FRIEDRICH-ALEXANDER-UNIVERSITÄT ERLANGEN-NÜRNBERG

Lehrstuhl für VWL, insbes. Arbeitsmarkt- und Regionalpolitik
Professor Dr. Claus Schnabel

Diskussionspapiere
Discussion Papers

No. 124

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March 2022

ISSN 1615-5831

Editor: Prof. Dr. Claus Schnabel, Friedrich-Alexander-Universität Erlangen-Nürnberg
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Economic complexity and environmental pollution: Evidence from the former socialist transition countries*

Florian Bucher[a], Lucas Scheu[b] and Benedikt Schröpf[c]

Abstract: This study examines the link between economic complexity and environmental quality by exploiting the similar starting points of the former socialist transition countries after the fall of the iron curtain. We refer to the extended theories of the Environmental Kuznets Curve (EKC), stating that environmental pollution follows an inverted u-shaped course with respect to economic complexity. Using comprehensive data of 27 countries for the period 1995-2017, our results show that the EKC can be found for countries whose complexity rose over time. Additionally, since the results for production-based and consumption-based CO_2 emissions are similar, we can discard emissions offshoring as a major explaining factor. Consequently, our findings suggest that more complex products are the drivers of the EKC. However, as the turning point is associated with high levels of pollution, our estimates imply that complexity may even exacerbate environmental issues in the short and middle run in less developed countries.

Zusammenfassung: In dieser Studie wird der Zusammenhang zwischen ökonomischer Komplexität und Umweltqualität untersucht, indem die ähnlichen Ausgangssituationen in den ehemaligen sozialistischen Transformationsländern nach dem Fall des Eisernen Vorhangs genutzt werden. Wir beziehen uns auf die erweiterten Theorien der Environmental Kuznets Curve (EKC), die besagen, dass die Umweltverschmutzung in Bezug auf die ökonomische Komplexität einem umgekehrt u-förmigen Verlauf folgt. Unter Verwendung umfassender Daten aus 27 Ländern für den Zeitraum 1995-2017 zeigen unsere Ergebnisse, dass die EKC für Länder nachgewiesen werden kann, deren Komplexität im Laufe der Zeit gestiegen ist. Da die Ergebnisse für produktions- und konsumbasierte CO_2-Emissionen ähnlich sind, können wir außerdem die Auslagerung von Emissionen als wichtigen Erklärungsfaktor ausschließen. Demnach legen unsere Ergebnisse nahe, dass komplexere Produkte die Treiber der EKC sind. Da der Wendepunkt jedoch mit einem hohen Grad an Umweltverschmutzung verbunden ist, deuten unsere Schätzungen darauf hin, dass höhere Komplexität die Umweltprobleme in weniger entwickelten Ländern kurz- und mittelfristig sogar noch verschärfen kann.

Key words: Economic Complexity, Environmental Kuznets Curve, Former Socialist States
JEL codes: O44, P28

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* For helpful comments and suggestions, we thank Boris Hirsch, Claus Schnabel, Martina Eckhardt, Stefan Okruch, Stephan Huber, Tobias Hartl and the participants of the Advancing Indicators of Regional Structural Change Workshop 2021, Jena, the 4th workshop in cooperation with the European Association for Comparative Economic Studies, Szeged and doctoral seminars at the National University of Public Service in Budapest and the FAU Erlangen-Nürnberg. We thank Denis Maksuti for excellent research assistance.

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1. Introduction

This decade will be marked by the so-called Green New Deal. The ecological transformation of the economy and the need to reduce environmental emissions are major issues of our time. To gain an understanding of the mechanisms of the interplay between economic transition and emissions, it is worth examining a past comprehensive transformation - that of the former socialist states.

The corresponding debates on the right way to tackle climate change are heavily polarized. While advocates of radical interventions are in favor of reducing resource and energy use with concepts of degrowth, proponents of market-based solutions rather demand industrial restructuring towards a greener and more sustainable growth path (e.g. Kallis et al., 2018; Hickel & Kallis, 2020; Fernandes et al., 2021). The underlying question of these debates is whether and how we can overcome the trade-off between environmental pollution and economic prosperity. This trade-off is described by the Environmental Kuznets Curve (from here on abbreviated as EKC) which, in its conventional variant, assumes a non-linear relationship between environmental pollution and GDP per capita in the form of an inverted U (Grossman & Krueger, 1995; Dinda, 2004).

In recent years, an increasing number of papers have returned their attention to the EKC. This interest is mainly because the so-called economic complexity approach by Hidalgo and Hausmann (2009) and subsequent work, such as Hausmann et al. (2014), has opened a fresh perspective on economic development. Hidalgo and Hausmann (2009) propose a product-based indicator that aims to relate the products an economy is exporting to its knowledge intensity or, framed differently, its innovation capabilities. Hidalgo and Hausmann (2009) refer to this knowledge or innovation intensity as *complexity* and frame their indicator as the Economic Complexity Index (from here on abbreviated as ECI). Thus, for economic complexity, the underlying question regarding the pollution-development nexus modifies as follows: Can we overcome the trade-off between environmental pollution and economic prosperity by developing more complex products? Since greener products are predominantly highly complex products, a complexity-driven bending of the EKC would suggest that more complex, and therefore greener products reduce environmental pollution from a certain threshold (Mealy & Teytelboym, 2020).[1]

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[1] In the course of this study, we refer to green products as products that are presumably associated with lower CO_2 emissions. Since our analysis is based on the country-level, we do not refer to individual products or goods that are produced in certain "green" industries.

Various papers have since analyzed the relationship between economic complexity and environmental pollution in order to verify the characteristic inverted u-shape of the EKC hypothesis (e.g. Neagu, 2019; Chu, 2021; Pata, 2021; Swart & Brinkmann 2020; Zheng et al., 2021). Chu (2021) examines the relationship with a sample of 118 countries and confirms the EKC, particularly for high-income countries. Neagu (2019) uses a sample of 25 countries that are members of the European Union and also finds an inverted U in favor of the EKC whereas Zheng et al. (2021) confirm the EKC by examining the pollution path of 16 leading exporting economies. In contrast, Pata (2021) and Swart and Brinkmann (2020) use time-series data for the USA and Brazil, respectively, and provide mixed evidence: The EKC is found to hold for the USA but not for Brazil. A related strand of literature examines the EKC with GDP per capita and adds ECI as an explanatory variable. While Can and Gozgor (2017), Doğan et al. (2019) and Leitão et al. (2021) report a negative relationship between CO_2 emissions per capita and economic complexity, Boleti et al. (2021) find that economic complexity increases CO_2, methane and nitrous oxide emissions.

We supplement the literature by examining the link between environmental pollution and economic complexity for the former socialist transition countries. The rationale for this specific sample choice is guided by a fundamental empirical challenge in the context of panel studies: it is generally unknown when exactly different countries enter the curve and if their starting points differ. The former socialist transition countries are presumably located at a similar point in their (economic) history with comparable institutional set-ups after the fall of the iron curtain. Hence, by making use of this "natural experiment", the economic development of different countries that starts at a fixed point in time can be analyzed. In addition, we extend the existing theoretical considerations by focusing on the products themselves, which is closer to the foundations of the economic complexity approach. Also, in our empirical examinations, we propose a sample split that is more consistent with the underlying EKC hypothesis than previous approaches. Methodologically, we use the Fixed Effects estimator and verify the inverted u-shape relationship with the U-test, proposed by Lind and Mehlum (2010). We estimate the parameters of the respective model for various indicators of environmental pollution, most importantly per capita carbon dioxide emissions (CO_2). To disentangle emissions offshoring explanations from conventional explanations of reduced emissions, we examine the relationship for both production-based and consumption-based CO_2 emissions.

The paper proceeds as follows. Section 2 gives an overview of the related literature and presents our general framework. Section 3 introduces the data used in this study and presents descriptive evidence. In section 4, we propose our methodological approach and describe the control variables used in our estimations. Section 5 presents the results of our empirical exercises and studies the robustness of our findings. Section 6 concludes.

2. The Link between Economic Complexity and Environmental Pollution

The relationship between economic growth and environmental pollution has become an important research topic in the field of environmental economics over the last three decades. One of the addressed key questions is whether environmental pollution is (at least initially) a necessary trade-off for economic growth. Against this background, the so-called Environmental Kuznets Curve has emerged as a model for describing and explaining the route of environmental pollution in the course of the development of a country. The origin of the model stems from Simon Kuznets, who examined the relationship between income inequality and economic growth. His discovered inverted u-shaped curve was subsequently coined Kuznets Curve (Kuznets, 1955). The environmental aspect was added after Grossman and Krueger (1995) found a similar u-shaped pattern for the relationship between environmental pollution (dark matter, sulfur dioxide, and suspended particles) and economic growth (in the sense of GDP per capita). This early evidence was further corroborated by the analyses of Panayotou (1993, 1997). The basic premise of the model is that if a country's income is low, emissions of certain pollutants would initially rise as income increases, but would then decline again after a certain threshold, despite further increases in income.

