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Reevaluating the Environmental Kuznets Curve for Carbon Dioxide Emissions: The Impact of New Technologies and Increasing Environmental Concerns

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Abstract

Carbon dioxide (CO_2) emissions pose a significant threat to the planet as they contribute to global warming, which then creates extreme environmental changes. Researchers concerned with these dangers therefore have studied the connection between economic growth and carbon emissions, with some focusing closely on the Environmental Kuznets Curve (EKC). This EKC pattern proposes that rising economic growth can lead to reduced carbon dioxide emissions as countries turn away from the pollution of fossil fuels toward more environmentally beneficial alternative sources of energy. A considerable number of studies have sought to evaluate the potential for the carbon dioxide EKC, frequently with disparate outcomes. Some of these studies have revealed a CO_2 EKC for specific countries or regions but other research has shown no carbon EKCs for the same areas. Most of these studies used different datasets, models, estimation techniques, and analysis to produce their results, but this lack of uniformity has led to widely differing outcomes. We seek to provide some stability by revisiting our previous study on the CO_2 EKC using the same variables, regions, and estimation technique but with more recent data. We therefore update our dataset to include the years 1980-2019 and use Generalized Methods of Moments (GMM) regression to assess how economic development in OECD and non-OECD countries impact the likelihood of the carbon EKC. We further analyze other common factors such as population growth, trade, urbanization, and energy use in terms of their influence on carbon emissions. We find that the N-shaped pattern for OECD countries from the previous study disappears in the current study. For the non-OECD region of Latin America, the new results show a CO_2 EKC but the African and Asian EKCs from the prior study vanished.

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1. Introduction

Global carbon dioxide (CO_2) emissions continue to rise, with the U.S. Energy Information Administration (EIA) projecting future increases due to an elevated use of fossil fuels for energy generation and consumption, particularly in non-OECD countries (EIA, 2021). This increase in carbon emissions has overwhelmed the normal planetary carbon dioxide cycle, where the previously the natural processes of the planet effectively recycled normal levels of CO_2 in the atmosphere and prevented a build-up of this dangerous Greenhouse Gas (GHG). Yet the constant burning of fossil fuels, wood, and other carbon-intensive sources of stored energy, though, has released vast amounts of carbon dioxide that the planet cannot completely regulate (Acheampong, 2018; Dogan et al., 2021; OECD, 2022; Fan et al., 2006; Sadorsky, 2009; Zafar et al., 2019). As CO_2 levels grow excessively worldwide, the planet warms and ecosystems face unprecedented transformations, usually for the worse (Dietz and Rosa, 1997; Heil and Selden, 2001; Shi, 2003). Droughts occur more often and for longer time periods, fires intensify and spread more rapidly, hurricanes worsen, and habitats disappear, among many other negative environmental impacts (Jha and Dev, 2024).

Hence, researchers have examined the effects of various influences on carbon dioxide emissions and then have used their results to suggest policies that could limit or reverse carbon emissions, such as adopting carbon trapping technologies (Raza et al., 2016). Multiple studies, though, place more reliance on the development of a carbon Environmental Kuznets Curve (EKC), which posits that carbon emissions naturally decrease as economies develop due to better technologies and a diminishing reliance on carbon-intensive energy sources (Cole et al., 1997; Cole, 2005; Dietz and Rosa, 1997; Dinda, 2004; Dutt, 2009; Galeotti and Lanza, 1999, 2005; Galeotti et al., 2006; Gielen et al., 2019; Sadorsky, 2009; Schmalensee et al., 1998; Sharma, 2011). However, many of these studies have produced distinct results that have disagreed with one another (Burnett et al., 2013b; Dogan and Seker, 2016a; Luzzati, 2015; Poudel et al., 2009), thereby creating considerable confusion about the validity of these various studies. For example, many studies have found a carbon EKC but other studies uncovered different emission patterns for the same regions or countries. The CO_2 literature abounds with these contradictions and differing results, confounding the ability to determine if the CO_2 EKC really does exist. Furthermore, some studies have examined only individual countries (Dogan and Turkekul, 2016; Kim et al., 2020; Tutulmaz, 2015), but this more limited approach does not reveal general EKC patterns. Consequently, the CO_2 EKC still needs further evaluation.

We contribute to the literature by taking the rare approach of revisiting a previous study (Beck and Joshi, 2015), using updated data from the World Bank Development Indicators 2022 but keeping the variables, model, and countries the same. We seek to determine whether the new dataset challenges or confirms the previous results, with the reliance on the same dynamic GMM estimation technique providing continuity and preventing the chaos that can come from different techniques showing diverse results. To compare carbon dioxide emission trends, we construct a panel dataset for OECD and non-OECD countries with the non-OECD additionally divided into the three regions of Africa, Asia, and Latin America. We further analyze how economic growth, population growth, better terms of trade, urbanization, and energy consumption impact the likelihood of an EKC for carbon dioxide.

