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Testing the Validity of N-shaped Environmental Kuznets Curve under Fossil and Non-Fossil Based Energy Consumption: Empirical Evidences from Developed Countries

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Abstract

This paper employs a pooled mean group approach to analyze panel data spanning 42 years from 15 developed countries. The primary objective is to assess the influence of varying levels of economic growth on carbon emissions, aiming to validate the existence of the N-shaped Environmental Kuznets Curve (EKC). Additionally, the study explores the detrimental effects of fossil fuel consumption on carbon emissions. What sets this study apart from the similar studies done in this area is its endeavor to examine the validity of different stages of the N-shaped EKC within contrasting scenarios of fossil and non-fossil based energy consumption. Notably, the findings of this study indicate that during the initial stage of the N-shaped EKC, economic growth exerts a substantial direct impact on environmental degradation, even in conjunction with non-fossil based energy consumption. Conversely, in the second stage of the N-shaped EKC, we observe an inverse relationship between accelerated economic growth and environmental degradation.

Keywords: Environmental Kuznets Curve, Carbon Emissions, Pooled Mean Group.

1. Introduction

To ensure a reasonable economic growth and to preserve the environment for current as well as future generations are the two important objectives for any country to pursue, but what is more important is to make the balance between the two, especially when they are found to be in contradiction to each other. It, therefore, becomes pertinent to ascertain the existence of any kind of relationship between these two objectives, and whether they are indeed in contradiction to each other.

Amongst the various research studies done in this regard, one of the most significant studies came in the form of the Environmental Kuznets Curve (EKC) hypothesis given by Grossman and Krueger[25] (1991), wherein they discovered an inverted U shaped relationship between economic growth and environmental degradation. However, in their subsequent study, Grossman and Krueger[26] (1995), observed an N-shaped relationship between income and environmental degradation, which was validated by several similar studies (Holtz-Eakin & Selden[28], 1995; Martinez-Zarzoso & Bengochea-Morancho[38], 2004; Poudel, Paudel, & Bhattarai[48], 2009; Akbostancı, Türüt-Aşık, & Tunç[2], 2009; Orubu & Omotor[42], 2011; Pérez & López[45], 2015; Yang & Qiu[65], 2016; Churchill, Inekwe, Ivanovski, & Smyth[16], 2018; Allard, Takman, Uddin & Ahmed[3], 2018).

Apart from validating Environmental Kuznets curve, this paper also attempts to study the impact of fossil as well as non-fossil fuel based energy consumption on environmental degradation to assess whether the same is on expected lines, i.e. fossil fuel aggravating environmental degradation and non-fossil fuel doing just the reverse.

However, what sets this study apart from the similar studies done in this area, is its attempt to study the impact of the interactive term of the contradictory forces of GDP per capita and energy cosumption, and to find out as to which out of the two factors shows stronger influence on environmental degradation. For this, the GDP per capita has been clubbed with non-fossil based energy consumption. Similarly, the quadratic form of GDP per capita has been clubbed with fossil-based energy consumption.

This section is followed by Review of Literature, which in turn, is followed by Research Methodology, Findings & Discussion, and Conclusion & Policy Recommendations in that order.

2. Review of Literature

The inverted U shaped relationship between economic growth and environmental degradation as propounded by Grossman and Krueger[25] (1991) through Environmental Kuznets Curve hypothesis, has since been revalidated by numerous researchers (Saboori *et al.*[52], 2012; Hussain *et al.*[29], 2012; Arouri *et al.*[8], 2012; Ahmed & Long[1], 2013; Ozturk & Acaravci[44], 2013; Apergis & Ozturk[6], 2015; Rajpurohit & Sharma[49], 2020).

Grossman and Krueger[26] (1995) had argued that EKC curve, at least for some pollutants, goes on to take N-shaped pollution income relationship, instead of remaining just inverted U shaped curve, as was propounded by them earlier (Grossman & Krueger[25], 1991). Similarly, Holtz-Eakin and Selden[28] (1995) investigated a panel of 130 countries for the period of 1951 to 1986 to conclude the existence of an N-shaped EKC.

