Primal-Dual Approach to Environmental Kuznets Curve Hypothesis: A Demand and Supply Side Analyses of Environmental Degradation.

gildas dohba dinga (gildoh1995@gmail.com)
University of Bamenda https://orcid.org/0000-0002-2272-972X
DOBDINGA CLETUS FONCHAMNYO
University of Bamenda
ELVIS DZE ACHUO
University of Dschang: Universite de Dschang

Research Article

Keywords: Environmental Quality, Economic Growth, EKC, primal-dual approach, DCCE

Posted Date: April 28th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-460199/v1

Primal-Dual Approach to Environmental Kuznets Curve Hypothesis: A Demand and Supply Side Analyses of Environmental Degradation.

GILDAS DOHBA DINGA[1], DOBDINGA CLETUS FONCHAMNYO[2] and ELVIS DZE ACHUO[3]

[1]Faculty of Economics and Management sciences, department of Economics, The University of Bamenda, Cameroon. Tel: (+237) 650696174, gildoh1995@gmail.com

[2]Associate Professor, Vice Dean in Charge of Teaching and programming in the faculty of economics and management sciences. The University of Bamenda, Cameroon. Tel: (+237) 677381419, dfonchamnyo@gmail.com

[3]Faculty of economics and management sciences, Depatment of economics, The University of Dschang, Cameroon. Tel: (+237) 675591831, elratina@ymail.com

Corresponding Author[1]: GILDAS DOHBA DINGA, Faculty of Economics and Management sciences, department of Economics, The University of Bamenda, Cameroon. Mathematics tutor MINESEC Cameroon. Tel: (+237) 650696174, **gildoh1995@gmail.com**

Primal-Dual Approach to Environmental Kuznets Curve Hypothesis: A Demand and Supply Side Analyses of Environmental Degradation.

Abstract

Global warming and its unavoidable negatives effects on man and the environment have been a key if not the most important issue occupying policy makers in the world at large today. The much talked about green economy nowadays seeks to achieve sustainable economic growth and development without compromising environmental quality. The relationship between environmental degradation and economic growth is largely explained by the environmental Kuznets Curve (EKC) hypothesis. By employing the basic postulation of the baseline EKC framework, this study proposes and tests the existence of a dualistic approach of the EKC hypothesis. Geometry is used to illustrate the proposed dualistic model. Meanwhile, the novel dynamic common correlation effect econometric technique is employed to test the existence of the dualistic EKC within a panel of 109 countries from 1995 to 2016. The outcome from the estimated models shows that, in the global sample, the existence of the dualistic U-shape and N-shape EKC hypothesis is validated. When the sample is split into sub samples based on income levels, the U-shape EKC hypothesis is validated for lower income and high income economies meanwhile, the N-shape dualistic EKC is mostly associated with high income economies.

Keywords: Environmental Quality, Economic Growth, EKC, primal-dual approach, DCCE.

JEL Code: C01, C02, C33, Q56, Y10.

1. Introduction

In a bid to combat climate change, enhance economic prosperity and attain the set goals of the 21st Conference of the parties (COP21 hereafter), it is very important to comprehend the effects of variations in economic growth on the environment (Allard et al. 2018). According to the IPCC (2014), continuous environmental degradation can lead to devastating consequences for humanity, with unavoidable effects like floods, droughts, adverse effects on growth, health and the destruction of ecosystems. According to goal number thirteen (13) of the United Nations Sustainable Development Goals - agenda 2030, emphasis is laid on the urgent need to take action towards combating climate change and its adverse impacts (UN, 2015). This clarion call to combat the negative effects of climate change and reduce global warming has been topical in the recent Conferences of the Parties (COP22, COP23, COP24) due to the damaging effects of climate change to nature as well as mankind. Thus, many targets have been agreed upon by nations geared towards keeping the rise in global temperature well below 2^{o}C.

The United Nations (2020) noted that although the COVID-19 outbreak may result in a 6% fall in Greenhouse gas emissions in 2020, this will still fall short of 7.6% annual reduction in order to limit global warming to 1.5 ^{o}. This is largely due to investments in fossil fuels which continuously show higher trends. Climate change has exacerbated the frequency and severity of natural disasters affecting more than 39 million people in 2018 (United nation 2020). Meanwhile goal number eight (8) of the UN Sustainable Development Goals emphasizes the need to promote sustained, inclusive and sustainable economies. Reconciling the desire of nations to achieve economic growth without degrading the environment is one of the major issues economists and policy makers around the globe are faced with today.

The debate as to whether increase in wealth and income will sow the seeds of increasing ecological problems or if continuous economic growth will always lead to more harm to Mother Nature or the environment have been a topical debate among economists and policy makers since the advent of the Environment Kuznets Curve (EKC) hypothesis since the early 1990s (Grossman and Krueger, 1991; Beckerman, 1992; Panayotou, 1993). The EKC hypothesis posit that environmental degradation and income indicate an inverted U-shape relationship, showing an increase in pollution at low income or output levels and consequently decreasing at high income levels. This relationship is illustrated in figure 1 below.

[Insert figure 1 here]

From Figure 1, it is noticed that as income increase from an initial low level, the rate of environmental degradation increases up to a certain maximum level, whereby an increase in income will be associated with a fall in environmental degradation (environmental improvement).

This hypothesis has been investigated in different countries using different proxies to account for environmental quality or degradation with diverse outcomes. Most studies have used different polluting greenhouse gases with CO_2 being the most used since the late 1990s till date (Ike et al., 2020; Ahmed et al., 2020; Al-mulali and Ozturk, 2016; Balaguer and Cantavella, 2016). Other greenhouse gases used include sulfur dioxide (SO_2) emission (Akbostancı et al. 2009). Authors like Ulucak and Bilgili (2018), Altıntaş and Kassouri (2020), Aydin et al. (2019), Ulucak and Apergis (2018) among others have noted the weaknesses of such measures of environmental quality. Recent authors have prioritisedthe use of ecological footprint which is a broader measure of environmental degradation. As noted by Wackemangel (2002), ecological footprint refers to how much environment is demanded by people and it observes how much biocapacity of Mother Nature is used up at a given time. The ecological footprint index accounts for cropland footprint, fishing grounds footprint, build-up land footprint, grazing land footprint and carbon footprint which is broader in scope than the frequently used greenhouse gases like CO_2. Using the ecological footprint equally allows for the use of peoples ecological budget or nature regenerative capacity (biocapacity). McDonald and Patterson (2004) noted that the use of ecological footprint helps to emphasize the direct and indirect impacts of consumption and production activities on the environment.

In this study, we make use of the ecological footprint and present a novel dualistic approach of investigating the EKC hypothesis. Our approach treats human extraction from nature as a demand side analyses meanwhile the remaining ecological carrying capacity of the world at any given time is observed as the supply of nature to mankind at any given time. We employ geometry to illustrate the dynamic relationship that can exist between the available degree of usage of Mother Nature and the available stock that Mother Nature offers at a given time. This illustration is done with the introduction of a duality box. In the same vein, we use mathematical expressions and signs to provide an insight on how the existence of the dualistic approach can be validated. We then use a panel of 109 countries to empirically investigate the newly proposed dualistic analyses of the EKC hypothesis. For the empirical investigation, we adopt the newly proposed dynamic common correlation effects (DCCE) technique proposed by Chudik and Pesaran (2015) due to the advantages it presents over conventional estimations techniques like the panel ordinary least square (OLS), dynamic OLS, fully modified OLS, system and difference generalized method of moment, pooled mean group, Panel smooth threshold regression technique among others.

2. Literature review

2.1. Theoretical framework

The IPAT equation developed by Ehrlich and Holden (1971) is believed to be the first well-known work on environmental quality. The IPAT equation describes the relation between pollution, population growth, per capita income and technology. Whence, the establishment of the Intergovernmental Panel on Climate Change in 1988 aroused research interest on the economic growth and environmental quality nexus thereby leading to the path-breaking work of Grossman and Krueger (1991). However, the theoretical basis in explaining the link between economic growth and environmental quality often makes reference to the Environmental Kuznets Curve (EKC) Hypothesis, which was born in the early 1990s following the celebrated works of Grossman and Krueger (1991), and Shafik and Bandyopadhyay (1992). Nevertheless, the EKC is named after Simon Kuznets, who in 1955 first hypothesized that as an economy grows, income inequality initially increases and then falls after a threshold level of income (Kuznets, 1955).

