00) | 20.34*** (0.00) | 37.68*** (0.00) |
| Breusch-Pagan LM | 309.90*** (0.00) | 1022.02*** (0.00) | 268.40*** (0.00) | 450.25*** (0.00) |

Notes: H₀ is "cross-sectional independence". p-values in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Turning now to heterogeneity, although the CEE countries in our sample are part of the EU, they differ across several dimensions. First, the Baltic countries (Estonia, Latvia, and Lithuania) were effectively members of the Soviet Bloc compared to the others that were only part of the Communist Bloc; as such, their economic system might have borrowed much more of the specificities of the former Soviet Union. Second, despite being part of the EU, differences in the geographical location of the countries (e.g. the relief, the maritime connections with the rest of the world, the neighboring countries) may have affected the degree of environmental pollution, as well as their economic development path. Third, given their national autonomy, environmental regulations and economic growth-designed

macroeconomic policies may equally differ across countries. Finally, although fairly close, the year of ascension to the EU was different for Bulgaria and Romania (Croatia joined EU only in 2013), and these countries display average national income levels, compared with large national income levels in the other CEE countries in our sample, in 2016 World Bank's classification. Taken together, these features suggest the existence of a certain degree of heterogeneity among CEE countries, consistent with the differences in CO2 dynamics previously emphasized.

3.2.2. Stationarity, and cointegration

We now look at the time-series properties of our data, i.e. their stationarity. Given the presence of cross-sectional dependence in our data, we apply several panel tests that are robust to cross-sectional dependence (i.e. the so-called "second-generation" stationarity tests), namely the popular Pesaran (2003) and Breitung & Das (2005) tests.² Table 2 displays the results of the tests without lags and with one lag (we include a constant and a trend for the level specification, and a constant for the difference specification). Overall, the tests reveal that the variables are I(1), i.e. integrated of order one.

Table 2. Stationarity analysis

| Test/ Variable | Pesaran (no lags) | | | | Breitung & Das (no lags) | | | |
|-------------------|-----------------------|---------|--------------------|---------|--------------------------|---------|--------------------|---------|
| | Level (const & trend) | | Difference (const) | | Level (const & trend) | | Difference (const) | |
| | t-bar | p-value | t-bar | p-value | lambda | p-value | lambda | p-value |
| CO2 | -2.671* | (0.097) | -4.432*** | (0.000) | -0.786 | (0.215) | -5.300*** | (0.000) |
| GDP | -2.524 | (0.209) | -2.925*** | (0.000) | 0.424 | (0.664) | -2.490*** | (0.006) |
| ENG | -2.904** | (0.019) | -4.865*** | (0.000) | -0.960 | (0.168) | -4.919*** | (0.000) |
| ECFR | -2.166 | (0.647) | -4.088*** | (0.000) | -0.322 | (0.373) | -2.265** | (0.011) |
| | Pesaran (one lag) | | | | Breitung & Das (one lag) | | | |
| | Level (const & trend) | | Difference (const) | | Level (const & trend) | | Difference (const) | |
| | t-bar | p-value | t-bar | p-value | lambda | p-value | lambda | p-value |
| CO2 | -2.248 | (0.542) | -3.242*** | (0.000) | -1.109 | (0.133) | -3.158*** | (0.000) |
| GDP | -2.562 | (0.175) | -2.306** | (0.035) | -0.652 | (0.257) | -3.294*** | (0.000) |
| ENG | -2.606 | (0.140) | -3.261*** | (0.000) | -1.004 | (0.157) | -2.587*** | (0.004) |
| ECFR | -2.106 | (0.718) | -2.644*** | (0.002) | -0.869 | (0.192) | -1.767** | (0.038) |

Notes: Pesaran (2003) H0 is "all series are non-stationary", and Breitung & Das (2005) H0 is "all panels contain a unit root". p-values in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Given that our series are non-stationary, we examine the potential existence of a cointegration relationship between variables using Pedroni's (1999, 2004) panel cointegration test. This test allows slope coefficients to vary across individuals. The null hypothesis of no cointegration between variables is examined using several statistics, that deal with the within dimension

² In the Pesaran (2003) test, the null hypothesis is that all series are non-stationary, while in the Breitung & Das (2005) test the null hypothesis assumes that all panels contain a unit root.

(Panel PP-statistic, and Panel ADF-statistic) and the between dimension (Group PP-statistic, and Group ADF-statistic). According to Pedroni (1999, 2004), the statistics in the first group restrict the autoregressive parameter to be identical for all individuals, in contrast to the second group statistics that allow the autoregressive parameter to vary across individuals.

Table 3. Cointegration analysis

| Pedroni Test | Individual Intercept | | Individual Intercept & Trend | |
|--------------------------------|-----------------------------|----------------|---|----------------|
| | statistic | p-value | statistic | p-value |
| <i>Within dimension</i> | | | | |
| Panel PP-Statistic | -1.881** | (0.029) | -2.373*** | (0.008) |
| Panel ADF-Statistic | -2.887*** | (0.001) | -2.742*** | (0.003) |
| Panel PP-Statistic (Weighted) | -2.635*** | (0.004) | -7.232*** | (0.000) |
| Panel ADF-Statistic (Weighted) | -3.911*** | (0.000) | -4.594*** | (0.000) |
| <i>Between dimension</i> | | | | |
| Group PP-Statistic | -1.605* | (0.054) | -10.297*** | (0.000) |
| Group ADF-Statistic | -3.671*** | (0.000) | -5.285*** | (0.000) |

Notes: Automatic lag length selection based on SIC with a maximum lag of 3. Newey-West automatic bandwidth selection and Bartlett kernel. The statistics' significance was determined by comparing calculated and tabulated values provided by Pedroni (1999). H0 is "no cointegration".***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table 3 depicts the results of the cointegration tests. All tests were conducted with individual intercept (first column), and individual intercept and trend (second column), while for the within dimension both unweighted and weighted tests were considered. Irrespective of the specification (with or without trend), the tests reject the null hypothesis of no cointegration.³

3.3. Methodology

Our previous analysis revealed the presence of cross-sectional dependence, heterogeneity, and cointegration. To account for these features, we draw upon the Mean Group (MG) estimator coined by Pesaran & Smith (1995), the Mean Group Fully Modified Least Squared (MG-FMOLS) estimator proposed by Pedroni (2000, 2001), and the Augmented Mean Group (AMG) estimator developed by Eberhardt & Teal (2008, 2010) and Eberhardt & Bond (2009). These estimators, in addition to performing fairly well in small sample macro panels, are particularly appropriate for macro panels with slope heterogeneity (Eberhardt, 2012).⁴ Besides, our results for CEE countries may be compared with those of recent contributions that used these estimators to examine the EKC (see e.g. Apergis, 2016).

