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GLOBAL ANTHROPOGENIC CARBON DIOXIDE EMISSION IN 2005: ENVIRONMENTAL KUZNETS CURVE HYPOTHESIS AND IMPLICATIONS FOR POLICY

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Abstract

Environmental Kuznets Curve (EKC) hypothesis provides support for public policies that emphasize economic growth at the expense of environmental degradation. This hypothesis postulates an inverted U-shaped relationship between economic growth and environmental degradation with plausible explanations. We contribute to the discussion on EKC hypothesis by focusing on anthropogenic carbon dioxide (CO_2) emission (a greenhouse gas) during an extreme year. In the year 2005, concentration of anthropogenic CO_2 became higher than the natural range observed over the last 650,000 years. Using econometric modeling of data from 122 countries for the year 2005, we study the key question: Does EKC hypothesis hold for anthropogenic CO_2 emission after controlling for energy consumption and environmental governance? We do not find statistical support for EKC hypothesis. But, we find that improvements in environmental governance reduces CO_2 emission. This suggests support for environmental policies that specifically promote CO_2 emission reduction and does not emphasize economic growth at the expense of environmental degradation.

Keywords: Environmental Kuznets Curve, Carbon Dioxide Emission, Environmental Governance

"We're running the most dangerous experiment in history right now, which is to see how much carbon dioxide the atmosphere can handle before there is an environmental catastrophe." - Elon Musk (USA Today, 22nd April 2013)

"With this Clean Power Plan, by 2030, carbon pollution from our power plants will be 32 percent lower than it was a decade ago. And the nerdier way to say that is that we'll be keeping 870 million tons of carbon dioxide pollution out of our atmosphere." - Barack Obama (Announcing the Clean Power Plan, 3rd August 2015)

"China has nationally determined its actions by 2030 as follows…To lower carbon dioxide emissions per unit of GDP by 60% to 65% from the 2005 level." - (China's report to UNFCC, 30th June 2015)

Introduction

CO_2 is a green house gas that traps heat in the environment and contributes to global warming. It is the main determinant of countries' environmental quality (Harvey, 1993). Several hypotheses have been put forward in the academic literature for mitigating global warming by reducing anthropogenic CO_2 emission. We focus on EKC hypothesis. EKC hypothesis states that a country's income increases with its pollution levels; but, at a certain level of income its pollution levels would start to decrease. This implies that pollution levels follow an inverted U-shaped relationship with income. One of the important implications of EKC is that growth and development in a country need not lead to environmental degradation. Five explanations are posited for the existence of EKC (Panayotou, 1997; Stern, 1998):

(a) changing composition of production and consumption of the country with increasing levels of income,

(b) preference for environmental quality as the country becomes developed,

(c) emergence of institutions to internalize externalities as the country becomes developed,

(d) increasing returns to scale associated with pollution abatement,

(e) developed countries exporting their pollution to less developed countries.

Two implications of understanding this relationship for policy makers are: (1) lack of statistical support for a turning point (in the inverted U-curve) would mean that high economic growth do not lead to reduced pollution levels. Thus, policies to reduce pollution must specifically target CO_2 reduction using *carrot-and-stick* measures rather than only promoting economic growth. (2) statistical support for a turning point would imply that economic growth automatically leads to reduced pollution levels (using EKC hypthesis). Hence, policies to reduce pollution can focus more on economic growth and wait for the download slope of the inverted U-curve.

2005 is an important year with respect to CO_2 emission (Solomon et al., 2007). The global concentration of anthropogenic CO_2 increased to 379 ppm from a pre-industrial value of 280 ppm in the year 2005 i.e. concentration of CO_2 in 2005 became higher than the natural range (180 to 300 ppm) observed over the last 650,000 years due to fossil fuel use and land-use change (Solomon et al., 2007). The year 2005 can be considered as a transition period or extreme year, where anthropogenic CO_2 emission crossed a major threshold. Interestingly, 2005 was also the second warmest year globally since 1880 (National Centers for Environmental Information, 2014). These facts raises some interesting questions regarding what actually happened during such an extreme year. This year is an appropriate empirical setting to study EKC hypothesis for anthropogenic CO_2 emission.