The results show that the EKC does not exist for OECD countries due to the insignificance of the economic growth variables *PCI* and PCI^2 and that it only exists for the Latin American region in the non-OECD countries. Population growth and trade openness similarly show insignificant outcomes for the OECD countries even though both also have a positive sign that normally would suggest they contribute to rising carbon emissions. In the non-OECD category, population growth is negative and significant only for the Asian region but trade openness is positive and significant for both Asia and Latin America. Interestingly, urbanization is negative and significant for the OECD countries but positive and significant for Latin America and Asia, signifying that the development of additional urban areas might help reduce emission rates in these regions. Finally, energy use remains negative and significant for the OECD countries and all non-OECD regions, suggesting that countries have begun to transform their energy use into less carbon intensive forms. The rest of the paper proceeds as follows: section 2 presents a selected review of the EKC literature, section 3 appraises the data, section 4 describes the empirical model, section 5 reviews the estimation results, and section 6 provides some conclusions.

2. Selected Literature Review

Rising carbon dioxide levels pose a grave threat to life on the planet. As a particularly efficient GHG, CO_2 warms the earth and consequently disrupts natural processes by excessively transforming a wide diversity of ecosystems. The planet is now in a period known as the Sixth Great Extinction, where numerous species have failed to adapt to a rapidly changing climate and thus have died off. Human life itself is imperiled, as the changing environment creates the potential for substantial refugee and resource problems. Researchers and environmentalists therefore have scrambled to find some solution to these elevated CO_2 levels. Some have advocated for an enhanced use of renewable energy sources that do not release carbon dioxide even as others have suggested various methods of carbon sequestering. A few, though, have argued that an Environmental Kuznets Curve for carbon dioxide will emerge that has an inverted U pattern of emissions, where carbon emissions at first increase with economic development but then decrease with further growth as a result of advancements in technology and a shift to a less industrial-based economy (Acheampong, 2018; Ahangari and Moradi, 2014; Bilgili et al*.,* 2016; Dogan et al*.,* 2021; Galeotti, 2007; Kasman and Duman, 2015; Martínez-Zarzosa et al., 2007; Nathaniel et al., 2021; Panayotou, 2003; Panayotou, 1997; Torras and Boyce, 1998). They hope that carbon emissions will naturally decrease and therefore present less of a threat to life overall.

Yet reducing atmospheric carbon dioxide is a complex issue. CO_2 has an externality problem where people are not directly affected by elevated CO_2 levels and therefore remain less motivated to pressure governments to enact change (Arrow et al., 1995; Dijkgraaf and Vollebergh, 2005; Dinda, 2004; Halkos, 2003; Lipford and Yandle, 2010; Panayotou, 2003; Shafik and Bandyopadhyay, 1992). Furthermore, the World Bank Development Indicators measure CO_2 production as coming from "the burning of fossils fuels and the manufacture of cement" (World Bank, 2022), leaving out the carbon emissions arising from forest fires, cooking fires, and other natural sources. Solutions to rising CO_2 levels therefore often do not address these forms of discharge, although the planetary carbon cycle has proven some adeptness in regulating these more natural releases. It does take time for the environment to store excessive carbon in the form of trees, plants, and absorption by the ocean.

Importantly, developed and developing countries often do not agree on how to limit carbon emissions, creating an impasse among countries that nevertheless do acknowledge the importance of carbon reduction (Rannard, 2022). Developed countries have reached high enough economic growth that they can devote time and resources towards repairing environmental damage, although these countries still produce copious amount of carbon dioxide (OECD, 2022). Developing countries, though, focus their attention on economic development based mostly on fossil fuel use; they fear that any policies imposing carbon dioxide emission restrictions might harm that growth (Rott et al., 2022). Without some type of consensus among all countries, carbon emissions will continue due to a seemingly unbreakable dependence on fossil fuels (EIA, 2021). Ironically, developed countries also appear reluctant to actually help developing countries with the costs of carbon mitigation, although they do pledge their support to the developing countries.