³ Given the large number of variables in the cointegration vector, there are not enough data to perform the Westerlund (2007) test. However, we report that when we restrict the cointegration vector to the most important variables, namely, CO2, GDP, GDP2, GDP3, and ENG, three of the four Westerlund tests reject the null hypothesis of no cointegration (results are available upon request), confirming the conclusions of the Pedroni (1999, 2004) panel cointegration test.

⁴ In particular, the AMG estimator accounts for cross-sectional dependence through adding a "common dynamic effect", while the (A)MG estimators produce unbiased results even if not all variables are nonstationary.

Starting from a simple fixed-effects slope-heterogeneity panel regression $y_{it} = \alpha_i + \beta_i x_{it} + u_{it}$, Pesaran & Smith (1995) coined the MG estimator that deals with parameters' heterogeneity by averaging the individual slopes obtained from individual OLS regressions for each member of the panel. Formally, the MG estimator can be written (see Hsiao & Pesaran, 2004)

$$\beta_{MG} = \frac{1}{N} \sum_{i=1}^N \beta_i. \quad (2a)$$

Moreover, we draw upon Pedroni (2000, 2001), to write the MG-FMOLS estimator as

$$\beta_{MG-FMOLS} = \frac{1}{N} \sum_{i=1}^N \left[\left(\sum_{t=1}^T (x_{it} - \bar{x}_i)^2 \right)^{-1} \left(\sum_{t=1}^T (x_{it} - \bar{x}_i) y_{it}^* - T \gamma_i \right) \right], \quad (2b)$$

with $y_{it}^* = (y_{it} - \bar{y}_i) - (\Omega_{21,i} / \Omega_{22,i}) \Delta x_{it}$ and $\gamma_i = \Gamma_{21,i} + \Omega_{21,i}^0 + (\Omega_{21,i} / \Omega_{22,i}) (\Gamma_{21,i} + \Omega_{22,i})$, with

$\Omega_i = \lim_{T \rightarrow \infty} E \left[\left(T^{-1} \sum_{t=1}^T z_{it} \right) \left(T^{-1} \sum_{t=1}^T z'_{it} \right)' \right]$ the long-run covariance of the stationary vector

$z_{it} = (u_{it}, \Delta x_{it})'$, which can be written as the sum between the contemporaneous covariance Ω_i^0 and the weighted sum of autocovariances, namely: $\Omega_i = \Omega_i^0 + \Gamma_i + \Gamma_i'$.

Finally, more recently, Eberhardt & Teal (2008, 2010), Eberhardt & Bond (2009), and Eberhardt (2012) developed the AMG estimator that accounts for both parameters heterogeneity and cross-sectional dependence. Having in mind the traditional panel model, the potential presence of cross-sectional dependence is captured by the structure of both unobservables and observables, namely $u_{it} = \phi_i + \lambda_i f_t + \varepsilon_{it}$ and $x_{it} = \xi_i + \lambda_i f_t + \gamma_i g_t + v_{it}$, with ϕ_i and ξ_i group fixed effects, f_t and g_t common factors with heterogeneous factor loadings λ_i , and ε_{it} and v_{it} white noises. The merit of this method is to move away from other estimation techniques for heterogeneous panels (e.g. Common Correlated Effects Mean Group estimator–CCEMG; Pesaran, 2006) that consider the unobservable common factors as a nuisance, by modeling them as a common dynamic process, namely $y_{it} = \alpha_i + \beta_i x_{it} + \eta_i t + d_i \varphi_t + e_{it}$, with φ_t the dynamic process variable constructed from a regression in first differences $\Delta y_{it} = \beta \Delta x_{it} + \sum_{t=2}^T \varphi_t \Delta D_t + e_{it}$, and $\eta_i t$ a linear trend. As a result,

the AMG estimator is

$$\beta_{AMG} = \frac{1}{N} \sum_i \beta_i. \quad (2c)$$

In the following, we will draw upon these estimators to analyze the relationship between GDP and CO2 in our panel of CEE countries.

IV. Results: aggregated analysis

4.1. Results

The estimation of the model (1) using the MG estimator is reported in column (1) of Table 4. Prior to discussing the main results, two remarks are worthwhile. First, we need to validate the long-run cointegration vector that was used to estimate the elasticities in Table 4. To this end, we retrieve the estimated residuals from the model (1), namely ECT , and add them in the following model $\Delta CO2_{it} = \delta_i + \theta ECT_{it-1} + \gamma_1 \Delta GDP_{it} + \gamma_2 \Delta GDP_{it}^2 + \gamma_3 \Delta GDP_{it}^3 + \phi \Delta X_{it} + \varepsilon_{it}$, with Δ the difference operator. Estimations of this model reported in Table A3 in the Supplementary Material show that the coefficient of the error correction term (ECT) is negative and significant, supporting the existence of a long-run relationship between GDP and CO2.

