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RESEARCH ARTICLE

REVISITING THE ENVIRONMENTAL KUZNETS CURVE: A PANEL DATA ANALYSIS

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Abstract: This research paper examines the empirical relationship between environmental quality (CO_2 emissions), economic growth, urbanization, and trade openness by using panel data of 31 years over the period of 1990 to 2020 of 15 countries. These 15 countries have been selected on the basis of low, moderate to high, and very high human development index categories as classified in indiastat.com. We used unit root test and cointegration test to verify the stationarity and the existence of long run relationship among the selected variables. Next, fixed effects and random effects models have been deployed for verifying the EKC hypothesis. Factual evidence disclosed that trade openness and population growth reduces CO_2 emissions. The existence of the EKC was also confirmed by the data. Further, the pairwise Granger causality test conducted demonstrates that CO2 emissions and GDP are causally related in both directions.

Keywords: *Environment quality, Economic growth, Environmental Kuznets Curve, Trade openness, Urbanization, Population growth.*

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INTRODUCTION

An undeniable impact of economic development is degradation of the environment, which if allowed to continue unabated, can violate the very notion of sustainable development that we are in the pursuit of. In fact it is argued that the relationship between economic growth and environment is bidirectional. Any change in the environment is bound to have its effect on the wellbeing of the economy through health impacts, impact on labour productivity and on the existence of the natural habitats. Economic development in turn, may harm the environment through production and consumption activities.

In this modern era, industrial wastes that are polluting the rivers, the vehicular emissions, effluents from chimneys of the households and the factories, transboundary pollution, increased greenhouse gases by way of burning fuel for heat, chemical reactions in laboratories, and increased deforestation are some of the major reasons behind the constant depletion in the quality of environment. Among the major pollutants are the suspended particulate matter (spm), sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO) and carbon dioxide (CO_2), which are heavily being generated through the economic as well as human activities.

The current literature is overflowing with researches on the relationship between environment and economic prosperity, and how they are intertwined. Keeping in line with the Kuznets curve hypothesis proposed by Simon Kuznets in 1955, that there is an inverse U shaped relationship between income inequality and economic development, several economists have argued to have observed a similar pattern of relationship between environmental quality and economic growth. Debate on this observation started in the 1990s, when

Panayotou first coined the term Environmental Kuznets Curve (EKC) in 1993 to indicate the inverted U nature of the relationship. It was suggested that at early stages of development as the country engages in productive activities, pollution also grows proportionately which negatively impacts the environmental quality. However at later stages of development, probably due to improved awareness among the masses and with the adoption of less polluting technologies, environmental quality gradually enhances.

According to Grossman and Krueger (1991), pollution is just a transitional problem that accompanies economic growth, an observation that was supported by some other authors as well (Beckerman, 1992; Cole *et. al.*, 1997). Shafik and Bandyopadhyay, (1992) on the other hand insisted that without targeted policies and investments in technology that reduce environmental degradation, the proposed and desired pattern would be unattainable. Some researchers have also pointed out about some additional underlying reasons behind the observed EKC curve. In recent times in the industrial countries access to cleaner water, adequate sanitation and better municipal waste disposal system have led to substantial improvements in their environmental quality.

In fact countries like Japan are actually spending substantial amount on pollution abatement to reduce their environmental concerns. Moreover, it is also argued that as nations become more developed they go through a structural change (de Bruyn *et. al.,* 1998), and they tend to move towards production of those commodities that are less polluting while importing the commodities that are more polluting from the developing countries, and in the process reducing their pollution levels substantially at higher per capita income levels.

SURVEY OF EXISTING LITERATURE

Akbostanci *et. al.* (2009) examined the relationship between environmental quality and income for Turkey at two levels. In the first level they studied the relationship between CO_2 emission and income per capita with the help of a time series model using co integration techniques for the period 1968 through 2003.

In the second stage they examined the relationship on two pollutants, namely PM_{10} and SO_2 and collected panel data on 58 provinces covering the period 1992 through 2001. The time series analysis for CO_2 emission depicted a monotonically increasing relationship with income per capita in the long run while an N-shaped trajectory was observed for both PM_{10} and SO_2.

Bruyn *et. al.* (1998) have drawn insights from the 'intensity-of-use' analysis and derived a growth model and estimated the relationship for three types of emissions, namely, CO_2, SO_2 and NO_X for the countries West Germany, Netherlands, UK and USA. They found that the time path of these emissions showed positive relationship with growth while they bestowed the reason for reduction in emissions on structural and technological changes in the economy.

Acemoglu *et. al.* (2012) developed a general equilibrium model wherein they incorporated innovation in the form of production of new goods that entails use of skilled workers. This innovation is then followed by a standardization process which acts as an engine of growth while at the same time posses as a barrier and hence growth is observed to be an inverted U function of competition and standardization rate.

Heerink *et. al.* (2001) added to the argument favoring the inclusion of additional variables apart from income per capita into the study pertaining to the EKC hypothesis such as a measure of income dispersion. They concluded that income inequality is negatively related to environmental degradation when the relation between household income and environmental damage is concave.