Hence, Grossman and Krueger (1991) posit that environmental degradation and income have an inverted U-shape relationship, with pollution increasing with income at low levels of income and decreasing with income at high levels of income. This shows that there is an initial direct relationship between pollution and income and a subsequent indirect relationship at high income levels, as seen in figure 1. We deduce from this position a new approach to this phenomenon by proposing that if at a given time t, the ecological asset (EA) of a given country or the world can be calculated, then this implies that the quantity of nature's ecological supply is known. Hence, nature's ecological asset at a time t+1 (supply (EAS) at the time t+1)) will be the difference between nature's ecological asset at the time t and the total demand from t to t+1. This can be represented mathematically as:

$$EAS_{t+1} = EAS_t - \delta(EAD) \qquad (1)$$

Where EAD denotes ecological assets demanded or used, EAS stands for ecological assets supplied and δ(EAD) is the rate of degradation of the environment or environmental demand from period t to period (t+1). Hence, it can be deduced that at the initial low income level of economic growth, there is a continuous fall in available biocapacity of a country up to a certain marginal level, but as the country moves to a high income level, there is improvement or increase in available biocapacity thereby showing an initial indirect relationship between available biocapacity and economic growth and a subsequent direct relationship as seen in figure 2.

[Insert figure 2 here]

Based on the primal EKC model proposed by Krugman and Gross and the corresponding dual model proposed in this study, it can be deduced that at a certain time t+p if the total of nature's demand is equal to the total nature's supply at the period t+(p-1) then, an environmental equilibrium is attained such that nature's supply is equal to nature's demand. This level of equality can be seen as the highest level at which societal demand from Mother Nature can be sustained (sustainably absorbed) by Mother Nature's supply. If at a given time t+(p+1), EAS is less than EAD, then the country or the world at that level will be operating at a deficit. At this point, increase pressure on the environment will be met with increasing negative effects (floods, plaque, hunger, pandemics among others) on the society since the absorptive capacity of the country or the world is less than societal pressure (ecological degradation).

On the other hand, if at the time t+(p+1), EAS is greater than EAD, then societal rate of consumption of mother earth's resources falls below the absorptive capacity and as such mother nature is able to limit the degree of the effect of environmental degradation. On a more specific note, it can be deduced that as human income or output rises while the rate of degradation is increasing, available absorptive capacity will be falling up to a certain level whereby the absorptive capacity will equal the rate of degradation. If after this point (Overshoot day) economic growth continues to degrade the environment, then we are moving to the situation of an environmental deficit. This situation of deficit will be a springboard of our basic presentation on the dual relationship between environmental overshoot and environmental pollution. This relation can be presented as in figure 3 below which we denote as the environmental duality box 1.

[Insert figure 3]

From figure 3, the initial available earth biocapacity (overshoot value) is the distance I_1-C_1. From the demand side, as economic growth increases from $I_1$to I_1, human demand of nature (ecological footprint) rises to point b and the area I_1-b_1-I_2 is the level of degradation of nature to attain the desired income I_2. Equally, from the supply side, due to the increase in human activity to attain the growth point I_2, available earth biocapacity drops by the area C_1-a_1-C_2. Since at this point ecological overshoot is still greater than ecological footprint, the world will be operating at an ecological surplus represented by the area a_1-e_1-b_1. Note that at this level, available environmental quality has fallen from the initial point I_1-C_1 to a_1-b_1. As countries continue to move to higher income levels, available biocapacity continue reducing. At income level I_3, the supply of nature is equal to demand and hence the overshoot day is attained. The line A-B is the overshoot day line and e_1 is the point of the overshoot day. This is the point where the distinctive analysis of our proposed environmental duality box 1, 2, 3 and 4 differs.

Figure 3 presents a scenario whereby as per capita income increases from I_3 to I_4, the overshoot curve continues to fall up to point a_2 for the supply side meanwhile the demand side curve continues to rise up to point b_2. At income level I_4, the world will be operating at an ecological deficit since EF is greater than EOS. This deficit is represented by the distance b_2-e_3-a_2. If the situation is not addressed through global oriented policies, and the EOS curve continues to fall up to point I_5, EF will equally attain point C_5, and at this point there will be a disaster given that the world's absorptive capacity of pollution will be zero and all of what nature offers must have been exhausted. The scenario presented by the area C_5-b_2-e_2-a_2-I_5 is one that the sustainable development goals are systematically seeking to avoid in the future and global consensus is imperative since this scenario will possibly bring chaos to the world.

[Insert figure 4]

The environmental duality box 2 presented in figure 4, shows a scenario that explains the basic EKC hypothesis within a dualistic framework. The dualistic relationship presents a situation whereby as economic growth increases consistently from point I_1 up to point I_3, EF or nature demand increase up to point e_2 and the supply of nature (EOS) falls from C_1 to e_2. At this point, EF = EOS and earth absorptive capacity is at its maximum and the overshoot day is reached. As income increases from I_3 to I_4, EF rather begins to fall consistently from e_2 to b_2 and pollution is reduced by the area e_2-e_3-b_2. In the same rationale from e_2, EOS starts rising due to improvement in positive environmental policy implementations, thereby creating a new surplus of Mother Nature. The gain or improvement of the environment is indicated by the area e_2 a_2 b_2. Such a feat can be attained if there is the development of environmentally friendly technologies, efficiency in the use of available resources among others. The rise and fall of the EF curve from I_1-e_2-I_5 presents an illustration of the EKC hypothesis. Conversely, the fall and rise of the EOS from C_1-e_2-C_5 presents the dual version of the primal EKC model proposed by Grossman and Kreuger (1995).

Authors like De Bruyn et al. (1998) argued that an N-shape EKC can occur given that when environmental degradation starts decreasing with an increase in income, beyond a certain income level, increase in income will again lead to an increase in environmental degradation. Torras and Boyce (1998) highlighted that such a scenario is possible if the scale effect overcomes the composition and technical effects. We equally present a dualistic framework to the N-shape EKC hypothesis.

[Insert figure 5]

From the duality box 3 presented in figure 5, as income increases from I_1 to I_3, ecological footprint increases from I_1 through b_1 to point e_2 and ecological overshoot falls from C_1 through a_1 to e_2. At this point, the C_1-I_1-e_2 area has been consumed from nature and EF equals EOS hence the earth's absorptive capacity is zero. Due to changes in technology and the adoption of environment-friendly policies, as income increases from I_3 to I_4, EF falls to b_2 and EOS increases to a_2 creating an ecological surplus of a_2-b_2 and the total area e_2-a_2-b_2 of societal environment is improved. Subsequently, as income increases from I_4 to I_5, the scale effect overcomes the composition and technical effects and EF starts increasing from b_2 to b_3, meanwhile EOS falls from a_2 to a_3. The movement of the EF curve through I_1-b_1-e_2-b_2-b_3 indicates the N-shape of the EKC proposed by authors like De Bruyn et al. (1998). Whence, the movement of the EOS curve through C_1-a_1-e_2-a_2-a_3 indicates the dual analyses of the N-shape EKC hypothesis proposed in this study.

[Insert figure 6]

Figure 6 presents a similar scenario as in figure 5 but for the fact that there is a twofold movement before the turning of the N-shape is produced and convergence occurs after deficit. From figure 6, as income increases from I_1-I_2, EF increase from I_1 to e_1 leading to a fall of EOS from C_1 to e_1. At this point, EOS= EF but as income increases from I_2-I_3, EF continues to rise up to a_1 while EOS continues to fall to b_1 thereby creating an ecological deficit of e_1-a_1-b_1. But as income increases from I_3-I_4, with the implementation of positive environmental policies, the EF starts falling while EOS starts rising up to e_3. Here, the initial ecological deficit created is reduced to zero and EF = EOS. As income increases from I_4-I_5, there is continues increase in EF to b_2 while EOS continues to fall to a_2 thereby creating an ecological surplus indicated by the area e_3-b_2-a_2. Equally, as growth increases from I_5-I_7, the scale effect overcomes the composition and technical effects and EF starts increasing again while EOS starts falling leading to a reduction in the initial surplus created to zero at point e_5 and a subsequent deficit after this point. In a world where many countries have already reached their overshoot day and with continuous increase in globalization, such a twofold convergent is equally possible due to interdependence between states. This is another version of explaining the N-shape EKC which haven't been considered in the literature but the possibility of attaining such feat within nations is very possible in the world today given that with globalisation, deficit in one country can be reduced by another since a positive environmental policy in a country can possibly have a spill over effect in another. This presents the undulating trend of the ecological indicators of the primal-dual analyses.