This paper is organised as follows. In section 2, we discuss relevant literature pertaining to our study questions. In section 3, we describe the econometric modeling methodology, including data and model specification, for the two questions. Section 4 explains model results and model diagnostics. We conclude with findings and avenues for further research in section 5.

Literature review

The first empirical evidence in favor of the EKC was presented by Grossman and Krueger (1995). The pollutants were sulphur dioxide and smoke emissions measured across countries over a time period and income was measured by GDP per capita. Since then, researchers have found mixed evidence for the existence of EKC for CO_2 emission by econometric modeling of cross-sectional and panel datasets. A summary of these studies can be found in Galeotti et al. (2006). To motivate our model, we discuss only relevant studies.

Aldy (2005) regressed a data set of 1960 to 1999 state-level CO_2 emission in the United States. He distinguished two types of CO_2 emission: consumption-based and production-based CO_2 emission. He used the following functional specification:

ln(CO_2 emission per capita) = f [ln(income per capita), ln(income per capita)^2, ln(heating degree days), ln(cooling degree days), coal production].

Evidence was found for the existence of EKC for consumption-based and production-based CO_2 emission. It was also found that consumption-based CO_2 emission peak at much higher income than production-based CO_2 emission. This suggested that individuals in high-income states do not consume less carbon intensive goods than those in lower income states; but, they consume more imported carbon-intensive goods and lower income states may be net exporters of carbon-intensive goods. Richmond and Kaufmann (2006) did not find support for EKC hypothesis for CO_2 emission. They regressed a panel dataset of 36 countries from 1973 to 1997. These include 20 developed countries (OECD) and 16 developing countries (non-OECD). They used the following functional specification:

CO_2 emission per capita = f (GDP per capita, GDP per capita^2, usage of coal, oil, natural gas).

Though the authors do not give a reason for their data not supporting EKC, Aldy (2005) had pointed out that EKC may not hold true for CO_2. This is due to the relative non-hazardous nature of CO_2 when compared to other hazardous pollutants like sulphur dioxide, lead oxide, etc. CO_2 may not be qualified as a pollutant that supports EKC. Jobert et al. (2012) found support for EKC by regressing a panel dataset of 55 countries from 1970 to 2008. They used the following functional specification:

CO_2 emission per capita = f (GDP per capita, GDP per capita^2, energy consumption per capita).

Impact of income on CO_2 emission by controlling for environmental governance is under-researched in this literature stream. Environmental governance encompasses a set of rules, processes, and practices that are related to the management of environment in its different forms (conservation, protection of natural resources, etc.) by institutions including government, business, and civil society groups (Lemos and Agrawal, 2006). It is known that improvements in environmental governance influences greenhouse gases' emission (Hempel, 1996). We hypothesize that higher environmental governance would reduce CO_2 emission. We also hypothesize that a country's environmental governance has an asymmetric impact on CO_2 emission i.e. an increase in environmental governance has an impact on CO_2 emission that is different from the impact due to a decrease in environmental governance. The intuition behind asymmetric impact is that we may not expect a significant large reduction in CO_2 emission due to better environmental governance, but we may expect a significant large increase in CO_2 emission if environmental governance degrades. There is a growing literature that studies impact of environmental governance on CO_2 emission (Dutt, 2009; Halkos and Tzeremes, 2013). We do not review this literature as our intention is to provide theoretical justification for using environmental governance as a control variable for testing EKC hypothesis. These motivates our study questions:

(1) Does EKC hypothesis hold for CO_2 emission by controlling for energy consumption and environmental governance?

(2) Does environmental governance have an asymmetric impact on CO_2 emission?