Since then, there has been a vast number of empirical studies trying to prove the characteristic reversed u-shape for various countries individually but also for different country sets, using a variety of pollution indicators (an overview of the empirical results can be found in the work of Lieb (2003) and Shahbaz and Sinha (2019)). Besides that, a large number of considerations have been put forward in the literature for the cause of this pattern. One of the most prominent arguments assumes that in countries with rising incomes, residents would shift their preferences to non-economic aspects, thus bringing issues such as environmental pollution to the fore (McConnell, 1997; Roca, 2003). Furthermore, it is argued that reductions in emissions may result from structural changes in production due to technological advances (De Bruyn et al., 1998). Another reasoning is based on the idea that, in the course of globalization, polluting industries would be shifted to less developed countries, thus explaining the decrease in emissions in developed countries and the increase in less developed countries (Suri & Chapman, 1998; Kearsley & Riddel, 2010). A further crucial aspect mentioned are the effects of innovations that enable wealthy countries to green their polluting production processes (Pasche, 2002). However, and despite all the studies and theoretical considerations, there is still no unambiguous scientific opinion on the existence of the EKC. On the contrary, a considerable body of criticism can be found in the literature, some of which strongly challenge both the basic theoretical concepts as well as the fundamental approach (Stern, 2004).

In recent years, a new indicator has been introduced to analyze the relationship between economic development and environmental pollution, namely the Economic Complexity Index proposed by Hidalgo and Hausmann (2009). This indicator assigns a metric complexity value to each economy based on export data, which can be interpreted as an indirect measure of the country's existing capabilities. This approach follows a growing body of literature suggesting that countries and regions do not arbitrarily diversify into new activities, but rather that the existing set of local capabilities conditions which new activities they will develop in the future (Boschma et al., 2015; Essletzbichler, 2015; Rigby, 2015; Hartmann et al., 2017; Neffke et al., 2011). In this context, one of the crucial aspects is that the underlying local capabilities result from a long (sometimes historical) process and are therefore difficult to build and copy from other regions (Boschma, 2017). This is due to their general form as a combination of different factors such as the region's infrastructure, natural resources, institutions, and the tacit nature of the knowledge involved (Hausmann, 2016; Maskell and Malmberg, 1999). It is further assumed that many (and particularly the decisive) capabilities represent tacit knowledge, meaning knowledge that is hard to transmit and acquire and that often needs years to be developed (Hausmann et al., 2014). The resulting framework has already been applied to different types of activities at different spatial scales. For instance, Neffke et al. (2011) apply this capability approach to study the development of industries at the regional level, while Guevara et al. (2016) used it to investigate the probability of a scientist, university, or country entering a new research area. By drawing on the Economic Complexity approach, we aim to apply the capabilities approach to the activity of environmental pollution to explore the extent to which these capabilities influence environmental pollution.

The aspect that makes the complexity approach compelling for this analysis is that it is one of the strongest tools to explain the income variance of countries and forecast relatively accurately the growth trajectories of countries (Hausmann et al., 2014). This feature potentially allows a novel perspective on the relationship between environmental pollution and economic development based on the corresponding complexity values of countries, while it is not too detached from the already existing considerations and evidence regarding the classical Environmental Kuznets Curve. Firstly, this is due to the underlying assumption that rising Economic Complexity values indicate an increasing knowledge and capability base in a society, which is arguably more consistent with the theoretical drivers of the relationship implied by the EKC. For instance, a growing knowledge base of a society could well translate into a preference shift towards demanding a more sustainable output or the development of more innovative and green products. Secondly, the Economic Complexity approach more conclusively deals with specific characteristics of countries, such as the natural resources intensity of their output, which are difficult to capture in the classical approach (Badeeb et al., 2020).

In addition, ECI can also be used to illustrate structural changes in production. This can be explained by the fact that the economic complexity of a country corresponds to the average complexity of its exported products. On this basis, it seems reasonable to examine the properties of the products in order to draw conclusions about structural changes and their environmental impact. If we now consider the least complex products, such as raw nuts (rank 2848), sesame seeds (2845), and natural rubber (2840)[2], it is noticeable that these are often raw products or products that contain only a small number of production steps which are mainly associated with manual labor and little mechanized activity, requiring a low level of capabilities (Observatory of Economic Complexity, 2021). Therefore, it seems plausible that countries that specialize in these products (finally resulting in a low economic complexity value) have a relatively low environmental footprint. To enhance the complexity of a country, it would need to diversify its economy into new industries and products. Here various authors argue that industries do not diversify randomly; rather, they diversify into industries and products for which the region or country has the necessary capabilities (Hidalgo et al., 2007). For instance, a country would first develop from the extraction of non-complex raw materials (e.g. raw cotton) to the processing of those raw materials into a more complex product (e.g. cotton shirts). If one looks at those more sophisticated products located in the middle of the complexity ranking, such as wrist-watches (1427), scissors (1449), and manicure or pedicure sets (1517), one can recognize that these are mostly large-scale production items with the characteristics of energy-intensive manufacturing processes.

As a result, it is reasonable to believe that the negative impact on the environment would increase. This would be further strengthened by the possibility of transferring production processes from other countries to this country (offshoring) based on the capabilities of a society that are now in place. As countries move to the highest level of complexity, the associated products show a shift from economies of scale to

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2 The ranking of those products is based on the 2019 complexity values provided by the Observatory of Economic Complexity, which ranks export products based on their HS96 (1998-2018) classification according to their complexity values. The ranking covers a total of 2848 products at 6-digit depth in 2019. In the course of readability, we have truncated the designation of the products to the essentials.

economies of scope. Examples for these highly complex products include machining centers for working metal (4), machines and mechanical appliances (having individual functions) (6), and medical, surgical instruments and appliances (magnetic resonance imaging apparatus) (13). In contrast to the less complex products, the associated value creation is increasingly based on the knowledge component and less on the production factors characteristic for mass production. In addition, the highly complex products are often products that are at the end of a global value chain, whereby the preceding energy-intensive processes can be outsourced to other countries. Moreover, the applied indicator must take into account the determinants of pollution in a globalized set of actors ranging from individuals to international corporations, which in turn are subject to the influence of national and international institutions as well as technological development. This makes the use of a wide-ranging indicator particularly compelling in the context of our study.

Previous studies have already shown that ECI has implications for institutions (e.g. Hartmann et al. 2017) and a positive interaction has been found between economic complexity and human capital (Zhu & Li, 2017), while ECI strongly correlates with traditional indicators of technological sophistication (Felipe et al., 2012). Furthermore, Mealy and Teytelboym (2020) showed that green and renewable energy products are more complex (defined as products that need a higher amount of capabilities) than typical products and therefore require more complex production capabilities. As a result, we argue that ECI is a supposedly better indicator of economic development in the context of the EKC than income (as measured by GDP per capita) as it captures a more tailored range of potential factors. We therefore hypothesize that the characteristic inverse u-shape curve also applies to the relationship between environmental pollution and economic complexity. Thus, in economies with low complexity, pollution would initially increase as complexity increases, and after a certain level of complexity, pollution would decrease despite further increasing complexity.

Following the presumption of this pattern, researchers have begun to study the link between economic complexity and environmental pollution for different countries. The body of literature is rapidly growing and the evidence is mixed so far. As such, the characteristic u-shaped curve has been validated for France (Can & Gozgor, 2017) and the USA (Pata, 2021) while it could not be documented for China (Yilanci & Pata, 2020) and Brazil (Swart & Brinkmann, 2020). Many papers also use cross-country variation to investigate the EKC hypothesis. Neagu (2019), for instance, identified the characteristic inverse u-shape for 25 states of the European Unions for the period 1995-2017. Doğan et al. (2019) examined 55 countries over the period 1971 to 2014 and divided them into three distinct groups to reflect their income levels. Their results suggest that economic complexity affects CO_2 emissions differently across development and income levels, increasing pollution in lower- and upper-middle-income countries and decreasing CO_2 emissions in high-income countries. In addition, Boleti et al. (2021) use a sample of 88 developed and developing countries for the period 2002 to 2012. Based on fixed-effects instrumental variable estimations, they found that while an increasing complexity value is associated with improved environmental performance, it is also associated with poorer air quality (higher PM2.5 pollution, CO_2, methane, and nitrous oxide emissions). Chu (2021), on the other hand, confirms the EKC hypothesis for CO_2 using a broader data set that includes 118 countries for the period 2002 to 2014. Zheng et al. (2021) examine the EKC hypothesis for the 16 leading exporting economies for the same period and found robust evidence in favor of the EKC.

Many studies focus on special groups of countries for which they aim to establish a structural link between economic complexity and environmental pollution. In this respect, Balsalobre-Lorente et al. (2022) confirm the existence of the EKC with economic complexity for the PIIGS countries (Portugal, Italy, Ireland, Greece, Spain). Using dynamic ordinary least square (DOLS) estimation regressions, they reveal evidence for an inverted-U and further a N-shaped connection between economic complexity and CO_2 for the period 1990-2019. Their results also indicate that high FDIs and urbanization have detrimental effects on environmental pollution. Leitão et al. (2021) report a negative link between economic complexity and CO_2 emissions for the BRICS countries (Brazil, Russia, India, China, South Africa) for the period of 1990-2015. More specifically, they document an inverted u-shape connection between income per capita and CO_2 emissions, and a negative connection between economic complexity and CO_2 emissions. In contrast, Nathaniel (2021) finds that economic complexity increase CO_2 emissions based on a sample of ASEAN countries (Philippines, Indonesia, Singapore, Malaysia, Thailand, and Vietnam). Alvarado et al. (2021) use a sample of 17 Latin American economies and find heterogeneous effects of economic complexity on the ecological footprint along its distribution, using a quantile regression approach.