The above paragraphs summarises the novel primal-dual approach to EKC analyses that this study is proposing in explaining the effect of growth on environmental quality and sustainability.

2.2. Some empirical evidence

Generally, from a review of the existing literature on the EKC hypothesis and the empirical investigations done this far in examining the dualistic approach proposed in this study, one would conclude without bias that existing studies have been principally based on the demand side analyses. Among the existing empirical works, Altıntaş and Kassouri (2020) estimated a heterogeneous panel model of 14 European countries from 1990 to 2014 and concluded that the ecological footprint is an appropriate environmental tool that fits the EKC prediction in contrast to CO_2 emissions. They equally highlighted that the EKC is sensitive to the type of environmental degradation proxy used. On their part, Ahmed et al. (2020) using the Driscoll-Kraay standard error pooled ordinary least square method on a sample of 90 belt and cross road countries concluded on an inverted U-shape between economic growth and CO_2 emission. Beyene and Kotosz (2019) employed the pooled mean group technique in a panel of 12 East African countries to examine the short and long run relationship between GDP per capita and CO_2 emission. Their outcome shows a short run U-shape EKC and a long run Bell shape.

While re-assessing the relationship between economic growth and pollution emissions (CO_2), Khan and Eggoh (2020) employed the panel smooth threshold regression (PSTR) technique in a panel of 146 countries from 1990-2016 and concluded on the existence of the EKC hypothesis on the global panel and the income specific sub-samples. Naqvi et al. (2020) employed the common correlated effect of mean group and augmented mean groupon a panel of 155 countries from 1990 to 2017 and examined the relationship between economic growth per capital, renewable energy, financial development and ecological footprint. While they concluded on the validity of the EKC hypothesis for high income countries, their results for other income groups where not reliable. Conversely, the EKC hypothesis was invalidated for a panel of 20 Latin American and Caribbean countries (Jardón et al., 2017) and 15 EU countries (Ameanu et al., 2018). However, Allard et al. (2018) sought to examine the N-shape EKC in a panel of 74 countries from 1992 to 2012 using CO_2 emissions as a measure of environmental degradation. The N-shape EKC hypothesis is validated in their study for all income levels except for the upper middle income countries. The N-shape EKC hypothesis has equally been confirmed by Özokcu and Özdemir (2017) for a sample of 26 OECD with the help of the Driscoll-Kraay Standard Errors technique. Using a panel of 28 OECD countries, Álvarez et al. (2015) employed the generalized least square to affirm the existence of the N-shape EKC. In the same vein, Friedl and Getzner (2003) used the pooled OLS and concluded on the existence of an N-shape EKC for Austria.

Withal, numerous studies have sought to investigate EKC hypothesis, with little or no consensus among scholars. Focus has been predominantly devoted towards the demand side analyses with little or no effort made to look at the supply side. It is within the backdrop of this gap in literature and quantitative approach that this study sought to propose a dual hypothetical analysis of the EKC phenomenon.

3. Methodological framework

3.1. Data description and sources

In order to verify the proposed primal-dual EKC hypothesis in this study, data were collected from two principal sources that is the world development indicators (WDI) and the Global

Footprint Network (GFN) data bases spanning from 1995 to 2016 for a total sample of 109 countries (see table 11). The study period is chosen based on data availability. While data for ecological footprint and ecological biocapacity were obtained from the GFN, data for economic growth per capita and other explanatory variables are obtained from the WDI database. The description of these variables can be found in table 1.

[Insert table 1]

3.2.Modelling framework

In order to examine the dualistic type analyses of the environmental problem, we construct two nonlinear models that simultaneously explain the demand and the supply side analyses. The baseline model proposed is given as:

$$Y = \alpha_1 X + \alpha_2 X^2 \qquad (2)$$

$$W = \beta_1 X + \beta_1 X^2 \qquad (3)$$

Equation 2 and 3 present the basic model of our dualistic approach to EKC analyses. From the two models, equation 2 denotes the demand side analyses that give the baseline model proposed by Grossman and Kreuger (1991) meanwhile we propose equation 3 as a supply side dual model of the basic primal model proposed by Grossman and Kreuger (1991). Y, X and W respectively denotes ecological footprint, economic growth per capita and ecological overshoot. The following analyses can be made from these equations. From table 2, if the coefficients of equations 1 and 2 verifies case 1 hypotheses, then there is no ECK curve and the dual relation shows continues pollution of the environment from the demand side and the continuous reduction of Mother earth's biocapacity, which is shown in figure 1. This shows a situation wherein, economic agents and policy makers are still to consider the negative effects of pollution to the environment and as such, they continue production without a clear cut cleaning policy in place. On the other hand, case two indicates that ecological footprint increases as income increases, reaches a maximum and then starts falling (EKC-hypothesis) while the ecological overshoot falls and reaches a certain minimum and then starts to rise (dual of the primal EKC model). This demand side and supply side type analyses is illustrated in figure two. Here, environmental cleaning policies are adopted and at a certain level further increase in income is accompanied with fall in pollution and increase in biocapacity.

In order to equally examine the N-shape ECK model and equally deduce it corresponding dual supply side shape, we examine the following relation:

$$Y = \alpha_1 X + \alpha_2 X^2 + \alpha_3 X^3 \qquad (4)$$

$$W = \beta_1 X + \beta_1 X^2 + \alpha_3 X^3 \qquad (5)$$

Equation 4 presents the primal of the N-shape EKC hypothesis meanwhile equation 5 gives the dual hypothesis we propose from the primal hypothesis. We make two possible analyses from these relations. Table 2 shows the variation of the different coefficients of the relation. Firstly, case 3 indicates that EF first increases, attains a maximum, begins to fall, attains a minimum, and then starts to increase. This explain the N-shape EKC hypothesis as shown in figure 3. Looking at the dualistic model we present, ecological overshoot (EOS) initially falls, reaches a minimum, tends to increase to a certain maximum and begins to fall again. This indicates that as policy makers implement environmental friendly policies within a nation due to the negative effects of past degradation, when environmental improvement is attained up to a certain level, economic agents tend to lose focus on combating pollution and as such pollution starts increasing again.

We further present another version of the N shape in case 4 wherein EF increases as EOS falls, attains a certain point of inflexion, after which it continues to increase while EOS equally continues to fall. The EF increases, attains another marginal level and starts to fall while the EOS continues to fall, attains the next marginal level and starts to increase. This scenario rather validates a long run convergence U-shape EKC, as the N-shape dual analysis is rejected while the U-shape is accepted.

[Insert table 2]

Case 5 presents a scenario wherein, EF increases, attains a certain marginal level and starts falling and continues to fall in the next marginal level. Meanwhile EOS decreases up to a certain marginal level and starts increasing. This rejects the N-shape and rather validates the U-shape EKC. Here, economic agents after realizing the negative effects of environmental degradation, put in place appropriate abatement policies and continue to implement these policies thereby achieving a better environment. Case 4 and 5 present another version of the U-shape EKC which is rarely discussed or analyzed in the existing literature but shows a possible policy outcome of the income/environmental relation.

3.3. Empirical model and technique

From the baseline model framework, we estimate a dynamic model. The estimated model is inspired from the model proposed by authors like Grossman and kreuger (1991), De Bruyn et al. (1998), Altıntaş and Kassouri (2020), Khan and Eggoh (2020) among others . The model can be specified as follows;

$$Y_{it} = \emptyset_i + \vartheta Y_{it-1} + \alpha_1 X_{it} + \alpha_2 X_{it}^2 + \alpha_3 X_{it}^3 + \lambda Z_{it} + \gamma_i f_t + \xi_{it} \quad (6)$$

$$W_{it}=\varphi_i + \rho W_{it-1}+\beta_1 X_{it} + \beta_2 X_{it}^2 +\beta_3 X_{it}^3 +\delta Z_{it} +\gamma_i f_t +\xi_{it} \quad (7)$$

Where ϑ, ρ, α_1, α_2, α_3, λ, β_1, β_2, β_3, δ in equation 6 and 7 are the parameters of the demand side and the supply side model to be estimated which are bounded by a finite constant and homogenous over cross-sectional units i. Z is a set of exogenous variables, i denotes the individual unit (country) and t the year. f_t denotes an unobserved common factor with heterogeneous factor loadings, γ_i and ξ_{it} are the idiosyncratic error terms.