We study these questions only for 2005, as this year provides an interesting empirical setting.

Econometric modeling methodology

We use data from 122 countries for the year 2005 and model using ordinary least-squares (OLS) regression. Table 1 summarizes the variables used, its description, and expected sign of coefficients when we run regression model. Data for all variables except environmental governance index was obtained from World Development Indicators, published by the Data & Research Group of World Bank (http://data.worldbank.org/). The Environmental Governance Index (EGI) for countries was obtained from Environmental Sustainability Index project of Yale University and Columbia University (http://sedac.ciesin.columbia.edu/data/collection/esi/). These are publicly available sources of data.

Table 1: Description of variables

Variables	Description	Expected sign of coefficients
Dependent variable		
CO_2 emission per capita	(CO_2 emission in metric tons)/population	
Independent variables		
GDP per capita	(GDP in thousand $)/ population	+
(GDP per capita)^2	-	-

Fossil fuel usage	(Fossil fuel energy consumption/Total energy consumption)*100	+
Clean fuel usage	(Alternative and nuclear energy consumption/Total energy consumption)*100	-
EGI	Composite index	-

CO_2 emission per capita include emission from fossil fuel burning and cement manufacture. It also includes emission from consumption of solid, liquid, and gas fuels and gas flaring. The intuition behind expected signs for each variable are as follows:

(a) +ve sign for GDP per capita is due to the upward slope of inverted U-shaped curve of EKC hypothesis.

(b) –ve sign for (GDP per capita)^2 is due to the downward slope of inverted U-shaped curve of EKC hypothesis. Square of GDP is used to capture the turning point in the inverted U-shaped curve.

(c) +ve sign for fossil fuel usage is due to increased CO_2 emission from vehicles, industries, etc. This variable may also explain some portion of the stringency of environmental regulation.

(d) –ve sign for clean fuel usage is because clean fuels does not produce CO_2 when generated i.e. CO_2 emission reduces when clean fuel usage is encouraged or appropriately incentivised in a country. This variable may also explain some portion of the stringency of environmental regulation.

(e) EGI is a composite index that captures corruption, percentage of total land area under protected status, rule of law, local activities by public, government effectiveness, knowledge creation in environmental science and policy, and World Economic Forum survey on environmental governance. This index includes the specific characteristics of environmental governance. Though higher CO_2 emission may seem to cause better environmental governance, we argue that this reverse causality does not explicitly exist. Better environmental governance in a country is not a result of higher CO_2 emission in that country. Rather, it is due to increased environmental literacy in that country, spill-over effects of environmental literacy and awareness from other countries, awareness of human-made damages to the environment that are directly not related to CO_2 emission, etc. (Damodaran, 2012; Davidson and Frickel, 2004; Mehta et al., 2001; Paavola, 2007).

The importance of using fossil fuel usage and clean fuel usage variables need separate emphasis. These variables capture various dynamics of the economy. If the country's economy is driven primarily by agriculture and power requirements are met by using fossil fuels, the fossil fuel usage variable captures it. But, if the power requirements are met by clean fuels, then the clean fuel usage variable captures it. If the country has a large number of motored vehicles and the fuel needs are met using fossil fuels / clean fuels, the respective variables capture it. Some countries may have environmental regulations to limit the usage of fossil fuels or promote the usage of clean fuels. These characteristics are also captured by fossil fuel usage and clean fuel usage variables.

Let us briefly explain how we decided on 122 countries and their characteristics. CO_2 emission for the year 2005 was available 230 countries in the World Bank database. But, EGI for the year 2005 was available only for 147 countries. We choose only those countries that had data for all the variables listed in Table 1. It turns out that 122 countries has all the required data. Out of these, 29% are from Asia, 29% from Europe, 21% from Africa, 11% from North America, 8% from South America, and 2% from Oceania. Thus, our sample includes high-income countries with strict environmental laws (ex: countries in North America, Europe, Oceania, Middle East part of Asia) and low-income countries with weak-moderate environmental laws (ex: countries in South Asia, South America). These 122 countries together contributed 57% of global CO_2 emission in 2005.

