The trade-off between GDP and CO2 emissions in poor countries: A dynamic common correlated effects approach for unbalanced panel data

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ABSTRACT

In recent years, the term "climate change" has been increasingly receiving a lot of attention from scholars and policy makers, adversely affecting the lives of people (mostly of the poor) around the world in the present, and threatening the environment quality in the future. With many concerns about environmental degradation, countries tend to transform economic growth models causing negative impacts on the environment, especially for those in the stage of industrialization and modernization. This study was aimed at investigating the trade-offs between economic development and climate change among poor nations – the most affected by and most likely causing to climate change. By using a dynamic common correlated effects approach for unbalanced panel data which deals with cross-sectional dependency and time-series persistence, the paper showed that GDP is strongly correlated to CO2 emissions both in the short and long run, and one of the reasons is the use of CO2-generating energy sources.

Keywords: CO2 emissions, cross-sectional dependency, economic development

JEL classification: C23, O44, Q54

INTRODUCTION

In the development progress, each region and country appears many commonly pressing problems. The more the economy grows, the more deleted fuel and energy sources due to the increasing consumption of non-renewable resources, the more damaged the natural environment, causing catastrophic natural disasters. It is widely supposed that economic growth not keeping pace with environment protection. One of the solutions to this problem is to build a green economy as proposed by The United Nations Environment Programme (2011). A green economy has low emissions, efficient use of resources, and social justice. In a "green economy", growth in income and employment is generated through public and private investments, along with reducing carbon dioxide emissions and pollution, and using energy and resources effectively as well as preventing biodiversity loss. In recent years, the term "climate change" has been increasingly receiving a lot of attention from scholars and policy makers, adversely affecting the lives of people (mostly of the poor) around the world in the present, and threatening the environment quality in the future. With many concerns about environmental degradation, countries tend to transform economic growth models causing negative impacts on the environment, especially for those in the stage of industrialization and modernization.

Developing countries are the most supposedly affected by climate change. The poor are indeed vulnerable to climate change (Rayner and Malone, 2001). According to the Intergovernmental Panel on Climate Change (IPCC) Report, less well-off countries are at risk of environmental pollution and find much difficult to enhance environmental quality under negative impacts from climate change (USGCRP, 2018). For example, it will take them longer (compared to the better-off) to recover the economy after suffering heavy losses from a natural disaster. Likewise, the United Nations Development Program states that nearly all of the effects of climate change affect developing countries (United Nations Development Programme, 2007). One of the evidences for this argument is that about 32 to 132 million people are being pushed into extremely poor circumstances because of climate change.

Although being the most vulnerable countries affected by climate change, poor countries also is the most likely CO2-causing countries. Accordingly, the trade-offs between economic development and environmental pollution at low-income levels are acknowledged by economists, that is, developing countries tend to discharge more and more in the future in the direction of economic development. Specifically, since 1991, the Environmental Kuznets Curve (EKC) has become a mean of describing the relationship between environmental quality and income per-capita over time (Grossman and Krueger, 1991). Economists used data on the environment as well as per capita income in countries to study this relationship. Additionally, many evidences showed that this nexus also follow an inverted-U-shape, that is, environmental degradation increases in the early stages of development, afterward reaches a peak or a turning point and starts to decline when income levels exceed a certain threshold. Subsequently, numerous later studies also show the relationship between economic growth and environmental pollution in different countries and regions.

The purpose of this study was to investigate the relationship between CO2, GDP, and energy consumption, and to measure their impacts over the long and short term in low- and middle-income countries. Focusing on solving the cross-sectional dependency and time-series persistence, I used the DCCE method developed by Ditzen (2018). The final DCCE estimation model was written in an ECM form; combining PMG method, its long-run estimated coefficients were pooled and its short-run coefficients mean-grouped. To ensure the consistency of estimation, the unit-root test, cointegration test and Hausman test were also adopted.

LITERATURE REVIEW

In-depth research into the relationship between economic development and environmental pollution has been going on for decades. In 1991, Grossman and Krueger first introduced the inverted U-shaped environmental Kuznets curve (EKC) in the study of the North American Free Trade Agreement (NAFTA) and air pollution in Mexico. They found a strong statistical relationship between environmental quality and per capita GDP for a cross-section of countries. This growth-pollution nexus was described as an inverted U-shape, similar to the relationship between inequality and growth proposed by Kuznets in 1955. Specifically, pollution increases in the same direction as economic growth at low levels of income but eventually decreases after reaching a certain level of income. Empirical research in many countries showed that GDP per capita of between $4,000 and $5,000 would reach this threshold.