Boyce (1994) emphasized that inequality is the cause behind environmental degradation and advocated that with greater inequality of power and wealth environmental degradation increases. The authors also hypothesized that the amount of pollution generating economic activity depends on the balance of power distributed between the net benefiters and the bearers of net cost from the activity.

Andreoni and Levinson (2001) put forward a static model on the EKC relationship where in the curve relates to the increasing returns to the technological link between the consumption of a desirable item and the abatement of the undesirable byproduct. However it does not depend on externalities or the dynamics of growth. They considered a one person economy to avoid the complications of presence of externalities so that the solution generated is Pareto efficient. Next they generalized the study to an economy having many persons.

Holtz-Eakin and Selden (1995) examined the relationship between growth and CO_2 emissions. They worked on global panel data and observed a diminishing marginal propensity to emit the gas with rise in per capita GDP. Based on their analysis they forecasted global emissions for the future.

Khanna and Plassmann (2004) have investigated the EKC hypothesis by estimating the income elasticities for five pollutants in the USA using the 1990 data, namely sulphur dioxide (SO_2), particulate matter (PM_{10}), carbon monoxide (CO), ground level ozone (O_3), and nitrogen oxides (NO_X). In their study they have observed the turning points in terms of change in the signs of the income elasticity for these pollutants. They wanted to find out the ease to spatially separate consumption from production as this was crucial in deciding the level of turning points of the pollutants.

Hussain and Dey (2021) scrutinized the relationship between economic development (indicated by Human Development Index) and environmental degradation (CO_2 emission). The main objective of the study is to test the heterogeneity in the association between HDI (Human Development Index) and CO_2 emission; to attain this, the authors collected panel data of 30 countries for the period of 27 years (i.e., from 1990 to 2016) from the world development indicators (source- World Bank). Collected data were analyzed by well-known statistical techniques such as pooled OLS and fixed effect models. The results revealed that there is a strong proof of Environmental Kuznets Curve (EKC) for both 30 countries and individual countries.

Chang *et. al.* (2021) applied an enhanced green Solow model to examine the connection between economic growth and air pollution. To attain the research objective, prefecture level data was collected from 284 cities in China for the period 2004 to 2015. The researchers used spatial dynamic panel data models to probe the Environmental Kuznets Curve; the model predicts an environmental Kuznets curve with an inverted U shape, with an earlier peak because of the abatement technology's spillover impact.

Wang *et. al.* (2023) inquired the impact of various factors (trade openness, human capital, renewable energy, and natural resources) on the carbon emissions. To achieve this end, data of 208 countries were collected for the period from 1990 to 2018. Collected data were analyzed by using Generalized method of moments and fully modified ordinary least squares, the findings demonstrate that EKC (Environmental Kuznets Curve) is verified when trade openness, human capital, use of natural resource rents are taken into account.

At the global level, the connection between income level and carbon emission displays a "inverted U-shape" curve. It is also found that before and after EKC turning points, the consumption of renewable energy and human capital has different effects on carbon emissions.

Bekun *et. al.* (2023) conducted a study on the relationship between the inflow of foreign direct investment and energy consumption in turkey. To attain this objective, the authors obtained time series data from 1970 to 2016. Data were analyzed by statistical techniques such as Pesaran's autoregressive and dynamic ordinary least squares, the researchers observed two significant findings in the study, first one that supported the pollution have significantly deteriorated Turkey's environment as a result of FDI inflow and the second finding is that renewable energy enhances environmental quality.

Li *et. al.* (2024) investigated the impact of geopolitical risk, natural resource rents, corruption, and energy consumption on the environment into the Environmental Kuznets Curve (EKC) framework. The authors collected panel data of 18 years i.e., from 2002 to 2020, from 38 countries. Data were analyzed by employing statistical techniques such as quantile regression model, the findings shows that the association between economic growth and carbon emissions is first suppressed, and subsequently strengthened, by natural resource rents. The results also signify that increasing energy intensity strengthened the relationship between increasing carbon emissions and economic growth.

Islam *et. al.* (2023) checked the impact of green house gas emission (CO_2, CH_4, and N_2O) on the economic growth in Bangladesh, taking these factors into the framework of Environmental Kuznets Curve. Data were collected for the period of 1976 to 2014. The researchers used the statistical techniques such as autoregressive distributive lag model, and VAR accounting approach to determine the causal relationship and the independent variables influences on dependent variable. The results disclosed that the Environmental Kuznets Curve hypothesis is valid to the emissions of N_2O; a bilateral causal relationship between GDP and CO_2 and a unilateral causal association between CH_4.

Zhan *et. al.* (2023) examined the connections between natural resources and technological up gradation in preventing the damage that the environmental pollution (i.e., CO_2) does to the environment in China by revisiting the Environmental Kuznets Curve. Collected data were analyzed through statistical methods such as Quantile Autoregressive Distributed Lag, the authors found in their study that rule of law and innovation of technology lowers CO_2 and the consumption of natural resources in China causes CO_2 levels to rise.