Martinez-Zarzoso and Bengochea Morancho[38] (2004) in their study conducted with respect to 22 OECD countries for the period 1975-1998, using Pooled Mean Group estimator, had also observed N-shaped EKC for majority of the countries. Poudel, Paudel and Bhattarai[48] (2009) carried out a similar research with respect to Latin American & Caribbean countries using Fixed Effects approach and concluded the existence of an N-shaped EKC.

Akbostancı, Türüt-Aşık and Tunç[2] (2009) had applied Johansen cointegration test on a panel data pertaining to the various provinces of Turkey and have found N-shaped EKC for SO_2 emissions. Orubu and Omotor[42] (2011) examined the impact of per capita income on organic water pollutants for 6 African countries for the period 1980-2002 using Random Effects and Fixed Effects methods to observe mixed results including the existence of cubic form N-shaped EKC.

Further, Pérez and López[45] (2015) evaluated CO2 emissions for a sample of 175 countries to find both an N-shaped as well as an inverted N-shaped EKC. A state-specific EKC analysis done with respect to United States of America using Engle & Granger two step methods (Engle & Granger[22], 1987) reveals N-shaped relationship for 18 of its states (Yang & Qiu[65], 2016). Similarly, out of the panel of 20 OECD countries evaluated for the period of 1870 to 2014, three countries have exhibited N-shaped EKC (Churchill, Inekwe, Ivanovski, & Smyth[16], 2018).

Allard, Takman, Uddin and Ahmed[3] (2018) analyzed the panel of 74 countries for the period of 1994 to 2012 and concluded the existence of N-shaped EKC for most of the countries except for some upper-middle income countries. The N-shaped EKC has also been validated by a number of studies carried out with respect to different countries at different times (Sengupta[54], 1997; Moomaw & Unruh[40], 1997; de Bruyn & Opschoor[18], 1997; de Bruyn, van den bergh, & Opschoor[19], 1998; Lieb[36], 2003; Dijkgraaf & Vollebergh[21], 2004; Choi, Heshmati, & Cho[15], 2010; Masih & De Mello[39], 2011; Zhang & Zhao[68], 2014; Yang, He, & Chen[64], 2015; Özokcu & Özdemir[43], 2017; Sinha, Shahbaz, & Balsalobre[60], 2018; Murthy & Gambhir[41], 2018).

Terrell[62] (2020) assessed the panel of 14 countries and observed not just N-shaped but in some cases even M-shaped EKC. Similarly, Giles and Mosk[24] (2003) had also found M-shaped EKC for Enteric Methane in their research pertaining to New Zealand. Further, there have also been some research studies, which have detected inverted N-shaped EKC curves (Yuan & Cheng[66], 2011; Özokcu & Özdemir[43], 2017)

Energy consumption, in general, and fossil fuel consumption, in particular, was found to have a significant and positive relationship with environmental degradation, as has been evidenced in several studies done in this regard (Chebbi[14], 2010; Sharif-Hossain[57], 2011; Madlener & Sunak[37], 2011; Sharma[58], 2011; Al-Mulali et al.[5], 2012; Iwata *et al.*[31], 2011; Shahbaz, Hye, Tiwari, & Leitão[55], 2013; Shahbaz, Tiwari, & Nasir[56], 2013; Sadorsky[53], 2014; Al-Mulali & Ozturk[4], 2015; Tang & Tan[61], 2015; Zakarya, Mostefa, Abbes, & Seghir[67], 2015; Jamel & Derbali[32], 2016; Zhu, Duan, Guo, & Yu[69], 2016; Behera & Dash[11], 2017; Rasiah *et al.*[51], 2018; Rajpurohit & Sharma[49], 2020; Sharma & Rajpurohit[59], 2022). However, there have also been few studies, which have concluded an inverse relationship between energy consumption and environmental degradation (Apergis et al.[7], 2010; Rasiah *et al.*[50], 2015).