Several theories could be used to explain the EKC, the first being Panayotou (1993) based on the economic development stages to explain the inverted U-shape. The structural change of a country from rural to urban and agriculture to manufacturing in the first stage of development can lead to environmental degradation. This development resulted in a high amount of greenhouse gas emissions. However, in the next period as the economic structure shifts from manufacturing to services, pollution could be reduced due to the decline in carbon-intensive industries. Additionally, technological advancement would be a reason to reduce emissions once a country reaches a stage of high income. This means that as countries get richer, they have more resources to improve their technology. As a result, obsolete technologies causing pollution are replaced by environmentally friendly ones (Galeotti and Lanza, 2005). Another explanation for EKC was that environmental quality could be considered as a normal or even luxury good (Beckerman, 1992). The income elasticity of demand for environmental quality is greater than zero or even greater than one. In this case, as income increases, the individual's perception of the environment is better, and then the demand for environmental quality is also higher. Furthermore, recent studies also proved the presence of EKC, typically the study of Atici (2009) in Central and Eastern European Countries and Apergis and Payne (2010) in Commonwealth of Independent States' countries.

Some studies also found the pollution-growth relationship with an N-shaped curve by estimating in a cubic equation form (Levinson, 2001). This curve illustrated pollution increasing at very low levels of economic growth, then starting to slip down at a certain threshold of income, and eventually rising again at the right end. Likewise, many studies agreed on the nexus between pollution and growth, but fail to support the traditional inverted-U shape. Wang *et al.* (2011) examined this nexus by running a panel vector error correction model for a dataset of Chinese provinces during 1995-2007 and showed that carbon dioxide emissions in long-run was attributed to energy consumption and economic growth. In 2011, Sharma investigated in 69 countries over the period 1985-2005 and found that GDP per capita and energy consumption were statistically significantly considered as determinants of carbon dioxide emissions.

While many studies showed that as the economy develops to a certain extent, environmental problems will be improved, some researchers rather pessimistically believed that pollution reduction is still difficult to achieve. Carbon dioxide emissions reduction is far less effective at a local level. A tragedy for the commons is that many people cause pollution but no one cleans up (Hardin, 1968). Thus, this leads to more and more pollution that accumulates and does not decrease despite high income levels, as in the US (Yandle, Vijayaraghavan and Bhattarai, 2002). These arguments clearly do not conform to EKC theory. In addition, Suri and Chapman (1998) also argued that environment improvement may not globally be achieved. Well-developed countries tend to export pollution-causing activities to poorer ones undergoing the industrialization process, which means there is nowhere for poor nations to discharge waste. This implies that it is difficult for developing countries to conduct environmental cleanup even if their economies have developed to a turning point in accordance with EKC theory.

Most recent research papers re-confirmed the complex relationship between carbon dioxide emissions and economic growth in different countries. Munir, Lean and Smyth (2020) criticized previous studies for being biased due to cross-sectional dependency, and thus run a new Granger non-causality approach for a dataset of ASEAN-5 between 1980 and 2016. Their findings support EKC and showed a one-way impact from GDP to carbon dioxide emissions in four countries. Similarly in the states of the US over the period 1997–2016, Salari, Javid and Noghanibehambari (2021) affirmed an inverted-U shape nexus following the EKC theory by using both static and dynamic panel data analysis. For analysis of sustainable development in European Union (EU) countries, Gardiner and Hajek (2020) found a long-run equilibrium between growth, energy consumption, carbon dioxide emissions as well as other macroeconomics indicators.

In short, the relationship between economic growth and greenhouse gas emissions remains a subject of controversy. Most of the research did not go into research in the group of poor countries - the most affected by climate change and in the period of industrialization. Moreover, most of these countries do not pay much attention to environmental issues, as well as little implementation of environmental economic policies, so the data of these countries is not subject to strong interference like developed countries. Another problem is the approach, to be clear, most previous studies have explained the economic relationship and environmental pollution based on the elasticity of environmental perception when income levels change. As analyzed above, such explanation will lead to many complex related issues, such as technology, population, environmental policy, etc. Therefore, in this paper, I considered CO_2 emissions as an undesirable product in the process of making economic products (GDP) along with energy consumption. If GDP is positively related to emissions, it reflects a trade-off between environmental quality and economic growth - one of the manifestations of unsustainable development. Another issue to focus on was that the methodology of panel data of previous studies lacks confidence because of cross-sectional dependence and time-serial persistence.