Jaeger *et. al.* (2023) re-examined the Environmental Kuznets Curve by considering both income and increase in population as sources of environmental problems. To achieve the purpose of the study, the authors collected a large set of new data for a period of 38 years from 1789 sites and analyzed this collected data by relevant statistical models. The results found that the environmental Kuznets curve is robust inverted U-shaped because of the correlations between rising income and rising population and air pollution.

Huang *et. al.* (2024) inquired on the effect of climate policy uncertainty on the economic growth by collecting panel data for the period of 1998 to 2021 from 47 nations. The researchers employed statistical methods such as pooled regression, fixed effect, and the generalized method of moment to analyze the collected data, the finding shows that the selected countries in the study have an inverted U-shaped Environmental Kuznets Curve.

Esmaeili *et. al.* (2023) assessed the effects of economic complexity, foreign direct investment (FDI) and the use of renewable energy on CO_2 emissions in N-11 countries. The authors obtained the data for period of 1995 to 2019 from different countries and analyzed by the statistical methods such as panel quantile regression. The authors found that the findings support the validity of the Environmental Kuznets Curve in the selected 11 countries due to economic complexity. Notably, in the early phase of industrialization; the influence of economic complexity is stronger and more significant.

Ghaderi *et. al.* (2023) reviewed the impact of foreign tourist arrival on the CO_2 emission in the framework of Environmental Kuznets Curve. The researchers obtained the data for the period of 1995 to 2018 from the Middle East and North Africa regions and employed statistical tool such as panel granger non-causality test. The results indicate that the arrivals of tourist lower CO_2 emissions; energy use and trade openness are the primary cause of CO_2 emissions. Additionally, the results demonstrated that first generation estimators supported the Environmental Kuznets Curve hypothesis.

Wen *et. al.* (2021) Investigates how economic growth affects carbon emissions and re-examines the environmental Kuznets curve in Suzhou, China. To attain this goal, the researchers obtained the data from Chinese annual year book for the period of 1998 to 2019. Statistical techniques were used such as linear and non-linear approach to co-integration for analyzing the collected data. The finding indicates that a long relationship between economic progress and CO_2 exists, observed an inverted U shaped Environmental Kuznets Curve. It is also pointed out that the industrial share and trade openness are positively correlated with rising carbon emissions. Energy consumption and carbon emissions have a slight but positive correlation.

Frodyma *et. al.* (2022) examined the association between CO_2 (i.e., production based and consumptions based emissions) and economic growth in European countries within the context of Environmental Kuznets Curve. The authors collected data for the period of 1970 to 2017 from World Bank report (world development indicators). Statistical methods used such as ARDL co integration, quadratic polynomial forms to test the hypothesis. The findings show that the EKC models were unable to adequately explain the correlation between economic growth and production based emissions in the majority of nations in Europeans Countries.

Jozwik *et. al.* (2021) scrutinized the long term association between CO_2 emissions and economic growth in certain Central European nations. The aim of the paper was to test the relationship between CO_2 and economic growth within the circle of Environmental Kuznets Curve; the researchers obtained the data for the period of 1995 to 2016 and employed the statistical techniques such as ARDL bound test. The result shows that the hypothesis of EKC is valid in Poland. It is also found that energy use raised CO_2 emissions in each of the selected nine countries.

Han and Jun (2023) verified the link between growth, CO_2 emissions, size of population, renewable of energy, magnitude of urban population and climate finance. To achieve this objective, the researchers gathered a panel data set for the period of 25 years (i.e., from 1990 to 2015) from 141 countries and analyzed the data by deploying standard regression analysis. The authors found in the article that the assumption of environmental Kuznets curve is justifiable in quadratic specification while the axiom of EKC is not stand true in case of cubic polynomial and clustered data.

Vektas and Ursavas (2023) scrutinized the effect of energy usage and globalization on the environment in the framework of environmental Kuznets curve. To verify the hypothesis of the ECK curve, the researchers obtained the data for the period of 1981 to 2015 from Organization for Economic Cooperation and Development countries. Data were analyzed by dynamic ordinary least square method. The finding shows that the economic cooperation and development countries have not shown significant impact of the selected variables on environment relationships. The authors concluded that the impact of globalization and usage of energy on environment is more significant in emerging nations.

Zayyana and Halliru (2023) examined the interrelationship between economic growth and environment by studying the role of the shadow economy and financial development in Nigeria. The authors obtained the data for the period of 29 years commencing from 1991 to 2020. The researchers employed threshold regression analysis to analyze the collected data. The result shows that the supposition of Environmental Kuznets Curve holds true and indicates that there exists an inverse relationship between environmental quality and the scale of shadow economy in lower as well as upper limits.

Ayad *et. al.* (2023) evaluated the hypothesis of Environment Kuznets Curve on government spending and economic growth. The authors tested the viability of EKC by integrating the ARMEY curve into EKC in the three most polluted countries in Africa: Algeria, Egypt, and South Africa. For this, data collected from 1970 to 2020 and the same analyzed with the statistical techniques such as ARDL equation. The results indicate that the composite model is valid in Algeria while the model is invalid for Egypt and South Africa.