We employ the novel dynamic common correlation technique proposed by Chudik and Pesaran(2015). This technique is adopted because of its novelty and the ability for the approach to account for cross sectional dependence. The non-consideration of cross sectional dependence by conventional estimation techniques has been identified by different authors as a source of biasness in estimation (Ali et al. 2020, Dinga et al. 2020, Neal, 2015). With the high degree of globalization in the world today, the interdependence between states has heightened tremendously, implying that empirical analyses that do not account for such interdependence will be biased. Within the framework of this study, considering that cross sectional dependence is very vital, economies with high level of pollution and where EF is already showing trends of surpassing the EOS can always pay low polluters with much more available biocapacity to conserve or to reduce their level of pollution so as to serve as a balance in the deficit in their respective countries. Such interdependence between environmental debtors and creditors has been a key way to maintain global pollution levels.

Before proceeding to estimate the different models, we first check our data for cross sectional dependence since this will help select appropriate estimation techniques and to choose between first or second generation tests. The Pesaran (2004) cross sectional dependence test and the

Pesaran (2015) cross dependence test are employed in this study. To ensure that our model does not suffer from spurious regression, we test our database for unit root test. We employ the second generation unit root test proposed by Pesaran (2003) CADF test and the Pesaran (2007) CIPS unit root test that accounts for cross sectional dependence. Slope homogeneity in panel data analyses has been highlighted as a key issue to address. Breitung (2005) noted that cross sectional dependence implied countries have similarities in development and as such ensuring cross sectional heterogeneity is vital for robust estimations. The most recent slope heterogeneity test by Pesaran and Yamagata (2008) that is an ameliorated version of that proposed by Swamy (1970) is adopted in this study. After taking into consideration the issue of slope homogeneity, we proceed to examine the panel for cointegration in order to establish the existence of a long term relationship. The Westerlund (2007) second generation cointegration test that considers cross sectional dependence is adopted in this study. After ensuring the panel is free from all the aforementioned issues that bias estimations and make them untrustworthy for inference, we proceed to estimating our dualistic models explained above using a nonlinear DCCE approach. Another key advantage of the DCCE technique is the ability to correct for small sample bias (Ditzen, 2016). The recursive mean technique of correcting small sample bias is adopted in this study. The data are compiled with the help of Microsoft excel and analyzed with STAT 14 software.

4. Empirical outcomes and discussions.

4.1. Descriptive statistics

Based on the results of the basic statistics of the variables considered as seen in table 1, the average performance of ecological footprint is 2.827 with a standard deviation of 2.238 and a minimum and maximum score of 0.481 and 16.965 respectively. This shows that the level of EF of the sample at large has been relatively large and rarely deviates above the average of the world. On the other hand, ecological overshoot indicates a mean, standard deviation, minimum and maximum value of 0.937, 7.975, -14.865 and 69.202 respectively. This implies that EOS is slightly positive on average within the sample and greatly deviates from the mean. The minimum value is indicative of how some countries are already ecological debtors. In the same vein, the average GDP, DINV, FDI and POP for the global sample of 109 countries within the period under study were 2.433, 22.47, 3.892, and 1.645 with standard deviations of 4.13, 7.541, 5.372 and 1.47 respectively. The result shows that deviation from the mean of growth per capital has been higher within the selected countries. Growth rate per capital has shown a negative value implying that at least for some countries, negative growth was noticed. Same holds for DINV, FDI and POP.

4.2. Cross sectional dependence and unit root test

With the advent of globalization, cross sectional dependence has become a vital component to consider when dealing with panel data analyses. This is due to the fact that the non-accounting of spillover effects of shocks from one country to another can lead to bias estimates and misleading inference. Cross sectional dependence equally permits us to make a choice between first or second generation tests. In this study, we employ the Pesaran (2004) and Pesaran (2015) cross sectional dependence test.

[Insert table 3]

The results presented in table 3 indicate that the null hypothesis of cross sectional independence for the Pesaran (2004) test is rejected at the 1% significance level for all the variables of the study. This shows that there is strong presence of cross sectional dependence. In the same vein, the null hypothesis of weak cross sectional dependence for the Pesaran (2015) test is rejected at the 1% significance level thereby confirming cross sectional dependence for all the variables.

[Insert table 4]

After confirming the presence of cross sectional dependence, we then examine the stationarity of the different variables. With the strong confirmation of cross sectional dependence, we make use of two versions of second generation unit root test, that is the CADF and CIPS test proposed by Pesaran in 2003 and 2007 respectively. From the panel unit root test result presented in table 4, the null hypothesis of non-stationary series for the CADF test is not rejected at level for EFP and EOS at all levels of significance, meanwhile the null hypothesis of homogeneous non-stationary series for the CIPS test is rejected at level for the two variables. At first difference, we reject the null hypothesis of both the CIPS and CADF test. This implies that EFP and EOS are stationary at first difference. In the same light, we fail to reject the null hypothesis of the CIPS test for DINV and POP thus we concluded that they are not stationary at level. At first difference, the null hypothesis of both the CIPS and CADF test are rejected for both DINV and POP implying that these variables are stationary at first difference. Equally, GDP, GDP2, GDP3 and FDI indicate the rejection of the null hypothesis of both unit root test. This shows that the variables are stationary at level.

4.3. Slope homogeneity and cointegration test

In the presence of cross sectional dependence, Breitung (2005) noted that this may imply that countries are having economic development similarities and as such determining cross sectional heterogeneity is important otherwise the estimates will be untrustworthy. The Pesaran and Yamagata (2008) slope homogeneity test is employed in this study. The results of the slope homogeneity test presented in table 5 indicates that both the EOS and the EF models reject the null hypothesis of slope homogeneity for both test statistics at the 1% level of significance. This shows that there is the existence of slope heterogeneity.

For cointegration, since there is the strong presence of cross sectional dependence, we only make use of a second generation cointegration test that accounts for cross sectional dependence. The result of the Westerlund (2007) second generation test presented in table 5 indicates that group and panel test statistics are able to reject the null hypothesis at different significant levels (1% and 5%) for the ecological footprint and ecological overshoot models. Specifically, the ecological footprint model indicates that all the group test (G_a, G_t) and the panel test (P_a, P_t) confirms rejection of the null hypothesis of no cointegration between EF and GDP2, DINV, FDI and POP. For GDP and GDP3, cointegration is confirmed for all test statistics except the P_t test statistics. This implies the strong presence of cointegration between EF and the variables of interest. Similarly, the cointegration relation between EOS and the different variables of the studies shows that the two group test statistics validates the presence of cointegration for all the different variables. On the other hand the panel test P_t confirms cointegration only for POP while P_a statistics rejects the null hypothesis for no cointegration relation for all variables except GDP. This result shows the validation of cointegration for most test statistics and as such we conclude that there is strong evidence of a long run relationship between the variables of the studies. With the confirmation of cointegration, we proceed to empirically estimate our different models.

4.4.Estimated outcome

Table 6 and 7 present the outcomes of the two basic models of our dualistic approach analyses. As highlighted above, the validation of a dualistic approach to environmental degradation analyses will depend on the different signs of GDP per capital variable in its different forms. We first start by estimating a linear model for both the EF and EOS equations. As indicated in model 1 and 7 in table 6 and 7 respectively, GDP is seen to have a positive sign in 1 and a negative sign in 7 showing that increase growth in the world increases pollution (demand side) and reduces available biocapacity (supply side) of the society at large. This result affirms a dualistic outcome for the linear relationship between growth in income and the demand/supply side environmental analyses. In order to empirically ascertain the dualistic model of the U-shape EKC hypothesis, we estimate model 2 and 8 without any explanatory variable. The results from model 2 indicate a positive sign for GDP and a negative sign for GDP2 thereby validating the U-shape EKC hypothesis which is in line with the findings of authors like Ahmed et al. (2020),Naqvi et al. (2020) for high income countries, Khan and Eggoh (2020), Beyene and Kotosz (2019) for low income countries, meanwhile the outcome contradicts Jardón et al (2017). For the supply side outcome shown in model 8, GDP is seen to have a negative sign while GDP2 shows a positive sign on ecological overshoot. This indicates a supply side inverted bell-shape for EOS. This result confirms our apriori hypothesis of a dualistic EKC hypothesis between EF and EOS. This shows that on the demand side, as per capital income increase within countries, there is an initial increase in environmental pollution up to a certain marginal level wherein, increase in per capita income leads to ecological improvement. In the same vein, on the supply side, the outcome implies that as income per capita increases, there is an initial decrease in available ecological biocapacity up to a certain marginal level before it starts improving.