We aim to complement this strand of literature by offering an examination of the EKC with respect to economic complexity for the former socialist transition countries. By that means, the selection of our sample is arguably closer to the underlying framework of the EKC since we follow countries in a transformation phase that started at the same time.

3. Data, Sample Split and Descriptive Statistics

Since most of the existing studies describe a gradual and country-specific structural shift towards a more complex and knowledge-based economy, the problem for cross-country studies emerges that they catch countries on different development stages at the same point in time. To minimize this potential source of bias, we chose the former socialist transition countries as a study object because they started their transitional shift from a socialist planned economy to a market economy parallelly, with the end of the East Bloc. After the deindustrialization of the socialist economies, the countries underwent a structural transformation. Increasing economic liberalization and integration into the world economy gradually led to an increase in capabilities. A shift of production factors and improvement of production processes is accompanied by changes in the complexity of manufactured products. Therefore, we argue that this specific country sample offers a unique opportunity to observe the structural shift that is implied by the EKC in a cross-country study design over a relatively short period of time. To our knowledge, we are the first to use the former socialist transition countries as a case study to examine the EKC hypothesis applying the economic complexity approach.

3.1 Data

We use a comprehensive panel-data set that contains 27 former socialist transition countries throughout 1995-2017. To limit possible skewing and unintended effects of the collapse of the Soviet Union, the year 1995 was chosen as the starting point with the presumption that at least most of the associated (unintended) influences will have been subsided by then. Additionally, consistent data on economic complexity is only available since 1995. The sample does not include the countries Serbia, Montenegro, and Kosovo, as no fully comprehensive data is available. In total, our sample contains 621 observations. For our explanatory variable of interest, the Economic Complexity Index (ECI), we use data from the Atlas of Economic Complexity Dataverse, provided by the Growth Lab at Harvard University (The Growth Lab at Harvard University, 2019). More specifically, we use the “Growth Projections and Complexity Rankings” dataset, which provides economic complexity values based on two product classification systems, namely the Harmonized System (HS, 1992) and the Standard International Trade Classification (SITC, Revision 2). We rely our analyses on the latter, however, altering the classification system does not change our results significantly.

For the environmental indicators analyzed in this study, we use the CO_2 and Greenhouse Gas Emissions Database, provided by Our World in Data (Ritchie & Roser, 2020). This dataset collects information from various data sources, namely the

Global Carbon Project for CO_2 emissions and the Climate Watch Portal for the greenhouse gas emissions. Our main environmental variables are the annual production-based and consumption-based emissions of carbon dioxide (CO_2), measured in tonnes per person. For robustness analyses, we also examine total methane, greenhouse gas and nitrous oxide emissions (including land use change and forestry), measured in tonnes of carbon dioxide-equivalents per capita as well as annual production-based emissions of carbon dioxide (CO_2), measured in kilograms per kilowatt-hour of primary energy consumption.[3] The control variables used in our estimations are extracted from the World Bank Development Indicators and cover various country characteristics (The World Bank, 2021a). The additional variables for our robustness analyses are extracted from World Bank Open Data (The World Bank, 2021b). An in-depth description of these variables follows in section 4.2.

3.2 Sample Split

Despite existing similarities between the former socialist transition countries, the transformation towards a liberal market economy occurred differently from country to country (Gros & Steinherr 2012). Countries with a higher endowment in natural resources and more entrenchment of the ruling elite during the socialist period – longer history under socialism – developed weaker institutions regarding „voice and accountability, government effectiveness, rule of law, regulatory quality, absence of corruption and political stability“ (Beck & Laeven, 2006). As we show in section 3.3, especially countries that were part of the Soviet Union, with longer history as socialist states, exhibit a negative development regarding Economic Complexity. This imposes a fundamental threat to the underlying EKC hypothesis, since it relies on the implicit assumption that the economic prosperity of a country increases with time. Reporting an inverse u-shaped relationship between complexity and pollution for countries with decreasing complexity would imply that these countries started at the end of the curve and moved back along it. For greater clarity, the problem is depicted in Figure 1. The left panel shows the stylized relationship in countries whose complexity decreased over time and the right panel in countries that became more complex over time. For the underlying EKC hypothesis to make sense, in panel (a) we would have to observe that the development starts at the right end of the curve and then follows its course. Statistically, this is detectable, but from a theoretical point of view this curve does not make sense as we would have to assume that the curve is entered at the “wrong” side of the curve.

[3] More information on the data is provided here: https://github.com/owid/CO2-data/blob/master/owid-CO2-codebook.csv.

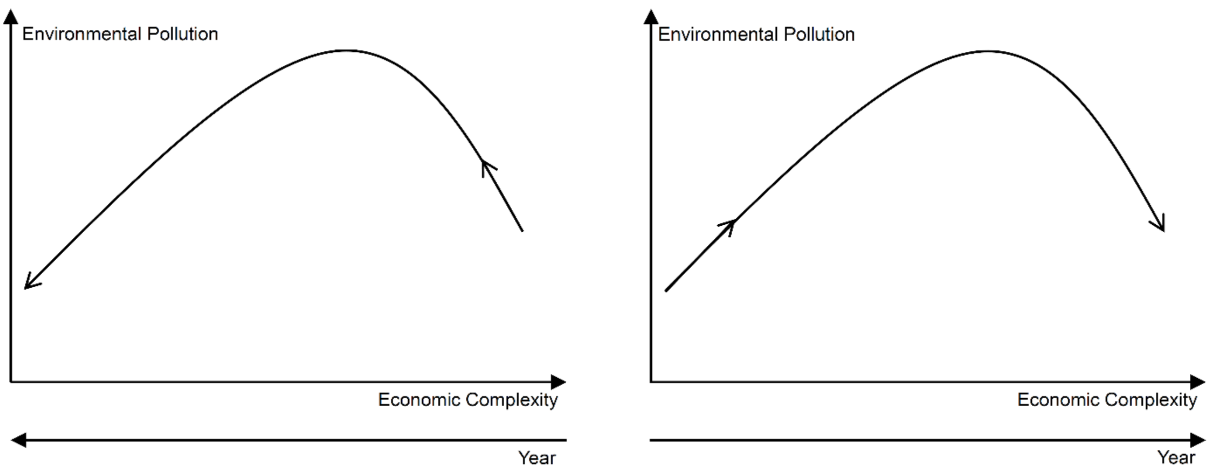

Figure 1: Stylized relationship between Economic Complexity and Environmental Pollution for countries with decreasing ECI over time (Left Panel) and for countries with increasing ECI over time (Right Panel)

Put differently, the EKC in fact describes a three-dimensional problem, with the three dimensions being environmental pollution, economic development, and time. The third dimension is, up to this point, largely neglected in the literature even though it is most relevant for studies that use economic complexity as an indicator. In contrast to GDP per capita, which on average reliably increases in the middle and long run, this is not necessarily the case with respect to the Economic Complexity Index. This arises from the fact that ECI is calculated based on the average complexity of the products an economy is exporting. It might be that export patterns of countries, and therefore, their set of exported products change. Additionally, ECI is a standardized measure and hence, its values can change solely based on changes in its mean and standard deviation. Therefore, it is not unusual that the complexity of countries decreases over time. In our case, this could be explained partly with the partial deindustrialization of some of the former Soviet Union countries, moving to a more natural resources based economic structure (see, for instance, Oldfield (2000) for Russia and Batsaikhan and Dabrowski (2017) for central Asia). To account for these different developments during the transformation phase and for the problem of decreasing ECI values, we divide our sample into two sub-groups. These groups are built by analyzing the evolution of economic complexity in each country. One group experienced an increase in their economic complexity over the observation period of 1995-2017, the other group experienced constant or decreasing complexities over time.[4]

[4] We performed this classification by regressing ECI on the year and considered a significant positive coefficient as an indicator for increasing complexity and an insignificant or negative coefficient as an indicator for constant or decreasing complexity. Alterations of this classification procedure (e.g., with regards to the standard errors) did not change the results significantly.