3. Research Methodology

A panel comprising of 15 developed countries namely Australia, Austria, Belgium, Canada, Denmark, Finland, Greece, Ireland, Japan, Netherlands, New Zealand, Norway, Spain, United Kingdom and United States for 42 years from 1979 to 2020 has been selected for this study, the entire database for which has been sourced from the World Bank website (World Bank[63], 2023).

This study does not limit itself to mere validation of EKC hypothesis depicting inverted U shaped relationship between income and environmental degradation, but goes beyond that to investigate the impact of further increase in income on environmental degradation to test the existence of N shaped relationship. This study, therefore, uses not just linear or quadratic but cubic form of GDP per capita as independent variables. Further, the impact of fossil fuel energy consumption, interaction of GDP per capita with non-fossil energy component, interaction of squared form of GDP per capita with fossil energy component, and one dummy variable for economic crisis of 2008 have also been included as independent variables. Accordingly, the basic model for this study can be represented as Equation 01 –

$$CO_{2_{it}} = \beta_0 + \beta_1 \mathrm{Y}_{it} + \beta_2 \mathrm{Y}_{it}^2 + \beta_3 \mathrm{Y}_{it}^3 + \beta_4 \mathrm{EF}_{it} + \beta_5 \mathrm{YENF}_{it} + \beta_6 \mathrm{Y}^2\mathrm{EF}_{it} + \beta_7 \mathrm{EC}_{it} + \mu_{it}$$

Equation (1)

Where CO_2 is the logged value of per capita CO_2 emissions, Y is the logged value of per capita gross domestic product, Y^2 and Y^3 are the squared and cubic values of logged value of per capita gross domestic product, EF is the logged value of the fossil fuel portion of total per capita energy consumption, YENF is the interaction of logged value of GDP per capita and the logged value of the portion of non-fossil energy consumption, Y^2EF is the interaction of squared value of logged GDP per capita and the logged value of the portion of fossil energy consumption and EC is the dummy variable representing economic crisis of 2008. The subscript i represents the number of cross-section units whereas the subscript t represents the number of years.

This paper uses the Pooled Mean Group (PMG) model (Pesaran *et al.*[47], 1999) given its suitability for dynamic panel analysis. PMG model can deal with the heterogeneity bias, while also taking care of the varying intercepts, short-run coefficients, and the error variances inherent across different countries (Das[17], 2011). The panel selected for this study has greater number of time periods as compared to the number of cross-sections, which is one of the prerequisite to ensure better estimation by averaging and pooling of data for any PMG model (Asteriou[10], 2009). Given these advantages, several similar research studies (Asafu-Adjaye *et al.*[9], 2016; Cetin[13], 2018; Rasiah *et al.*[51], 2018; Jibrilla[33], 2018; Ghorashi and Rad[23], 2018; Bekun *et a.l*[12], 2019) have also relied upon PMG Model.

In order to establish autoregressive relationship, the lagged values of the dependent as well as independent variables have been introduced through equation 2, which expresses the unrestricted specifications of ARDL model for the dependent variable CO_2(y).

$$nly_{it} = \sum_{j=1}^{p} \theta_{ij} nly_{i,t-j} + \sum_{j=0}^{q} \gamma'_{ij} nlx_{i,t-j} + \mu_i + \varepsilon_{it} \quad \text{Equation (2)}$$

Where y is the logged value of per capita carbon emissions and is used as a scalar response variable, x is the vector of all the independent variables as expressed in equation (1). θ and γ are the coefficients of the lagged dependent and explanatory variables respectively. Similarly, μ and ε represent the fixed effect and stochastic error terms respectively. While the subscripts i (i=1, 2, 3 ….N) denote the entities, the subscript t (t =1, 2, 3…T) denote the time periods. For computing the error correction model, equation (2) has been modified into equation (3).

$$\Delta nly_{it} = \psi_i ECT_{it} + \sum_{j=1}^{p} \theta_{ij} \Delta nly_{i,t-j} + \sum_{j=0}^{q} \gamma'_{ij} \Delta nlx_{i,t-j} + \mu_i + \varepsilon_{it} \quad \text{Equation (3)}$$