DATA AND METHODOLOGY

Data and expected sign

To assess the relationship between environmental pollution and economic growth in poor countries, this paper used macro data from the World Bank in 79 low- and lower-middle income countries (see Appendix A) in the period of availability. For the clarification of study object, the term “poor countries” is inconsistent with the concept of “developing countries” (including the upper-middle income additionally) or “emerging countries” (countries with economic transformation). To estimate the DCCE model, I used three data variables: CO_2 emissions (World Bank, 2020a), GDP constant 2010 (World Bank, 2020b), and Energy consumption (World Bank, 2020c); and then took the log of all as described in Figure 1. Figure 1-a, plotting the relationship between CO_2 and GDP, basically showed that there was a positive relationship between these two variables. Moreover, the correlation test between the variables also illustrated that there was little correlation between the two variables GDP and ENG (Figure 1-c).

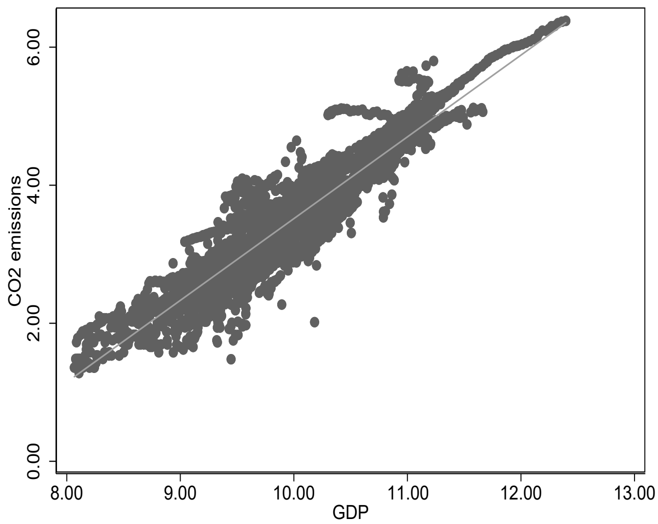
It could be seen that I did not use GDP per-capita to measure economic development, but GDP constant 2010 because of two reasons. First, the purpose of the study was not to test the EKC theory mainly because of old-fashion and controversy. Second, as mentioned in “literature review”, I would explain the relationship between pollution and economic development on the relation to the function of production. In addition, macro indicators such as international investment or trade volume were not included in the model because these factors are strongly correlated with GDP in poor countries. Furthermore, being a determinant of CO_2 emissions, energy consumption was also included as a regressor. Using the variable GDP to measure economic development, and adding the variable energy consumption as a determinant of CO_2 emissions in this study were similar to recent studies of Munir, Lean and Smyth (2020) in ASEAN+5 countries; Salari, Javid and Noghanibehambari, (2021) in U.S. states; and Gardiner and Hajek (2020) in European Union countries. In the end, this study would not be able to cover fully environmental issues as well as sustainable development, but only consider climate change which is measured by CO_2 emissions.

Figure 1. Overview of variable analysis

a. Descriptive analysis

Variable	Mean	Min	Max	Obs.
CO2	3.26	0.56	6.38	4093
GDP	9.87	8.07	12.47	3616
ENG	2.64	0.98	3.69	1899

b. The GDP-CO2 nexus (pooled)



c. Correlation analysis

	CO2	GDP	ENG
CO2	1		
GDP	0.90	1	
ENG	0.46	**0.30**	1

CO2 = Carbon dioxide emissions, GDP = GDP constant 2010, ENG = Energy consumption

Methodology

Two important issues ignored by conventional panel data models (Fixed Effects Model and Random Effects Model) are cross-sectional dependence and time-serial persistence. According to Bond (2002), macro data is usually persistent time series, that is, the data in the following years is strongly correlated with of previous years. Therefore, the estimation models for long-time panel data should consider the dynamics of these factors. For large panel data, cross-sectional dependence (CD) should be rigorously considered as mentioned in the study of Munir, Lean and Smyth (2020). One of appropriate reasons for this CD issue lies in the spatial relationship or, more precisely, neighboring countries often interact strongly economically. The similarities in geography, climatic conditions, and natural resources cause effective economic policies to be copied, so there is a spillover effect of economic policy among neighboring countries, including environmental policy. There are two types of cross-sectional dependence defined by Chudik, Pesaran and Tosetti (2011) – strong (based on the unobserved common factor approach) and weak (based on the spatial autocorrelation approach).