3.3 Descriptive Statistics

Table 1: List of countries and summary statistics in the two groups

Increasing ECI (Group 1)	Constant and Decreasing ECI (Group 2)
	Albania
Belarus	Armenia
Bosnia and Herzegovina	Azerbaijan
Bulgaria	Georgia
Croatia	Kazakhstan
Czech Republic	Kyrgyzstan
Estonia	Moldova
Hungary	Mongolia
Latvia	Northern Macedonia
Lithuania	Russia
Poland	Tajikistan
Romania	Turkmenistan
Slovakia	Ukraine
Slovenia	Uzbekistan

This section presents descriptive statistics about the data set and its crucial variables. A key element of our study is the sample split; therefore, we provide summary statistics for both groups of countries. Table 1 presents the list of countries according to their respective groups. The countries Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia belong to the group of increasing ECI countries. The other group consists of Albania, Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Mongolia, Northern Macedonia, Russia, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan and is characterized by constant or decreasing complexities over time. It is interesting to note that the latter group predominantly consists of countries that formerly belonged to the Soviet Union and are rather located in Central Asia whereas the former group predominantly consists of countries that are now members of the European Union. This emphasizes that the former socialist transition countries are very heterogeneous, even though their starting point has been similar. The summary statistics presented in Table 2 further illustrate these heterogeneities. Table 2 shows summary statistics of the two variables of interest, namely the Economic Complexity Index (ECI) and the CO_2 emissions per capita, and, in addition, of GDP per capita for both constructed country groups. Following Chu (2021), we rescaled ECI such that it is strictly positive which makes the coefficients in the following estimations easier to interpret. More precisely, we added +2 to the raw ECI values to ensure that no value falls beneath zero. We played around with the exact rescaling procedure and found no meaningful impact on our results. Also note that ECI itself is already standardized (Hausmann et al., 2013).

Table 2: Summary statistics for both country groups

	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
	ECI	ECI	CO_2 per capita	CO_2 per capita	GDP per capita	GDP per capita
Mean	2.95	1.76	6.76	4.73	16,554	8,467
Median	2.87	1.83	6.15	3.56	16,784	7,173
Maximum	3.79	2.93	14.96	17,03	29,797	24,638
Minimum	2.16	0.41	0.89	0.29	3,074	1,533
Std. dev.	0.42	0.57	2.88	4.15	5,855	5,583
N	299	322	299	322	299	322

Note: ECI values refer to the rescaled version of the variable and therefore deviate from the official data.

As can be seen, the group of countries with an increasing ECI is comparably complex, with an average of 2.95. In contrast, the constant and decreasing ECI countries exhibit an average complexity of 1.76. Since ECI is a unitless measure, these absolute values can in principle only be interpreted within the complexity ranking. However, to gain a better understanding of the meaning of these values, one can exemplarily look at products that are associated with the same complexity. For instance, products such as cranes and derricks (designed for mounting on road vehicles) or wheeled tractors exhibit a complexity of around 2.95. In contrast, products such as ceramic building bricks or articles of leather or of composition leather exhibit a complexity of 1.76 (The Observatory of Economic Complexity, 2019).[5] The difference between the two groups is also reflected in the per capita GDP values. On average, GDP per capita in the first group (increasing ECI) is nearly twice as high as in the second group (decreasing or constant ECI). A huge difference between the two groups can also be found when comparing the per capita CO_2 emissions. The first group emits an average of 6.76 tons of CO_2 per capita while the latter groups' emissions only amount to 4.73 tons per capita, on average. Hence, among the group of former socialist transition countries, the most complex countries are the heaviest polluters.

The heterogeneity of our sample is also visible in Figure 2 where the per capita CO2 emissions are plotted against economic complexity for both groups. In the interest of greater clarity, we show the yearly averages of these two variables. As can be seen, the relationship of interest tremendously varies by group of countries considered. While for the countries whose complexity decreased or barely changed over time, a negative relationship can be documented, Figure 2 reveals a relationship that resembles an inverse u-shaped form for the countries whose complexity rose over time. This is a first hint that the EKC describes the CO2-ECI path of the increasing ECI countries decently, while it seems that it is not a useful model for the second group of countries, the ones with decreasing or constant complexity. Hence, there

5 The complexity of those products refers to the year 2019 and are based on the HS96 (1998-2018) classification provided by the Observatory of Economic Complexity. Note that here we rescaled ECI, therefore our values deviate from the official values by 2 units.

are two layers of non-linearity to deal with in our study. The first layer is implied by the EKC and the proposed inverse u-shaped relationship. The second layer comes through the heterogeneity of the countries considered. In our view, it is essential to consider both layers to gain a more accurate picture of the underlying relationship.

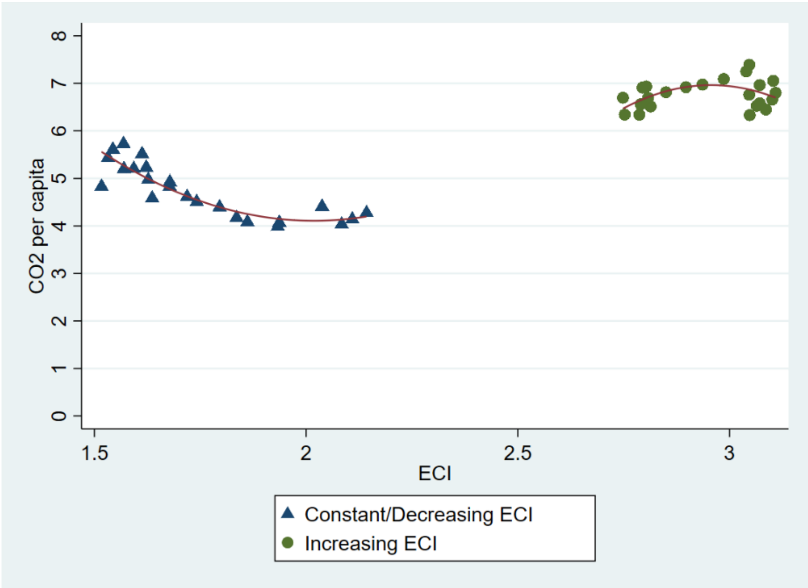

Figure 2: Average CO_2 per capita vs. average Economic Complexity for both groups

4. Empirical Analysis

In the empirical analysis, we aim to examine the relationship between economic complexity and environmental pollution, as measured with carbon dioxide (CO_2) emissions per capita. More precisely, the inverse u-shaped relationship between these two variables, as proposed by the Environmental Kuznets Curve hypothesis, is under investigation. Therefore, we include the Economic Complexity Index (ECI) and its square as main explanatory variables in our regressions. In section 2, we described three different strands of explanation for the prevalence of the EKC, namely the preference shift towards more environmental awareness, the development of green innovations, and the offshoring of emission-intensive industries to less developed countries. In our empirical analysis, we therefore differentiate between production-based and consumption-based CO_2 emissions to examine the offshoring hypothesis more directly. We argue that if offshoring was the dominating factor, we should see that in the production-based emissions but not necessarily in the consumption-based emissions.

4.1 METHODOLOGICAL APPROACH

As the underlying relationship between economic complexity and environmental pollution describes country-specific economic developments, we propose a fixed-effects model to examine the EKC hypothesis. By that means, we can exploit within-country variation. We apply the standard approach from the literature and identify the EKC by including both a linear and a squared term of the Economic Complexity Index as explanatory variables. The coefficient of the linear term of ECI in the regression should be positive and significant which corresponds to the upward-sloping part of the curve while the coefficient of the square of ECI should be negative and significant which indicates a declining slope of the curve or, put differently, a concave course of the EKC. Additionally, we test for joint significance of ECI and ECI^2 and apply the U-test, proposed by Lind and Mehlum (2010) to identify an inverse u-shaped course of the EKC. The U-test calculates the maximum (since we assume an inverse U) of the function y=f(x), where in our case y represents per capita CO_2 emissions and x represents economic complexity. It also provides confidence intervals for the extremum point and checks whether it lies within the data range. Finally, we scrutinize the plausibility of these extremum points and the course of the curves resulting from our estimates. To this end, we also show linear predictions of the CO_2 emissions along the distribution of ECI for the estimated parameters of our models. The equation describing the model to identify the curve takes the following form:

$$CO_{2p.c.,i,t} = \alpha_0 + \beta_1 CO_{2p.c.,i,t-1} + \beta_2 ECI_{i,t} + \beta_3 ECI^2_{i,t} + \beta_4 GDP_{p.c.,i,t} + X_{i,t}\delta + \gamma_i + \omega_t + \varepsilon_{i,t}$$

In this model, $X_{i,t}$ represents a matrix of control variables, γ_i represents country fixed effects, ω_t captures time fixed effects and $\varepsilon_{i,t}$ is a random error term. We regress the CO_2 emissions per capita, as measured in metric tons, on ECI and its square and on GDP per capita to study the effect of economic complexity, conditional on income. This is important since we want to disentangle economic complexity from factors that can possibly increase the income of an economy (such as natural resources) but do not reflect economic complexity. Therefore, we are not considering ECI as a proxy for income but as a source of additional information, specifically capturing the capabilities of a society. We also include a one-period lag of the dependent variable to capture the dynamic nature of the underlying process. In addition, we include various control variables which are described in more detail in the next section. To account for general year-specific shocks we also include time dummies in every specification.

4.2 Control Variables

In our estimations, we control for a battery of country-specific variables that are related to CO_2 emissions and economic complexity to isolate the effect of innovative capabilities of an economy on its environmental pollution. In the choice of the control variables, we closely follow the previous literature and particularly rely on the work of Boleti et al. (2021) and Chu (2021). We include agriculture and industry value added proportionally to total GDP to control for the sector composition of an economy (Boleti et al., 2021). We also control for the proportion of exports and imports in total GDP to capture the impact of trade openness on environmental pollution. This relationship has been examined by a large body of research (e.g., Antweiler et al., 2001; Frankel & Rose, 2005; Kasman & Duman, 2015). These studies rather suggest that trade openness of countries does not have large detrimental effects on environmental quality. In addition, natural resources rents as a percentage of GDP are included to control for the natural resources' intensity of the outputs of the considered countries as these presumably have a large impact on the CO_2 emissions (Alvadaro et al., 2021).