Where $\psi_{i,t-1}$ is the coefficient for error correction term ($ECT_{it} = nly_{i,t-1} - \alpha_i nlx_{i,t-j}$) or the speed with which it gets adjusted towards the long-run equilibrium and in order to establish the stable equilibrium ECT is required to have the negative coefficient ($-\alpha_i$). As one of the prerequisites of PMG model, all the cross-section entities must exhibit homogeneity in their long-run coefficients (i.e. $\lambda=\lambda_i$), and the same is required to be established through empirical testing (Hausman[27], 1978). The maximum likelihood approach is applied to compute the unknown coefficient $\psi_i = -(\sum_{j=1}^{p} \theta_{ij})$. However, the PMG approach allows for heterogeneity amongst the various short-run coefficients (Das[17], 2011). Equation (4) expresses the estimators.

$$\alpha_{PMG} = \frac{\sum_{i=1}^{N} \alpha_i}{N}; \beta_{PMG} = \frac{\sum_{i=1}^{N} \beta_i}{N}; \theta_{jPMG} = \frac{\sum_{i=1}^{N} \theta_{ij}}{N}, j = 1,2,3 \ldots, p-1\ ; \ \gamma_{jPMG} = \frac{\sum_{i=1}^{N} \gamma_{ij}}{N}, \ j = 1,2,3\ldots, q-1$$

Equation (4)

4. Findings and Discussion

Three types of Unit Root tests i.e. Augmented Dickey-Fuller (Dickey and Fuller[20], 1981), LLC (Levine *et al.*[35], 2002) and IPS (Im *et al.*[30], 2003) have been applied on the dependent as well as all the independent variables selected for this study to check for the data stationarity, and in turn, the suitability thereof for application of PMG model. The results of the unit root tests as shown in Table 01, confirm that all the variables have data stationarity at the first difference at 1% significance level, and therefore, qualifies the requirement of PMG model of having the data stationarity at either level or at the first difference.

Table 1: Panel Unit Root Test Results (p-values)

	Stationarity Check at Level			Stationarity Check at 1st Difference		
Variables	LLC	IPS	ADF	LLC	IPS	ADF
CO_2	0.7453	0.7857	0.4430	0.0000***	0.0000***	0.0000***
Y	0.0000***	0.0678*	0.1302	0.0000***	0.0000***	0.0000***
Y^2	0.0000***	0.1911	0.3268	0.0000***	0.0000***	0.0000***
Y^3	0.0000***	0.3946	0.6011	0.0000***	0.0000***	0.0000***
EF	0.7954	0.9571	0.8278	0.0000***	0.0000***	0.0000***

YENF	0.0000***	0.2437	0.0316**	0.0000***	0.0000***	0.0000***
Y^2EF	0.0000***	0.1377	0.2767	0.0000***	0.0000***	0.0000***

Source: Computed by the authors using EViews 9.

Notes: (1) *** = 1% level, **= 5% level, and *= 10% level of significance (Indicates the significance of all p -values at the respective degrees of freedom).
(2) Null hypothesis: series has a unit root.
(3) LLC = Levin, Lin, Chu test; IPS = Im, Pesaran, Shin test; and ADF = Augmented Dickey–Fuller test.

The PMG test using unrestricted model (Pesaran *et al.*[47], 1999) is applied after taking three lags of all the variables selected for this study, and the results thereof are shown in Table 02. The Error Correction Coefficient of – 0.35 depicting the speed with which short-run coefficients adjusts into long-run coefficient has the expected value and sign, and that too, at 1% significance level. Table 02 also displays the results of the Hausman Test (Hausman[27], 1978) and Pesaran CD test (Pesaran[46], 2004) to check the cross-section random effects and the cross-section dependence respectively, and accordingly confirming the pertinence of the data for PMG model.

