Essays on Econometric Analyses of Economic Development and Effects on Health, Environmental Damage and Natural Resource Depletion

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Contents

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List of Tables

List of Acronyms and Abbreviations

CC	Consumer Choice
CO_2	Carbon (Emissions)
CPI	Consumer Price Index
CV	Contingent Valuation
DRC	Dose Response Coefficient
DRF	Dose Response Function
EKC	Environmental Kuznets Curve
EU	European Union
GDP	Gross Domestic Product
GMM	Generalised Method of Moments
GNI	Gross National Income
GNP	Gross National Product
NO_X	Nitrogen Oxide
OB	Oaxaca and Blinder
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
PM	Particulate Matter
PPP	Purchasing Power Parity
SO_2	Sulphur Oxide
UK	United Kingdom
US	United States
USEPA	United States Environmental Protection Agency
VSL	Value of Statistical Life
WDI	World Development Indicators
WHO	World Health Organisation
WR	Wage-risk
WTP	Willingness to Pay

Abstract

The main part of this thesis is composed of three separate chapters, each using an innovative approach to analysing externalities from economic activity. The general introduction and overall conclusion sections complete the structure of the thesis. Chapter one examines the value of statistical life, an essential parameter used in ascribing monetary values to the mortality costs of air pollution in health risk analyses. This willingness to pay estimate is virtually non-existent for most developing countries. In the absence of local estimates, two major benefit transfer approaches lend themselves to the estimation of the value of statistical life: the value transfer method and the meta-regression analysis. Using Nigeria as a sample country, we find that the latter method is better tailored than the former for incorporating many characteristics that vary between study sites and policy sites into its benefit transfer application. It is therefore likely to provide more accurate value of statistical life predictions for very low-income countries. Employing the meta-regression method, we find Nigeria's value of statistical life estimate to be $489,000. Combining this estimate with dose response functions from the epidemiological literature, it follows that if Nigeria had mitigated its 2006 particulate air pollution to the World Health Organisation standards, it could have avoided at least 58,000 premature deaths and recorded an avoided mortality related welfare loss of about $28 billion or 19 percent of the nation's GDP for that year.

The second chapter applies the quantile fixed effects technique in exploring the CO_2 environmental Kuznets curve within two groups of economic development (OECD and Non-OECD countries) 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 may depict a flawed summary of the prevailing income-emissions nexus depending on the conditional quantile examined. We also extend the Machado and Mata decomposition method to the Kuznets curve framework to explore the most important explanations for the carbon emissions gap between OECD and Non-OECD countries. We find a statistically significant OECD-Non-OECD emissions gap and this contracts as we ascend the emissions distribution. Also, 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. The decomposition further reveals that there are non-income related factors working against the Non-OECD group's greening. We tentatively conclude that deliberate and systematic mitigation of current CO_2 emissions in the Non-OECD group is required.

The final chapter employs the Arellano-Bond difference GMM method in investigating the oil curse in OECD and Non-OECD oil exporting countries. Empirical studies investigating the natural resource curse theory mostly employ cross-country and panel regression techniques subject to endogeneity bias. Also, most of these studies employ GDP in its aggregate or per-capita terms as the outcome variable in their analyses. However, the use of GDP measures of income for resource curse investigations does not portray the true incomes of resource intensive economies. Standard national accounts treat natural resource rents as a positive contribution to income without making a corresponding adjustment for the value of depleted natural resource stock. This treatment, inconsistent with green national accounting, leads to a positive bias in the national income computations of resource rich economies. Our paper deviates from most empirical studies in the literature by using the Arellano-Bond difference GMM method. We test the robustness of the curse in the predominantly used measures of national income, GDP, by investigating the theme in genuine income measures of economic output as well. We employ two alternative measures of resource intensity in our explorations: the share of oil rents in GDP and per-capita oil reserves. Our results provide evidence of the curse in Non-OECD countries employing aggregate and per-capita measures of genuine income. On the other hand, we find oil abundance to be a blessing rather than a curse to the OECD countries in our sample.