In order to examine the N-shape environmental Kuznets curve hypothesis and its proposed dualistic relation, we estimate equation 3 and 9 without any explanatory variable in table 6 and 7 respectively. The outcome shows that for the demand side, the existence of the N-shape EKC hypothesis is approved for our global sample since the coefficient of GDP, GDP2 and GDP3 are positive, negative and positive respectively. For the supply side, an inverted N-shape EKC hypothesis is validated for the general sample since the signs of GDP and it corresponding polynomial values alternate that is negative, positive and negative. This outcome reaffirms the dualistic approach to environmental quality analyses proposed in this study and it is in line with our apriori expectation.

For robustness of the results, we estimate the baseline model with the inclusion of other explanatory variables systematically for the demand side analyses (4, 5, and 6) and the supply side analyses (10, 11, 12). The outcome indicates that the signs of the income per capital remain consistently the same as in the baseline model with the inclusion of different explanatory variables both for the ecological footprint models and the ecological overshoot models. Equally, the constants of the EF estimated model are all positive whereas those of the EOS estimated models are all negative, which shows that with a growth in income set at zero, other factors will significantly increase EF and equally decrease EOS. This reaffirms the dualistic nature of outcome between the traditional demand side analyses and the newly proposed supply side analyses in this study.

Concerning the goodness of fit of the estimated models, all the F-statistics of the different models estimated for the EF (1 to 6) and those estimated for the EOS (7-12) are all significant at 1%. This shows global fitness of all the models. Equally cross sectional dependence is confirmed in all equations since all the CD-statistics rejects the null hypothesis of no cross sectional dependence.

In order to capture disparity of outcome that may occur due to income levels disparity, and to equally make comparative analyses, we reexamine the dualistic U-shape and N-shape environmental Kuznets curve hypothesis for lower income countries (LIC), lower middle income countries (LMIC), upper middle income countries (UMIC) and high income countries (HIC). The outcome of the income level analysis for the dualistic approach proposed in this study is presented in table 8 for the EF analyses and table 9 for the EOS analyses. From the results of the EF (demand side) estimate, the U-shape EKC hypothesis is validated at all income levels (LIC, LMIC, UMIC, HIC), but comparatively, this results seems to show less significances for LIC and turns to be more significant for LMIC where both the quadratic and the linear coefficients are seen to be significant at 5% level of significance. Equally, cross sectional dependence is confirmed in all the sub panels. For the N-shape baseline income level comparison presented in column 17, 18, 19 and 20, LIC and HIC within the panel indicates sufficient information to validate the N-shape EKC hypothesis, but this result is seemingly more significant for HIC. Meanwhile, for LMIC and UMIC countries estimate, the N-shape hypothesis is not valid. The results show that, a longer period is taken for LMIC to start experiencing amelioration in environmental quality meanwhile for UMIC after experiencing environmental amelioration through decrease in EF, these economies will rarely return back to environmental degradation as proposed by the N-shape EKC. This none validity of the model for LMIC and UMIC can be due to the transition of different economies from one income level to another.

As shown by the supply side income level analyses in table 9, for the baseline result of the corresponding dualistic U-shape EKC, the outcome affirms the existence of the U-shape dual EKC as proposed in this study for LMIC, UMIC and HIC. But this outcome is not true for LIC which shows an initial positive value and a negative value for the quadratic term. This result validates a dualistic dual outcome from the primal outcome obtained for LMIC, UMIC and HIC for the demand side analyses above. For the inverted N shape analyses for different income levels, model 25 to 28 indicate that an inverted N-shape is only validated for the UMIC and the HIC. But the outcome is more significant for HIC. This result highlights the importance of cross sectional dependence in the analyses of the dualistic relation in environmental quality analyses, since the dual-primal relation is more validated for high income countries and the CD-test statics is only highly significant for HIC. The non-consideration of the high income countries which are seemingly the highest polluters in the world today will bias the estimate of all the sub panels and lead to the non-validation of the N-shape dualistic EKC hypothesis.

In order to ascertain the robustness of the outcome obtained from this study, we conduct second generation unit root test on all the 28 estimated models. The results obtained from the CADF and CIPS second generation unit root test presented in table 10 indicate that, the null hypothesis of panel residuals containing unit root is rejected for all the 28 models for the CADF and CIPS test. This shows that our estimated results are stable and valid for all the inferences made.

5. Conclusion

In this study, we sought to present a new approach of analyzing the nexus between environmental degradation and income in the world. On the one hand, we analyzed the demand side of human activities from nature with the use of ecological footprint and on the other hand, nature supply side was analyzed with the use of nature ecological overshoot. We employed geometry to present our basic dualistic analyses meanwhile mathematical demonstration is employed to elucidate the expected dualistic model. To test our proposed dualistic model, we used a balanced panel of 109 countries from 1995 to 2016. Given the level of globalization in the world today, we first test our data for cross sectional dependence using the Pesaran (2004, 2015) cross sectional dependence test in order to choose appropriate test and estimation techniques. With the confirmation of cross sectional dependence in our data, we employed second generation tests for unit root, cointegration and slope homogeneity that account for cross sectional dependence.

Our adopted estimation technique is the dynamic common correlation technique proposed by Chudik and Pasaran (2015) that accounts for cross sectional dependence within panels. From the different results obtained, there is clear evidence of the existence of our proposed dual U-shape and dual N-shape EKC. Equally, when we separate our panel into different income levels, the Dual U-shape EKC hypothesis is validated for all our sub panels but for LIC. For the income level dual N-shape EKC hypothesis, the dual N-shape is confirmed principally in HIC. Based on these outcomes, this study proposes the following recommendations:

The equilibrium or maximum absorbable level of pollution where biocapacity equals the pollution level should be determined both at individual country level and the world at large, so as to encourage countries to clean their environment and stay below this equilibrium point in order to avoid future environmental disasters. This should be a principal task for international organizations like the United Nations.

Advanced economies should aid less developed economies with new and efficient abatement technologies that will help this economies better clean their environment. The developed economies should equally give ample financial aid to developing and less industrialized countries especially those with high available biocapacity in order for these economies to adopt cleaner and environment-friendly industrialization policies, like the encouragement of renewable energy sources.

The enhancement of data collection techniques in middle income and low income countries and the consideration of countries with limited information about environmental degradation are necessary, in order to obtain accurate information with respect to biocapacity and rate of environmental degradation. The availability of adequate information on biocapacity and the rate of environmental degradation will help policymakers to better handle the problem of environmental pollution in a global and holistic manner and promote interstate cooperation in such key issues that affect humanity.

Declarations

- **Ethics approval and consent to participate**
    - Not applicable.
- **Consent for publication**
    - Not applicable
- **Availability of data material**

The data sets used and/or analyzed during the current study are available from the corresponding author on request.

- **Competing Interests**

The authors declare that they have no competing interest.

➢ Funding

No funding was received for this manuscript.

➢ Authors Contribution

GDD participated in the conceptualization, writing, analyses and interpretation in the manuscript

DCF participated in the conceptualization, writing, editing and interpretation of the manuscript.

DEA reading and editing

6. References

Ahmad M, Jiang P, Majeed A, Raza MY (2020) Does financial development and foreign direct investment improve environmental quality? Evidence from belt and road countries. Environmental Science and Pollution Research*, 27*: 1-16

Akbostancı E, Türüt-Aşık S, Tunç Gİ (2009) The relationship between income and environment in Turkey: is there an environmental Kuznets curve?. Energy policy 37(3): 861-867

Ali S, Yusop Z, Kaliappan SR, Chin L (2020) Dynamic common correlated effects of trade openness, FDI, and institutional performance on environmental quality: evidence from OIC countries. Environmental Science and Pollution Research 27:11671–11682. 1-12. https://doi.org/10.1007/s11356-020-07768-7

Allard A, Takman J, Uddin, GS, Ahmed A (2018) The N-shaped environmental Kuznets curve: an empirical evaluation using a panel quantile regression approach. Environmental Science and Pollution Research 25:5848–5861 https://doi.org/10.1007/s11356-017-0907-0

Al-Mulali U, Ozturk I (2016) The investigation of environmental Kuznets curve hypothesis in the advanced economies: the role of energy prices. Renewable and Sustainable Energy Reviews 54: 1622-1631.

Altıntaş H, Kassouri Y (2020) Is the environmental Kuznets Curve in Europe related to the per-capita ecological footprint or CO2 emissions?. Ecological Indicators *113*: 106187.