However, several studies have provided some evidence for a carbon EKC where continuing economic development has resulted in fewer carbon emissions (Apergis, 2016; Dietz and Rosa, 1997; Dutt, 2009; Galeotti and Lanza, 1999, 2005; Nabi et al., 2020; Peng et al., 2025). Further studies have shown that only OECD or highly developed economies have experienced a CO_2 EKC (Cole, 2005; Galeotti et al., 2006; Iwata et al., 2010; Schmalensee et al., 1998). Kasman and Duman (2015) found an EKC for selected EU countries while Raza and Shah (2018) discovered the EKC for the G7 countries. Zafar et al. (2019) revealed an EKC for selected OECD countries even as Dogan and Seker (2016a) observed it for countries of the EU.

Other studies, though, have uncovered little or no evidence for a carbon dioxide EKC, where either CO_2 emissions have continued to rise with economic growth or other factors besides economic development helped to reduce carbon emissions (Chen et al., 2022; Cole et al., 1997; Dijkgraaf and Vollebergh, 2005; Dogan and Turkekul, 2016; Galeotti, 2007; Luzzati, 2018; Shafik and Bandyopadhyay, 1992; Wang, 2012; World Bank, 1992). Bölük and Mert (2014) evaluated 16 EU countries but failed to support the EKC for CO_2. Similarly, Isik et al. (2021) looked at 8 OECD countries but did not find the carbon EKC.

Additional studies have suggested that the strong emphasis developing countries place on growth above all else has resulted in rapid increases in their carbon emissions that potentially will negate the chance of an EKC later (Lipford and Yandle, 2010; Schmalensee et al., 1998). To benefit from an EKC, these countries would need to reach a very high level of development by constantly exploiting their resources (Cole, 2003). This approach could trigger the scale effect that leads to ever increasing emission of carbon dioxide (Bilgili et al., 2016; Nathanial et al., 2021). Some of these countries, though, may never reach the required level of development due to lack of resources, thereby preventing the EKC from emerging to help decrease CO_2 emissions. In our previous study, we found an N-shaped curve; other studies also have found that an initial apparent EKC can turn into the N-shape with further development (Galeotti, 2007; Musolesi and Mazzanti, 2010). The argument is that a reduction in carbon emissions due to technology or an economic shift would provide only temporary decreases in carbon emissions that once again rise at even higher levels of development. Such a pattern can occur due to not only a car culture but also the need for ever more energy production from carbon heavy sources.

The literature abounds with multitudes of studies that have such differing results, which makes understanding the processes behind a carbon EKC more difficult. In addition, diverse studies use different datasets, regression techniques, and time frames that make it more difficult to discover whether the carbon EKC truly exists (Burnett et al., 2013b; Dogan and Seker, 2016a; Luzzati, 2015; Poudel et al., 2009). Hence we decided to revisit our earlier study by using the same econometric technique and variables but with an updated dataset from the same source to determine if the new results differed from the previous ones.

3. Data

Although single-country studies can reveal the trends affecting an individual country's production of carbon dioxide internally, they do not give insight into the overall patterns of emissions. The country-specific approach only illuminates a part of the EKC puzzle since it is not possible to extrapolate individual country results to a higher level of global trends and attain accurate outcomes. A global approach could reveal overall carbon emission trends better, but global datasets have problems in that some countries do not collect much data on CO_2 emissions and too many diverse countries provide conflicting data that makes determining a global EKC extremely difficult. Hence we focus on groupings of similarly situated countries based on their economic status and shared regional geographies, with the expectation that regional EKC patterns have much to reveal about economic development and its implications for CO_2 emissions. We therefore in our study look at various OECD countries and the non-OECD regions of Africa, Asia, and Latin America to check for possible carbon EKCs.

We use World Bank Development Indicators (World Bank, 2012, 2022) to create enhanced panel datasets with more recent data, covering 1980 to 2019. Table 1 describes the variables of the study and presents summary statistics for the OECD countries as well as for the three non-OECD regions. It shows each variable's mean and standard deviations.

Table 1: Definition of Variables and Summary Statistics for OECD and Non-OECD regions