Table 4. Aggregated estimates

| Dependent variable: CO2 | | | |
|--------------------------------|------------------------|------------------------|-----------------------|
| | MG | MG-FMOLS | AMG |
| | (1) | (2) | (3) |
| GDP | 760.968** (356.031) | 457.226*** (75.771) | 525.619* (289.662) |
| GDP ² | -76.852** (35.910) | -46.567*** (7.713) | -53.153* (29.465) |
| GDP ³ | 2.587** (1.207) | 1.580*** (0.261) | 1.793* (0.999) |
| ENG | 1.136*** (0.107) | 1.147*** (0.042) | 0.902*** (0.128) |
| ECFR | -0.183*** (0.061) | -0.180** (0.087) | -0.146* (0.086) |
| CDP | | | 0.907*** (0.219) |
| Observations | 220 | 209 | 220 |
| Pattern | increasing | increasing | increasing |
| GDP for concavity change | 9.9004 (\$19,938) | 9.8182 (\$18,365) | 9.8812 (\$19,559) |

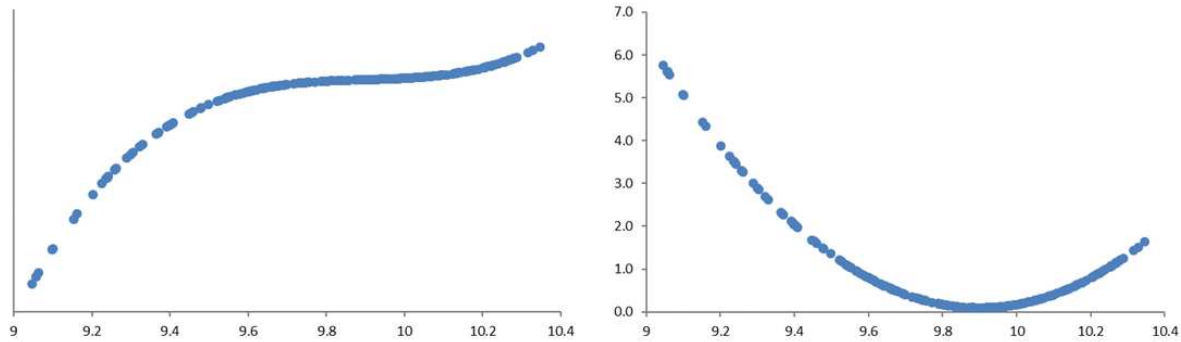
Notes: Reported MG coefficients are unweighted averages across countries. Long-run covariances in MG-FMOLS are estimated using Bartlett kernel with Newey-West fixed bandwidth. Common Dynamic Process (CDP) included as an additional regressor in AMG, and reported coefficients are unweighted averages across countries. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Second, regarding control variables, as expected there is a significant and positive link between energy consumption and CO2 emissions for the CEE countries. In addition, higher economic freedom is related to a decrease in CO2 emissions, suggesting that the process of economic liberalization contributed to the reduction of pollution in CEE countries in the long-

run. In line with our expectations, this finding may capture the transition from a planned to a market economy, during which heavy industries were replaced by more environmental-friendly ones.

Let us now discuss the main results. As shown by column (1) in Table 4, all GDP terms in our third-order polynomial specification significantly affect CO2 in our panel of CEE countries.⁵ Furthermore, the positive (negative) sign for the cubic and linear (squared) term suggest that the relationship between GDP and CO2 is *N*-shaped. However, the two estimated GDP values that cancel the first derivative are not local extrema, making the estimated relationship between GDP and CO2 to be increasing (see Figure 2a). Nevertheless, our analysis reveals magnitude nonlinearities: around the GDP level associated to the change in concavity (estimated at around 9.90, namely around 19,900 USD), the increase in CO2 following an increase in GDP is fairly mild, while this increase is stronger as we move away from this value towards low and high GDP values, as illustrated by Figure 2b.

Figure 2. The estimated relationship between GDP and CO2 (aggregated analysis)
 (2a) the estimated relationship CO2/GDP (2b) the derivative $dCO2/dGDP$



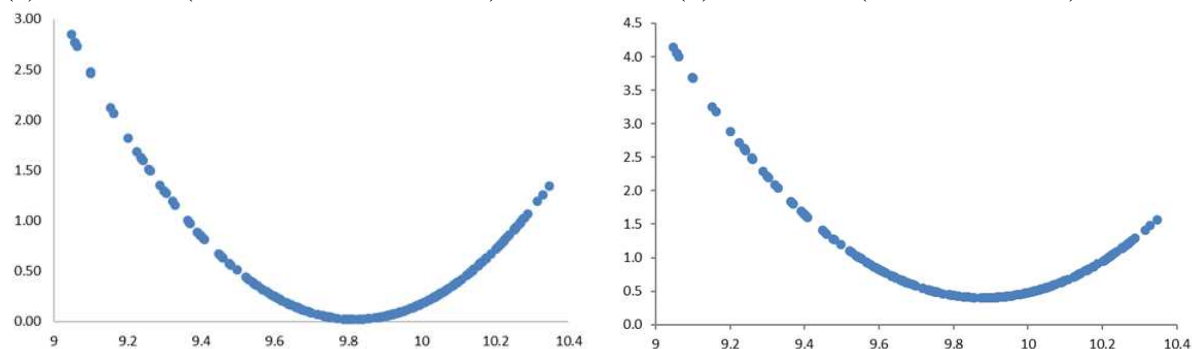
4.2. Robustness: alternative methods

So far, our findings were based on the MG estimator. In the following, we explore the robustness of our results to the use of two alternative estimators, namely MG-FMOLS and AMG. Estimations reported in columns (2) and (3) of Table 4 show the following. First, all variables exert a significant effect on CO2, and their sign is consistent with what was previously found using the MG estimator. In particular, the coefficient of the CDP term is significant in the AMG estimation, suggesting the presence of some common CO2 dynamics that may be related, among others, to some footprints associated with the past communist regime. Second, estimations in the corresponding columns of Table A3 in the Supplementary Material reveal a negative and significant coefficient of the error correction term (*ECT*),

⁵ As a counterfactual, GDP terms are not statistically significant in the quadratic model (results are available upon request).

supporting the long-run relationship between GDP and CO2 arising from the MG-FMOLS and AMG estimators. Third, this relationship is increasing, and the GDP level associated to a change in its concavity is comparable to our previous estimations based on MG, namely around 9.82 (18,400 USD) and 9.88 (19,600 USD) respectively. Finally, as shown by Figures 3a-b, the change in CO2 following a change in GDP follows the same U-shape as for the MG estimator, and still displays important differences in magnitude for low and high GDP values.