Dealing with two these issues, the most recent and reliable approach is Dynamic Common Correlated Estimator (DCCE) model developed by Chudik and Pesaran (2015). DCCE model is a perfect combination of Pooled Mean Group (PMG) proposed by Pesaran, Shin and Smith

(1996) and Common Correlated Effects (CCE) estimation by Pesaran (2006). The CCE model is written in the form of the following equation for a large-N country and large T-year panel data:

$$CO2_{i,t} = \alpha_i GDP_{i,t} + \beta_i ENG_{i,t} + \gamma_i \overline{CO2}_t + \delta_i \overline{GDP}_t + \eta_i \overline{ENG}_t + \epsilon_{i,t} \ (1)$$

$$\overline{CO2}_t = \frac{1}{N}\sum_{i=1}^{N} CO2_{i,t}\,;\ \overline{GDP}_t = \frac{1}{N}\sum_{i=1}^{N} GDP_{i,t}\,;\ \overline{ENG}_t = \frac{1}{N}\sum_{i=1}^{N} ENG_{i,t}\,;$$

$$with\ i = 1, \dots, N;\ t = 1, \dots, T.$$

In which, CO2, GDP, ENG, and ϵ denote carbon dioxide emissions, gross domestic product, energy consumption, and error term respectively. The presence of cross-section means of $\overline{\mathrm{CO2}}_t$, $\overline{\mathrm{GDP}}_t$, and $\overline{\mathrm{ENG}}_t$ – as known as CCE estimators which relatively eliminate impacts of unobserved common factors (strong CD) generated by the cross-sectional dependency – under strict exogeneity of these variables makes the estimation model consistent (Pesaran, 2006). However, CCE estimation is effective only for static rather than dynamic panels (Chudik and Pesaran, 2015). Adding into (1) a lagged dependent variable which is not strictly exogenous causes inconsistency in the estimation model, thus Chudik and Pesaran (2015) proposed to add $P_T = \sqrt[3]{T}$ lags of cross-section means to solve this problem and possibly reduce weak CD. The equation (1) is re-written as follows:

$$\begin{aligned} CO2_{i,t} = {} & \kappa_i CO2_{i,t-1} + \alpha_i GDP_{i,t} + \beta_i ENG_{i,t} \\ & + \sum_{p=0}^{P_T} \gamma_{i,p} \overline{CO2}_{t-p} + \sum_{p=0}^{P_T} \delta_{i,p} \overline{GDP}_{t-p} + \sum_{p=0}^{P_T} \eta_{i,p} \overline{ENG}_{t-p} + \epsilon_{i,t} \ (2) \end{aligned}$$

To estimate the short- and long-run relationship, applied to PMG approach which estimates heterogeneous short-run effects and homogeneous long-run effects, the equation (2) is converted into an error correction (EC) model:

$$\begin{aligned} \Delta CO2_{i,t} = {} & \phi_i (CO2_{i,t-1} - \alpha_i GDP_{i,t} - \beta_i ENG_{i,t}) + \alpha'_i \Delta GDP_{i,t} + \beta'_i \Delta ENG_{i,t} \\ & + \sum_{p=0}^{P_T} \gamma_{i,p} \overline{CO2}_{t-p} + \sum_{p=0}^{P_T} \delta_{i,p} \overline{GDP}_{t-p} + \sum_{p=0}^{P_T} \eta_{i,p} \overline{ENG}_{t-p} + \epsilon_{i,t} \ (3) \end{aligned}$$

In which, ϕ_i denotes the EC speed of adjustment towards the equilibrium, and α'_i and β'_i measure the immediate or short-run impacts while α_i and β_i imply the long-run. To perform this model, we also run Panel Unit-root tests and Cointegration test to check the validity of dynamic panel data. Moreover, because of unbalanced panel data with divergent T among countries, I ran DCCE models with different P_T lags, and then performed F-test, CD-test, and Hausman test to choose the best model for this research. For this purpose, F-test determines model fitting with the null hypothesis of R-squared (also known as the coefficient of determination) being zero; Pesaran's CD-test detect cross-section dependency of error terms under the null hypothesis of weakly cross-sectional dependency (Pesaran, 2015); and Hausman test indicates whether coefficients can be considered as equal across countries, more precisely, whether application of pooling coefficients is appropriate (Ditzen, 2018). For this research, I performed DCCE estimation according to the paper of Ditzen (2018), which additionally tests the model consistency including collinearity issues.