Variable	Description of the Variables	Mean	Std.Dev.	Obs.
OECD				
CO_2	CO_2 emissions (metric tons per capita)	9.77	4.69	880
PCI	GDP per capita (constant 2000 US$)	38612.35	19052.72	853
POPG	Population growth (annual %)	0.61	0.53	879
TOT	Net barter terms of trade index (2000 = 100)	100.82	18.17	460
URBAN	Urban population (% of total)	76.32	10.72	880
ENGY	Energy use (kg of oil equivalent per capita)	4363.43	1829.97	792
Non- OECD Regions				
Latin Am.				
CO_2	CO_2 emissions (metric tons per capita)	2.39	2.62	880
PCI	GDP per capita (constant 2000 US$)	5695.35	3598.74	840
POPG	Population growth (annual %)	1.52	0.75	880
TOT	Net barter terms of trade index (2000 = 100)	126.10	51.15	831
URBAN	Urban population (% of total)	64.85	15.98	880
ENGY	Energy use (kg of oil equivalent per capita)	1213.53	1722.22	771
Asia				
CO_2	CO_2 emissions (metric tons per capita)	3.07	3.58	440
PCI	GDP per capita (constant 2000 US$)	6677.48	11423.40	440
POPG	Population growth (annual %)	1.61	0.89	440
TOT	Net barter terms of trade index (2000 = 100)	99.20	22.87	417
URBAN	Urban population (% of total)	42.37	26.11	440
ENGY	Energy use (kg of oil equivalent per capita)	1281.66	1480.89	386
Africa				
CO_2	CO_2 emissions (metric tons per capita)	1.41	2.38	480
PCI	GDP per capita (constant 2000 US$)	2177.24	2094.37	480
POPG	Population growth (annual %)	2.65	0.70	480
TOT	Net barter terms of trade index (2000 = 100)	129.31	45.71	480
URBAN	Urban population (% of total)	42.94	13.66	480
ENGY	Energy use (kg of oil equivalent per capita)	752.10	676.74	418

To be consistent with our previous study, we have used the same variables. We also chose to use these common variables due to the contradictory results coming from the literature concerning how they influence carbon emissions; we seek to bring clarity to whether these variables do impact CO_2 releases. For the dependent variable, we utilize the CO_2 emission rate, *CO_2*, which the World Bank measures in terms of metric tons per capita[1]. The World Bank Indicators include only emissions from cement manufacturing as well as the use of

[1] The World Bank uses data for CO_2 from climatewatchdata.org/ghg-emissions.

fossil fuels in production and consumption (World Bank, 2012, 2022). The World Bank information does not contain data about emissions from other sources, such as forest fires, volcanic events, or other more natural causes of carbon emissions. For the independent variables of the model, we use the lagged dependent variable, economic growth (*PCI*), economic growth squared (PCI^2), population growth, terms of trade, urbanization, and general energy consumption. Because CO_2 does have an externality issue that slows governmental response to rising emission levels, we use a lag term for the dependent variable, CO_{2t-1}, to determine if countries produce increasing emissions over time. This lagged dependent variable also allows the model to better account for the dynamics of the data. *PCI* signifies per capita GDP and its quadratic form, PCI^2, is included as the way to measure the presence (or not) of a CO_2 EKC. A positive *PCI* and negative PCI^2 indicates the existence of an EKC. Economic growth often significantly contributes to rising CO_2 levels due to a rising reliance on heavily polluting industries. The scale effect also matters, where a growing economy requires more resources and develops those resources rapidly and often without environmental considerations.

Many studies in the EKC literature have used population growth, *POPG*, to measure how a rising population might impact resources use as well as influence emission trends (Dinda, 2004; Fan et al., 2006; Martínez-Zarzosa et al., 2007). Some studies have found that population growth can increase CO_2 emissions as ever rising numbers of people demand and consume more resources (Dogan et al., 2021; Nabi et al., 2020; Nawaz et al., 2020; Shi, 2003). Other studies, though, have asserted that CO_2 emissions do not necessarily rise because of population growth (Chen et al., 2022; Casey and Galor, 2017; Dutt, 2009), with even low population countries experiencing higher levels of carbon emissions. A further argument states that even countries that have a high population can reduce emissions through technological advances and a shift in the economy. Hence we have no pre-conceived notion of how population growth might impact carbon emissions, making it a worthwhile variable to study. We very specifically use overall population growth in terms of how it impacts *per capita* emission concentrations to measure the potential for increases in CO_2 levels at the aggregate level beyond individual contributions.

Trade openness is another variable often relied upon in the literature and it does provide some interesting implications for carbon dioxide emissions; we use the independent variable *TOT*, the net barter terms of trade index, that acts as a measure of trade openness. Some studies have shown that more open trade often can lead to higher carbon emissions from increased economic development (Antweiler et al., 2001; Cole, 2005; Isik et al., 2021; Kasman and Duman, 2015; Sharma, 2011). Other studies instead have suggested that more open trade allows countries to import better technology in terms of energy efficient devices, cost-effective pollution control measures, and greater administrative efficiency that all help to mitigate CO_2 emissions (Acheampong, 2018; Al-Mulali et al., 2015; Dogan and Seker, 2016a, 2016b; Raza and Shah, 2018; Zafar et al., 2019). Although we seek to resolve these differences, there is a problem of missing datapoints for some countries that can hamper a final determination of trade's impact on CO_2 emissions.