Figure 3. The estimated relationship between GDP and CO2 (aggregated analysis)
 (a) derivative (MG-FMOLS estimator) (b) derivative (AMG estimator)



4.3. Robustness: additional controls

First, previous evidence suggests the presence of a unit root in our series. In order to see if our results are polluted by the presence of persistence, we include lagged main variables in the main regressions.⁶ As illustrated by columns (1a)-(1b)-(1c) in Table 5, accounting for these variables leaves qualitatively unchanged the relationship between CO2 and GDP, which still displays the monotonically-increasing shape already emphasized.

Second, we extended the cointegration vector to account for several additional variables. In column (4) of Table 5 we consider the effect of globalization (*GLOB*), measured by the log of the globalization index of the KOF Swiss Economic Institute (see Dreher, 2006, and Gygli et al., 2019), to capture the important structural transformations of CEE countries starting the 1990s. Although globalization is not found to significantly affect CO2 (see column (4)), the significance and shape of the effect of GDP on CO2 are consistent with the main estimations.⁷

Third, we account for a large number of additional control variables that may seize different countries' structural characteristics (see Table A1 in the Supplementary Material for definitions of these variables). In column (3) of Table 5 we account for the sectoral structure

⁶ We thank an anonymous Referee for suggesting this robustness test.

⁷ Additional estimations based on a wide number of alternative measures of globalization confirmed the lack of a significant effect on CO2, and the robustness of the GDP-CO2 relationship in the largest majority of cases (results are available upon request).

of the economies between agriculture (*AGR*), industry (*IND*), and services (*SERV*), all expressed in percentage of GDP. Next, given the extent of privatizations in these countries, column (4) adds the influence of foreign direct investment (*FDI*). Moreover, to seize changes on the labor market, column (5) includes labor productivity (*LABORPROD*). In addition, column (6) includes the economic complexity index (*ECI*) that may capture overall changes in productive capacities. Finally, the human development index (*HDI*) introduced in column (7) is intended to control for a wider perspective of economic development. Results in columns (3)-(7) show that the impact of these variables on CO₂ is mostly not significant, confirming the robustness of our main specification. More importantly, accounting for them leaves qualitatively unaffected the impact of GDP on CO₂, which describes a monotonically-increasing shape consistent with our benchmark estimations.

Table 5. Robustness: additional variables

| Dependent variable: CO2 | (1a) | (1b) | (1c) | (2) | (3) | (4) | (5) | (6) | (7) |
|--------------------------|------------------------|------------------------|------------------------|------------------------|-----------------------|------------------------|------------------------|-------------------------|------------------------|
| GDP | 880.963** (429.583) | 842.512** (424.400) | 678.545** (334.629) | 764.535** (329.586) | 803.014* (464.291) | 794.784** (389.377) | 682.815** (272.722) | 687.529*** (228.463) | 808.657** (350.066) |
| GDP ² | -88.756** (43.157) | -84.923** (42.707) | -68.401** (33.573) | -77.127** (33.285) | -81.099* (46.811) | -80.263** (39.244) | -68.713** (27.369) | -69.637*** (23.031) | -81.122** (35.242) |
| GDP ³ | 2.981** (1.445) | 2.854** (1.432) | 2.299** (1.122) | 2.594** (1.120) | 2.730* (1.573) | 2.702** (1.318) | 2.305** (0.915) | 2.351*** (0.773) | 2.712** (1.183) |
| ENG | 1.042*** (0.088) | 1.113*** (0.117) | 0.977*** (0.102) | 1.151*** (0.113) | 1.066*** (0.115) | 1.063*** (0.115) | 1.060*** (0.099) | 1.093*** (0.090) | 1.051*** (0.080) |
| ECFR | -0.244** (0.117) | -0.241** (0.116) | -0.154 (0.115) | -0.131* (0.074) | -0.233** (0.108) | -0.249** (0.102) | -0.234*** (0.078) | -0.246*** (0.060) | -0.145 (0.098) |
| CO2 _(t-1) | 0.097* (0.054) | 0.147*** (0.047) | 0.147*** (0.047) | | | | | | |
| GDP _(t-1) | -0.137* (0.075) | -0.213*** (0.072) | -0.213*** (0.072) | | | | | | |
| GLOB | | | | -0.300 (0.240) | | | | | |
| AGR | | | | | 0.050 (0.042) | 0.035 (0.038) | 0.016 (0.039) | 0.045 (0.042) | 0.047 (0.038) |
| IND | | | | | -0.047 (0.175) | -0.003 (0.182) | -0.040 (0.164) | 0.014 (0.162) | -0.097 (0.182) |
| SERV | | | | | 0.067 (0.448) | -0.015 (0.462) | -0.180 (0.476) | 0.012 (0.395) | -0.006 (0.361) |
| FDI | | | | | | 0.005 (0.014) | 0.006 (0.021) | 0.006 (0.023) | 0.027 (0.027) |
| LABORPROD | | | | | | | 0.011 (0.230) | 0.058 (0.203) | 0.007 (0.158) |
| ECI | | | | | | | | -0.032 (0.058) | -0.033 (0.053) |
| HDI | | | | | | | | | -0.887 (0.819) |
| Observations | 209 | 209 | 209 | 220 | 220 | 220 | 220 | 220 | 220 |
| Pattern | increasing | increasing | increasing | increasing | increasing | increasing | increasing | increasing | increasing |
| GDP for concavity change | 9.9239 | 9.9179 | 9.9148 | 9.9099 | 9.9000 | 9.9008 | 9.9361 | 9.8726 | 9.9672 |

Notes: Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

4.4. Alternative measures of environmental quality

Our analysis is conducted using CO₂ as a measure of environmental quality. Although this is the most popular measure in the literature, we draw upon existing studies that considered alternative measures of environmental quality. Using the main specification, Table 6 reports the estimated effect of GDP on the log of per capita biocapacity (*BIOCAP*) as a measure of the capacity of the biosphere to regenerate; the log of per capita ecological footprint (*ECOFT*) as a measure of natural resources required for humans' needs; and the log of per capita sulphur dioxide (*SO₂*). When considering the significance of the largest GDP polynomial across the three methods used (MG, MG-FMOLS, and AMG), results are consistent with our main findings. Indeed, except for the absence of a nonlinear effect on *ECOFT*,⁸ the influence of GDP on different measures of environmental quality displays the monotonically-increasing shape that we emphasized for CO₂. Consequently, our main results are confirmed when using several alternative measures of environmental quality.