Declaration

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General Introduction

An economic goal targeting a sustained increase in welfare revolves around a mix of policies propelling qualitative and quantitative changes in industrialisation, human capital, environmental quality, organisational restructuring, political and bureaucratic institutions to name a few. However, the avenues often sought in increasing welfare – especially the emphasis on sustaining economic growth and income – generate a flow of externalities from the production and consumption spectrums of economic activity. Notable of these externalities is the atmospheric pollution primarily induced by fossil fuel combustion leading to global warming and anthropogenic climate change. Fossil fuel combustion also generates a stock of air pollutants that are hazardous to human health. Sustainable management of vast natural resource endowments is another problem resource rich economies have to contend with.

The primary objective of this thesis is to contribute to a better understanding of the inter-relation between economic and environmental sustainability as well as sustainable management by public authorities of natural resource rents in low-income countries. To attain this objective, this thesis seeks to employ appropriate econometric methods to achieve the following secondary objectives:

- To estimate and monetise the mortality related benefits associated with mitigating outdoor particulate air pollution in developing economies using Nigeria as a case study.
- To empirically explore the validity of the popular Environmental Kuznets Curve theory for carbon emissions across a collection of geographical and economic bloc of countries.
- To empirically investigate the oil curse theory between OECD and Non-OECD economic blocs of oil exporting economies.

The thesis comprises three separate articles (or chapters) addressing each of the secondary objectives adopting an alternative thesis format. Though the articles investigate different research problems, they are all related to the thesis' primary objective of contributing to a better understanding of the inter-relation between management of (air) pollution externalities and a judicious management of natural resource rents in developing economies. A thesis in an alternative format provides invaluable experience of writing articles for publication in peer reviewed academic journals. In addition, it is becoming increasingly popular and standard over the last ten years to write economics doctoral theses in this format. For all three chapters of the thesis, I was in charge of writing up the articles, developing all the econometric models and implementing these, all data collection, obtaining the empirical results and interpreting and summarising the findings. My supervisors offered guidance, profound insights and help to solve any problems I encountered during the entire project. This same level of effort and contribution by me and my supervisors was put into publishing the first article. We plan to publish the other two chapters in an identical fashion.

The first article of the thesis entitled "Estimating Mortality and Economic Costs of Particulate Air Pollution in Developing Countries: The Case of Nigeria" monetises the mortality related benefits associated with the mitigation of outdoor particulate pollution in developing economies. This monetisation process employs the value of statistical life (VSL), a fundamental concept commonly used by environmental economists in analysing the fatal risks of air pollution. The VSL represents an individual's or society's willingness to pay for a marginal reduction in mortal risk (see Viscusi and Aldy, 2003). This willingness to pay estimate is virtually non-existent for most developing economies. In the absence of local estimates, two benefit transfer approaches lend themselves to the estimation of the value of statistical life: the value transfer method and meta-regression analysis. The former method transfers and calibrates either a point VSL estimate, a measure of central tendency from a group of original willingness to pay studies or administratively approved estimates from a developed economy, particularly the US or the UK. On the other hand, meta-regression analysis is a statistical method that combines the results of several VSL studies to provide a willingness to pay prediction function to be used for an out-of-sample approximation. Evidence from previous studies support the stylised fact that meta-regressions lead to more accurate predictions than value transfers (see Boyle et al., 2010; Kaul et al., 2012; Rosenberger and Loomis, 2003). Contrary to this fact, a majority of studies in the developing world – and a handful of studies in the developed world also – employ the latter method in estimating policy site VSL (see Zhou and Tol, 2005; Quah and Boon, 2003).

This article contributes to the general literature on the valuation of non-market goods and services associated with estimating health and economic costs of air pollution in two major ways. Foremost, to my knowledge, the paper is the first to monetise the mortality related benefits associated with improving air quality in a developing economy employing a VSL estimate provided by the meta-regression method. The chapter uses Nigeria as a representative developing economy for this investigation. Second and perhaps more importantly, the paper compares VSL estimates provided by both value transfer and meta-regresssion approaches, investigating which of the two provides more reliable VSL approximations for low-income economies. It finds the latter to be the superior method. This paper is collaborative work with my supervisors – Prof. Ada Wossink and Dr. Mika Kortelainen – and it is published in *Environmental and Resource Economics*, 54(3): 361-387. The published version of the paper with only a few slight revisions is presented as the first chapter of the thesis.