We use the following linear specification to test for EKC hypothesis:

CO_2 emissions per capita = f (GDP per capita, GDP per capita^2, fossil fuel usage, clean fuel usage, environmental governance index).

To test for the asymmetric impact of EGI on CO_2 emission, we use the method that has been previously used in retail store setting to test for the asymmetric impact of customer satisfaction on retail store sales (Gomez et al., 2004). We prepare a dataset using two steps. In the first step, we sort the dataset in ascending order of CO_2 emission (to rank-order the dataset along the variable of interest) and compute first differences for all variables. For example,
Δ CO_2 emission per capita = [CO_2 emission per capita for $(n+1)^{th}$ country] – [CO_2 emission per capita for n^{th} country].
In the second step, we create a new variable that takes 0 (when the change in EGI is positive) and negative values of index change (when the change in EGI is negative). This is illustrated in Table 2.

Table 2: Illustration of variable creation

EGI	Δ EGI	Δ EGI_negative
5	-	-
10	5	0
8	-2	-2
12	4	0
10	-2	-2
10	0	0

The values presented in Table 2 are only for the purpose of illustration and not actual values. We run regression on differences of successive values of the variables. We use the following specification to run regression:

Δ CO_2 emission per capita = f (Δ GDP per capita, Δ GDP per capita^2, Δ fossil fuel usage, Δ clean fuel usage, Δ EGI, Δ EGI_negative).

The coefficient of Δ EGI gives the average change in Δ CO_2 emission for a unit increase in Δ EGI. Sum of coefficients of Δ EGI and Δ EGI_negative gives the average change in Δ CO_2 emission for a unit decrease in Δ EGI.

Models results and diagnostics

Test for EKC hypothesis

Summary statistics of the dataset revealed a very high standard deviation for GDP per capita (around 14,500), moderate standard deviations for other variables (CO_2 per capita had 5, fossil fuel usage and clean fuel usage had 27 and 16 respectively), and low standard deviation for EGI (around 0.7). The high variances of variables may require a log transformation to reduce the scale effect. We explore this later, after modelling the linear specification. The regression coefficients and their statistical significance are summarized in Table 3.

Table 3: Results of OLS regression*

Variable	Expected sign of coefficient	Estimated coefficient	Standard error	p-value
GDP per capita	+	.0008	9.76E-05	0.0001
(GDP per capita)^2	-	-1.01E-08	1.75E-09	0.0001
Fossil fuel usage	+	.05	0.01345	0.0001
Clean fuel usage	-	-.02	0.0218	0.394
EGI	-	-3.98	0.7480	0.0001

***** We have not presented the regression equations and results in a way that is usually presented in econometric modeling based papers. This is to help improve the readability of our paper, considering the interdisciplinary nature of this journal. 9.76E-05 (= 0.0000976) is a number represented using the exponential notation E.

The estimated model, presented in Table 3, is statistically significant i.e. it has an F-value of 47.5 that is statistically significant at $\alpha = 5\%$. The estimated model fits significantly better than a model with no predictors. The five variables explain 67% of the variation in CO_2 emission per capita. The signs of estimated coefficients match with our expected signs. The expected signs were based on the literature. Thus, the signs of estimated coefficients are in conformance with the literature. Except for clean fuel usage variable, the coefficients for all other variables are statistically significant at $\alpha = 5\%$. The non-significance of clean fuel usage could be due its collinearity with fossil fuel usage. We suspect some collinearity between the two because countries that have 100% fossil fuel usage will have 0% clean fuel usage. An interesting insight we obtain from the statistical non-significance of clean fuel usage is focussing on clean fuel usage alone is not sufficient to reduce CO_2 emission. Policy makers also need to focus on fossil fuel usage to reduce CO_2 emission. The preliminary results presented in Table 3 supports the EKC hypothesis for CO_2 emission. Next, we next take a critical look at two assumptions of the classical linear regression model: no multicollinearity and no heteroscedasticity, and see if these are violated in our regression model. High multicollinearity, heteroscedasticity would lead to misleading statistical inferences. To avoid this, we test the two assumptions.