Table 6. Aggregated estimates with alternative measures of environmental quality

| Dependent variable | BIOCAP | ECOFT | SO₂ |
|---------------------------|----------------------------|-------------------|----------------------------|
| | (1) | (2) | (3) |
| GDP | 886.597*** (234.709) | 0.204* (0.118) | 6420.179* (3914.598) |
| GDP ² | -90.669*** (23.692) | | -642.467* (393.764) |
| GDP ³ | 3.093*** (0.798) | | 21.413* (13.209) |
| Main specification | Yes | Yes | Yes |
| Estimator | All (MG reported) | All (MG reported) | MG |
| Type of relation | Similar to CO ₂ | Linear | Similar to CO ₂ |
| Observations | 209 | 209 | 207 |

Notes: Reported aggregate results with alternative measures of environmental quality (biocapacity, ecological footprint, and sulphur dioxide emissions), are selected based on the significance of the largest polynomial GDP variable with the three considered estimators MG, MG-FMOLS, AMG. The analyzed period is 1996-2014 for *BIOCAP* and *ECOFT* (the 1996 data for Bulgaria was extrapolated), and 1996-2015 for *SO₂* (due to some missing data, the panel is unbalanced). Long-run covariances in MG-FMOLS are estimated using Bartlett kernel with Newey-West fixed bandwidth. Common Dynamic Process (CDP) included as an additional regressor in AMG, and reported coefficients are unweighted averages across countries. Standard errors in round brackets, p-values in square brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

V. Results: country analysis

Estimations performed at the aggregated level reveal that the shape of the CO₂-GDP relationship is monotonically-increasing, and in particular there are no turning points despite the presence of nonlinear terms (GDP² and GDP³). The absence of turning points at the aggregated level may be due to, among others, either the lack of such turning points for the

⁸ Several existing studies fail to find nonlinearities between GDP and ecological footprint; see the excellent review of Destek et al. (2018). Besides, similar to Ulucak & Bilgili (2018), an inverted-U curve would emerge in our analysis if we take out energy consumption.

majority of countries in our sample, or to the presence of opposite dynamics at country-level that somehow compensate at the aggregated level. Therefore, adding to the previous section devoted to an aggregated analysis, we explore in this section potential country-specificities in the relationship between GDP and CO2, all the more that, as previously emphasized, the CEE countries in our sample are characterized by heterogeneity. To better focus on such heterogeneities, we draw upon the AMG estimator, which conveniently filters common dynamic effects.

5.1. Results

Estimations that assume a cubic relationship between GDP and CO2 are reported in Table 7a. Interestingly, only in four countries (Croatia, Estonia, Poland, and Slovakia), the effects of the three polynomial terms in GDP are statistically significant. Besides, while in Croatia and Estonia results seem to suggest the presence of an *N*-curve, in Poland and Slovakia the estimated link seems to follow an inverted-*N* pattern.

Table 7a. Country-specific estimates (cubic specification)

| | Bulgaria | Croatia | Czech R. | Estonia | Hungary | Latvia | Lithuania | Poland | Romania | Slovakia | Slovenia |
|------------------|-------------------|-----------------------|-------------------|---------------------|-------------------|------------------|-------------------|----------------------|-------------------|----------------------|--------------------|
| GDP | 298.0 (806.9) | 3102.4*** (256.5) | 953.8 (822.0) | 546.8** (227.8) | 520.6 (888.1) | 11.5 (170.8) | -160.0 (282.6) | -225.6*** (83.1) | 467.7 (453.3) | -476.7*** (180.3) | 743.4 (1151.6) |
| GDP ² | -32.27 (27.29) | -316.61*** (82.70) | -93.00 (81.53) | -55.73** (23.08) | -51.87 (89.77) | -1.48 (17.75) | 16.48 (28.71) | 23.11*** (8.51) | -48.43 (47.16) | 48.34*** (18.24) | -73.22 (114.02) |
| GDP ³ | 1.165 (0.968) | 10.769*** (2.824) | 3.022 (2.695) | 1.893** (0.779) | 1.723 (3.024) | 0.060 (0.614) | -0.563 (0.972) | -0.789*** (0.289) | 1.670 (1.634) | -1.633*** (0.614) | 2.403 (3.761) |
| Controls | | | | | | Yes | | | | | |
| CDP | | | | | | Yes | | | | | |

Note: Common Dynamic Process (CDP) included as an additional regressor. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table 7b. Country-specific estimates (quadratic specification)

| | Bulgaria | Czech R. | Hungary | Latvia | Lithuania | Romania | Slovenia |
|------------------|--------------------|----------------------|-----------------------|----------------------|-------------------|-------------------|--------------------|
| GDP | -8.914* (5.147) | 38.872** (19.724) | 33.573*** (10.720) | -5.184*** (1.693) | 1.534 (4.954) | 7.405 (6.677) | 15.291 (10.140) |
| GDP ² | 0.488* (0.269) | -1.920** (0.968) | -1.684*** (0.536) | 0.265*** (0.087) | -0.043 (0.249) | -0.378 (0.346) | -0.762 (0.495) |
| Controls | | | | Yes | | | |
| CDP | | | | Yes | | | |