We gauge urbanization with the variable *URBAN*, another common variable in the literature. The World Bank defines urbanization as "the urban population of the countries as a percentage of the total population of the countries" (World Bank, 2022). Studies have shown that increased urbanization can lead to more carbon emissions in that growing cities have a greater dependence on produced goods versus natural goods and generally have centralized the means of production, and thus carbon emissions, close to the cities as well (Cole and Neumayer, 2004; Fan et al., 2006; Kasman and Duman, 2015; Sharma, 2011). Conversely, that centralization can create more efficiency in the distribution of goods and services as well as encourage a greater spread of green technology to help reduce emissions (Liddle, 2014; Wang et al., 2021). Urbanization thus can have conflicting influences on carbon emissions, with a concern that the negative aspects might overwhelm the positive ones. Hence it becomes important to measure how it actually does impact carbon emissions for the diverse areas of the study.

The last variable is energy use, *ENGY*, and it represents "the use of primary energy before transformation to other end-use fuels" (World Bank, 2012). Much of the literature has asserted that energy use directly contributes to CO_2 emissions through the consumption of fossil fuels that drive the economy (Acheampong, 2018; Bölük and Mert, 2014; Dogan and Seker, 2016a, 2016b; Halicioglu, 2009; Isik et al., 2021; Kasman and Duman, 2015; Nawaz et al., 2020; Sharma, 2011; Zafar et al., 2019; Zhang and Cheng, 2009). Because fossil fuels essentially are stored carbon, the burning of these energy sources releases copious amounts of that carbon into the atmosphere. Other studies therefore have encouraged the development of clean, renewable energy sources that do not produce carbon emissions, helping a country to decrease its overall CO_2 releases (Aguilera and Aguilera, 2012; Al-Mulali et al., 2015; Bilgili et al., 2016, 842; Dogan et al., 2021; Iwata et al., 2010; Nathaniel et al., 2021; Nawaz et al., 2020; Raza and Shah, 2018). However, renewable energy has a scaling problem in that most countries have not adopted enough of these technologies to substantially impact their carbon emission levels. The U.S. Energy Information Administration further argues that "Renewable energy use is driven by favorable technology costs and government policy, but it does not replace petroleum and other liquid fuels absent future technology breakthroughs or significant policy changes" (EIA, 2021). As a result, we agree with Atici (2009) that energy use can act as an effective proxy for technological development, with a positive sign indicating that these countries still rely more heavily on older carbon-based technologies to produce energy.

4. Empirical Model

The CO_2 EKC literature abounds with a wide variety of different econometric techniques and datasets, making the results differ from one study to the next. We therefore decided to update our previous article using the same econometric method but with more current data to determine if any changes have occurred over time. We avoid the use of random or fixed effects models that cannot accurately depict the patterns found with dynamic data, as with CO_2. Their problems with endogenous variables and heteroskedasticity make these techniques far less reliable and effective (Cole, 2003). Hence we use the Generalized Method of Moments (GMM) econometric technique to investigate the more complex, nonlinear relationships among variables. GMM better accounts for changing data over time, thereby controlling for autocorrelation (Burnett et al., 2013a). As an instrumental variable estimation technique, GMM produces more efficient and consistent results that solve for country-specific error terms (Halkos, 2003; Maddison, 2006; Sharma, 2011).

The energy use regressor, *ENGY*, has a potential endogeneity concern since there is such a direct link between CO_2 emissions and fossil fuels. We accordingly instrument this variable with a one period time lag so as to remove the direct link between the two variables, allowing us to determine properly how they interact. The error term for GMM becomes "white noise" (Halkos, 2003), which thus prevents the rise of serial correlation and simultaneity bias. For GMM, all independent variables except the lagged dependent variable then become exogenous and are valid as instruments.[1]

We base our equation on a modified form of the Arellano-Bover/Blundell-Bond (1995, 1998) GMM dynamic panel-data estimation, which helps deal with the problems of biasness found with earlier forms of GMM by incorporating "further restrictions on the initial conditions process" (Blundell and Bond, 1998) to allow GMM to deal with time observations smaller than normal. It accounts for heteroskedasticity and serial correlation as well. We specify the equation in an expanded logarithmic form based on balanced panel data for the OECD countries and the non-OECD regions. The equation is as follows:

$$\Delta\ln CO_{2it} = \beta_1\Delta\ln(CO_{2i,t-1}) + \beta_2\Delta\ln(PCI_{it}) + \beta_3\Delta\ln(PCI_{it})^2 + \beta_4\Delta\ln POPGit + \beta_5\Delta\ln TOT_{it} + \beta_6\Delta\ln URBAN_{it} + \beta_7\Delta\ln(ENGY_{i,t-1}) + \Delta\varepsilon_{it} \qquad (1)$$

where CO_2 signifies carbon dioxide emissions; (CO_{2t-1}) characterizes the lagged dependent variable; *PCI* designates per capita GDP, PCI^2 indicates the quadratic form of GDP per capita, *POPG* is population growth, *TOT* signifies trade, *URBAN* denotes urbanization, *ENGY* designates energy use, ε_{it} is the standard error term; subscript $_i$ equals the country, and subscript $_t$ characterizes the time period.