Chapter two entitled “The Environmental Kuznets Curve at Different Levels of Economic Development: A Counterfactual Quantile Regression Analysis for CO_2 Emissions” investigates the famous Environmental Kuznets Curve (EKC) theory for carbon emissions. This theory posits that the early stages of an economy’s developmental process are associated with increasing environmental pollution. However, after the attainment of a threshold level of income, further progress is associated with declining environmental pollution. Empirical investigations of the theory typically employ per-capita estimates of income and emissions as indicators of economic progress and environmental depletion respectively. Also, most empirical studies exploring the income-emissions nexus employ a panel dataset of countries and these studies rely almost exclusively on the use of conventional longitudinal econometric techniques especially fixed and random effects methods. These methods have attracted considerable criticism on various grounds (see Stern, 2004). A major criticism stems from the methods’ focus on estimating the rate of change in the conditional mean of emissions (as a quadratic or cubic function of income) thereby estimating constant slope coefficients across heterogeneous countries. However, estimating constant slope coefficients across heterogeneous nations implies that the procedures are incapable of capturing country level heterogeneity in Kuznets curve explorations. This shortcoming of conventional estimation methods spurs the need for the application of alternative techniques with a greater flexibility of capturing country level heterogeneity in Kuznets Curve investigations.

This paper contributes to the growing empirical literature on the EKC by exploring the validity of the CO_2 income-emissions nexus across different quantiles of the conditional distribution of emissions. The chapter employs the quantile fixed effects method to provide empirical insights in the distributional heterogeneity of this relationship. This method corresponds to a random coefficients setup allowing for heterogeneous income-emissions relationships at different conditional quantiles of the emissions distribution. The technique is capable of identifying various relationships that may be missed by the application of conventional mean regressions thereby providing an opportunity for a more comprehensive examination of the carbon EKC theory. To my knowledge, this paper is the first to comprehensively employ this technique to introduce distributional heterogeneity in exploring CO_2 income-emissions nexus. The chapter empirically examines the relationship between per-capita measures of CO_2 emissions and GDP for the entire world and different sub-sets of countries – OECD, Non-OECD, West, East

Europe, Latin America, East Asia, West Asia and African regions. An exploration of the EKC at different percentiles of the conditional distribution of emissions is necessary due to two main reasons. Foremost, the conditional median estimates – one of the percentiles covered by the conditional quantile method – are more robust to outliers on the dependent variable than estimates of the conditional mean (Koenker, 2004, 2005). Second, the conditional mean estimation only characterises the mean effect of income on emissions thereby failing to characterise the full distributional impact. The information gained by examining the effect of income on a measure of central tendency – mean or median – of a particular emissions distribution may not be necessarily informative for other quantiles except these effects are not different from those at the other regions (see for instance Huang et al., 2007; Flores et al., 2013). Thus, conditional quantile estimation provides an opportunity for a richer exploration of the CO_2 income-emissions nexus as it allows an assessment of the impact of income across the entire conditional distribution of emissions, not only its conditional mean.

The final chapter entitled "An Investigation of Oil Curse in OECD and Non-OECD Oil Exporting Economies Using Green Measures of Income" explores the natural resource curse theory in major OECD and Non-OECD oil producing economies. This theory posits that economies with vast natural resource endowments often record lower growth rates than resource scarce economies. Thus, natural resource abundance inhibits growth. The literature ascribes the Dutch disease, poor quality of institutions, rent seeking and corruption as mediums through which resource abundance translates to lower growth. Existing empirical studies investigating the theory regress a measure of economic output, GDP in its aggregate or per-capita term, on a variable capturing natural resource intensity and other factors that affect economic progress. However, the use of standard GDP estimates for resource curse investigations does not portray the 'true incomes' of resource intensive economies as traditional national income accounts records natural resource rents as a positive contribution to GDP without making a corresponding adjustment to depleted natural capital stock. This system of national accounts fails to consider that the depletion of a natural capital stock is essentially the liquidation of an asset, thus, natural resource extraction should not be treated as a positive contribution to GDP (Hamilton and Clemens, 1999). As a result, traditional national accounting procedures lead to a positive bias in the GDP computations of resource intensive economies. This shortcoming of standard GDP measures of income therefore requires the application of greener and more sustainable indicators of economic output in resource curse investigations. Also, a majority of empirical studies investigating the curse employ standard panel and cross-country estimation techniques subject to endogeneity bias.