Kalisvaart *et. al.* (2023) examined the viability of Environmental Kuznets Curve by studying the relationship between the green house gas emissions and gross domestic product in the provinces and territories of Canada. The researchers obtained the panel data from 1990 to 2020. Statistical methods such as pooled and fixed regression analysis, the result shows that the assumption/hypothesis of EKC is supported, indicating the rising economic growth in the region of Canada is likely to result in a decline in greenhouse gas emissions.

Rjoub *et. al.* (2022) evaluated the relationship between CO_2 and economic growth for the selected nations (Mexico, Indonesia, Nigeria, and Turkey). The authors obtained data for the period of 1960 to 2019 with the help of new method bootstrap and analyzed the collected data by vector auto regression process. The findings show that the selected countries are not moving in the direction of sustainable development, the authors concluded that the selected countries should pay attention on their ecosystem when making the environmental policies.

Leitao *et. al.* (2023) assessed the impact of FDI, renewable and non-renewable energy, CO_2 emissions on the economic growth. To achieve the purpose of the study, the authors collected data from 1990 to 2018 for visegrad countries. Data were analyzed by descriptive analysis, correlation; and ARDL model. The finding shows that there is a significant positive relationship between CO_2 emissions and economic growth and per capital is negatively correlated with CO_2.

Sharma *et. al.* (2023) attempted to determine the Indian tourism-induced Environmental Kuznets Curve (EKC) origin point. To attain the aim of the study, the researchers obtained time series data for the period of 1980-2019 and data were analyzed by using statistical tool such as ARDL. The finding of the study shows that there exists a long run association between CO_2 and selected variables (energy consumption, per capital income). The authors suggested to depend more on green energy production and less on fossil fuels for economic development.

Aydin *et. al.* (2023) checked into the impact of use of renewable energy, research and development investment on energy, patent on the economic growth in the European countries within the framework of EKC. To test the axiom/ assumption, data were collected for the period of 1990 to 2018. The findings indicate that the assumption of EKC is absolutely to be true in Finland while in Austria and Netherlands, the usage of renewable energy leads to smaller footprint.

Goldman and Zhelyazkova (2023) conducted a study on the nexus between carbon emissions and economic growth (GDP) in Europe in the framework of EKC. To attain the objective of the study, the researchers collected data for time span of 1995 to 2022 and analyzed the collected data by panel VAR specifications. The finding shows that there is a positive long term correlation between economic growth and carbon emissions in two regimes. It is also found that economic growth measured in terms of GDP is consistently decreasing in the first regime whereas in second regime GDP is continuously increasing.

Mosconi *et. al.* (2020) investigated the role of spatial and space dimensions in EKC (Environmental Kuznets Curve) in Italy. To achieve the aim of the study, the collected the data from various sources and applied the geographical weighted regression analysis. The authors found that spatial and spaces are significant characteristics in ecological economics.

Yuerong *et. al.* (2024) scrutinized the impact of select variables (digital trade, green technology innovation) on the ecological foot print by taking into account the consumption of renewable energy, economic growth, and globalization. To test the hypothesis of the Environmental Kuznets Curve, the researchers obtained panel dataset for the time span of 2000 to 2019 for the countries (Brazil, Russia, India, China, and South Africa). Collected data analyzed by well known statistical techniques such as panel quantile regression analysis, ARDL technique. The authors found that the digital trade, green technology have a positive impact on the environment.

Magazzino *et. al.* (2023) attempted to find the long run association among the selected variables (carbon emissions, GDP in real terms, and the consumption of energy) by selecting nine advanced economies. To attain this goal of the study, the authors gathered data for the period of 1870 to 2008 and analyzed the data by employing both parametric and semi-parametric regression models. The findings corroborate the inverted U-shaped interrelationship between CO2 and real GDP for a sample of nations, but they do not support the Environmental Kuznets Curve (EKC) for the post-1950s period.

Once again, to sum up, contradictory empirical findings about the assumption of Environmental Kuznets Curve have been observed in the past studies. Despite the fact that the past studies have enhanced the insight regarding the Environmental Kuznets Curve, there is still lack of studies that test the axiom of EKC considering the Human Development Index. Therefore, this study is an attempt to examine the long run relationship between economic growth and environmental quality in the framework of EKC by taking into account the Human Development Index of 15 countries.

The rest of the paper is designed as follows: Section 3 highlights the data source and methodology. Section 4 describes the justification of the variables chosen for the research. Section 5 discusses the result and section 6 concludes the research work.

DATA SOURCE AND METHODOLOGY

In the standard EKC models per capita emission levels represent environmental quality and is modeled as a quadratic function of income per capita and a set of other control variables. The present study attempts to delve into this EKC dynamics once more. A panel data consisting of 15 countries for 31 years (1990 through 2020) have been chosen for the purpose.

The countries have been selected on the basis of their HDI values as reported in indiastat.com database for the year 2021. Indiastat.com has categorized the countries in terms of their HDI rank into Very High Human Development, High Human Development, Medium Human Development, and Low Human Development countries. Five countries with very high HDI (Switzerland, Norway, Australia, South Korea and Canada), five countries with high to medium HDI (Iran, Egypt, South Africa, Brazil, India) and rest with low HDI (Pakistan, Sudan, Madagascar, Gambia, Nigeria) have been included in the study.