Note: Common Dynamic Process (CDP) included as an additional regressor. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table 7c. Country-specific estimates (linear specification)

| | Lithuania | Romania | Slovenia |
|----------|---------------------|------------------|-------------------|
| GDP | 0.802*** (0.095) | 0.155 (0.211) | -0.055 (0.214) |
| Controls | Yes | | |
| CDP | Yes | | |

Note: Common Dynamic Process (CDP) included as an additional regressor. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

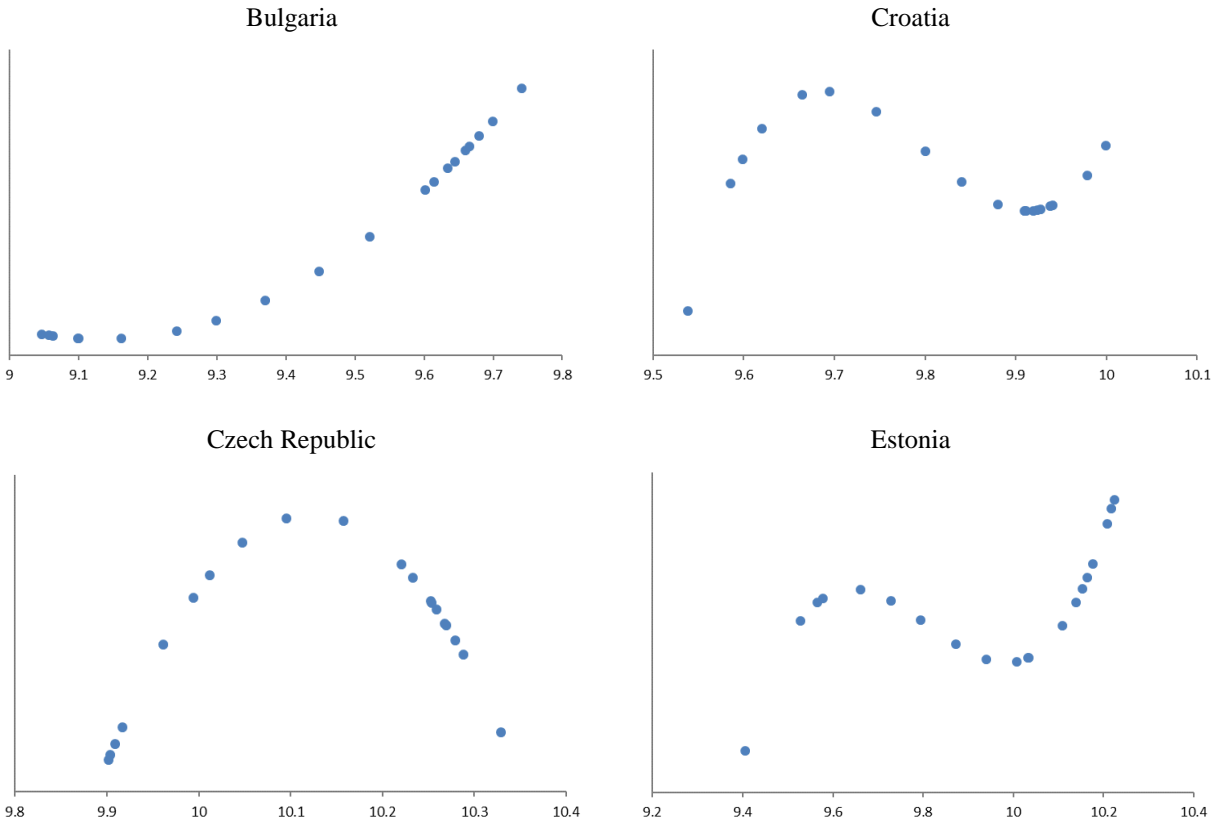
Keeping these results in mind, we assume next a quadratic function for the remaining CEE countries. Estimations presented in Table 7b show that the effect of the two GDP terms is statistically significant in Bulgaria, Czech Republic, Hungary, and Latvia, and only slightly not significant in Slovenia (the associated p-values equal 0.13 and 0.12). However, while in the Czech Republic and Hungary the relationship between GDP and CO2 seems to present an inverted-U shape, a U-shaped pattern seems to occur for Bulgaria and Latvia.