RESULTS AND DISCUSSION

Firstly, I ran panel unit root tests to check the stationarity of variables at level and first difference without time trend and drift term. Because of unbalanced panel data, it is appropriate to conduct augmented Dickey–Fuller (ADF) tests (Fisher-type) under the null hypothesis of all country groups containing unit roots. The values of *statistic* are calculated based on the modified inverse chi-squared transformation developed by Choi (2001), at three different significance levels of 1% (***), 5% (**) and 10% (*), when both T and N are assumed to tend to infinity. *Lagged differences* indicate the number of lags used in the ADF regression model. Moreover, I also specified that these tests subtract the cross-sectional averages to reduce undesirable effects of CD according to the study of Levin, Lin and James Chu (2002). Figure 2 shows results of panel unit root tests, which three variables are all stationary at first difference.

Figure 2. Panel unit root test results

Variables	Level		First difference	
	Statistic	Lagged differences	Statistic	Lagged differences
CO2	8.95 ***	0	206.29 ***	0
	4.94 ***	1	106.14 ***	1
GDP	0.03	0	117.00 ***	0
	1.34 *	1	59.81 ***	1
ENG	10.11 ***	0	79.74 ***	0
	0.47	1	39.35 ***	1

Source: Calculated from Stata software

Next, I performed a new panel cointegration test proposed by Westerlund (2005) under the null hypothesis of no cointegration, specifying that all country groups are cointegrated and subtracting cross-sectional means. The test results of dependent variable CO2 and independent variables GDP and ENG shows the Variance Ratio (VR) statistic of -2.54 at significance level of 1%, that is, *all panels are cointegrated*.

Then, I ran DCCE models with many options: short-run estimation (Pooled or Mean Group), long-run estimation (Pooled or Mean Group), and P_T lags (0, 1, 2, 3); along with performing conformity tests. The P-values of F-test and CD test, and adjusted R-squared were reported in Appendix B. It can be seen that EQ02, EQ03, EQ07 and EQ10 are statically consistent. Because EQ02 and EQ03 are set in the same pattern of PMG estimation (Mean Group short-run estimation, and Pooled long-run estimation) but different P_T lags (1 to 2), EQ02 with higher adjusted R-squared is preferred over EQ03. Following this, I compared the appropriateness of pooling between EQ02, EQ07 and EQ10 by Hausman test. The first Hausman test, whether EQ10 is preferred over EQ07, shows the statistic value of 57.33 at significance level of 1%, that is, it denies the null hypothesis and EQ07 is preferred. For the second Hausman test, there is no significance to reject that EQ02 is preferred over EQ07. In short, *EQ02 is the most preferred model*, and is described as Figure 3.

Figure 3. The best DCCE model for short- and long-run estimation

	Coef.	Std. Err	Z-statistic	P-value
Short Run Est. (MG)				
ΔENG	**0.93**	0.22	4.25	**0.00**
ΔGDP	**0.30**	0.17	1.82	**0.07**
Long Run Est. (Pooled)				
EC speed of adjustment	**-0.43**	0.10	-4.22	**0.00**
ENG	0.51	0.79	0.65	0.52
GDP	**1.03**	0.51	2.00	**0.05**
F-test	1.54 ***			
CD test	-2.01 **			
R-squared	0.66			
Adjusted R-squared	0.54			

Source: Calculated from Stata software

$$\left(\Delta CO2_{i,t} - 0.93\Delta ENG_{i,t} - 0.30\Delta GDP_{i,t}\right) = -0.43\left(CO2_{i,t-1} - 0.51ENG_{i,t} - 1.03GDP_{i,t}\right) + e_{i,t} \quad (4)$$

Combined with the DCCE model, the equation (3) is simply converted into (4) with $e_{i,t}$ indicating the residuals (including cross-sectional averages). Specifically, the left side denotes the short-run relationship, the right side the long-run relationship and the EC speed of adjustment of -0.43. In short-run, both energy consumption and GDP statistically significantly cause the increase of carbon dioxide emissions, but the former to a greater extent. In long-run, the estimation result shows that there is a trade-off between past carbon emissions and GDP at the rate of 1.03/1.00 (over three times greater than in short-run 0.3/1.00). The EC speed of adjustment of -0.43 implies that the level of emissions in the past could affect the present. In short, carbon dioxide emissions is dependent on only short-run energy consumption, mainly long-run GDP, and past values of itself. As expected, these outcomes are not surprising, just once again confirming the causal relationship between economic growth and CO2 emissions as in previous studies, typically recently Gardiner and Hajek (2020); Munir, Lean and Smyth (2020); Salari, Javid and Noghanibehambari (2021) for examples.