Moreover, we include two spatial variables, namely population density and the share of the urban population. Both variables can influence CO_2 emissions since the demand of urban areas might exacerbate environmental issues (Balsalobre-Lorente et al., 2022). On the other hand, more urbanized countries might have developed more efficient solutions for environmental problems or managed to establish more environmental awareness (Boleti et al., 2021). As in Chu (2021), we also consider an institutional variable that captures the conditions under which a society can develop products, production processes and innovation. Therefore, we include the Civil Liberties Index from the Freedom House Indicator. It might be the case that a freer society increases CO_2 emissions by exploiting the extended set of (business) opportunities; however, it is also possible that more civil liberties support the process of developing less CO_2 intensive products.

5. Empirical Results

5.1 The Link between CO_2 Emissions and Economic Complexity

In this section, we present the results concerning our main outcome variables of interest, namely the production-based and consumption-based carbon dioxide (CO_2) emissions per capita. We start by taking the production-based emissions as a dependent variable and later extend the analysis by examining consumption-based

CO_2 emissions. At first, the results for the full sample of all 27 former socialist transition countries will be depicted. After that, we take a finer look at the data by splitting the sample and re-run the analysis with the chosen sub-samples.

In Table 3 the results for the full sample are presented. We start by estimating the parameters of the model without control variables in column (1) and extend this model with the set of control variables described above. In column (2) we include the control variables that capture the output composition of the countries, in column (3) we include the spatial controls and in column (4) we also consider our institutional variable. The model depicted in column (4) is our preferred one with the full set of control variables. As can be seen, the parameters of interest, namely *ECI* and ECI^2, show the expected signs in columns (2) to (4).

Table 3: The link between CO_2 per capita and economic complexity, fixed effects estimations, 27 former socialist transition countries

	(1)	(2)	(3)	(4)
$CO_{2p.c.,t-1}$	0.867***	0.815***	0.797***	0.796***
	(0.03)	(0.03)	(0.04)	(0.04)
ECI	-0.012	0.595	0.494	0.501
	(0.49)	(0.47)	(0.47)	(0.46)
ECI^2	-0.038	-0.127	-0.115	-0.117
	(0.11)	(0.11)	(0.12)	(0.12)
GDP per capita	0.000**	0.000***	0.000***	0.000***
	(0.00)	(0.00)	(0.00)	(0.00)
Agriculture (% of GDP)		-0.029**	-0.027**	-0.027*
		(0.01)	(0.01)	(0.01)
Industry (% of GDP)		0.002	0.002	0.002
		(0.01)	(0.01)	(0.01)
Trade (% of GDP)		-0.005***	-0.006***	-0.006***
		(0.00)	(0.00)	(0.00)
Natural Resources Rents (% of GDP)		0.013	0.011	0.011
		(0.01)	(0.01)	(0.01)
Population Density			-0.009	-0.008
			(0.01)	(0.01)
Urban Population			0.026	0.026
			(0.02)	(0.02)
Civil Liberties				-0.012
				(0.05)
Constant	0.817	0.756	0.178	0.191
	(0.64)	(0.78)	(1.36)	(1.34)
Joint Significance?	X	X	X	X
Inverse U?	-	X	X	X
Turning Point	-	2.338	2.146	2.134
R^2	0.786	0.795	0.797	0.797
N	594	573	573	573

Dependent variable: Average per capita production-based CO_2 emissions (CO_2/population), measured in tons per year. All regressions include time dummies. ✓ indicates joint significance or significant inverse U at least at the 10% level, X indicates insignificance. Clustered standard errors in parentheses. */**/*** indicates statistical significance at the 10/5/1 percent level. No data on agriculture available for Armenia.

However, the coefficients are not statistically significant at any conventional significance level. The same applies for the joint significance of *ECI* and ECI^2 and the U-test. Therefore, we cannot find evidence for an inverse u-shaped relationship between economic complexity and CO_2 emissions for the full sample of all 27 former socialist transition countries. These results are consistent with our descriptive findings presented in Figure 2 and our considerations regarding the three-dimensionality of the underlying relationship, expressed in the Environmental Kuznets Curve.

To address this challenge, we have split the country sample according to the country-specific evolutions of ECI over time, as outlined in the previous sections. In Table 4, we present the results for the countries with increasing complexity as these are of main interest, given our theoretical considerations. We include the same set of control variables as before and extend every specification with one additional group of control variables. As can be seen, the coefficient of ECI is positive and the coefficient of ECI^2 is negative in every depicted specification. Moreover, both linear and squared terms of ECI are highly significant throughout all four specifications.

The same holds true for the joint significance of both linear and squared term of ECI and for the U-test, applied in every specification. Therefore, the results presented in Table 4 suggest that the CO_2 emissions in the group of countries that became more complex over time indeed follow an inverse u-shaped pattern with respect to economic complexity. We do not show the results for the countries with decreasing or constant complexity as the coefficients of both linear and squared term of ECI are insignificant and small throughout all specifications, but they are available upon request. We conclude that the EKC is not a useful model to describe the CO_2-ECI path of this group of transition countries and therefore focus on the first group (increasing ECI) from here on.

Except for trade (% of GDP) and natural resources rent (% of GDP) all coefficients of the control variables are insignificant and, in most cases, very small. With regards to the trade variable, the negative coefficient is consistent with the findings of, for instance, Antweiler et al. (2001). Hence, higher trade openness is rather associated with slightly lower environmental pollution for the considered countries. Throughout all specifications, natural resources rents as a percentage of total GDP have positive, highly significant, and comparably large coefficients, which suggests that the exploitation of natural resources exerts large detrimental effects on environmental pollution. Not surprisingly, there is a strong positive association between the CO_2 emissions and its lag from the previous period.

Table 4: The link between CO_2 per capita and economic complexity, fixed effects estimations, 13 countries with increasing complexity

	(1)	(2)	(3)	(4)
$CO_{2p.c.,t-1}$	0.737***	0.694***	0.686***	0.687***
	(0.10)	(0.09)	(0.09)	(0.09)
ECI	5.185**	5.323**	4.747***	4.755***
	(2.05)	(1.81)	(1.46)	(1.46)
ECI^2	-0.915**	-0.911**	-0.833***	-0.834***
	(0.35)	(0.31)	(0.24)	(0.24)
GDP per capita	-0.000	0.000	0.000	0.000
	(0.00)	(0.00)	(0.00)	(0.00)
Agriculture (% of GDP)		-0.010	0.003	0.003
		(0.02)	(0.02)	(0.02)
Industry (% of GDP)		0.025	0.022	0.022
		(0.02)	(0.02)	(0.02)
Trade (% of GDP)		-0.005**	-0.005*	-0.005*
		(0.00)	(0.00)	(0.00)
Natural Resources Rent (% of GDP)		0.152***	0.159***	0.160***
		(0.04)	(0.04)	(0.04)
Population Density			-0.021	-0.020
			(0.01)	(0.01)
Urban Population			0.009	0.008
			(0.03)	(0.02)
Civil Liberties				0.007
				(0.06)
Constant	-5.199**	-5.942**	-3.726	-3.767
	(2.28)	(2.14)	(3.67)	(3.84)
Joint Significance?	✓	✓	✓	✓
Inverse U?	✓	✓	✓	✓
Turning Point	2.834	2.922	2.849	2.849
R^2	0.731	0.746	0.748	0.748
N	286	286	286	286

Dependent variable: Average per capita production-based CO_2 emissions (CO_2/population), measured in tons per year. All regressions include time dummies. ✓ indicates joint significance or significant inverse U at least at the 10% level. X indicates insignificance. Clustered standard errors in parentheses. */**/*** indicates statistical significance at the 10/5/1 percent level.

To better grasp the relationship of interest, Figure 3 depicts the link between ECI and CO_2 per capita, resulting from the estimates of specification (4) in Table 4. The chosen range on the x-axis is given by the minimum and maximum of ECI in the respective subsample. The other complexity values depicted on the x-axis represent the 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentile of the subgroup-specific distribution of ECI. The inverse U that is implied by the EKC is visible, as well as the turning point at an economic complexity of approximately 2.85 which is highlighted by the dashed vertical line in Figure 3. The turning point roughly coincides with the median of the distribution and is associated with CO_2 emissions of around 7 tons per capita. However, note that the 95% confidence intervals are very wide at the distribution tails and largely overlap. This is not surprising given our small sample with just 286 observations. Nonetheless, for this sample, the inverse u-shape can be documented.