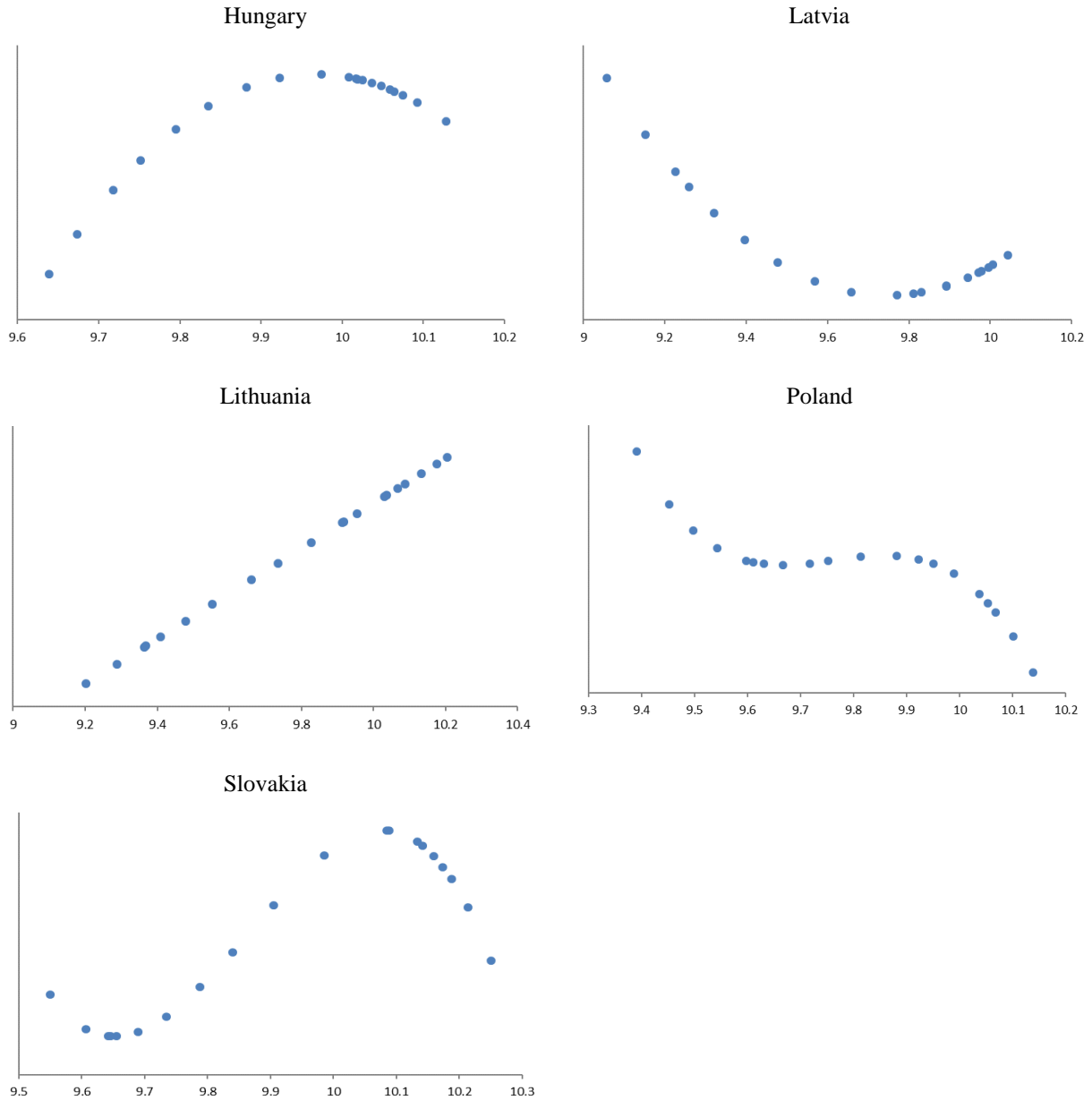
Finally, estimations in Table 7c, in which we assume a linear relationship for the remaining CEE countries, reveal a positive link in Lithuania, and the absence of a statistically-significant relationship between GDP and CO2 in Romania and Slovenia.

5.2. Patterns

Country-level results revealed differences among the eleven CEE countries in our panel. For a better view, Figure 4 depicts the relationship between GDP and CO2 for the nine CEE countries in which a statistically-significant link was found.

Figure 4. The estimated relationship between GDP and CO2 (country analysis)





From a general perspective, these charts reveal important heterogeneities in the relationship between GDP and CO₂ among the CEE countries in our panel, as several patterns emerge. First, Croatia and Estonia are characterized by an extended EKC *N*-shaped curve, suggesting that further economic development might be associated with an increase in CO₂ emissions. Second, such an extended EKC was equally found in Poland and Slovakia, except that its shape is inverted-*N*. In these countries, further economic growth and lower CO₂ emissions seem to be possible. Third, the Czech Republic and Hungary display traditional inverted-U EKC, in which further economic development might be associated with a decline in CO₂ emissions. Fourth, on the contrary, in Bulgaria and Latvia the relationship follows a U-shape, suggesting that future economic growth might be associated with increasing CO₂ emissions.

Fifth, no threshold effects were found in Lithuania, in which the GDP-CO2 link is positive. Finally, in Romania and Slovenia our results suggest the absence of a clear-cut statistical relationship between GDP and CO2.

This multitude of shapes reveals the complexity of the relationship between GDP and CO2 in CEE countries. In particular, there is a striking difference with respect to the monotonously-increasing link emphasized for the entire sample. Taken together, these two findings suggest that adopting a policy that may seem appropriate at the aggregated level may result in unwanted consequences in some CEE countries.

5.3. Turning points

Turning points in the relationship between pollution and economic development received much attention in the related empirical literature mainly with respect to the estimated values, while Bernard et al. (2015) provide an excellent analysis of their mere existence. Overall, there is hardly any consensus, as existing studies highlight that their exact values depend upon a large number of factors, such as e.g. the level of economic development, the variables used as proxy for environmental quality, or the model employed (see e.g. Lopez-Menendez et al., 2014, or Sulemana et al., 2017, for recent studies emphasizing such differences in estimated GDP values related to CO2 emissions turning points).

In our analysis, the presence of different GDP values for turning points (see Table 8) is somehow insulated from these sources of heterogeneity, since they are obtained using the same method (AMG estimator), for the same pollutant (CO2), and when controlling for the same domestic (energy consumption) and external (economic freedom) factors. Consequently, differences in these turning points may well reproduce structural heterogeneities among the CEE countries in our sample.

Table 8. Turning points

| Country | Cubic function | Quadratic function |
|----------|--|-----------------------------------|
| Croatia | <i>peak</i> : 9.6866 (\$16,100) <i>trough</i> : 9.9132 (\$20,195) | |
| Estonia | <i>peak</i> : 9.6437 (\$15,424) <i>trough</i> : 9.9836 (\$21,668) | |
| Poland | <i>trough</i> : 9.6666 (\$15,782) | |
| Slovakia | <i>peak</i> : 9.8593 (\$19,135) <i>trough</i> : 9.6523 (\$15,558) <i>peak</i> : 10.0778 (\$23,809) | |
| Bulgaria | | <i>trough</i> : 9.1327 (\$9,253) |
| Czech R. | | <i>peak</i> : 10.1216 (\$24,875) |
| Hungary | | <i>peak</i> : 9.9677 (\$21,326) |
| Latvia | | <i>trough</i> : 9.7467 (\$17,098) |

Notes: Local extrema are computed using the first derivative of CO2 with respect to GDP. All reported estimated GDP values associated with turning points are in the range of observed GDP values for each country.

