

A counterfactual quantile regression analysis for co2 emissions economics essay

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Abstract

This paper applies the quantile fixed effects technique in exploring the CO₂ EKC within two groups of economic development (OECD and Non-OECD) and six geographical regions – West, East Europe, Latin America, East Asia, West Asia and Africa. A comparison of the findings with those of the conventional fixed effects method reveals that the latter is likely to depict a flawed summary of the prevailing income-emissions nexus. Additionally, the Machado and Mata decomposition method shows that the statistically significant OECD-Non-OECD emissions gap contracts as we ascend the emissions distribution and that — had the Non-OECD group the incomes of the OECD group— the former would pollute 26 to 40 percent more than the latter, *ceteris paribus*. Moreover, the decomposition reveals that there are other non-income related factors working against the Non-OECD group's greening. We tentatively conclude that deliberate and systematic mitigation of current CO₂ emissions in the Non-OECD group is required. JEL

Classification: Q56, Q58
Key Words: CO₂, decomposition analysis, Environmental Kuznets Curve, income-emissions nexus/relationship, economic growth/progress/development, environmental damage/pollution/degradation, quantile fixed effects method

1. 0 Introduction

The late 1950s ushered in a theory in development economics whose roots protruded into other fields of economic specialisation. Kuznets (1950) posited that the early stages of a country's developmental process are associated with increasing income inequality. However, after the attainment

of a certain level of development,[1]progress is then associated with declining inequality. Inherent in this theory is the conception that development is both the cause and remedy for inequality. Following the works of Shafik and Bandyopadhyay (1992) and Grossman and Krueger (1991, 1995), an environmental economics refinement of Kuznets' theory led to the formulation of the Environmental Kuznets Curve (EKC) hypothesis. This essentially hypothesises an inverted U-shaped relationship between per-capita emissions and GDP, with the former and latter measured on the ordinate and abscissa planes of a graph respectively.[2]Since the inception of the EKC theory, the income-emissions nexus has stirred considerable debate in the environmental economics literature. Advocates suggest that the only way to achieve good environmental standards is through rising incomes (Romero-Avila, 2008). Accordingly, higher income economies can invest more in greening and consumers in these economies are not only able to spend more on environmental protection but they can intensify their demand for a cleaner environment by advocating for stringent environmental regulations. These views led Beckerman (1992) to suggest that " in the long-run, the surest way to improve your environment is to become rich." Similarly, Panayotou (1993) stated that an improvement in environmental quality " is an inevitable result of structural and behavioural changes accompanying economic growth." A far-fetched implication of these strongly held views is that developing countries are too poor to be green and very little in the way of environmental clean-up is conducted in these countries (Perman and Stern, 2003). Thus, a reliance on such prescriptions may lead to a misleading interpretation of the EKC; that economic growth is

both the cause and remedy to environmental damage in the long-run, thereby disparaging the relevance of environmental policies in the growth process.[3]The prescriptions of advocates are treated with even greater scepticism when emphasis is laid on the cliché of environmental sustainability and pollutants with trans-boundary effects. It is common knowledge that global warming and climate changes primarily caused by anthropogenic CO₂ emissions are arguably the biggest environmental challenge confronting the world. Hence, it becomes very worrisome how the needs of the future generation's climate and environment could be adequately catered for if we continued with business as usual emissions without deliberate and systematic efforts to mitigate current emissions. Essentially, we cannot afford to rely on the belief that emissions will automatically peak then eventually decline when the world achieves a certain level of economic development at some point in time. Thus, there is need for a critical evaluation of the CO₂ EKC as this may provide signals on the relevance of strategically applying feasible mitigation instruments or relying on the prescriptions of the theory to curb emissions. Moreover, the customary econometric methods used in investigating the CO₂ income-emissions nexus have attracted considerable criticisms (see for instance Stern, 2004). So far, the literature largely employs a panel dataset of countries and it relies almost exclusively on the use of conventional longitudinal econometric techniques. These procedures focus on estimating the rate of change in the conditional mean of emissions as a function of income.[4]Essentially, they assume constant coefficients across heterogenous countries thereby implying that though the level of per-capita

emissions may differ between countries at any particular income level, the income elasticity is unvarying in all countries at a given income level (Stern, 2004). Despite the fact that the largely employed panel techniques offer intriguing summary statistics of the impact of per-capita income on per-capita emissions, they often conceal the (large) heterogeneity of countries or regions in the sample investigated (see Huang et al., 2007, for instance). Thus, the focus on means may be inappropriate as the income regressors may not determine the mean only but also other parameters of the conditional distribution of emissions (see, for instance, Mills and Waite, 2009; Halkos, 2011). This computational shortcoming of the traditional estimation method spurs the need for the application of alternative estimation techniques with a greater flexibility of capturing the heterogeneity of countries in CO2 Kuznets Curve investigations. Given this background, our paper contributes to the existing empirical literature in two ways. First, we employ the quantile fixed effects technique in exploring the CO2 Kuznets Curve. Besides its greater flexibility and robustness in comparison to the conventional panel technique, this method allows a more thorough investigation of the income-emissions relationship by assessing how income affects different observations (or countries) based on their location on the conditional distribution of emissions (see Koenker, 2004, 2005). The method provides deeper insights into the income-emissions relationship by allowing heterogeneous marginal effects across the distribution of emissions. Therefore, it identifies more subtle effects that would be missed by the application of conventional panel regressions, thus providing a more comprehensive exploration of the income-emissions nexus (Alexander et al.,