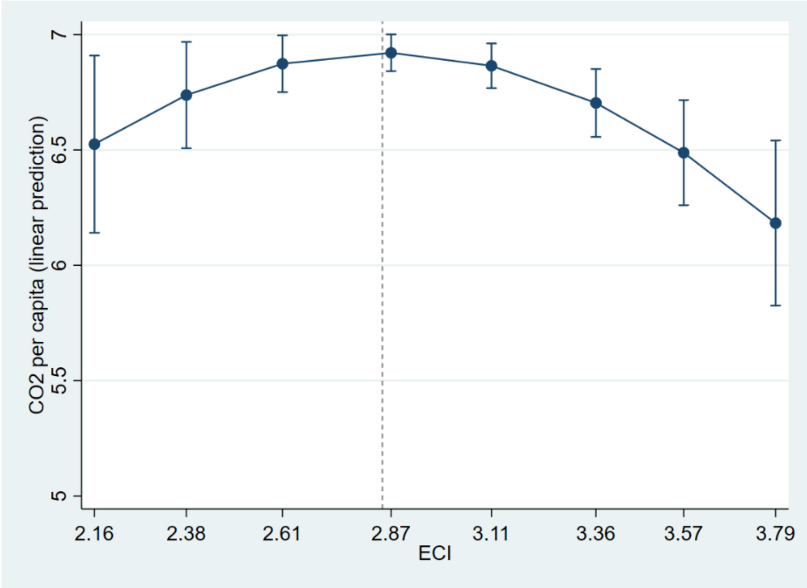

Figure 3: Estimated CO_2-ECI function for the increasing ECI countries

To evaluate magnitude and economic significance of our results, we further analyze the marginal effects of ECI on CO_2 for different values of ECI. Therefore, Table 5 presents the marginal effects at different points of the distribution of ECI for the group of countries with increasing complexity. Additionally, we calculate how, on average, a country's per capita CO_2 emissions would change when its economic complexity moves forward along the distribution.

For instance, increasing complexity from the minimum, 2.16, to the 25th percentile, 2.61, is on average and ceteris paribus associated with an increase of CO_2 emissions of approximately 350 kilograms per capita. In contrast, increasing complexity from the median, 2.87, to the 75th percentile, 3.35, is on average and ceteris paribus associated with a decrease of CO_2 emissions of around 212 kilograms per capita. Going further to a complexity value of 3.57, which represents the 90th percentile of the distribution, additional CO_2 savings of 220 kilograms per capita can on average be realized.

Table 5: Predictive margins with respect to ECI

Point of distribution	ECI	Predicted CO_2 p.c. (SE)	ΔCO_2 p.c.
Minimum	2.16	6.525 (0.196)	-
25th percentile	2.61	6.874 (0.063)	0.349
Turning point	2.85	6.921 (0.041)	0.047
50th percentile	2.87	6.921 (0.041)	0.000
75th percentile	3.35	6.709 (0.074)	-0.212
90th percentile	3.57	6.489 (0.116)	-0.220
Maximum	3.79	6.189 (0.181)	-0.300

Note: ECI values refer to the rescaled version of the variable and therefore deviate from the official data. This exercise is based on the estimates of specification (4) in Table 4.

Thus, from the turning point to the 90th percentile, the overall CO_2 savings that are associated with the higher complexity amount to 432 kilograms per capita.

Our findings hitherto suggest that the EKC is a valid model to describe the CO_2-ECI nexus for our sub-sample of former socialist transition countries whose complexity increased over time. Hence, at first, an increase in complexity is associated with higher CO_2 emissions. However, there exists a threshold, after which the CO_2 emissions decrease with increasing complexity. This threshold is the extremum point of the CO_2-ECI function, which is calculated by the U-test. We can make use of this extremum point and ponder it against the data to check for the plausibility of our estimation results. In specification (4), the sign of ECI switches from positive to negative after a complexity value of approximately 2.85. Comparing this to Figure 2 shows that this threshold is quite plausible as it also lies within the range of the visual extremum point.

To better assess the complexity value after which the CO_2 emissions start to decrease, we additionally show the distribution of the Economic Complexity Index for our full sample in Figure 4. The vertical dashed line indicates the extremum point of approximately 2.85 that corresponds to the specification in column (4). Figure 4 reveals that the complexity value of 2.85 is comparably large as it is located on the right side of the histogram. Hence, countries must reach relatively high levels of complexity to reduce CO_2 emissions again. This has important implications for policymakers in poorly complex countries if they want to reduce CO_2 emissions by making their products more complex. They would have to accept substantially rising CO_2 emissions as they climb up the complexity ladder before a positive effect of complexity on environmental pollution can be realized.

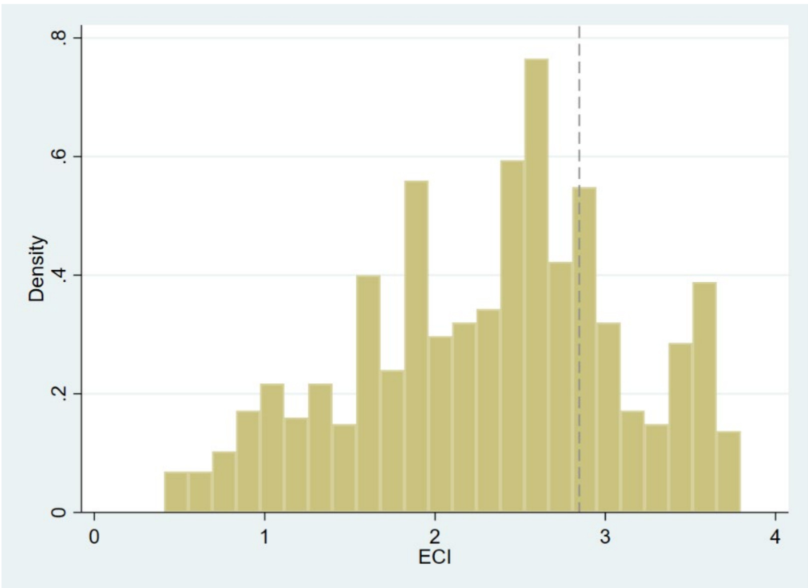

Figure 4: Distribution of ECI in the full sample

Up to now, these results are consistent with the explanation that countries achieved to decrease their CO_2 emissions by developing more complex products. As outlined in section 2, one alternative explanation for the observed pattern could be that some countries might have made an effort to reduce CO_2 emissions by offshoring CO_2-intensive production. Especially richer countries could have both incentive and scope to do so. Therefore, we explicitly examine the per capita consumption-based CO_2 emissions in the following. If the economies did just outsource their CO_2-intensive production at high stages of complexity but did not alter their actual environmental footprint we would not expect to see an inverted u-shaped pattern concerning consumption-based CO_2 emissions. However, inspection of Table 6 suggests that this does not seem to be the case.

Table 6: The link between consumption-based CO_2 per capita and economic complexity, fixed effects estimations, 13 countries with increasing complexity

	(1)	(2)	(3)	(4)
$CO_{2p.c.,t-1}$	0.498***	0.501***	0.488***	0.488***
	(0.07)	(0.07)	(0.07)	(0.07)
ECI	5.913***	7.002***	7.354**	7.340**
	(1.79)	(2.16)	(3.03)	(3.11)
ECI^2	-0.971***	-1.141***	-1.213**	-1.210**
	(0.27)	(0.34)	(0.46)	(0.48)
GDP per capita	0.000***	0.000***	0.000***	0.000***
	(0.00)	(0.00)	(0.00)	(0.00)
Agriculture (% of GDP)		0.013	0.028	0.028
		(0.01)	(0.02)	(0.02)
Industry (% of GDP)		0.001	-0.001	-0.001
		(0.02)	(0.02)	(0.02)
Trade (% of GDP)		0.001	0.001	0.001
		(0.00)	(0.00)	(0.00)
Natural Resources Rents (% of GDP)		0.118	0.119	0.118
		(0.11)	(0.12)	(0.12)
Population Density			-0.009	-0.010
			(0.02)	(0.02)
Urban Population			0.029	0.029
			(0.02)	(0.02)
Civil Liberties				-0.006
				(0.09)
Constant	-5.829*	-7.964**	-9.499	-9.460
	(2.73)	(3.59)	(7.34)	(7.52)
Joint Significance?	✓	✓	✓	✓
Inverse U?	✓	✓	✓	✓
Turning Point	3.044	3.068	3.032	3.032
R^2	0.690	0.694	0.696	0.696
N	264	264	264	264

Dependent variable: Average per capita consumption-based CO_2 emissions (CO_2/population), measured in tons per year. All regressions include time dummies. ✓ indicates joint significance or significant inverse U at least at the 10% level. X indicates insignificance. Clustered standard errors in parentheses. */**/*** indicates statistical significance at the 10/5/1 percent level. No data available for Bosnia and Herzegovina.

The results are very similar to those obtained from the previous estimations where we analyzed production-based CO_2 emissions. Table 6 reveals a positive and significant coefficient of the linear term of ECI and a negative and significant squared term of ECI as well as indication for joint significance and an inverse u-shaped relationship.

Hence, the inverse u-shaped course of CO_2 emissions with respect to economic complexity can be found, both when analyzing production and consumption-based emissions. Our results therefore suggest that more complex, and presumably greener products are the main drivers of the EKC. However, with our data at hand, we cannot further discriminate between the two remaining strands of explanations, namely the preference shift versus the technological development of greener products.