The findings can be explained that GDP, being a macroeconomic indicator, takes a long time to convey its impacts (potentially due to the institution), where carbon dioxide is a product of energy consumption (fossil fuels for examples), and environmental awareness of past emission levels could mitigate air pollution level. In addition, the impact coefficient of ENG in the short term can also indicate one of the main causes of pollution - polluting energy sources, specifically, one unit of energy consumption generates 0.93 unit of carbon dioxide. Considering the EKC theory, it can be said that poor countries have not yet reached the level of development that they can transform to an environmentally friendly growth model. In other words, economic development in poor countries is not sustainable, at least in terms of climate change due to CO2 emissions.

CONCLUSION

Economically, sustainable development is referred the economy uncorrelated with environmental degradation, especially when climate change is becomingly worse and worse at global and local level. Accordingly, the less well-off are the most vulnerable and should be paid attention to. To compound this puzzle, the introduction of EKC implies that pursuing CO2-intensive growth models is one of the main causes of environmental pollution in poor countries. This study investigated the short- and long-run relationship between economic development (GDP) and climate change (carbon dioxide emissions) in 79 low- and lower-middle income countries. Because of the presence of cross-country dependence and time-series persistence, I performed a DCCE model to gain consistency of estimation.

The estimation results showed that GDP has impacts on CO2 in both the short and long run. Specifically, it represented a trade-off between economic development and air pollution at a rate of 1.03/1 in the long run and 0.3/1 in the short term. This study also pointed out that one of the major reasons for this problem is the use of high-polluting energy sources in poor countries, when a unit of energy consumption generates 0.93 unit of carbon dioxide emissions on average. All of the above showed that the growth models in these countries are not sustainable, and with huge trade-offs for the nature environment.

The topic of research on sustainable development is indeed not novel, but very essential, and needs to be fully evaluated in many aspects. In this study, I only evaluated air pollution without investigating other types of pollution such as soil and water. Although CO2 is the main cause of climate change and air pollution, other kinds of waste should also be considered (SO2 and NO2, for instance). Furthermore, in order to recommend effective measures against pollution problems, it is necessary to conduct a number of more in-depth studies of the main causes, typically outdated technology in FDI projects. Finally, the trend of using and developing renewable energy sources is one of the key measures to solve environmental problems in general and climate change in particular. Such studies on environmental protection related to the development of new energy sources should also be noted in the coming time.

DECLARATIONS

Availability of data and materials

The datasets used and/or analysed during the current study are obtained from World Development Indicators https://databank.worldbank.org/source/world-development-indicators.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

This paper has only one author.

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Ethics approval and consent to participate

Not applicable because this paper does not report on or involve the use of any animal or human data or tissue.

Consent for publication

Not applicable because this paper does not contain data from any individual person.

Authors' information (optional)

Not applicable.

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APPENDIX

Appendix A. List of poor countries

Code	Region	Income Group	Country Name
AFG	South Asia	Low income	Afghanistan
AGO	Sub-Saharan Africa	Lower middle income	Angola

Code	Region	Income Group	Country Name
BDI	Sub-Saharan Africa	Low income	Burundi
BEN	Sub-Saharan Africa	Lower middle income	Benin
BFA	Sub-Saharan Africa	Low income	Burkina Faso
BGD	South Asia	Lower middle income	Bangladesh
BOL	Latin America & Caribbean	Lower middle income	Bolivia
BTN	South Asia	Lower middle income	Bhutan
CAF	Sub-Saharan Africa	Low income	Central African Republic
CIV	Sub-Saharan Africa	Lower middle income	Côte d'Ivoire
CMR	Sub-Saharan Africa	Lower middle income	Cameroon
COD	Sub-Saharan Africa	Low income	Congo, Dem. Rep.
COG	Sub-Saharan Africa	Lower middle income	Congo, Rep.
COM	Sub-Saharan Africa	Lower middle income	Comoros
CPV	Sub-Saharan Africa	Lower middle income	Cabo Verde
DJI	Middle East & North Africa	Lower middle income	Djibouti
DZA	Middle East & North Africa	Lower middle income	Algeria
EGY	Middle East & North Africa	Lower middle income	Egypt, Arab Rep.
ERI	Sub-Saharan Africa	Low income	Eritrea
ETH	Sub-Saharan Africa	Low income	Ethiopia
FSM	East Asia & Pacific	Lower middle income	Micronesia, Fed. Sts.
GHA	Sub-Saharan Africa	Lower middle income	Ghana
GIN	Sub-Saharan Africa	Low income	Guinea
GMB	Sub-Saharan Africa	Low income	Gambia, The
GNB	Sub-Saharan Africa	Low income	Guinea-Bissau
HND	Latin America & Caribbean	Lower middle income	Honduras
HTI	Latin America & Caribbean	Low income	Haiti
IND	South Asia	Lower middle income	India