2010).[5]Moreover, the method is more robust to outlier observations on the dependent variable (see Koenker, 2004; Wang, 2011; Flores et al., 2012). To the best of the authors' knowledge, this paper is the first to employ this technique to investigate the CO₂ Kuznets curve. We examine the relationship of carbon emissions and GDP per capita for the world, OECD countries, Non-OECD countries and six geographical regions; West, East Europe, Latin America, East Asia, West Asia and Africa. Second, to proffer feasible (pollution) mitigation actions, it is worth exploring further the most important reasons accounting for differences in carbon emissions distribution from one economic group to another. Following the labour economics literature, these explanations are reached using decomposition techniques. This literature has extensively employed the Oaxaca (1973) and Blinder (1973) decomposition method to decompose gaps in wage distributions between males and females, whites and blacks or skilled and unskilled employment amongst other uses (see for example DiNardo et al., 1996; Hertz et al., 2008; Fortin et al., 2010). Its extension to the EKC framework provides an opportunity to decompose the gap in CO₂ emissions distribution between the two economic groups considered (OECD and Non-OECD) into two key factors contributing to the gap; differences in characteristics between the two groups and differences in returns to characteristics between the two samples. Thus this allows us to disentangle whether cross-group differences in CO₂ are associated with group-specific economic development or from differences in the distribution of common characteristics or covariates in one group as compared to the other. The method as originally proposed by Oaxaca and Blinder (OB) decomposes the

mean gap of the outcome variable only, thereby raising distributional concerns as with the conventional panel methods mentioned above. This has spurred improvements to the OB method, the most notable being an extension to various quantiles of the distribution of the outcome variable (Fortin et al., 2010). Obviously, such an improvement moves in tandem with the quantile estimations of the CO2 income-emissions nexus explored in this paper. To separate the effects of differences in OECD and Non-OECD covariate distributions from differences in returns to covariates for each quantile of the distribution of the emissions gap, we employ the Machado and Mata (2005) quantile extension of the OB decomposition technique. Again, to the best of our knowledge, our paper is the first to systematically employ this quantile decomposition technique to investigate the income-emissions relationship. The rest of the paper is organised as follows: section two surveys empirical evidence on the subject; section three presents the methods and data to be employed for the study's estimations; section four analyses the main results of the estimations; and the final section summarises the study's findings and proffers policy recommendations.

Survey of Literature

The pioneering work of Grossman and Krueger (1991) provides a theoretical framework for an inverted U-shaped relationship between economic development and environmental quality. These analysts investigated the impact of rising incomes – primarily resulting from increased trade flows from the North American Free Trade Area – on environmental quality. Using cross-sectional data on pollution and per-capita incomes for a group of developed and developing countries, their study found that sulphur dioxide

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and dark matter (smoke) concentrations increased and then decreased with low and high levels of per-capita incomes respectively; thereby confirming the EKC. This study paved way for the emergence of the EKC (strong) advocates' recommendation that environmental clean-up is an inevitable and eventual process of growth (see Beckerman, 1992). The purported notion that economic progress automatically leads to greening has led to a plethora of studies investigating the theme, thus, making the EKC a subject of long standing debate in the environmental economics field. In fact, the hypothesis is one of the most investigated themes in the field of applied environmental economics (see for instance Galeotti et al., 2009). Analysts of the subject can be generally classified as optimists or sceptics; the former consisting of those taking the hypothesis to suggest that economic growth is untimely good for the environment and the latter consisting of those pointing to methodological flaws in deriving the EKC or advocating caution in interpreting the causes and implications of the hypothesis (Nahman and Antrobus, 2005). Grossman and Krueger (1991) argue that there are three basic mediums in which progress impacts on the environment; scale, technique and composition effects. The scale effect implies the rudimentary reasoning that an increased scale of economic activity leads to greater pollution, *ceteris-paribus*. Hence, pollution rises with growth. The technique effect connotes the idea that progress may be associated with improvements in production techniques and adaptation of greener technologies; thereby implying an environmental enhancement effect of growth. Development may pave way for a change in the composition of economic production - moving from intensive, heavy machinery driven and (thereby) heavy polluting