Álvarez A, Balsalobre D, Cantos JM (2015) Public budget for energy RD&D and the effects on energy intensity and pollution levels. Environ Sci Pollut Res *22(*7): 4881–4892

Armeanu D, Vintilă G, Andrei JV, Gherghina ŞC, Drăgoi MC, Teodor C (2018) Exploring the link between environmental pollution and economic growth in EU-28 countries: Is there an environmental Kuznets curve? PLoS One 13, e0195708. https://doi.org/10.1371/journal.pone.0195708

Aydin C, Esen Ö, and Aydin R (2019) Is the ecological footprint related to the Kuznets curve a real process or rationalizing the ecological consequences of the affluence? Evidence from PSTR approach. Ecological indicators *98*: 543-555.

Balaguer J, Cantavella M (2016) Estimating the environmental Kuznets curve for Spain by considering fuel oil prices (1874–2011). Ecological Indicators 60: 853-859.

Beckerman W (1992) Economic growth and the environment: Whose growth? Whose environment?. World Development 20: 481–496.

Beyene SD, Kotosz B (2019) Testing the environmental Kuznets curve hypothesis: an empirical study for East African countries. International Journal of Environmental Studies DOI: 10.1080/00207233.2019.1695445

Breitung J (2005) A parametric approach to the estimation of cointegration vectors in panel data. Econ Rev 24: 151–173

Chudik A, Pesaran, MH (2015) Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors. Journal of Econometrics, 188(2): 393–420.

De Bruyn SM, van den Bergh JC, Opschoor JB (1998) Economic growth and emissions: reconsidering the empirical basis of environmental Kuznets curves. Ecological Economics *25*(2): 161-175.

Dinga GD, Fonchamnyo DC, Nginyu GG, Njuh CJ (2020) Short and long run dynamic common correlation effects of external capital inflow on economic growth in SSA countries. Asian Journal of Economic Modelling 8(4): 218-226.

Ditzen J (2016) *Xtdcce: estimating dynamic common correlation effects in STATA*, in United Kingdom Stata Users Group meetings 2016(NO. 08), Stata Users.

Ehrlich PR, Holden JP (1971) Impact of population growth. Science, 171(3977): 1212–1217.

Friedl B, Getzner M (2003) Determinants of CO_2 emissions in a small open economy. Ecological Economics 45:133–148.

Grossman GM, Krueger AB (1991) Environmental impacts of a North American Free Trade Agreement. NBER, Working Paper No. 3914.

ICPP Change IC (2014). Mitigation of climate change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 1454.

Khan M, Eggoh J (2020) Investigating the direct and indirect linkages between economic development and CO_2 emissions: a PSTR analysis. Environmental Science and Pollution Research 1-14.

Kuznets S (1955) Economic growth and income inequality. The American Economic Review, 45(1): 1-28.

McDonald GW, Patterson MG (2004) Ecological footprints and interdependencies of New Zealand regions. Ecological Economics 50(1-2): 49-67.

Neal T (2015) Estimating heterogeneous coefficients in panel data models with endogenous regressors and common factors. Workblacking paper.

Özokcu S, Özdemir Ö (2017) Economic growth, energy, and environmental Kuznets curve. Renewable and Sustainable Energy Reviews *72*: 639-647.

Panayotou T (1993) Empirical tests and policy analysis of environmental degradation at different stages of economic development. Working Paper WP238, Technology and Employment Programme, International Labour Office, Geneva.

Pesaran MH (2003) Simple Panel Unit Root Test in the Presence of Cross Section Dependence. University of Cambridge, Faculty of Economics (DAE). Cambridge Working Papers in Economics 0346.

Pesaran MH (2004) General diagnostic tests for cross section dependence in panels. CESifo Working Papers No. 1233, 255-60.

Pesaran MH (2007) A simple panel unit root test in the presence of cross-section dependence. Journal of Applied Economics *22*(2): 265–312.

Pesaran, M. H. (2015). Testing weak cross sectional dependence in large panels. Econometric Reviews 34: 1089-1117.

Pesaran MH, Yamagatta T (2008) Testing slope homogeneity in large panels. Journal of Econometrics *142*(2): 50-93.

Shafik N, Bandyopadhyay S (1992) Economic growth and environmental quality: Time series and cross-country evidence. Background paper for the World Development Report, Washington DC: The World Bank.

Swamy PAVB (1970) Efficient inference in a random coefficient regression model. Econometrica 38: 311–323

Torras M, Boyce JK (1998) Income, inequality, and pollution: a reassessment of the environmental Kuznets curve. Ecological economics 25(2): 147-160.

Ulucak R, Apergis N (2018) Does convergence really matter for the environment? An application based on club convergence and on the ecological footprint concept for the EU countries. Environmental Science and Policy 80: 21-27.

Ulucak R, Bilgili F (2018) A reinvestigation of EKC model by ecological footprint measurement for high, middle and low income countries. Journal of cleaner production 188: 144-157.

Westerlund J (2007) Testing for error correction in panel data. Oxford Bulletin of Economics and Statistics 69: 709-748.

[Insert table 11]