As measure of environmental quality, CO_2 emission per capita has been considered. In addition to the standard GDP per capita measured in terms of PPP (constant 2017 international $) and the square on GDP per capita that are usually considered in the standard EKC, as external factors that indirectly control environmental quality, the study includes population growth, trade openness, and urbanization to explain the pollution dynamics. Country wise data on these variables have been taken from World Development Indicators for the above mentioned time period.

Model Specification

To verify the validity of the EKC relationship at the world level we adopt a log-log panel specification of the form:

$$\log\left(\frac{CO_{2,it}}{POP_{it}}\right) = \beta_0 + \beta_1 \log\left(\frac{GDP_{it}}{POP_{it}}\right) + \beta_2 \log\left(\frac{GDP_{it}}{POP_{it}}\right)^2 + \beta_3 \log(POP\ GRW_{it}) + \beta_4 \log(Urbanization_{it}) + \beta_5 \log(Trade\ Openness_{it}) + \varepsilon_{it}$$

Where $\frac{CO_{2,it}}{POP_{it}}$ refers to the per capita CO_2 emission levels, $\frac{GDP_{it}}{POP_{it}}$ refers to per capita income, and $POP\ GRW_{it}$ refers to population growth which is measured in terms of annual percentage. As for the other explanatory variables, urbanization is measured in terms of urban population as a percentage of total population and trade openness is measured in terms of trade as a percentage of GDP. In the log-log specification of the model the coefficients depict the elasticities. The EKC hypothesis will be supported if we get the standard value of the coefficients $\beta 1 > 0$ and $\beta 2 < 0$ and the turning point $TP_{inc} = \exp(-\frac{\beta 1}{2\beta 2})$ is at a value within the range of observed per capita income.

Before undertaking the econometric analysis two preliminary tests, namely, the unit root test and the test for cointegration are conducted on the panel data.

Unit Root Test and Panel Cointegration Test

To examine whether the variables of interest are stationary we perform the set of panel unit root tests developed by Im-Pesaran-Shin and by Levin-Lin-Chu. The tests are performed both on the levels data and their first differences. All the variables are log transformed. Individual effects and individual linear trends are included.
We assume the following AR (1) process for the panel unit root test:

$$Y_{it} = \rho_i Y_{it-1} + \square_i Z_{it} + \varepsilon_{it}$$

$i = 1, 2, 3, \ldots\ldots, N; \quad t = 1, 2, 3, \ldots\ldots, T.$

There are T time points and N cross sections in the panel. Z_{it} is the vector of exogenous variables, and ρ_i is the autoregressive coefficient. $|\rho| < 1$ implies that Y_{it} is stationary while $|\rho| = 1$ impliesY_{it} is non stationary. Lastly, ε_{it} is the error term and assumed to be mutually independent idiosyncratic disturbance. It is pertinent to mention here that while the Im-Pesaran-Shin test (developed by Maddala and Wu, 1999) allow ρ_i to vary freely across cross-sections, the Levin- Lin- Chu test assumes that ρ_i is common across cross-sections, so that $\rho_i = \rho$ for all i.

Once the presence of unit root is established and the order of integration is determined, a panel cointegration test is necessary to test for any long-run relationship between the integrated variables. We choose the Pedroni panel cointegration test and the Johansen Fisher Panel cointegration test for the purpose.

Pedroni test have seven statistics, out of which the first four are panel statistics that are based on 'within' dimension and the last three are group statistics which are based on 'between' dimension.

Regression Models

Our study attempts two regression models for panel data analysis, namely the fixed effects and random effects models. We cannot attempt the pooled regression technique here if cointegration is supported by the tests, indicating presence of long term relationship among the variables, since in that case application of pooled OLS technique shall give asymptotically biased estimates.

Granger Causality Test

We next intend to pursue the pairwise Granger causality test to understand the direction of relationship between CO_2 per capita and the chosen variables, which can be of three types: Unidirectional, bidirectional or no causality. The following bivariate regressions shall be run:

$$Y_{it} = \alpha_{oi} + \alpha_{1i}Y_{it-1} + \cdots + \alpha_{ki}Y_{it-k} + \beta_{1i}X_{it-1} + \cdots + \beta_{ki}X_{it-k} + v_{it}$$

$$X_{it} = \alpha_{oi} + \alpha_{1i}X_{it-1} + \cdots + \alpha_{ki}X_{it-k} + \beta_{1i}Y_{it-1} + \cdots + \beta_{ki}Y_{it-k} + v_{it}$$

Here t indicates the time dimension while i represent the cross-sectional dimension of the panel. The stacked causality test by Granger, (1969) assumes the panel data as one large stacked dataset.

Justification of Variables

GDP per capita: The standard EKC model proposes that there is an inverted U relationship between pollution and economic development. As discussed earlier, this is because in the initial stages of development, growth of manufacturing sector causes environmental degradation owing to generation of industrial wastes and effluents. But in higher stages of development the process is reversed as countries become environmentally aware and use pollution abatement technologies. In this study we have used per capita GDP in terms of PPP at constant 2017 international dollars as a proxy for economic development.