industries to services and light manufacturing industries. Closely linked to this is the perception that increasing incomes does not only enhance consumers' effective demand for a greener environment but this demand is also augmented by advocating for stricter environmental regulations. However, as most firms are clearly driven by profits, the enforcement of tighter environmental regulations in high-income economies may lead to the migration of heavy polluting industries from high-income to low-income economies, to take advantage of laxer environmental regulations in the latter economies. This form of industry migration is termed Pollution Havens Hypothesis (see for instance Dinda, 2004; Hill and Magnani, 2002). Consequently, the composition effect turns up an ambiguous effect on environmental quality depending on whether the country assessed is high-income (developed) or low-income (developing). From the pollution havens perspective, the general expectation is that it should lead to environmental improvements and depletion in the former and latter, respectively.[6]It is worth noting that the role of this industry-type migration as a major indicator of environmental degradation or greening still remains largely uncertain in the environmental economics literature (see for instance, Grossman and Krueger, 1996; Cole, 2003). Grossman and Krueger's (1991) explanations spurred a proliferation of empirical studies on the subject; to confirm or refute the Kuznets Curve proposition. Analysts applied a variety of methods in their investigation with a great deal of available studies examining a group of countries employing cross-sectional and panel techniques, particularly the fixed effects method. However, the basic assumption behind pooling time-series data of different countries into one

panel is that environmental quality - economic development trajectory would be the same for all countries; thereby inferring homogenous slopes across the entire sample. This assumption neglects the heterogeneity arising from cross-country variations; due to different economic, social, political, structural and biophysical differences which may have varying effects on environmental quality (Dinda, 2004). Surveying the extant literature on the EKC for CO₂, Dijkgraaf and Vollebergh (2005) examined the hypothesis in a panel of 24 OECD countries. Applying the fixed effects technique to a data-set on CO₂ emissions, per-capita income, population and energy consumption spanning from 1960 to 1997, this study confirmed the inverted U-shaped income-emissions relationship but raised doubts on its finding after conducting a test of slope homogeneity across countries in the sample. The null of slope homogeneity largely assumed by the conventional panel fixed effects method was strongly rejected. Consequently, the authors question the practice of pooling various countries together in Kuznets Curve investigations. Additionally, they challenged the existence of an overall CO₂ EKC as a result of the flawed homogeneity assumption of traditional panel techniques. Thus, they suggested a further exploration of the CO₂ income-emissions relationship using more flexible panel methods that are capable of capturing the heterogeneity issues often inherent in longitudinal data analysis. Following the identified need for a more flexible technique capable of capturing countries' heterogeneity, Musolesi et al. (2010) employed the hierarchical Bayes estimator to show that different CO₂ income-emissions dynamics are associated with different economic and geographical groupings. Using a panel data-set of 109 countries spanning from 1959 to

2001, the study validated the EKC theory in 15 European Union countries, OECD countries and G-7 countries. The hypothesis was also confirmed for the combined sample of countries considered but a monotonically rising relationship was found for the Non-OECD and group of 40 poorest countries in the analysis. Additionally, the authors conducted a preliminary test for the null of slope homogeneity using Swamy's (1971) chi-square test statistic. This null was strongly rejected. Further, the study found that the EU but not the US, was most responsible for the EKC in the G-7 countries and the full sample. In sum, they noted that the full sample analysis conceals some interesting and critical income-emissions dynamics. Various studies employed other panel econometric techniques in their exploration of the EKC (see for instance Romero-Avila, 2008; Galeotti et al., 2009). However, as earlier noted, a great deal of these studies examines the income-emissions nexus at the conditional mean of emissions. To the best of our knowledge, the only exception is the recent study by Flores et al. (2012) who applied the conditional quantile fixed effects method to a US state level data-set spanning from 1929 to 1994 to investigate nitrogen oxide (NOX) and sulphur oxide (SO₂) EKC. This method explains the income-emissions relationship at different percentiles of the conditional distribution of emissions, thereby being able to capture state (country) level heterogeneity in the sample. Their study confirmed the EKC for all quantiles of the conditional distribution of NOX considered. However, mixed results were found for the SO₂ scenario; both an EKC and a monotonically increasing relationship were found. Most importantly, the study found that the traditional mean fixed effects method provides more optimistic turning point income levels than the quantile fixed

effect method in the case of NOX; the latter technique provides turning point incomes that are 19 to 36 percent higher than the former. Based on these authors' analysis, it is therefore not surprising that the largely employed traditional fixed effects technique influences the suggestion that progress is a panacea to pollution. To the best of our knowledge, no study thus far has employed the quantile fixed effects technique in investigating the CO2 income-emissions nexus. Our paper aims to fill this methodological gap.