Figures

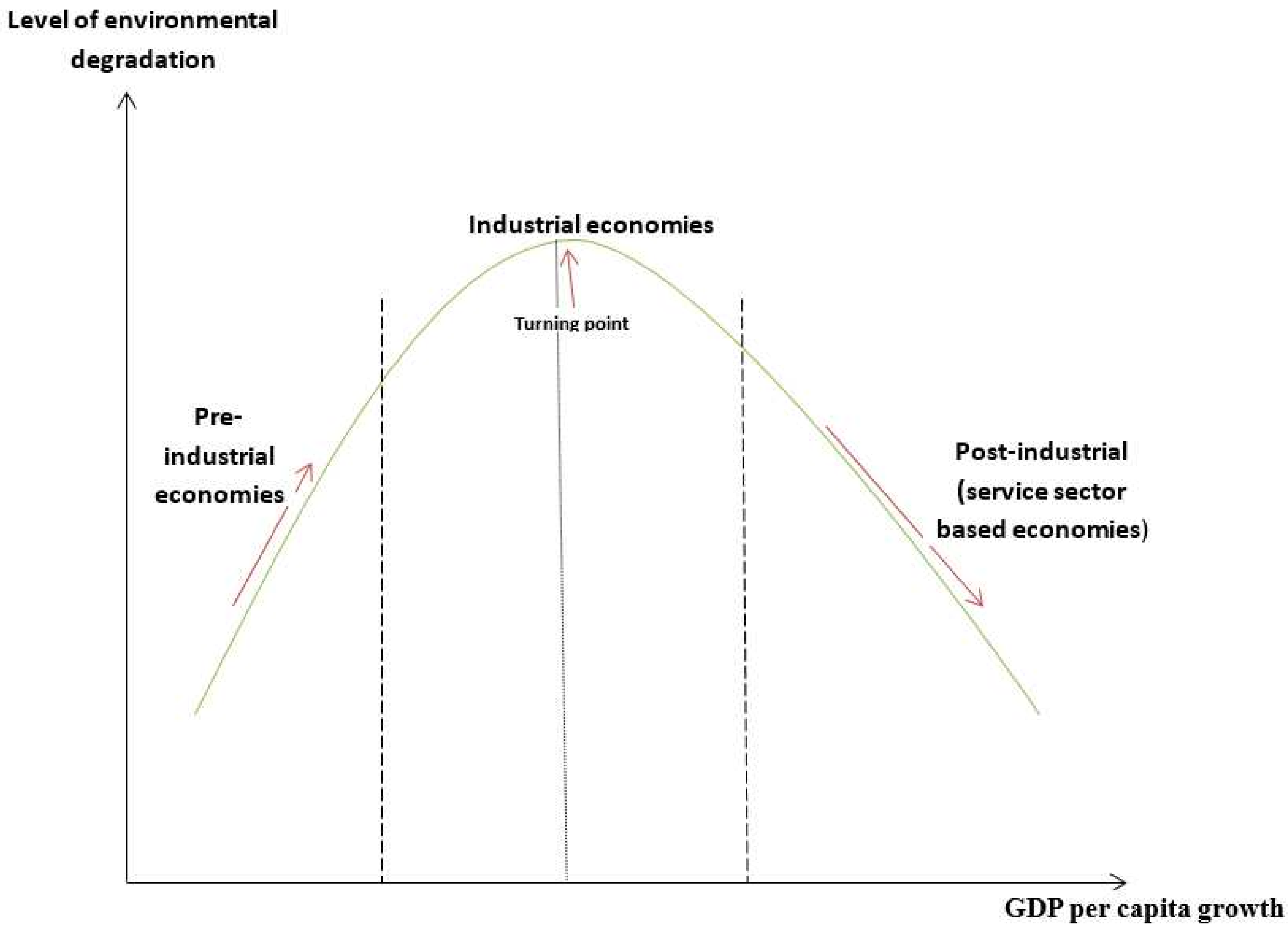

Figure 1

Basic Primal EKC

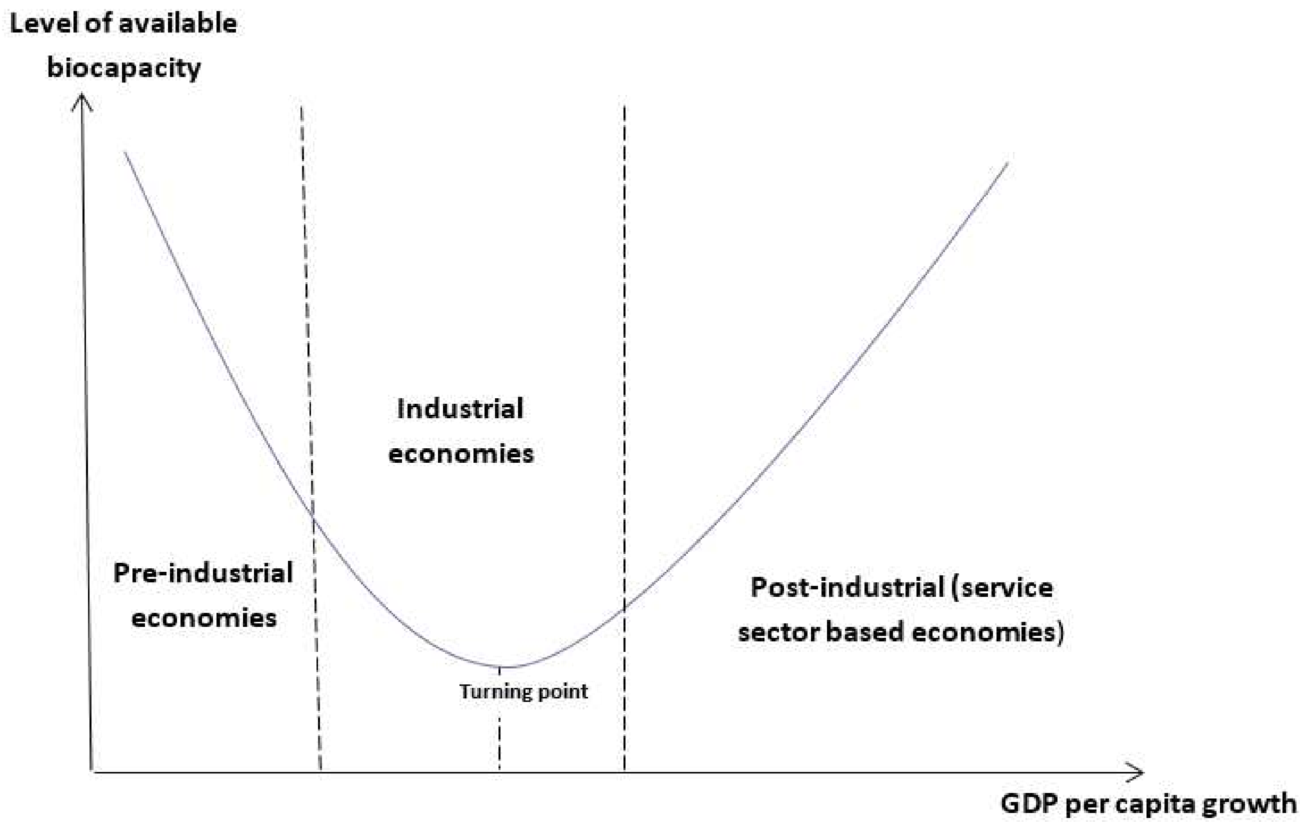

Figure 2

Basic Dual EKC

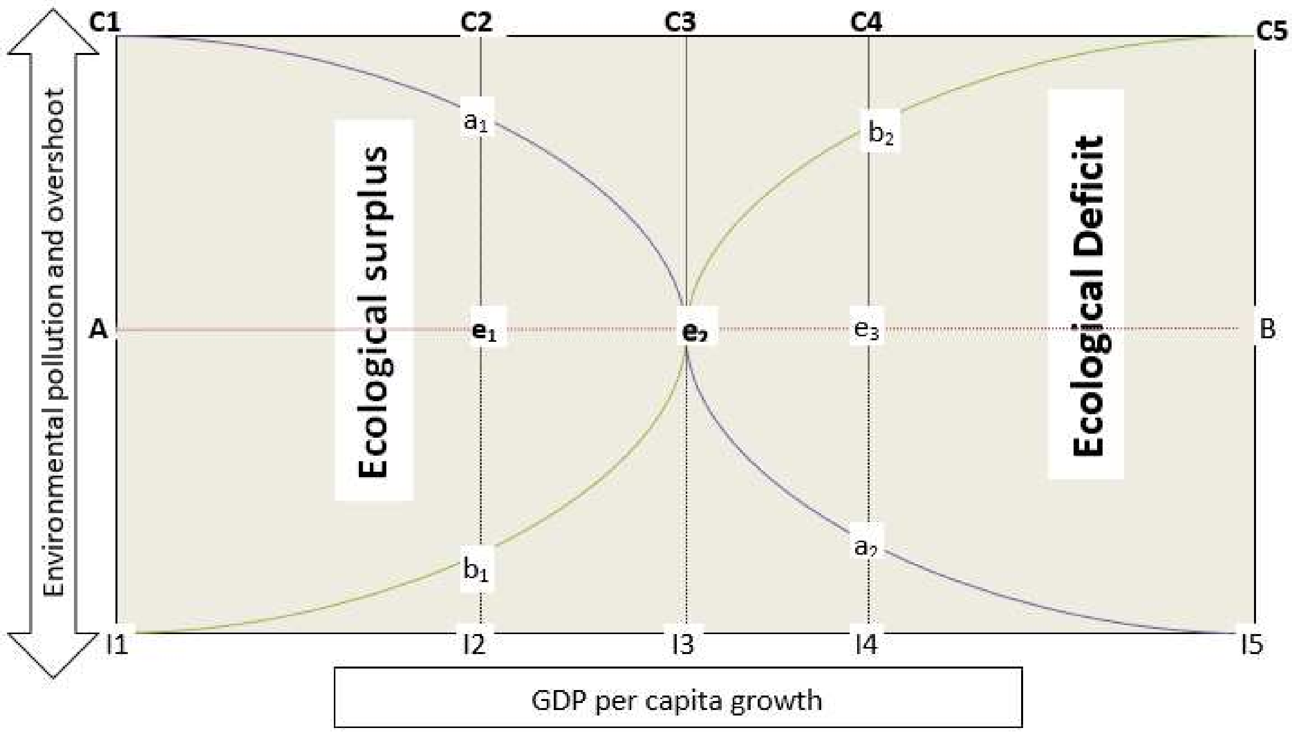

Figure 3

Environmental duality box 1.