5. Estimation Results

Table 2 presents the outcomes of the GMM estimation for the dependent variable CO_2. It depicts the z-values for each variable as well. The econometric and statistical significance of the independent variables show positive and negative aspects. The test for no autocorrelation in the differenced error term AR(1) is significant and rejects the null hypothesis of no serial correlation for the OECD countries and all three non-OECD regions; the second-order test AR(2) does not reject the null hypothesis, which reveals that autocorrelation among the variables is not present.

[1] Please see Arellano and Bond (1991), Arellano and Bover (1998), Blundell and Bond (1997), and Halkos (2003).

Table 2: GMM Estimation Results (Dependent var. log of CO_2)

Variables	Model 1		Model 2		Model 3		Model 4	
	OECD		Latin.Am.		Asia		Africa	
lnCO₂(L1)	0.928	***	0.735	***	0.903	***	0.850	***
	0.017		0.022		0.019		0.025	
lnPCI	0.662		1.096	***	0.128	**	0.127	
	0.768		0.274		0.067		0.363	
lnPCI^2	-0.032		-0.064	***	-0.006		0.003	
	0.036		0.016		0.004		0.025	
POPG	0.003		0.006		-0.018	**	-0.025	
	0.006		0.013		0.010		0.037	
TOT	0.014		0.027	**	0.016	***	0.031	
	0.030		0.016		0.018		0.036	
URBAN	-0.204	***	0.143	***	0.122	***	-0.012	
	0.095		0.042		0.036		0.075	
ENGY(L1)	-0.807	***	-0.743	***	-0.353	***	-0.616	***
	0.073		0.074		0.061		0.171	
Constant	-3.362		-7.076	***	-1.195	***	-1.594	
	3.889		1.272		0.381		1.528	
Number of Observations	338		668		352		406	
Number of Countries	22		21		11		12	
Wald chi2 test	6198.950	***	10882.860	***	49042.620	***	4749.020	***
Arellano-Bond Test for zero autocorrelation AR(1)	-1.880	***	-1.997	**	-2.259	**	-2.179	**
Arellano-Bond Test for zero autocorrelation AR(2)	-1.181		1.572		1.184		1.088	

Notes: Significance at 10% shown by *; at 5% by **; and at 1% by ***. L1 stands for lag of one period.

The lagged dependent variable CO_2 *(L1)* for the 22 OECD countries is positive and statistically significant at the 1% level, denoting that elevated CO_2 emissions happen unceasingly from the past to the future. We find that *PCI* is positive and that PCI^2 is negative, which ordinarily might suggest an EKC where carbon emissions decline at a later point in time/development. Such an outcome also seemingly would contradict our earlier article that found an N-shape pattern. However, *PCI* and PCI^2 both are statistically insignificant, which implies that the EKC might not be the true emission pattern for the OECD countries. We therefore do not support the results of Cole (2005), Galeotti et al. (2006), and Schmalensee et al. (1998). It appears that the OECD countries have reached a point where carbon emissions do not follow any set patterns, perhaps due to diverse environmental pressures placed on the governments of those countries or a differing ability to limit emissions.

Population growth, *POPG*, is not significant, as with the earlier study; this result questions whether a larger population necessarily leads to more CO_2 emissions in OECD countries. Possible technological advances also could account for this outcome as they can mitigate emissions coming from even a large population. We therefore cannot corroborate Chen et al. (2022), Dogan et al. (2021), Dutt (2009), Fan et al. (2006), Nabi et al. (2020), or Nawaz et al. (2020). Also like the earlier study, trade openness, *TOT*, shows positive and insignificant signs and therefore cannot confirm nor deny other studies (Acheampong, 2018; Al-Mulali et al., 2015; Antweiler et al., 2001; Cole, 2005; Isik et al., 2021; Kasman and Duman, 2015; Raza and Shah, 2018; Sharma, 2011; Zafar et al., 2019). Such results are not unexpected given the high degree of open trade among the OECD countries. The implication is that further investigations studies should focus specifically on these two variables as they relate to CO_2 emissions to reveal more accurately whether they influence carbon levels.