Econometric Framework

Following the traditional EKC reduced form framework, this paper models per-capita CO2 emissions as a cubic polynomial function of per-capita income as follows:(1)[7]Equation (1) represents a conventional longitudinal fixed effects relationship where $\ln ems$ is the log of per-capita CO2 emissions; $\ln inc$, $\ln inc^2$ and $\ln inc^3$ denote the log of per-capita income and its squared and cubic terms, respectively; the subscripts i and t denote country and time period respectively; α_i is unobserved time invariant country specific effects; γ_t is time specific effects accounting for time varying omitted variables and stochastic trends common to all countries; ϵ_{it} is the random error term; β_1 , β_2 and β_3 are the slope parameters to be estimated. However, as earlier stated, the model above provides a homogenous income-emissions relationship for all countries in the sample, thus, not being able to capture the existing heterogeneity amongst the countries. To bridge this gap, this paper employs a quantile fixed effects version of equation (1). The quantile transformation of this equation is given by:(2)where Q denotes quantile regression, τ denotes selected quantiles (0.1, 0.25, 0.5, 0.75 and 0.9) and all other variables are as previously defined. Since both the time series and

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cross-section dimensions of our sample are (arguably) large, this paper assumes heterogeneous distributional shifts; that is, $\alpha_i(\tau)$ and $\gamma_t(\tau)$ vary between quantiles (see Koenker 2004). Our dataset employs a globally representative sample and the richness of this data enables the estimation of country and time fixed effects at each quantile with good precision. The quantile fixed effects model in equation (2) captures the heterogeneity of the countries in the sample by providing different marginal effects based on each observation's position on the conditional distribution of emissions.

[8] This technique paves way for a comprehensive understanding of the varying income-emissions relationships in-built in a single EKC system. To sum, it is worth noting that quantile regression is not the same as applying OLS to different sub-sets of the data obtained by dividing the complete data-set into different percentiles of the response variable. Doing this would amount to an incomplete use of the entire data-set. Quantile regression uses the entire data-set in obtaining estimates for each conditional quantile considered; however, some observations get more weight than others depending on the conditional quantile considered. For instance, an estimation of the quantile regression function for a low quantile, say $\tau = 0.25$, for examining the effect of income on emissions in the lower tail of the emissions distribution is very different from estimating a mean regression when we condition on data on the lower tail of the distribution. Thus, $Q_{\text{emsit}}(0.25/\ln_{\text{incit}})$ is not the same as $E(\text{emsit}/\text{emsit} < c, \ln_{\text{incit}})$, for some appropriately chosen c meant to capture the lower tail of the distribution. There is no theory that informs the choice or interpretation of the parameter

c while τ has a natural interpretation (see Alexander et al., 2008; Wagner, 2004 for more details).

Decomposition Procedures

To further investigate the OECD-Non-OECD emissions gap, we employ the Machado and Mata (2005) extension of the BO decomposition to a quantile distribution system. This technique decomposes the emissions differential of the OECD vs Non-OECD countries at each quantile into a component attributable to differences in covariates between the OECD and Non-OECD groups and another component attributable to differences in the returns to covariates between the two groups. The former component is generally referred to as the endowment or explained effect and the latter the coefficient, returns or unexplained effect. The use of the terms 'explained and unexplained effects' stems from the interpretation that the two effects are explained by the covariates and other factors unaccounted for in the model respectively. This interpretation of the returns effect plays a role in our paper's decomposition analysis in the next section. The Machado and Mata (2005) decomposition technique hinges on the generation of a counterfactual distribution of (log) emissions for Non-OECD countries; the distribution of CO₂ emissions that would have prevailed in the Non-OECD group if it had the same income as the OECD group but retained the returns to its income. Essentially, the counterfactual exercise answers the question, what would happen to the Non-OECD's emissions distribution if its characteristics was as in the OECD group but it maintained the returns to its characteristics? A comparison of the counterfactual and estimated emissions distribution for the Non-OECD group yields the OECD-Non-OECD emissions

gap attributable to differences in covariates. The remainder of the gap is then attributable to differences in returns to covariates. This method relies on the estimation of a marginal density function of (log) emissions that is consistent with the estimated conditional quantile process defined by:

(3) Where X is a vector of the covariates (income, income₂, income₃ and the fixed effects), β is a vector of quantile regression coefficients to be estimated and group denotes the two economic groupings (OECD and Non-OECD).

[9] The Machado and Mata algorithm is outlined as follows: Generate a random sample of size m from a uniform distribution $U[0, 1]$ to obtain τ_j for $j = 1, 2, \dots, m$. These are the quantile regression coefficients to be estimated; $\beta_{\text{group}}(\tau_j)$. Use the OECD covariates to generate fitted values $\text{ems}^*_{\text{Non-OECD}}(\tau) = X_{\text{OECD}}\beta_{\text{Non-OECD}}(\tau)$. [10] For each τ_j this generates N Non-OECD fitted values, where N is the number of observations in the OECD sample. We denote $f(\ln \text{emsgroup})$ as an estimator of the marginal density of log emissions based on the observed sample and $f^*(\ln \text{emsgroup})$ an estimator of the marginal density of emissions based on the generated sample. The counterfactual densities are denoted $f^*(\ln \text{emsgroup}; X_{\text{OECD}})$ for the density that would prevail in Non-OECD countries if these countries' covariates were distributed as in OECD countries but retained the returns to their own covariates. [11] The raw differential in emissions distributions between OECD and Non-OECD groups compares the counterfactual with the observed densities of emissions in the two groups. Hence, the overall gap from $f(\ln \text{emsgroup}_{\text{OECD}})$ to $f(\ln \text{emsgroup}_{\text{Non-OECD}})$ at each quantile is decomposed as follows:

(4) where \ln denotes natural logs and all other variables are as previously defined. [12] The first term (in brackets) on the right-hand side of equation (4)

measures the contribution of differences in endowments to the raw differential at the τ th percentile; the explained effect. The second term measures the contribution attributable to differences in the coefficients to the emissions gap at the τ th quantile; the unexplained effect. By providing answers to which of the two effects contributes more to an estimated OECD-Non-OECD emissions gap, this procedure provides more insights on the EKC exploration. This decomposition exercise is not merely appealing for the extra econometric expositions it offers. It also identifies economically feasible ways of reducing the emissions gap thereby being informative in suggesting feasible mitigation strategies.[13]

Data Description and Summary Statistics

Following the vast EKC literature, this paper proxies economic development and environmental damage with per-capita GDP and per-capita CO₂ emissions respectively. We employ data on annual per-capita GDP measured in 1990 International Geary-Khamis dollars obtained from the Maddison Dataset at www.ggdcc.net/MADDISON/oriindex.htm. Data on annual CO₂ emissions (in metric tons per-capita) from fossil fuel burning, cement manufacture, and gas flaring are obtained from the World Bank's World Development Indicators (2009). The data-set comprises an unbalanced panel of yearly observations covering 154 countries, with the time period spanning from 1960 to 2007. This is a globally representative sample and the data set is large in both time-series and cross-sectional dimensions. Also, the large number of countries covered increases the diversity of investigated countries and regions in comparison to previous EKC studies. Table 1 provides a list of all the countries in the sample based on their economic and geographical

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contiguity. Each country is classed into the OECD or Non-OECD bloc, or one of the six geographical regions covered; West, East Europe, Latin America, West Asia, East Asia and Africa. Table 2 presents summary statistics of the income and emissions variables employed in this study, separated by economic and geographical groupings. The mean per-capita income for the two economic groups and seven regions considered - World, OECD, Non-OECD, West, East Europe, Latin America, East Asia, West Asia and Africa are \$5, 169, \$12, 531, \$3, 223, \$14, 588, \$5, 340, \$4, 329, \$3, 771, \$7, 594, and \$1, 628 respectively. As expected, the Western and African regions have the highest and lowest average per-capita incomes respectively. The minimum and maximum per-capita income observations for the complete sample - \$207 and \$42, 916 - are Zaire's (Congo Kinshasa) 2001 and Qatar's 1973 per-capita incomes, respectively. For all groupings, the mean income is considerably higher than its corresponding median observation, with an exception of the OECD, Western and East European groups where the mean and median observations are reasonably identical. The table also provides the maximum, minimum and standard deviation (sd) values of per-capita income for other regions considered. Conversely, the corresponding mean per-capita CO₂ emissions for the two economic groups and seven regions discussed in the preceding paragraph (in chronological order) are 4. 4, 8. 5, 3. 4, 9. 1, 6. 8, 2. 3, 2. 5, 12. 7, and 0. 9 metric tons per-cubic meter respectively. Contrary to a priori expectation of the OECD and/or Western groups to record the highest mean per-capita emissions, the West Asian region turns-up with the highest per-capita emissions while the African region records the lowest. However, it may be worth noting that the Western

region records the highest mean emissions in absolute but not per-capita terms. Just as in the case of income, the mean per-capita emissions for the entire grouping is considerably higher than its corresponding median observation. The only exceptions where these two observations are practically not too different are the OECD, Western and East European groups. For the global sample, the minimum and maximum per-capita emissions observations, 0.0005567 and 105.736 metric tons per-cubic meter, are Somalia's 1991 and Qatar's 1963 emissions respectively. The table also provides the minimum, maximum and standard deviation values of per-capita emissions for the other groups considered.

Results and Discussions

For the purpose of an elucidatory comparison across econometric procedures, we present results for the quantile fixed effects estimations and the traditional mean fixed effects technique in table 3. In this table, the estimated income coefficients (in level, quadratic and cubic terms) and intercept for each economic and geographical group and the five different quantiles considered ($\tau = 0.1, 0.25, 0.5, 0.75$ and 0.9) are presented in the first five columns of the quantile section of the table. The last column labelled "Mean" presents the corresponding results for the conditional mean estimation.[14]As a conventional practice, we report bootstrapped and robust standard errors for the conditional quantile and conditional mean estimates in parenthesis, respectively. The results in table 3 are complemented by the diagrams in figure 1. The figure provides a pictorial representation of the fitted curves of the estimated income-emissions relationship for the five conditional quantiles considered, as well as the