Population Growth: With the growth in population there is a threat of uncontrolled industrialization and urbanization, and hence depletion of natural habitats. With population growth, the pressure on the environment increases alarmingly as people engage in land clearance and increased land use. Further, there is increase in the production of wastes and vehicular emissions, which leads to both air and water pollution. The impact of population growth on environmental quality can be either positive or negative, depending on the stage of economic development of a country.

Urbanization: In order to fetch greener pastures people from rural areas are migrating to urban areas, with an expectation to finding good jobs and prosperity. This phenomenon is observed worldwide which has already put an immense pressure on the cities, since with growing urban population demand for urban housing also increases. With increase in population threat to the cities also come from increased pollution due to high energy consumption, disposal of solid wastes into the water bodies, deforestation and vehicular emissions, leading to environmental degradation in the form of poor air and water quality. Urbanization has been included in our augmented version of EKC as a control variable, to note its impact on the EKC dynamics.

Trade Openness: International trade has been found to have direct connection with the state of environment quality. According to the 'pollution haven hypothesis' jurisdictions having less stringent environmental standards will attract more polluting industries from the countries having high environmental standards. On the other hand, 'pollution halo hypothesis' is of the opinion that trade can lead to reduction in environmental degradation worldwide, on account of use of eco-friendly technologies by the big multinationals. Thus the impact of trade openness on the environment is worth studying.

Emissions: Researchers over the years have tried several pollutants and some works have examined the EKC relationship using the environmental indicators such as sulphur dioxide (SO_2), nitrous oxide (NO_X), suspended particulate matter (SPM), carbon monoxide (CO), and carbon dioxide (CO_2). Others have used greenhouse gas, ozone layer, water quality and sometimes waste management for the purpose. Our present study used carbon dioxide emissions as a proxy for air quality due to the availability of data for developing and developed countries.

RESULTS AND DISCUSSION

Summary Statistics

We begin with a summary of the descriptive statistics on the chosen variables. The statistics are calculated on the original values. Table 1 below provides the summary statistics of the chosen variables for the years 1990 through 2020 and also the units in which the variables have been measured. Result shows that GDP per capita has the highest mean and median compared to the other variables, followed by urbanization and trade openness.

Standard deviation helps to understand the variability in the dataset around the mean and is useful in comparing the variables. It is found to be highest for GDP per capita and lowest for population growth, indicating that GDP per capita differs hugely between the selected nations while population growth figures differ the minimum in the dataset.

Table 1: Descriptive statistics for the chosen variables

Variable Name	Measure Unit	Mean	Median	S.D	Min	Max
CO_2emissions per capita	Emissions metric tons	5.068	2.265	5.445	0.06507	18.52
GDP per capita	PPP (constant 2017 international $)	19789	10431	20764	1373	70857
Population Growth	Annual Percentage	1.721	1.530	0.8556	0.1379	4.042
Urbanization	Urban population as Percentage of total population	57.67	59.54	21.00	23.57	87.07
Trade Openness	Trade as Percentage of GDP	49.60	45.37	23.28	1.219	133.7

Note: Authors' calculation

Unit Root Test and Panel Cointegration Test Results

The unit root tests are next performed to check for any non-stationarity in the panel data. The Im-Pesaran-Shin Panel Unit Root Test and Levin- Lin- Chu Panel Unit Root Test are used for the purpose. The former test assumes individual unit root process while the latter assumes common unit root process. The tests are run on the variables at log-levels and at first difference and the results are presented in the Tables 2 and 3 below.

Table 2: Im-Pesaran-Shin Panel Unit Root Test Results (assumes individual unit root process)

Variable	At Level			At First Difference		
	Statistic	Prob.	Stationary	Statistic	Prob.	Stationary
CO_2 Emission Per Capita	1.91446	0.9722	No	-9.58281	0.0000	Yes
GDP Per Capita	0.86327	0.8060	No	-6.95256	0.0000	Yes
GDP Per Capita Squared	3.31216	0.9995	No	-7.30643	0.0000	Yes
Population Growth	-0.63397	0.2630	No	-6.08495	0.0000	Yes
Urbanization	0.48641	0.6867	No	-2.14482	0.0160	Yes
Trade Openness	-1.86567	0.0310	No	-11.9086	0.0000	Yes

Note: All the variables are log transformed. Lag lengths are selected using AIC. Constant and trend included.
Unit Root Null Hypothesis: All the panels contain unit root
Alternative Hypothesis: Some panels are stationary

Table 3: Levin- Lin- Chu panel unit root test result (Assumes common unit root process)

Variable	At Level			At First Difference		
	Statistic	Prob.	Stationary	Statistic	Prob.	Stationary
CO_2 Emission Per Capita	2.88674	0.9981	No	-5.61657	0.0000	Yes
GDP Per Capita	0.24231	0.5957	No	-7.84354	0.0000	Yes
GDP Per Capita Squared	3.98066	1.0000	No	-7.95292	0.0000	Yes
Population Growth	2.63150	0.9957	No	-4.29057	0.0000	Yes
Urbanization	-0.03496	0.4861	No	-2.95193	0.0016	Yes
Trade Openness	-0.33089	0.3704	No	-6.97121	0.0000	Yes