Code	Region	Income Group	Country Name
KEN	Sub-Saharan Africa	Lower middle income	Kenya
KGZ	Europe & Central Asia	Lower middle income	Kyrgyz Republic
KHM	East Asia & Pacific	Lower middle income	Cambodia
KIR	East Asia & Pacific	Lower middle income	Kiribati
LAO	East Asia & Pacific	Lower middle income	Lao PDR
LBR	Sub-Saharan Africa	Low income	Liberia
LKA	South Asia	Lower middle income	Sri Lanka
LSO	Sub-Saharan Africa	Lower middle income	Lesotho
MAR	Middle East & North Africa	Lower middle income	Morocco
MDA	Europe & Central Asia	Lower middle income	Moldova
MDG	Sub-Saharan Africa	Low income	Madagascar
MLI	Sub-Saharan Africa	Low income	Mali
MMR	East Asia & Pacific	Lower middle income	Myanmar
MNG	East Asia & Pacific	Lower middle income	Mongolia
MOZ	Sub-Saharan Africa	Low income	Mozambique
MRT	Sub-Saharan Africa	Lower middle income	Mauritania
MWI	Sub-Saharan Africa	Low income	Malawi
NER	Sub-Saharan Africa	Low income	Niger
NGA	Sub-Saharan Africa	Lower middle income	Nigeria
NIC	Latin America & Caribbean	Lower middle income	Nicaragua
NPL	South Asia	Lower middle income	Nepal
PAK	South Asia	Lower middle income	Pakistan
PHL	East Asia & Pacific	Lower middle income	Philippines
PNG	East Asia & Pacific	Lower middle income	Papua New Guinea
PRK	East Asia & Pacific	Low income	Korea, Dem. People's Rep.
PSE	Middle East & North Africa	Lower middle income	West Bank and Gaza

Code	Region	Income Group	Country Name
RWA	Sub-Saharan Africa	Low income	Rwanda
SDN	Sub-Saharan Africa	Low income	Sudan
SEN	Sub-Saharan Africa	Lower middle income	Senegal
SLB	East Asia & Pacific	Lower middle income	Solomon Islands
SLE	Sub-Saharan Africa	Low income	Sierra Leone
SLV	Latin America & Caribbean	Lower middle income	El Salvador
SOM	Sub-Saharan Africa	Low income	Somalia
SSD	Sub-Saharan Africa	Low income	South Sudan
STP	Sub-Saharan Africa	Lower middle income	São Tomé and Principe
SWZ	Sub-Saharan Africa	Lower middle income	Eswatini
SYR	Middle East & North Africa	Low income	Syrian Arab Republic
TCD	Sub-Saharan Africa	Low income	Chad
TGO	Sub-Saharan Africa	Low income	Togo
TJK	Europe & Central Asia	Low income	Tajikistan
TLS	East Asia & Pacific	Lower middle income	Timor-Leste
TUN	Middle East & North Africa	Lower middle income	Tunisia
TZA	Sub-Saharan Africa	Lower middle income	Tanzania
UGA	Sub-Saharan Africa	Low income	Uganda
UKR	Europe & Central Asia	Lower middle income	Ukraine
UZB	Europe & Central Asia	Lower middle income	Uzbekistan
VNM	East Asia & Pacific	Lower middle income	Vietnam
VUT	East Asia & Pacific	Lower middle income	Vanuatu
YEM	Middle East & North Africa	Low income	Yemen, Rep.
ZMB	Sub-Saharan Africa	Lower middle income	Zambia

Code	Region	Income Group	Country Name
ZWE	Sub-Saharan Africa	Lower middle income	Zimbabwe