conditional mean. Thus, the lines labelled quant10, quant25, quant50, quant75, quant90 and mean represent the estimated curves for the 10th, 25th, 50th, 75th, 90th percentiles and the mean, respectively. In these diagrams, the solid curves represent a significant income-emissions relationship - where the three income variables are statistically significant - and the light dotted curves represent an insignificant relationship, where one or more of the income variables are statistically insignificant. The figure therefore provides pictorial evidence confirming or refuting the proposition of an inverted U-shaped relationship between per-capita CO₂ emissions and per-capita income. If an inverted income-emissions relationship exists, it also provides pictographic evidence of the turning point level of income for the estimated Kuznets Curve relationship. For the global sample, an examination of the shape of the estimated curves and the significance of the income coefficients reveals that there is evidence in support of the EKC in all scenarios; the five conditional quantiles and conditional mean. Despite the curves of the income-emissions relationship being almost identical across conditional quantiles and mean albeit lying on different sections of the plane in the diagram, the estimates for the conditional quantile results are relatively different at different quantiles of the conditional distribution of emissions. In a nutshell, the conditional quantile and conditional mean estimations provide a turning point of about \$15,300 to \$19,600 and \$17,600 respectively (see table 3 and figure 1); these estimates are considerably higher than the global mean per-capita income, \$5,169. The mean estimation therefore provides optimistic turning point levels of income for countries with emissions in the upper tail of the emissions distribution - 0.75

and 0.9 quantiles - and gets this approximation just about right for countries in the median and 0.25 quantiles. However, it estimates a relatively high turning point for countries with emissions in the 10th percentile. Regardless of the global sample providing evidence of the EKC hypothesis for all conditional quantiles considered and conditional mean too, the conditional quantile results provide a more rigorous and informative analysis of the turning points of this ascertained relationship. Similarly, the OECD results show a significant EKC relationship for all conditional quantiles and mean. However, the relatively late curvature of the plotted coefficients for this group indicates that these countries had to attain very high income levels before growth culminated into environmental improvements; if at all these turning points were not also influenced by policies aimed at mitigating carbon emissions. The conditional quantile and conditional mean techniques provide turning point incomes of about \$22,000 to \$31,000 and \$24,600 respectively. These turning points are at least approximately two times higher than the mean income for this group, \$12,500. The conditional quantile regression results for the Non-OECD sample turn up an insignificant positive monotonic income-emissions relationship. The only exception is the result for the 0.9 quantile which shows a significant relationship with prospects of an eventual decline.[15] In contrast, the conditional mean results depict a significant EKC relationship with a turning point income of \$35,900. There is a large disparity between this turning point income and the mean income of this group, \$3,223. Such a disparity raises considerable doubts on how the countries in this group will reach this turning point income given that virtually all of them have per-capita incomes way less than that

depicted by the turning point. More importantly, the two different income-emissions relationships portrayed by the conditional quantile and conditional mean techniques shows that the latter may provide erroneous summaries of the prevailing relationship. The former is more rigorous in its examination of the income-emissions nexus thereby providing a clearer picture of the prevailing relationship. Next, for the Western region, the conditional quantile technique estimates a significant income-emissions relationship for the 10th and 25th percentiles only. The conditional mean approach depicts a significant relationship as well. The entire family of curves for the Western region indicates evidence of an inverted U-shaped income-emissions relationship, albeit some being insignificant. These curves are almost identical across the different conditional quantiles and mean. The diverging inferences on statistical significance show that while the conditional mean technique provides significant evidence in favour of the EKC hypothesis for all the countries in the region, the conditional quantile method is more elaborative and informative by indicating that the estimated relationship may not be significant for observations with emissions in the median and upper tail conditional distribution. Concentrating on the turning points provided by the significant curves, it is therefore suffice to say that the results of the conditional quantile and conditional mean estimations provide turning points of about \$17, 500 to \$19, 200 and \$18, 200, respectively. These turning points are higher than the mean income for this region, \$14, 588. However, this disparity in turning point and mean income is not as remarkable as in the global and OECD samples. The overall results for the East European region show a monotonically rising income-emissions

relationship. The conditional mean estimation depicts this relationship as insignificant. However, as presented by the conditional quantile estimations, the relationship is actually significant for the median and upper tail quantiles - 75th and 95th percentiles. This result therefore belabours the likelihood of the former technique giving less information on the distribution of emissions than the latter method. The Latin American region provides an interesting case where different forms of income-emissions relationship are obtained between different conditional quantiles and the conditional mean. The 0.1 and 0.25 quantiles show a monotonically rising income-emissions relationship, albeit the former relationship being insignificant. Also, the median and conditional mean results show a positive (but insignificant) EKC relationship with prospects of an eventual decline. On the other hand, the 0.75 and 0.90 quantiles show an inverted U-shaped relationship. However, this evidenced EKC relationship is significant for the 90th percentile only, with the relationship being marginally insignificant for the 75th percentile.