Nevertheless, urbanization, *URBAN*, does have a negative and significant result, contrary to the prior study. This outcome signifies that further urbanization can lead to fewer carbon emissions as the benefits of urbanization begin to outweigh its negative attributes. We thus confirm Liddle (2014) and Wang et al. (2021) that centralizing even more resources and people into the cities and adopting better public transportation creates more opportunities for pollution reduction measures to operate more efficiently.

Energy use, *ENGY*, likewise shows a negative and significant outcome, thereby confirming the prior study. This result also counters other studies that argued energy use would increase CO_2 emissions (Acheampong, 2018; Bölük and Mert, 2014; Dogan and Seker, 2016a, 2016b; Halicioglu, 2009; Isik et al., 2021; Kasman and Duman, 2015; Nawaz et al., 2020; Sharma, 2011; Zafar et al., 2019; Zhang and Cheng, 2009). Since we use energy use as a proxy for technological development, this outcome implies that the OECD countries have begun to rely on more environmentally favorable renewable energy sources that do not produce carbon emissions (Aguilera and Aguilera, 2012; Al-Mulali et al., 2015; Bilgili et al., 2016, 842; Dogan et al., 2021; Iwata et al., 2010; Nathaniel et al., 2021; Raza and Shah, 2018). They also could have further developed technologies designed to limit or clean the carbon dioxide emissions before they enter the atmosphere.

We compare the results for the three different non-OECD regions to find that although some of these regions share common outcomes, for most of the variables the regions differ from one another. The lagged dependent variable *C02(L1)* was positive and significant for all three regions, denoting that carbon dioxide emissions continue from year to year at relatively high levels. However, only the non-OECD region of Latin American has a carbon EKC, with *PCI* positive and significant but PCI^2 negative and significant. For both the regions of Africa and Asia, PCI^2 is insignificant with only Asia demonstrating a significant positive sign for *PCI*. Hence these two regions do not provide evidence of an EKC, which partially contradicts the earlier study that did show an EKC for Africa and Asia. It appears that the countries of the Latin American region have reached a level of development that contributes to a decline of carbon emissions but the other two regions have experienced a reversal in that they continue to have growing CO_2 releases. Africa and Asia are rapidly developing regions where restrictions on carbon pollution might harm further economic growth, making these regions less likely to attempt to curb those emissions. We therefore can confirm Cole (2003), Dasgupta et al. (2002), Lipford and Yandle (2010) and Schmalensee et al. (1998). Perhaps reforestation efforts in Latin America additionally have contributed to its EKC.

As with the prior study, population growth, *POPG*, demonstrates a negative and significant result for the region of Asia and an insignificant outcome for the Latin American region; contrary to our study, though, the African region shows a negative and insignificant outcome whereas before it had a positive and significant sign. Possibly the additional years of data have muddled the African CO_2 pattern through different emission levels among the countries of this region. Even though the Asian region experiences some of the highest rates of population growth, the rising population does not seem to produce larger carbon dioxide releases. Feasibly, technological expansion or the reliance on intensive human capital rather than machines to produce goods allows this region to limit its emissions. Hence we confirm Chen et al. (2022) and Dutt (2009).

Trade openness, *TOT*, has a positive and significant result for the countries of Asia and Latin America but not for those of Africa, which shows an insignificant effect. The previous study showed positive and significant outcomes for the Asian and African regions, though. Trade openness particularly for the Asian countries contributes to higher carbon dioxide releases, possibly due to rising economic development and thus more trade; hence an enhanced scale effect is occurring (Bilgili et al., 2016; Dinda, 2004; Grossman and Krueger, 1995; Nathaniel et al., 2021; Panayotou, 1997, 2003). The additional data suggests that African countries have yet to reach the level of trade openness that would lead to higher emissions, but that the Latin American region has experienced a rise in trade that would lead to an increase in CO_2 emissions.

Like in the previous study, urbanization, *URBAN*, shows significant and positive signs for Asia and Latin America and insignificant outcomes for the African region. We again verify Liddle (2014) and Wang et al. (2021). The African countries might not have yet urbanized enough to suffer from the increased emissions due to the more concentrated amount of people and production in cities that urbanization seems to foster in the other non-OECD regions.