Note: All the variables are log transformed. Lag lengths are selected using AIC. Constant and trend included. Null Hypothesis: Panels contain unit root
Alternative Hypothesis: Panels are stationary

According to both Im-Pesaran-Shin and Levin- Lin- Chu tests all the variables are non stationary at levels but are stationary at first difference, indicating that they are integrated of order 1. It is then customary to check whether there is any long term relationship between the variables and hence we go for the cointegration test proposed by Pedroni and Johansen Fisher for panel data. Pedroni test allows for heterogeneity across the cross section of countries and the null hypothesis of the test is of no co-integration. While Pedroni test is residual based and taken from Engel Granger two step tests, Johansen Fisher test is a system based co-integration test for the whole panel set. Tables 4 and 5 below reports the results of the two cointegration tests.

Table 4: Pedroni panel data test result

Statistic	Value	P-value	Weighted value	P-value	Decision
Panel v-statistic	-0.509637	0.6948	-0.872938	0.8087	No cointegration
Panel rho-statistic	1.740194	0.9591	2.031819	0.9789	No cointegration
Panel PP-statistic	-2.739452	0.0031	-2.784195	0.0027	Cointegration
Panel ADF-statistic	-3.177903	0.0007	-3.359173	0.0004	Cointegration
Group rho-statistic	3.597300	0.9998	--	--	No cointegration
Group PP-statistic	-5.299718	0.0000	--	--	Cointegration
Group ADF - statistic	-4.101799	0.0000	--	--	Cointegration

Note: All the variables are log transformed. Lag lengths are selected using AIC. Intercept and trend included.
Null Hypothesis: *No Cointegration*
Alternative Hypothesis: *Cointegrated Panel*

As given in table 4 the first two panel statistics (v and rho) results indicate that there is no cointegration while the other two (panel PP and panel ADF) indicate towards cointegration. Again among the group statistics, group rho statistics point towards no cointegration while group PP and group ADF tests reject the null hypothesis of no cointegration.

Since for the majority of the tests the null hypothesis is rejected hence we accept cointegration among the chosen variables.

The Johansen Fisher panel test on cointegration set the hypothesis on the number of co-integrating equations.

Table 5 below shows the result of the test fitted to our dataset. From our test result we found that the null hypotheses that there are no cointegrating equation in the model is rejected, the hypotheses of at most 1, at most 2 and at most 3 cointegrating equations are also rejected, but the hypothesis that there are at most 4 cointegrating equations could not be rejected.

This is confirmed by both Trace test as well as by the Maximum Eigen test. Hence we reject the null hypothesis of no cointegration and conclude that there is cointegration among the variables which supports the existence of long run relationship between them.

Table 5: Johansen fisher panel co-integration test

Unrestricted Co-integration Rank Test (Trace and Maximum Eigen Values)				
Hypothesized No of CE(s)	**Fisher Stat.* (from trace test)**	**Prob.**	**Fisher Stat.* (from max-eigen test)**	**Prob.**
None	274.5	0.0000	176.9	0.0000
At most 1	135.1	0.0000	83.62	0.0000
At most 2	78.60	0.0000	52.02	0.0076
At most 3	53.25	0.0056	49.41	0.0143
At most 4	30.46	0.4423	30.46	0.4423
*Probabilities are computed using asymptotic Chi square distribution.				

Note: Author's Computation using Eviews

Estimating the FE and RE Models

After the preliminary tests have been conducted we now proceed towards checking the validity of the EKC relationship. For the purpose, both the panel regression models, namely, random effects (RE) and fixed effects (FE) have been run and the results compared. Table 6 provides the results from where we find that both the models show significant positive coefficient for GDPPC and significant negative coefficient for GDPPC squared, giving evidence in favor of the standard EKC relationship in terms of GDP per capita. The estimated turning point is at PPP (constant 2017 international $) 23632 for the FE model and at PPP (constant 2017 international $) 47450 for the RE model. Both the values are well within the range of the chosen dataset. Population growth is found to have a significant negative effect on CO_2 emission per capita. This might be because increased population growth leads to some lifestyle changes such as decreased housing size which in turn helps to reduce carbon dioxide emissions.

Table 6: Fixed and random effects estimation result

Variable	Fixed Effects		Random Effects	
	Coefficient (Std. error)	**p-value**	**Coefficient (Std. error)**	**p-value**
Constant	−15.0240 (7.45293)	0.0634 *	−15.1666 (7.67338)	0.0481 **
GDPPC	2.93021 (1.29350)	0.0399 **	2.74451 (1.27992)	0.0320 **
$GDPPC^2$	−0.145487 (0.0628386)	0.0363 **	−0.127445 (0.0667995)	0.0564 *
Population Growth	−0.0458263 (0.0260145)	0.1000 *	−0.0363587 (0.0232451)	0.1178
Urbanization	0.396987 (0.758465)	0.6089	0.458428 (0.715571)	0.5218
Trade Openness	−0.0588396 (0.0275062)	0.0505 *	−0.0540785 (0.0298310)	0.0699 *
R^2	0.994037			
No of Observations	465		465	
Breusch-Pagan test Chi square (1)			5749.69	0
Hausman Test			11.8759	0.036529

Note: Author's Computation using Gretl.