[16] Again, these findings reiterate the additional informational gains associated with the application of the conditional quantile over the conditional mean technique; the latter conceals more information than it reveals. Inasmuch as this informational gain justifies the sole use of the conditional quantile method as an analytical tool, there is also need for the use of the technique to at least complement the conditional mean method for a more in-depth expository analysis of the income-emissions nexus. The conditional quantile results for the 75th and 90th percentiles provide within sample turning points of about \$10,900 and \$13,400 respectively. These turning points are higher than the mean income for this region, \$4,329. In

addition to the interesting finding of mixed EKC relationships provided by different percentiles within the conditional quantile method on one hand and the conditional mean technique on the other, these results have far reaching implications. Most importantly, the results confirm Dasgupta et al's (2002) argument that environmental clean-ups are possible in developing countries and that peak levels of environmental damage in these countries will be lower than in developed countries (Stern, 2004). Consequently, the inverted U-shaped income-emissions relationship may not exist in developed countries only, but in developing countries as well. There are some developing countries adopting equally stringent environmental control standards as the developed countries. Thus, the argument of no regulatory capacity in developing countries as proposed by the advocates of the EKC theory may be flawed. Therefore, this therefore casts doubts on advocates' proposition that the achievement of economic development is the only panacea for environmental damage. As a result, policies aimed at shifting energy use from dirty to cleaner sources whilst promoting the mitigation of carbon emissions should move in tandem with policies promoting economic development; rather than solely relying on the former for achieving environmental clean-ups. For the East Asian region, the 0.75 and 0.90 quantiles show a significant EKC relationship despite the negative slopes of the two curves falling at a very slow rate (see table 3 and figure 1). The curves for the other quantiles and for the mean show a rising income-emissions relationship with prospects of an eventual decline, though this relationship is insignificant. The estimated curves for the 0.75 and 0.90 quantiles intersect those for the median and mean. These curves provide

within sample turning point incomes of about \$22, 900 and \$22, 000 respectively. However, these turning points are higher than the mean income of the region, \$3, 711. Just as in the Latin American scenario, the results for this region further reiterate Dasgupta et al.'s (2002) argument of developing countries being able to successfully implement pollution mitigation policies, especially the market based instruments. Not surprisingly, Dasgupta et al. (2002) precisely cited one of the countries in this region - China - as a prime example of a developing country being able to implement strict environmental control measures. Again, this finding throws doubt on the dictate of the EKC advocates that the only way to achieve a decent level of environmental quality is by achieving a decent level of economic development. The West Asian and African regions show a monotonically increasing income-emissions relationship. With an exception of the conditional mean and median regressions, the monotonic relationship depicted by the West Asian region is generally insignificant. The same applies to the African sample where only results for the 0. 10, 0. 25 and 0. 50 conditional quantiles are significant. Following our findings of mixed evidence of the income emissions relationship across the global sample, two economic blocs and six geographical regions analysed on one hand and different quantiles of the conditional distribution of emissions and conditional mean on the other hand, a holistic appraisal of these results suggests that one income-emissions relationship does not fit the entire world. An estimated income-emissions relationship could be monotonic, inverted U-shaped [or (inverted) N-shaped too] depending on the conditional quantile considered and the unique economic, social, structural and environmental

characteristics of each economic or geographical grouping. Obviously, our scrutiny of the global finding of an inverted U-shaped relationship by both the conditional quantile and conditional mean techniques reveals that while the relationship may hold in a few cases, it cannot be generalised across a wide range of economic and geographical regions facing different levels of economic development. In cases where the relationship is confirmed, the slope of the positive segment of the curve is steeper than the negative segment thereby implying that emissions increases at a faster rate than it declines. Moreover, our results indicate that the conditional mean technique is prone to providing flawed summaries of an underlying income-emissions relationship since it only concentrates on evaluating the effects of the regressors on the mean. Since the conditional quantile method covers the entire conditional distribution of the response variable, the technique provides a more rigorous, informative and compelling examination of the income-emissions nexus. The method also provides a basis for capturing countries' heterogeneity while examining the EKC theory; by assessing how per-capita income affects emissions based on a country's observation on the emissions distribution.

Decomposition Analysis

To decompose the OECD-Non-OECD emissions differential into gaps attributable to differences in endowments on one hand and differences due to returns to endowments on the other hand, we follow the Machado and Mata (2005) procedure outlined above.[17] Table 4 presents the results of this estimation. The first, second and third columns in this table present the five percentiles for which the decomposition is evaluated, the raw emissions