5.2 Robustness Analysis

In this section, we examine the robustness of our findings. We focus on the estimations we conducted with the sample of countries with increasing complexity. First, we investigate if considering suitable alternative or additional control variables changes our results. Second, we consider other indicators of environmental pollution or progress, such as methane emissions per capita, nitrous oxide emissions per capita, greenhouse gas emissions per capita and energy use per unit CO_2. Third, we alter the functional form of the underlying relationship by applying regression splines instead of including linear and squared terms of ECI. Note that the inclusion of a broader set of control variables or the application of alternative environmental measures will partly result in fewer observations. To ensure comparability, we replicated all our estimations from the previous section with the reduced sample sizes and found no significant impact on the results.

We start by analyzing changes in our results by altering the set of control variables and present the respective estimation results in Table 7. In column (1), additional control variables are considered that aim to additionally reflect foreign investment activities and the energy composition and intensity of an economy. We therefore include net FDI inflows (% of GDP), alternative and nuclear energy use (% of total energy use) and electric power consumption (kWh per capita). In column (2), we replicate our estimations with alternative variables and substitute the Human Development Index for GDP per capita, the share of exports for the share of total trade and three Governance Indices from the World Bank (Political Stability, Government Effectiveness, and Control of Corruption) for the Civil liberties indicator. Inspection of Table 7 shows that in both specifications the coefficient of ECI is positive and the coefficient of ECI^2 is negative. Additionally, linear and squared terms of ECI are jointly significant and the U-test identifies an extremum point to the underlying CO_2-ECI-function. The specification with the alternative controls also exhibits a turning point of around 2.85, which is consistent with our previous findings.

However, it is striking that the turning point resulting from the model with the additional controls in column (1) is substantially lower than in every other specification. As a result, the EKC implied by the first specification in Table 7 exhibits a quite distinct course. To better assess the differences, we plot the EKCs that follow from all estimations we conducted with production-based CO_2 emissions per capita so far. The results are presented in Figure 5. For greater clarity, we only depict the point estimates and do not report confidence intervals here. Note, however, that the confidence intervals largely overlap between the different curves. As can be seen, five of the six estimated curves look very alike and hardly deviate from the curve depicted in Figure 3. The inverse u-shaped course is clearly visible. In contrast, the curve that is associated with the additional controls specification in Table 7 looks quite differently. It rather reveals a concave decreasing course and not an inverse U, even though a slightly upward sloping part is visible. Thus, we cannot conclude that our results are robust to the specific choice of the control variables. However, we think that even the curve associated with the additional control specification exhibits strong similarities to the other curves, particularly in its non-linearity and downward sloping part.

Table 7: The Link between CO_2 per capita and economic complexity: Estimations with additional and alternative control variables

	(1) Additional Controls	(2) Alternative Controls
$CO_{2p.c., t-1}$	0.378***	0.562***
	(0.12)	(0.12)
ECI	2.883**	5.548**
	(1.07)	(1.97)
ECI^2	-0.583***	-0.969**
	(0.18)	(0.34)
GDP per capita	0.000	
	(0.00)	
Agriculture (% of GDP)	0.008	0.077**
	(0.02)	(0.03)
Industry (% of GDP)	0.044*	0.040
	(0.02)	(0.03)
Trade (% of GDP)	-0.005*	
	(0.00)	
Natural Resources Rents (% of GDP)	0.077	0.163**
	(0.05)	(0.06)
Population Density	-0.025	-0.053**
	(0.03)	(0.02)
Urban Population	0.051	0.019
	(0.03)	(0.02)
Civil Liberties	-0.055	
	(0.10)	

Net FDI inflows (% of GDP)	0.003	
	(0.00)	
Alternative & Nuclear Energy Use	-0.014**	
	(0.01)	
Electric Power Consumption	0.001**	
	(0.00)	
HDI		5.660*
		(3.09)
Exports (% of GDP)		-0.004
		(0.01)
Political Stability		-0.264
		(0.16)
Government Effectiveness		-0.052
		(0.22)
Control of Corruption		0.172
		(0.25)
Constant	-4.093	-6.931
	(4.98)	(4.31)
Joint Significance?	✓	✓
Inverse U?	✓	✓
Turning Point	2.471	2.863
R^2	0.781	0.694
N	245	245

Dependent variable: Average per capita production-based CO_2 emissions (CO_2/population), measured in tonnes per year. All regressions include time dummies. ✓ indicates joint significance or significant inverse U at least at the 10% level. X indicates insignificance. Clustered standard errors in parentheses. */**/*** indicates statistical significance at the 10/5/1 percent level. Data for alternative and nuclear energy use and electric power consumption only available until 2014. No data on FDI per GDP (HDI) for Bosnia and Herzegovina before 1998 (2000). No data on Governance Indices for the years 1995, 1997, 1999 and 2001.

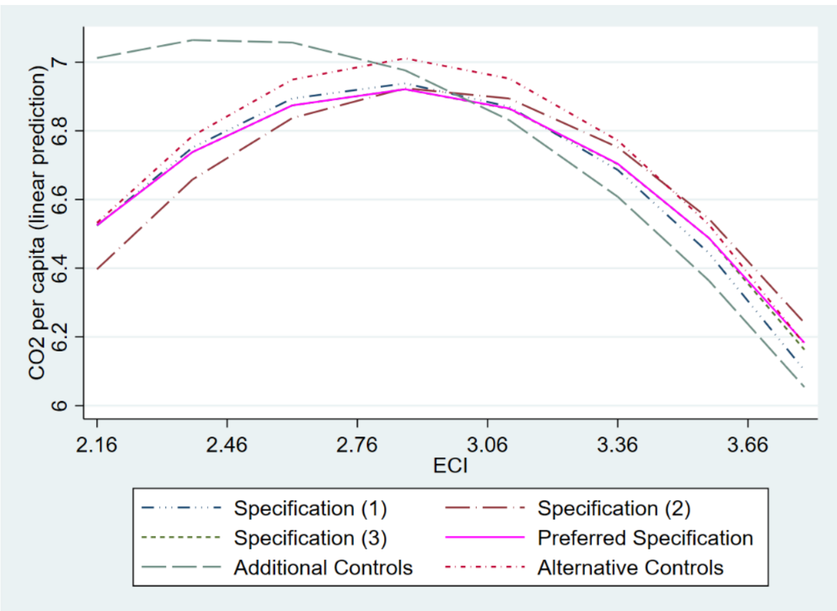

Figure 5: Estimated Environmental Kuznets Curves for production-based CO_2 emissions per capita, based on six different specifications. Note: Confidence intervals are omitted for greater clarity.

Table 8: Alternative Environmental Pollution Indicators

	(1) Methane p.c.	(2) Nitrous Oxide p.c.	(3) GHG p.c.	(4) CO_2 per unit Energy
One Year Lag	0.835***	0.713***	0.804***	0.694***
	(0.04)	(0.10)	(0.05)	(0.03)
ECI	0.380**	0.386***	5.263	0.150**
	(0.15)	(0.11)	(4.06)	(0.06)
ECI^2	-0.068**	-0.069***	-1.029	-0.026**
	(0.03)	(0.02)	(0.66)	(0.01)
Controls	✓	✓	✓	✓
Constant	-0.895	-0.643	-16.500	-0.227*
	(0.57)	(0.58)	(10.75)	(0.11)
Joint Significance?	✓	✓	✓	✓
Inverse U?	✓	✓	X	✓
Turning Point	2.816	2.805	2.558	2.923
R^2	0.899	0.655	0.770	0.817
N	273	273	273	285

Dependent variables: (1) Total methane emissions including land use change and forestry, measured in tonnes of carbon dioxide-equivalents per capita; (2) Total nitrous oxide emissions including land use change and forestry, measured in tonnes of carbon dioxide-equivalents per capita; (3) Total greenhouse gas emissions including land use change and forestry, measured in tonnes of carbon dioxide-equivalents per capita; (4) Annual production-based emissions of carbon dioxide (CO_2), measured in kilograms per kilowatt-hour of primary energy consumption. All regressions include time dummies and the full set of control variables outlined in section 4.2. ✓ indicates joint significance or significant inverse U at least at the 10% level. X indicates insignificance. Clustered standard errors in parentheses. */**/*** indicates statistical significance at the 10/5/1 percent level. The time period is 1995-2016 as no data for 2017 is available.

Next, we alter the dependent variable in our analysis. Up to now, only CO2 emissions have been used as an indicator for environmental pollution. Now we use data on methane emissions per capita, nitrous oxide emission per capita, greenhouse gas emissions per capita and CO2 per unit energy and return to our preferred set of control variables. Table 8 presents the results of this exercise. To save space, we do not report the coefficients of the control variables here. As can be seen, the coefficients of the linear and squared terms of ECI have the expected signs and are jointly significant for all considered pollution indicators. Moreover, the U-test rejects a monotone or u-shaped course and identifies a plausible extreme point to the pollution-complexity function in the case of methane emissions per capita, nitrous oxide emissions per capita and CO2 emissions per unit energy. However, for greenhouse gas emissions per capita we can only find very weak evidence in favor of the EKC as linear and squared term of ECI are not significant and the U-test does not identify a significant inverse U. In addition, the turning point is substantially lower that in the other specifications, hinting towards an asymmetric curve with weakly increasing emissions at low complexity values. Nevertheless, our findings are quite robust to altering the indicator for environmental pollution.