Source: The World Bank 2020,

https://wits.worldbank.org/CountryProfile/Metadata/en/Country/all

Appendix B. DCCE models with different options

	EQ01	EQ02	EQ03	EQ04	EQ05	EQ06	EQ07	EQ08	EQ09	EQ10	EQ11	EQ12
Short Run Estimation												
ΔENERGY	M	M	M	M	M	M	M	M	P	P	P	P
ΔGDP	M	M	M	M	M	M	M	M	P	P	P	P
Long Run Estimation												
EC speed of adjustment	P	P	P	P	M	M	M	M	P	P	P	P
GDP	P	P	P	P	M	M	M	M	P	P	P	P
ENG	P	P	P	P	M	M	M	M	P	P	P	P
P_T lags	0	1	2	3	0	1	2	3	0	1	2	3
P-value of F-test	0.00	0.00	0.03	1.00	0.00	0.00	0.01	1.00	0.00	0.00	0.41	1.00
P-value of CD test	0.36	0.04	0.08	0.16	0.43	0.12	0.09	0.28	0.25	0.06	0.07	0.04
Adjusted R-squared	0.56	0.54	0.43	0.37	0.44	0.41	0.45	0.46	0.24	0.21	0.27	0.26

Source: Calculated from Stata software

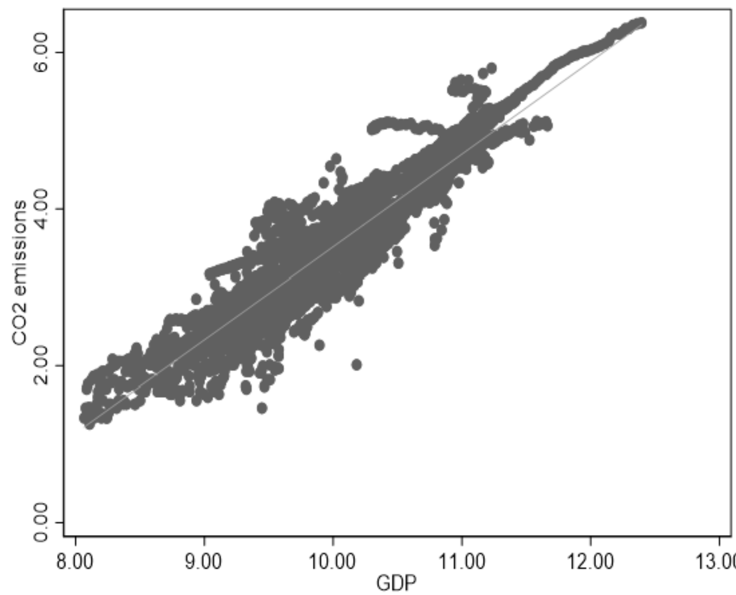
Notes: P = Pooled, M = Mean Group

Figures

a. Descriptive analysis

Variable	Mean	Min	Max	Obs.
CO2	3.26	0.56	6.38	4093
GDP	9.87	8.07	12.47	3616
ENG	2.64	0.98	3.69	1899

b. The GDP-CO2 nexus (pooled)



c. Correlation analysis

	CO2	GDP	ENG
CO2	1		
GDP	0.90	1	
ENG	0.46	**0.30**	1

CO2 = Carbon dioxide emissions, GDP = GDP constant 2010, ENG = Energy consumption

Figure 1

Overview of variable analysis

Variables	Level		First difference	
	Statistic	Lagged differences	Statistic	Lagged differences
CO2	8.95 ***	0	206.29 ***	0
	4.94 ***	1	106.14 ***	1
GDP	0.03	0	117.00 ***	0
	1.34 *	1	59.81 ***	1
ENG	10.11 ***	0	79.74 ***	0
	0.47	1	39.35 ***	1

Figure 2

Panel unit root test results. Source: Calculated from Stata software

	Coef.	Std. Err	Z-statistic	P-value
Short Run Est. (MG)				
ΔENG	**0.93**	0.22	4.25	**0.00**
ΔGDP	**0.30**	0.17	1.82	**0.07**
Long Run Est. (Pooled)				
EC speed of adjustment	**-0.43**	0.10	-4.22	**0.00**
ENG	0.51	0.79	0.65	0.52
GDP	**1.03**	0.51	2.00	**0.05**
F-test	1.54 ***			
CD test	-2.01 **			
R-squared	0.66			
Adjusted R-squared	0.54			

Figure 3

The best DCCE model for short- and long-run estimation. Source: Calculated from Stata software