differential between OECD and Non-OECD countries (at their corresponding percentiles) and the 95 percent bootstrapped confidence intervals for the estimated raw differentials respectively. The next two columns present estimates of the raw differential attributable to differences in endowments with their corresponding 95 percent confidence intervals respectively; the counterfactual Non-OECD marginal density if all covariates were distributed as in the OECD group versus the estimated Non-OECD marginal density. The final two columns present estimates of the raw differential attributable to differences in returns to endowments with their corresponding 95 confidence interval respectively; the OECD estimated marginal versus the counterfactual Non-OECD marginal density if all covariates were distributed as in the OECD countries. Further, the table presents standard errors of the estimated raw differentials, endowment and coefficient effects directly below the point estimates in parenthesis. The proportions of emissions differential attributable to the explained and unexplained effects are presented in curly brackets next to the estimates of these effects. In table 4, the OECD-Non-OECD emissions gap is positive and significant at all quantiles investigated. However, the differential contracts as we ascend the emissions distribution. This result confirms the a priori expectation arising from the data summary section of the paper that the OECD countries have polluted more than the Non-OECD countries. Further, the explained and unexplained effects contribute about 50.66 to 52.43 percent and 47.57 to 49.34 percent of the emissions gap respectively. Despite the slight dominance of the former in explaining this gap, its contribution diminishes whilst ascending the specified percentiles. The reverse is the case for the coefficient effect. Essentially,

since differences in natural logs are approximately equal to percentage differences (see Baiocchi and Aftab, 2006; Costa-Font et al, 2009), the estimated raw differentials imply that the OECD countries emitted about 66 to 369 percent more than the Non-OECD group. More so, if every other thing remained as status-quo but the Non-OECD sample had the OECD sample's distribution of income, the former would pollute about 25.66 to 39.77 percent more CO₂ than the latter. Since the results of the unexplained effect also account for a significant proportion of the emissions gap, these results therefore imply that there may be other important non-income related factors explaining the estimated emissions gap – such as technological gap, structural differences or pollution havens – not accounted for in this paper. Combining the decomposition results with the results of the EKC estimations, these therefore imply that even in the face of rising per-capita incomes in the Non-OECD countries, thus far, this development has not been promising for the environment. Equally important is the likelihood that there is a huge technological (and regulatory) gap between the OECD and Non-OECD groups. Notwithstanding the (slight) dominance of the covariate over the returns effect in explaining the OECD-Non-OECD emissions gap, our results show that the difference in income levels between the two groups explains a great deal of the differences in the shapes of the EKC curves earlier analysed.

Conclusion

The EKC hypothesis posits that the early stages of economic progress are associated with increasing environmental damage. However, after the attainment of a threshold level of income, progress leads to environmental

improvements. Graphically, this denotes an inverted U-shaped relationship between income and environmental degradation; with the former and latter measured on the abscissa and ordinate planes of a graph respectively. Advocates of this theory prescribe that achieving economic development is the solution to environmental pollution; thereby, undermining the relevance of environmental policies in mitigating pollution. On the other hand, sceptics accept the possibility of an inverted U-shaped relationship between income and pollution, but suggest caution in interpreting the causes and implications of the hypothesis. Deviating from conventional methods of EKC investigations, we applied the quantile fixed effects technique in exploring the CO₂ EKC within two groups of economic development (OECD and Non-OECD) and six geographical regions – West, East Europe, Latin America, East Asia, West Asia and Africa. A comparison of the findings obtained from the use of this technique with those of the conventional fixed effects method reveals that the latter is inadequate in capturing distributional heterogeneities within the panel sample under scrutiny and it is very likely to depict a flawed summary of the prevailing income-emissions nexus under different distributional structures. In cases where it is successful in capturing the prevailing relationship, it often conceals more information than it reveals. The paper finds the quantile fixed effects method to be more rigorous and informative in its exploration of the income-emissions relationship. In whole, we confirmed existence of a significant EKC in the global, OECD and western samples. Interestingly, the hypothesis was confirmed in the Latin American and East Asian regions too thereby reiterating Dasgupta et al's (2002) stance that environmental clean-ups are also achievable in developing countries.

Thus, turning points may not exist for developed countries alone, but also for developing countries. Further, our study extended decomposition techniques largely used in labour economics to the EKC framework in order to provide an additional investigation of the OECD-Non-OECD emissions gap. This decomposition analysis yielded the finding that the OECD group emitted about 60 to 369 percent more CO₂ than its Non-OECD counterpart, depending on the quantile evaluated. Furthermore, if the Non-OECD had the same incomes as the OECD group but every other thing remained at status-quo, the former would pollute about 26 to 40 percent more than the latter. Moreover, we found that there are other important non-income related factors not captured in this paper militating against the Non-OECD group's greening; such as the shortage of advanced and cleaner production technologies, structural differences and pollution haven amongst others. In sum, our exploration of the income-emissions nexus reaches the following clear-cut conclusions; first, no single income-emissions relationship fits all countries of the world; second and most importantly, although our paper finds evidence of the EKC across different levels of economic development, policy makers (especially in developing countries) should ensure that policies in promoting progress move in tandem with those promoting greening; such as policies geared towards a shift to the use of cleaner energy sources. Besides individual country efforts to achieve greening, the clean development mechanism, joint implementation and emissions trading programs of the Kyoto Protocol should provide greater impetus for mitigating CO₂ emissions.