Multicollinearity: We suspect multicollinearity among independent variables. Some portion of variation in GDP per capita can be explained by fossil fuel usage, clean fuel usage and environmental governance i.e. a developing country's economy (captured by GDP) may be powered by fossil fuels whereas a developed country's economy may be powered relatively less by fossil fuels and more by clean fuels. Developing countries may also have weak environmental governance when compared to developed countries. The classical symptom of multicollinearity i.e. high R^2 and few significant t-ratios, was not found in our estimated model. We obtained the Variance Inflation Factor (VIF) values for variables. VIF values for GDP per capita and (GDP per capita)^2 is between 10 and 20. As our model is grounded in theory, we believe that multicollinearity (measure by VIF values) may not pose a serious problem. The low standard errors for GDP per capita and (GDP per capita)^2 may also be due to the high variance of respective variables.

Heteroscedasticity: We suspect the error variance to be non-constant due to heterogeneity of countries owing to the cross-sectional nature of data. The White's test yielded a statistically significant (at $\alpha = 5\%$) chi-square value. This supported the existence of non-constant error variance. White's robust standard errors corrected for heteroscedasticity did not alter the statistical significance of the variables. This is shown in Table 4. Hence, the preliminary results of our estimated model still hold.

Table 4: White's robust standard errors

Variable	Standard error (OLS model)	p-value (OLS model)	Robust standard error	New p-value
GDP per capita	9.76E-05	0.0001	0.0001	0.0001
$(\text{GDP per capita})^2$	1.75E-09	0.0001	2.53E-09	0.0001
Fossil fuel usage	0.0134	0.0001	0.0093	0.0001
Clean fuel usage	0.0218	0.394	0.0162	0.252
EGI	0.7480	0.0001	1.3722	0.004

The presence of heteroscedasticity may also be due to incorrect model specification. To test this, we conducted Ramsey's Regression Equation Specification Error Test (RESET). This test supported the hypothesis that model is mis-specified. As we included only those variables that are theoretically grounded, we believe that there could be a functional form mis-specification i.e. a linear specification may not model cross-sectional data. Due to high variance of GDP per capita and $(\text{GDP per capita})^2$, we took a log transformation of these two variables. The regression models run on various functional forms and their diagnostics are summarized in Tables 5 and 6. Note that among the independent variables, only GDP per capita and $(\text{GDP per capita})^2$ were log transformed.

Table 5: Models on various functional forms

	log-log model		**lin-log model**		**log-lin model**	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
GDP per capita	0.538	0.1	-11.492	0.0001	0.00009	0.0001
$(\text{GDP per capita})^2$	0.006	0.724	0.916	0.0001	-1.15E-09	0.0001
Fossil fuel usage	0.024	0.0001	0.054	0.003	0.034	0.0001
Clean fuel usage	0.007	0.006	-0.032	0.154	0.012	0.0001
EGI	-0.329	0.001	-4.099	0.0001	-0.107	0.329

Table 6: Model diagnostics

	log-log model	lin-log model	log-lin model
White's test result at $\alpha = 5\%$	No support for heteroscedasticity	Support for heteroscedasticity	No support for heteroscedasticity
RESET test result at $\alpha = 5\%$	No support for model mis-specification	Support for model mis-specification	Support for model mis-specification

The log-log model provided no statistical support for heteroscedasticity and model mis-specification. But, the sign of coefficient for clean fuel usage is not intuitive. Also, the squared term of GDP per capita is not significant (even at $\alpha = 70\%$). The results of log-log model suggest that EKC hypothesis may not hold for CO_2 emission. Support for model mis-specification implies that either we are omitting a relevant variable or using the wrong functional form. Model mis-specification results in biased coefficients and inferences (i.e. standard errors, p-values). We adhere to the results of log-log model because we have more confidence in the coefficients and inferences (i.e. they are not biased). Though the preliminary results (using a linear specification that was found to be mis-specified) supported EKC hypothesis, we would have more confidence in the results of log-log model.