Next, urbanization has been found to have a positive effect on the pollutant although the effect is insignificant. Trade openness on the other hand has a significant negative impact on CO_2 emission per capita. This seems to support the 'Pollution Halo Hypothesis' which observes that the efficient and eco-friendly technologies used by the multinationals help in reducing pollution across the globe. From the analysis it is revealed that a one percent increase in trade openness might reduce emissions by around 0.06 percentage points according to FE model and by 0.05 percentage points according to the RE model. This is in contrast with the other studies which reported a positive relationship between the two variables.

The Breusch-Pagan test rejects the null hypothesis that the variance of the unit specific error is zero. To compare between FE and RE models, the Hausman test was conducted whose result signaled towards appropriateness of the fixed effects model as the null hypothesis that the GLS estimates are consistent has been rejected.

Granger Causality Test Result

Next a pair wise Granger causality test was done to investigate the direction of causality between CO_2emissions per capita and the other variables chosen in the study.

Table 7: Pairwise Granger Causality Test

Null Hypothesis	F- Statistic	Prob.	Remarks
GDPPC does not Granger cause CO_2 emissions per capita	6.98508	0.0010	Bidirectional
CO_2 emissions per capita does not Granger cause GDPPC	4.29910	0.0142	

Null Hypothesis	F- Statistic	Prob.	Remarks
Urbanization does not Granger cause CO_2 emissions per capita	11.1797	2.E-05	Unidirectional
CO_2 emissions per capita does not Granger cause urbanization	2.16886	0.1156	

Null Hypothesis	F- Statistic	Prob.	Remarks
Trade Openness does not Granger cause CO_2 emissions per capita	3.41169	0.0339	Unidirectional
CO_2 emissions per capita does not Granger cause Trade Openness	0.99978	0.3688	

Null Hypothesis	F- Statistic	Prob.	Remarks
Population Growth does not Granger cause CO_2 emissions per capita	5.76847	0.0034	Unidirectional
CO_2 emissions per capita does not Granger cause Population growth	2.94132	0.0539	

Results show that while bidirectional causality exists between GDPPC and CO_2 emissions per capita, unidirectional causality exists between urbanization and CO_2 emissions per capita, trade openness and CO_2 emissions per capita, and population growth and CO_2 emissions per capita, the direction of causality being from urbanization, population growth and trade openness to CO_2 emissions per capita.

CONCLUSION

The study attempted to relook into the environment and economic development dynamics in terms of the standard EKC hypothesis. A panel data on 15 countries, in their various stages of social and economic wellbeing as indicated by their HDI index, have been collected for 31 years from 1990 through 2020. A quadratic equation in terms of GDPPC has been considered to regress CO_2 emissions per capita along with some additional controlling variables such as urbanization, trade openness and population growth. Preliminary tests of unit root (Im-Pesaran-Shin Panel Unit Root Test and Levin-Lin-Chu unit root test) suggest that the variables are non-stationary at the levels while stationary at first difference. Tests of cointegration such as the Pedroni panel cointegration test and Johansen Fisher cointegration test were conducted. Pedroni test has seven statistics (first four based on 'within' dimension and last three based on 'between' dimension), out of which four were in favor of cointegration while three were in favor of no cointegration. So we conclude that majority of the Pedroni test statistics favored cointegration. On the other hand Johansen Fisher panel cointegration test suggests that there are at most 4 cointegrating equations. The standard EKC hypothesis has been verified using both random effects (RE) and fixed effects (FE) model. Both the models justified the inverted U in terms of GDP per capita. While RE model estimated the turning point at PPP (constant 2017 international $) 47450, the FE model estimated it to be PPP (constant 2017 international $) 23632. The Hausman test showed fixed effect as the more appropriate technique. Results also indicate that trade openness and population growth have significant negative impact on CO_2 emissions per capita while urbanization has an insignificant impact on the indicator. The R^2 of the FE model is 0.994037 which is quite satisfactory. Lastly, pairwise Granger Causality test was conducted between CO_2 emissions per capita and the other variables considered in the study. Bidirectional causality was observed between GDPPC and CO_2 emissions per capita while unidirectional causality was observed from urbanization to CO_2 emissions per capita, population growth to CO_2 emissions per capita and trade openness to CO_2 emissions per capita. As regards policy implication, since it is a panel data analysis the one-size-fits all strategy cannot be recommended in this case. However, the common prescriptions for the countries might be to become richer, to increase the amount of environmental awareness among the masses and also to bring about a gross change in their behavioral pattern which can hugely impact the extent of environmental damage.

The research work could be improved by incorporating the effects of additional variables such as energy use, degree of environmental stringency adopted by the governments and other institutional and social factors in the model and including more pollutant indicators. Future research can be extended on these lines to throw additional light into the EKC dynamics.

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