For the following robustness test, we study how our results change when we alter the functional form of our specified models. Until now, we identified the EKC by including linear and squared terms of ECI and studied their joint significance and the extremum point to the CO_2-ECI function. Here, we apply regression splines to identify the underlying relationship. Therefore, we make use of the extremum points, given by the U-test, of our preferred specifications (i.e., those with the full set of control variables) for all dependent variables we considered up to now. Following Chu (2021), we construct a dummy variable to split the CO_2-ECI function into the two segments that are predicted by the EKC: an upward-sloping part and a downward-sloping segment. Hence, in the case of CO_2 emissions per capita, our dummy variable equals one if ECI takes values above the extremum point of 2.85 (from Table 4) and zero if ECI takes values beneath the extremum point of 2.85. The extremum points referring to the other dependent variables can be found in Table 6 and Table 8. Finally, we include the interaction of ECI and this dummy variable to study the relationship depending on ECI being below or above the extremum point.

Table 9: Alternative functional form: regression splines

	(1) CO_2 p.c.	(2) Cons. CO_2 p.c.	(3) Methane p.c.	(4) Nitrous Ox. p.c.	(5) GHG p.c.	(6) CO_2 per energy
One Year Lag	0.697***	0.508***	0.857***	0.720***	0.810***	0.694***
	(0.09)	(0.07)	(0.03)	(0.10)	(0.04)	(0.02)
ECI	0.496*	0.772	0.028	0.037	0.425	0.021
	(0.24)	(0.63)	(0.03)	(0.03)	(1.23)	(0.01)
Above Turning Point	3.096***	6.208*	0.153	0.258**	3.654	0.102**
(dummy)	(0.85)	(3.02)	(0.10)	(0.09)	(3.04)	(0.05)
ECI x Turning Point	-1.088***	-1.992*	-0.056	-0.091**	-1.441	-0.036**
Dummy	(0.27)	(0.98)	(0.04)	(0.03)	(1.20)	(0.02)
Controls	✓	✓	✓	✓	✓	✓
Constant	2.322	-0.359	-0.076	-0.155	-6.809	-0.050
	(3.44)	(4.51)	(0.33)	(0.50)	(6.56)	(0.06)
R^2	0.745	0.696	0.895	0.654	0.769	0.816
N	286	264	273	273	273	285

Dependent variables: (3) Total methane emissions including land use change and forestry, measured in tonnes of carbon dioxide-equivalents per capita; (4) Total nitrous oxide emissions including land use change and forestry, measured in tonnes of carbon dioxide-equivalents per capita; (5) Total greenhouse gas emissions including land use change and forestry, measured in tonnes of carbon dioxide-equivalents per capita; (6) Annual production-based emissions of carbon dioxide (CO_2), measured in kilograms per kilowatt-hour of primary energy consumption. All regressions include time dummies and the full set of control variables outlined in section 4.2. Clustered standard errors in parentheses. */**/*** indicates statistical significance at the 10/5/1 percent level.

The results for all considered indicators of environmental pollution are presented in Table 9. For our main variable of interest, the production-based CO_2 emissions per capita, the results confirm our previous findings. The coefficient of ECI, which represents the partial effect for all ECI values below the turning point, is positive and significant. This indicates that below the turning point, higher complexity is associated with higher CO_2 emissions, as implied by the EKC. In contrast, the interaction term between ECI and the threshold dummy is negative and in absolute terms higher than the value of the coefficient of ECI, which suggests that the partial effect for all ECI values above the turning point is negative. This, in turn, indicates that after the turning point, a higher value of economic complexity is associated with lower per capita CO_2

emissions, as implied by the EKC. This is consistent with our previous results and shows that our findings with respect to production-based CO_2 emissions per capita do not hinge on the choice of the underlying functional form.

The results for the other applied indicators are less clear. The interaction term is negative and in absolute terms higher than the coefficient of ECI throughout all specifications, but it is not always statistically significant. Additionally, the coefficient of ECI is not precisely estimated in all specifications (2)-(7). Therefore, we can only find weak evidence for an inverse u-shaped relationship between complexity and various environmental pollution indicators when applying regressions splines. However, it should be noted that the results presented in Table 9 do not stand in stark contrast to our findings from previous estimations. Moreover, it is interesting to see that when applying regression splines, it seems that the upward sloping part of the curve is harder to detect. This is in line with the results of the model with additional control variables. If anything, it therefore seems that there is a tendency towards a weak upward sloping part and a strong downward sloping part of the curve.

In this section, we showed that our findings are quite robust to substituting the set of control variables, the main dependent variable, and the underlying functional form of the model, even though some specifications rather point towards a rather weakly upward sloping part of the curve. We additionally checked for the sensitivity of the relationship by restricting the observation period to 2004-2017 to evaluate if the bending of the curve was mostly due to the accession to the EU. If it were the case that the countries were on a positive ECI-CO_2 path, which has been only reversed by the entry into the EU, then we would not expect to see an inverse U over the observation period 2004-2017. However, we still find an inverse U with an upward sloping part below the turning point. Additionally, we experimented with the classification into the two sub-groups and found no large impact of single countries classified as increasing ECI or decreasing/constant ECI on our results. We also conducted the whole analysis based on a sample split into three groups (increasing vs. constant vs. decreasing ECI) and found robust evidence in favor of the EKC. For the sake of brevity, we do not report these estimations, but they are available upon request.

6. Conclusion

Following a recently emerging research strand, we have examined the nexus between environmental pollution and economic complexity for the former socialist transition countries. To this end, we have extended the previous conceptual foundations of this approach to include a more in-depth consideration of the underlying products and a sample selection and split that is more suitable for studying the question at hand than previous approaches. Based on the EKC hypothesis we should expect an inverse u-shaped relationship between environmental pollution and economic development as an economy progresses and becomes more complex.

Our empirical results suggest that the characteristic U-shape can be found for specific subsamples of the considered countries and not for the full sample. We document a significant inverse u-shaped relationship between CO_2 emissions and economic complexity for countries whose complexity increased over time. In those countries the CO_2 emissions have been increasing with growing complexity until they reached a certain threshold after which they started to decrease. We think that our estimates represent credible evidence in favor of the EKC even though some robustness tests point into the direction of a rather negative concave course of the curve. To the least, throughout all our estimations we credibly showed that the relationship between environmental pollution and economic complexity is non-linear and turns negative for higher complexity values.

Based on the extensive literature, we introduced three different strands of explanation for the existence of the EKC and differentiated between a preference shift towards more environmental awareness, a shift towards greener and more complex production technologies and the offshoring of emission-intensive industries to less developed countries. To examine the possible role of emissions offshoring, we analyzed the evolution of consumption-based CO_2 emissions with respect to economic complexity. It turns out that the inverse u-shaped relationship can also be documented for the CO_2 emissions that arise from domestic consumption patterns, leading to the conclusion that emissions offshoring does not play a major role. Therefore, our results point towards more complex and greener products indeed being the drivers of the inverse u-shaped course, implied by the EKC. With our data at hand, we cannot assess whether this is rather a demand-driven process where a preference shift towards more environmental awareness induced a more rapid and rigorous production of greener goods or if it reflects supply-side technology shocks that facilitated the development of more sustainable products. In our view, disentangling these strands of explanation is an attractive avenue for further research.

It should be noted that this analysis faces some drawbacks. With respect to the broader context of the ECI/CO_2 nexus, the results could be due to specific particularities of the chosen sample. Also, it is quite possible that the effects of the transition were not absorbed as early as 1995, as had been assumed in this paper and accordingly other unintended effects might have influenced the results. Furthermore, the sample of the countries with increasing complexities mostly consists of member states of the European Union and therefore other institutional factors might have influenced the emissions path of these countries. Moreover, our sample size is comparably small which reduces the statistical power of our estimates, on which we base our conclusions.

An additional important, albeit not surprising finding of our analysis is that the turning point after which the emissions start to decrease is associated with very high levels of pollution. This can be documented throughout all our estimations. Hence, for the EKC to unfold its positive effects on environmental pollution and, ultimately, climate change, it is necessary to accept substantial adverse effects in the form of higher pollution levels beforehand. If we were to extrapolate these findings to the development and emissions path of currently underdeveloped countries, we would either have to accept that emissions would further rise as these countries develop or somehow prohibit them from developing, to reduce CO_2 emissions. It should therefore be kept in mind that this dilemma can potentially be an obstacle for joint actions to fight climate change. Hence, for policymakers it remains challenging to choose the right path in fighting climate change and simultaneously enhancing the standards of living. Relying solely on the power of the EKC may not be sufficient as the implied rise of the CO_2 emissions might be too high and socially and environmentally unacceptable. Our findings nonetheless show that it is generally possible to reduce CO_2 emissions by developing more complex and innovative products. From a policy perspective, it therefore might be sensible to pursue green innovation and industrial policies more resolutely to actively dissolve the trade-off between economic development and environmental pollution.

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