Differing in part to the earlier study that only had the Latin America and Asia regions with negative and significant signs, energy use, *ENGY*, shows a negative and significant outcome for all the non-OECD regions. This outcome indicates that the contributions to carbon emissions by energy utilization is decreasing, implying that environmentally beneficial technologies have begun to spread more widely as suggested by other studies (Aguilera and Aguilera, 2012; Al-Mulali et al., 2015; Bilgili et al., 2016; Dogan et al., 2021; Dogan and Seker, 2016a; Iwata et al., 2010; Nathaniel et al., 2021; Raza and Shah, 2018). In addition, it appears that African countries have begun to develop or import technologies to help mitigate carbon emissions. However, neither the OECD region nor the three non-OECD regions have done enough to substantially reduce the CO_2 releases that continue to pose a grave danger to the planet.

6. Conclusion

We reexamine our past study but with more updated data from a longer time period to determine if the added data would lead to different results. We find that in some cases we can verify the prior study, yet for other variables we discover a change has occurred in the outcomes. As with the previous study, we discover that population growth, trade openness, and energy use follow the same patterns for the OECD countries; population growth and trade openness remain insignificant and energy use is significant and negative. However, economic growth for OECD countries diverges from the earlier study in that it now shows a potential EKC, though insignificant, rather than the previous N-shape. Hence it becomes more difficult to determine if the new data actually counters the prior study. In the current study, urbanization presents a different result in that it now has a negative and significant outcome whereas previously the OECD countries demonstrated a positive and significant result. This change indicates that the OECD countries have benefitted from further urbanization, perhaps due to better effects from centralization or efficiency.

In terms of the non-OECD regions, the two studies again share a few common outcomes but diverge with other variables. In terms of economic development, only Latin America demonstrates the EKC pattern whereas before the African and Asian region did. This reversal implies that additional growth has created detrimental outcomes for the countries of Africa and Asia by prompting greater carbon emissions. The Latin American countries appear to have reversed some of their emission trends with additional economic development. For population growth, the Asian region still has a negative and significant result and the Latin American region again shows insignificant outcomes. The African region, though, went from positive and significant in the earlier study to insignificant currently, suggesting that population growth in Africa is more complex and thus requires more studies to reveal how population growth impacts carbon emissions. Trade openness also differed from the past study in that the Latin American region currently reveals a positive and significant outcome, where before it was insignificant. The African region went from significant and positive to insignificant, as with the population growth variable. Trade openness therefore has a more diffuse influence on carbon emissions in the African region. Urbanization, though, reveals the same results from the earlier study where it leads to more carbon emissions as cities in these countries enlarge. Energy use differs only in part where all the non-OECD regions now display negative and significant outcomes where previously Africa presented insignificant outcomes. Perhaps the African countries have caught up to the other regions in the partial use of non-polluting energy sources.

Overall, then, the OECD countries generally exhibit similar patterns of influence on carbon emissions with only a few changes. Yet the non-OECD regions of Africa, Asia, and Latin American have experienced different trends with the same variables used by our previous study, showing some interesting developments. Part of these variations might have appeared due to the World Bank adopting different data collection methods in the past decade, which has created more accurate depictions of what happens among these countries. Moreover, the additional years of data reveal in further detail how these variables affect carbon dioxide emissions. CO_2 patterns change over time and from a variety of circumstances, including the pandemic. Like all studies on CO2, our contribution is limited by the available data from many countries as well as the tendency of carbon dioxide to traverse country borders. Only a constant re-evaluation of the data can eventually uncover the true carbon dioxide emission patterns. Hence future studies should continue to monitor and evaluate the impact these variables can have on carbon releases.

The importance of studying carbon emissions has not diminished over time, though; it remains critical to reduce CO_2 emissions in both developed and developing countries. Nevertheless, these countries still face the same problem. They depend too much on fossil fuels to generate economic growth, which applies to the developed countries as much as it does to the developing countries. Although the developed countries generally have the technology and finances to achieve needed change, they also have indicated less willingness to share those resources with the developing countries as seen with the inability to negotiate environmentally sound carbon dioxide policies at many of the Conference of the Parties to the United Nations (COP) meetings.

We still argue that countries ought to regulate carbon emissions and educate their people more fully as to the dangers of unrestricted carbon emissions to current and future generations. Yet even raised awareness of the dangers of a warming planet brought upon by rising carbon dioxide levels often cannot counter the externality of carbon dioxide that makes the threat less immediate to people's lives. They even now have difficulty in connecting the worsening environmental situations to rising levels of carbon dioxide and thus place less pressure on governments to enact positive change. Governments therefore need to incentivize both business and citizens to reduce fossil fuel energy usage in both developed and developing countries. Future research should strive to create some uniformity among diverse studies to reduce confusion and disparate results. In addition, researchers should explore more fully the interactions between carbon emissions, economic growth, and energy production to encourage a stronger reliance on renewable and non-polluting sources of energy generation.

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Conflict of interest

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