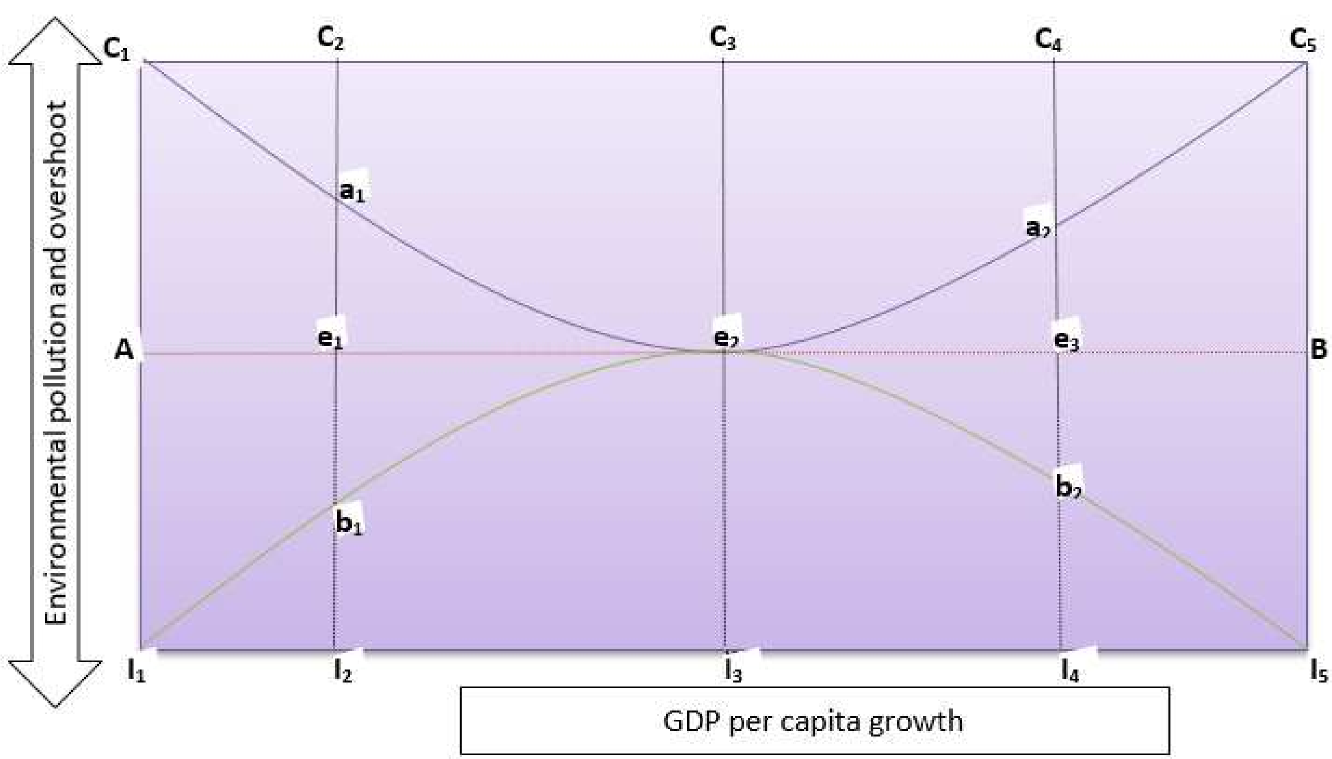

Figure 4

Environmental duality box 2.

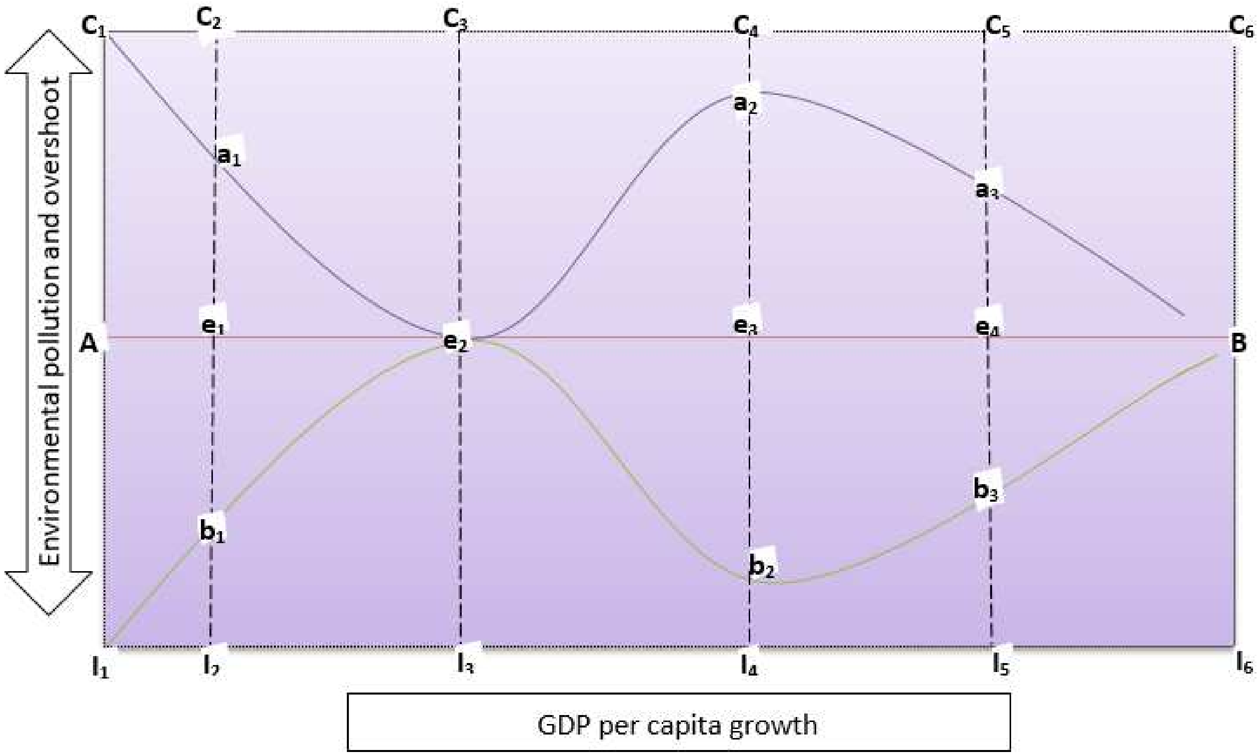

Figure 5

Environmental duality box 3.

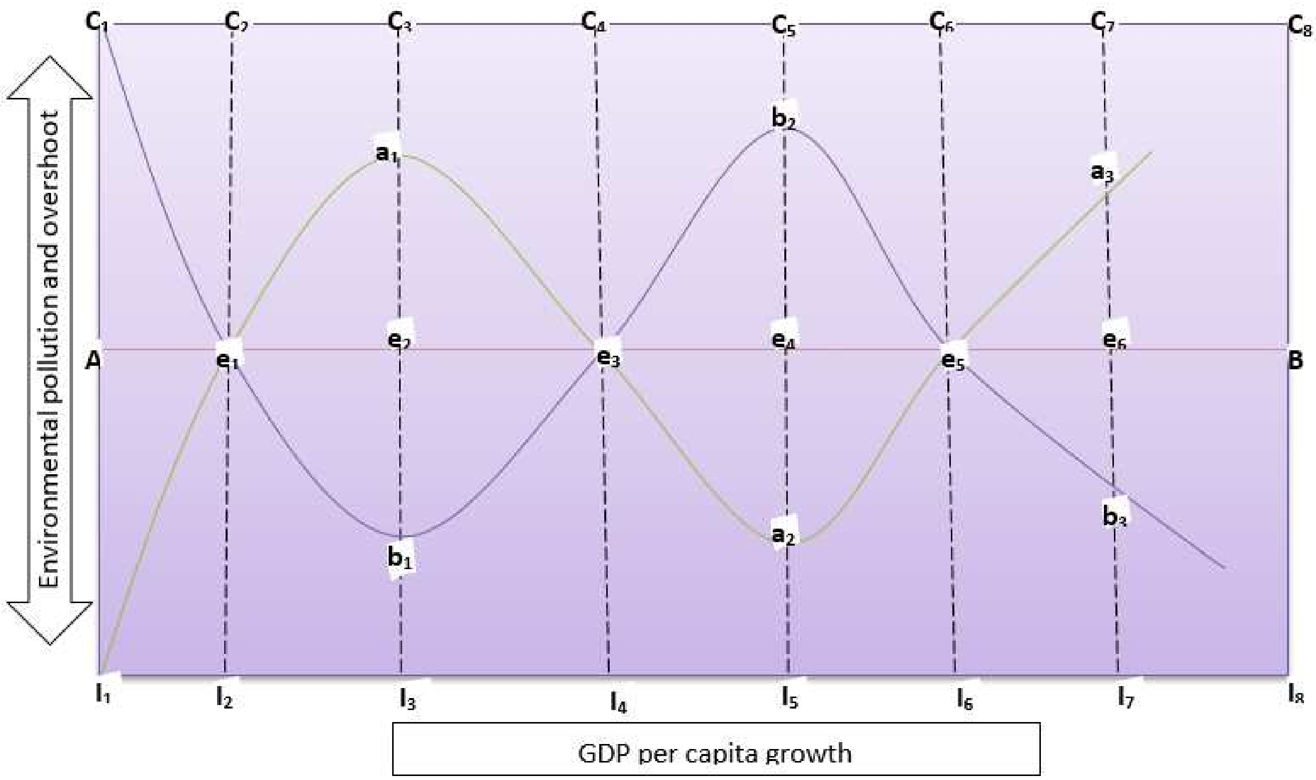

Figure 6

Environmental duality box 4.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- TablesESPR.docx