Table 2: Pooled Mean Group (PMG) Estimation

Dependent Variable: D(CO^2)
Sample: 1977 2015
Selected Model: ARDL(3, 3, 3, 3, 3, 3, 3, 3)

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
Long Run Equation				
Y	7.769355	3.044226	2.552161**	0.0113
Y^2	-0.814241	0.311399	-2.614787***	0.0095
Y^3	0.030568	0.010575	2.890620***	0.0042
EF	0.233462	0.007632	30.58878***	0.0000
YENF	0.017457	0.003052	5.720442***	0.0000
Y^2EF	-0.008724	0.000819	-10.65664***	0.0000
EC	-0.091431	0.012805	-7.140184***	0.0000
Short Run Equation				
COINTEQ01	-0.353927	0.126048	-2.807862***	0.0054
D(CO^2(-1))	-0.071227	0.090972	-0.782953	0.4344
D(CO^2(-2))	-0.008950	0.074678	-0.119854	0.9047
D(Y)	4.258702	12.55202	0.339284	0.7347
D(Y(-1))	-6.729945	9.073964	-0.741676	0.4590
D(Y(-2))	-5.199001	6.273554	-0.828717	0.4081
D(Y^2)	-0.351209	1.252524	-0.280401	0.7794
D(Y^2(-1))	0.643319	0.901041	0.713973	0.4759
D(Y^2(-2))	0.471257	0.631356	0.746421	0.4561
D(Y^3)	0.010799	0.039720	0.271892	0.7859
D(Y^3(-1))	-0.021623	0.029584	-0.730912	0.4655
D(Y^3(-2))	-0.015699	0.021290	-0.737364	0.4616

D(EF)	0.115184	0.035749	3.222018***	0.0014
D(EF(-1))	-0.011500	0.033419	-0.344113	0.7311
D(EF(-2))	-0.004329	0.024324	-0.177982	0.8589
D(YENF)	0.018975	0.037333	0.508272	0.6117
D(YENF(-1))	-0.011896	0.010834	-1.097985	0.2733
D(YENF(-2))	0.048323	0.061728	0.782830	0.4345
D(Y^2EF)	-0.005951	0.007260	-0.819780	0.4131
D(Y^2EF(-1))	0.004670	0.004863	0.960482	0.3377
D(Y^2EF(-2))	0.004432	0.007656	0.578880	0.5632
D(EC)	0.030665	0.013760	2.228655**	0.0267
D(EC(-1))	0.011592	0.021192	0.547027	0.5849
D(EC(-2))	-0.025123	0.036652	-0.685439	0.4937
C	-10.53837	3.760202	-2.802607***	0.0055
Pesaran CD Test	1.512737		p-Value	0.1303
Hausman Test	5.177765		p-Value	0.6383

Source: Computed by the authors using EViews 9.

Notes: *** = 1% level, **= 5% level, and *= 10% level of significance (Indicates the significance of all p -values at the respective degrees of freedom).

The long-run coefficients of all the independent variables as shown in Table 02 confirm that they influence the carbon emissions in a significant way and in the expected direction. The GDP per capita (Y), its squared form (Y^2) and its cubic form (Y^3) exhibit positive ($\beta_1>0$), negative ($\beta_2<0$) and positive ($\beta_3>0$) long-run coefficients respectively, implying an N-shaped relationship of income with carbon emissions.

To assess the impact of fossil fuel based energy consumption, the per capita energy consumption is multiplied with the percentage of fossil fuel in total energy consumption to proxy the consumption of fossil energy (EF), which, as expected, is found to have positive and significant impact on carbon emissions at 1% significance level.