Test for asymmetric impact of EGI

We use the model specification described in Section 3 to study the asymmetric impact of EGI. A question naturally comes up at this point: to answer question 1, log-log model was used; but, to answer question 2 why did we not take the first differences of log of variables? This is because, first differences of log of variables are a relative change and not an absolute change. Our interest is to test for an absolute change in EGI. The regression results are summarized in Table 7.

Table 7: Regression model for testing asymmetric impact

Variable	Coefficient	p-value
Δ GDP per capita	0.0000126	0.706
Δ (GDP per capita)^2	-1.11E-10	0.821
Δ Fossil fuel usage	-0.0005344	0.937
Δ Clean fuel usage	-0.0005976	0.925
Δ EGI	-0.3384572	0.222
Δ EGI_negative	0.3988523	0.305

If there was any asymmetric impact, the following results should have occured:
(a) coefficient of Δ EGI should be negative and statistically significant,
(b) coefficient of Δ EGI_negative should be statistically significant,
(c) sum of coefficients of both the variables should have a positive sign and higher (in absolute value) than the coefficient of Δ EGI.
The results show different coefficients signs for Δ EGI and Δ EGI_negative. The p-values of Δ EGI and Δ EGI_negative are not significant at $\alpha = 5\%$. As expected, the coefficient sign for Δ EGI is negative. Sum of coefficients of Δ EGI and Δ EGI_negative has a positive sign and is 0.06. By strictly following the statistical method, this estimated model does not support our hypothesis of asymmetric impact. But, once we relax the strict 5% statistical significane criteria and allow more tolerance for error, the obtained p-values (0.222 and 0.305) can be interpreted more meaningfully. A careful look at the results reveal that there may *some kind* of an asymmetric impact of environmental governance on CO_2 emission. It is to be noted that this method is a simple (or naïve) test for asymmetric impact and more rigorous tests can be done using sophisticated methods (Frondel et al., 2015).

Conclusion

Though we found support for our hypothesis that increase in environmental governance reduces anthropogenic CO_2 emission, we did not find support for the asymmetric impact of environmental governance. However, our results do indicate the plausibility of finding an asymmetric impact. We do not find statistical support for EKC hypothesis across countries during the transition period (or exterme year) i.e. the year 2005. Interestingly, we seem to find support for a rival hypothesis to EKC. This is the carbon lock-in hypothesis (Unruh, 2000). This hypothesis says that carbon emission from countries will not reduce (contrary to EKC hypothesis) because countries get *locked* into fossil fuel based systems and are unable to come out of it due to the inertia created by technological and institutional forces. Explicit testing of carbon lock-in hypothesis needs to be done separately and is not part of this paper. But, our results suggest a plausibility of finding support for carbon lock-in hypothesis for the year 2005. So, we have two key take-aways in this paper: (1) During the transition period, CO_2 emission did not reduce for countries with high economic growth (2) Improved environmental governance reduces CO_2 emission even in an extreme year like 2005.

The simple cross-sectional regression model, developed in this paper, can be improved by including other relevant variables and employing sophisticated estimation procedures like quantile regression. The global environmental change that happened in the year 2005 is under-researched. More research could be done on other pollutants or greenhouse gases to under this global environmental change that happened in 2005 or other important years. For example, a recent report by National Centers for Environmental Information (2015), describes 16 warmest years from 1880 to 2015. EKC hypothesis for important greenhouse gases can be studied during these time periods.

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