According to Table 8, the estimated GDP turning points are fairly different across countries. For example, considering the case in which no other turning point follows a peak, the peak in CO₂ emissions is estimated at around (in thousands USD) 19 for Poland, 21 for Hungary, 24 for Slovakia, and 25 for the Czech Republic, namely a difference of up to around 30% among countries. In the same vein, considering the case in which no other turning point precedes a trough, the trough in CO₂ emissions is estimated at around (in thousands USD) 9 for Bulgaria, 16 for Poland and Slovakia, 17 for Latvia, namely a difference of up to around 80% between countries. Besides, after a peak at around 15 (16), Estonia (Croatia) experiences a trough at around 22 (20), namely before the peak of 25 in the Czech Republic. Similarly, following a trough at around 15, Poland experiences a peak at 19, namely before the trough of 20 in Latvia.

5.4. Discussion

The simple comparison of the shape of the CO₂-GDP relationship and its turning points reveals important differences across countries. Although identifying such differences is a fairly complicated task, we can take a closer look at several important structural characteristics of the CEE countries in search of some potential common patterns.

To this end, after dropping countries in which the relationship between CO₂ and GDP is not statistically significant (Slovenia and Romania), we split the remaining countries in two groups based on the sign of the relationship for large GDP values. Indeed, looking at large GDP values could provide information about the CO₂ dynamics in the years to come, given that all countries in our sample present an upward trend in GDP during the studied period. The first group contains countries in which a higher GDP increases CO₂ for large GDP values, namely: Croatia and Estonia (N-shaped), Bulgaria and Latvia (U-shaped), and Lithuania (monotonically increasing). The second group includes countries in which a higher GDP reduces CO₂ for large GDP values, namely: Poland and Slovakia (inverted-N), and the Czech Republic and Hungary (inverted-U). Then, we look at the relative ranking of the countries in the two groups with respect to the decreasingly-ordered variables included in columns (3)-(7) of Table 5, namely: agriculture, industry, services, foreign direct investment, labor productivity, the economic complexity index, and the human development index.

The results can be summarized as follows. The first three countries with the highest share of agriculture—on average during the period 1996-2015—belong to the first group, while the two countries with the lowest share of agriculture are from the second group. Next, the clustering of countries is more pronounced if we consider the share of the industry: the

first three (last four) countries with the highest average industry share in GDP belong to the second (first) group. In addition, the first (last) three countries with the highest (lowest) average share of services in GDP belong to the first (second) group. Therefore, the structure of the economy seems to matter, as further increases in GDP in the years to come may be associated to lower CO₂ emissions in countries in which the agriculture and the services sectors are relatively weak, and the industry sector is relatively large. Assuming that the industry sector is the largest contributor to CO₂ emissions, this finding may be related to the fact that CEE countries that present a relatively important industry sector are those that managed to transform their obsolete plants into newer plants that benefit of cleaner technologies.

Moreover, while no clear patterns seem to emerge with respect to the share of foreign direct investment, the first (last) three countries with the highest (lowest) labor productivity belong to the second (first) group. A possible explanation is that high labor productivity may go hand in hand with newer, and possibly less polluting, technologies. This can be all the more the case that allows the best identification of the two groups is the economic complexity index: the first four countries with the highest ECI belong to the second group, while the remaining five countries with the lowest ECI are part of the first group. Economic complexity can signal the presence of new and complex productive technologies, such as an increase in GDP may be associated with a reduction of CO₂ emissions.

Finally, except for Estonia, the first five countries with high average levels of the human development index belong to the second group, and the four countries with the lowest HDI belong to the first group. This suggests that increases in GDP could be associated with lower CO₂ emissions in countries with relatively high levels of HDI, probably because a large HDI is equally reflecting an important interest for a wide range of economic goals, including the environmental quality.

VI. Policy implications, and future research topics

We analyzed in this paper the relationship between CO₂ and GDP in CEE countries. While at the aggregated level an increase in GDP was found to be robustly associated with an increase in CO₂ (whose magnitude depends on the GDP level), strong differences in the shape of this relationship were unveiled at country level. These differences span from the absence of a statistically-significant link to the presence of multiple thresholds, and result in particular into strong heterogeneities regarding the turning points in the GDP-CO₂ link in CEE countries.

Considering the overall findings, some important policy implications could be emphasized. Despite an aggregated upward trend of the CO₂-GDP link, some CEE countries managed to secure both higher GDP and lower CO₂ emissions. Drawing upon simple correlations that must be taken with much caution, we unveil that such a negative link between further GDP increases and lower CO₂ emissions may occur in countries with a large and clean industry sector, in which high labor productivity supports complex techniques. Such countries should be analyzed more in detail, as they could provide useful insights on how to accommodate higher economic growth with a decrease in pollution, possibly complementing appropriate policies that are already known from the existing literature (e.g. the adoption of more environmentally-friendly policies, the internalization of externalities, or the adoption of regulations against pollution-havens).

From a more general perspective, the conclusions of our study highlight the danger of a unique environmental policy at the EU level. Indeed, such a unique policy could differently affect the economic activity of CEE countries, given the heterogeneities we emphasized in the link between pollution and economic activity at country-level. Conversely, a policy that would account for country-differences, for example regarding the efforts that were already made to fight pollution or with respect to countries' individual CO₂-GDP relationship, may outperform a unique policy in ensuring economic growth without damaging the environment.

Building on our conclusions, future work could draw upon more disaggregated country-level data to deepen our understanding of the heterogeneities we unveiled at a macroeconomic level in the pollution-growth nexus in CEE countries. In the same vein, it would be interesting to study the effect of (unexpected) changes in environmental regulation at the national level, and particularly the way firms adjust their activity to cope with such changes (possibly in relation to their production factors, and particularly research and development investment, see Alam et al., 2019). Finally, given that CEE countries are still emerging countries, a study of population's perception of environmental goals and their integration in governments' welfare function, possibly from a political economy perspective, could foster our comprehension of motivations and challenges related to the promotion of environmental-friendly economic development.

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