The interaction of GDP per capita and non-fossil energy consumption (YENF) is found to have positive and significant relationship with carbon emissions at 1% significance level, depicting a stronger impact of GDP per capita, so much so that despite this economic growth being fueled by non-fossil energy, it increases environmental degradation. Similarly, the interaction of the squared value of GDP per capita with fossil fuel energy consumption (Y^2EF) is found to have negative and significant relationship with carbon emissions at 1% significance level, thereby again depicting the stronger impact of GDP per capita in congruence with EKC hypothesis, so much so that despite being associated with fossil energy consumption, it has negative relationship with carbon emissions. This proves that it is not just the type of fuel consumption, but the kind of technology used and the efficiency thereof, which plays a more critical role in determining the level of environmental degradation. During the initial stage of economic growth, when an economy does not have enough resources to afford efficient technology, it results into increased carbon emission, even if the same is supported by non-fossil fuel consumption. Similarly, in the next stage, as the economy becomes developed enough, it can afford clean and green technologies and, therefore, can grow while keeping the carbon emissions under control, even if the same is fueled by fossil-based energy consumption. However, a desperate attempt to grow even further by overstretching the resources will increase the level of carbon emissions again, thereby making the EKC N-shaped.

The financial crisis of 2008 represented by dummy variable EC is found to have negative and significant relationship with environmental degradation at 1% significance level.

The result of Kao cointegration test (Kao[34], 1999), as displayed in Table 03, confirms the presence of cointegration among variables selected for this study at 1% significance level.

Table 3: Kao Residual Cointegration Test

	t-Statistic	Prob.
ADF	-5.638627***	0.0000

Source: Computed by the authors using EViews
Notes: *** = 1% level, **= 5% level, and *= 10% level of significance (Indicates the significance of all p -values at the respective degrees of freedom).

5. Conclusion and Policy Recommendations

This research study has analyzed a panel of 15 developed countries for 42 years from 1979 to 2020 using Pooled Mean Group approach to assess the impact of different degrees, variants and combinations of income and energy consumption on carbon emissions.

The impact of varying degrees of increase in income depicted by GDP per capita, its squared and cubic forms on carbon emissions exhibits an N-shaped relationship, thereby validating the advanced level of Environmental Kuznets Curve (Grossman & Krueger[26], 1995). The initial level of economic growth in any economy is fuelled by inefficient and not so environment friendly technologies, and therefore has a positive relationship with carbon emissions. However, as the economy progresses and people demand a better and healthier standard of life, the demand for better environment also increases. Moreover, the availability and affordability of clean and green technologies enables the economy to control carbon emissions, despite higher economic growth, and hence a negative relationship. However, this relationship remains sustainable only upto an extent, beyond which any further attempt to achieve reckless economic growth again results into an increase in the carbon emissions, thereby making the EKC N-shaped. This is an important revelation, and makes a case for accelerating economic growth only to the extent it remains responsible enough to take care of the larger interest of society, and needs to be monitored and controlled as soon as it starts going out of control.

The fossil fuel based energy consumption, on the expected lines, has positive and significant impact on carbon emissions. This calls for the requirement of using non-fossil fuel based or more efficient and environment-friendly energy sources to drive the economic growth.

However, when the combined effect of GDP per capita and non-fossil based fuel consumption is analyzed, it is the GDP per capita, and not the type of fuel, which was observed to have dominant impact. That is, despite being associated with non-fossil based fuel energy consumption, the GDP per capita, in the developing stage of any economy, was found to have a positive and significant impact on carbon emissions, thereby indicating that it is not just the type of energy, but several other factors like the kind of technologies, the carelessness towards environment etc. which can result into environmental degradation.

Similarly, during the second stage of development, despite being associated with fossil-based energy consumption, the higher growth in GDP per capita impacts the carbon emissions negatively, thereby proving again, that it is the not just the type of fuel in energy consumption, but the level of economic growth and the other incidental factors like the use of efficient and green technologies, and the demand for cleaner environment etc. which play a dominant role in determining the level of carbon emissions. Governments, therefore, should not focus only on the type of fuel and energy consumption, but also on the various other factors influencing the growth in GDP, and in turn, carbon emissions.

The negative impact of economic crisis or recession on carbon emission can be attributed to the reduced industrial and economic activities. A detailed sector-wise analysis of economic activities during and after the crisis can help us identify the sectors or activities responsible for varying degrees of carbon emissions, and accordingly the necessary corrective actions can be undertaken.

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