This chapter contributes to the existing empirical literature in two major ways. First, it investigates the oil curse in major OECD and Non-OECD oil producing economies using genuine income measures of economic output. This indicator provides a closer approximation of the ‘true incomes’ of resource intensive economies relative to standard GDP measures as it accounts for natural capital depreciation in its national income accounting. Second, the article deviates from a majority of the empirical literature by employing the difference GMM estimation technique to control for endogeneity bias. The chapter employs two competing measures of oil intensity in its explorations: share of oil rents in GDP and per-capita oil reserves. The two measures effectively translate to indicators of oil dependence and abundance respectively. The first measure is widely employed for resource curse investigations (see Neumayer, 2004; Bjorvatn et al., 2012) and the latter is in line with Brunnschweiler and Bulte (2008) who argue for the use of stock based measures in resource curse explorations.

The presentation of the three chapters is followed by an overall conclusion section. This summarises the major findings of the articles and combines them into a coherent research piece. It also reflects on the policy implications of the findings and provides a critical appraisal of the methods used in achieving the three secondary objectives of the thesis.

CHAPTER ONE

Estimating Mortality and Economic Costs of Particulate Air Pollution in Developing Countries: The Case of Nigeria

1.1 Introduction

As economies intensify production and consumption activities with the aim of achieving growth and development, these activities often move in tandem with external consequences posing a dangerous threat to human health and the environment. In particular, the harmful effect of air pollution on human health is an issue of global concern. The epidemiological literature has established links between particular air pollutants and human health risks, such as respiratory and cardiovascular diseases. However, in order to aid in setting priorities for public decision making, policy makers are not merely concerned about the linkage between air pollution and adverse human health but more about facts relating to the costs and benefits of mitigation. Policy makers are often confronted with a choice of how resources should be allocated to pollution control and therefore environmental management, education, health care, infrastructural development and a variety of other pressing economic needs. Consequently, a benefit-cost assessment of the health and economic costs of air pollution is an essential input in public decision making. If potential mitigation benefits are substantial, this would highlight the necessity of incorporating environmental management into a nation's developmental policies.

There exist different types of air pollutants – particulate matter (PM), methane, nitrogen oxide, sulphur dioxide and ozone amongst others. Among these pollutants, recent studies have consistently identified PM as the most hazardous to human health. Chronic exposure to PM exacerbates respiratory and cardiovascular diseases such as common flu, pneumonia, bronchitis and asthma (see Ruckerl et al., 2011). These may lead to premature mortality. The monetised mortality cost of particulate pollution accounts for approximately 90 percent of its total health cost (see Ostro, 2001; Akbostanci et al, 2009; Dickie and List, 2006; Zhang et al., 2008). These estimates explain why epidemiological and environmental economic analysts place much importance on PM and its mortality effect. Particles are measured in micrograms per cubic meter ($\mu g/m^3$) of air sampled and PM_{10} is the most common measure of inhalable PM, defined as solid particles with an aerodynamic diameter of less than or equal to ten micro-meters (Pope, 2007).

The most reliable way of measuring the mortality effect of air pollution in a particular area is to conduct epidemiological studies for that area. To capture both acute and chronic effects,[1] a large cross-section of individuals should be studied prospectively for at least ten years, measuring both the air pollution concentrations to which they are exposed and other factors that affect the risk of death – smoking habits, family history, and body mass index amongst others (Cropper and Simon, 1996). Associated with the quantification of mortality effects is its corresponding monetisation into an economic cost. This process employs the value of a statistical life (VSL), a fundamental concept commonly used by environmental economists in analysing fatal risks of air pollution. The VSL represents an individual's or society's willingness to pay (WTP) for a marginal reduction in the risk of dying (see for instance Viscusi and Aldy, 2003).[2] This paper focuses on estimating the health related benefits associated with improving air quality in Nigeria. To do this well, we ideally would have primary data from which to estimate VSL, and then tie this to primary epidemiological data to translate the VSL estimate into a total benefits estimate. However, as both data collections are costly and time-prohibitive, we often rely on benefit transfer, which is an approach for estimating the costs and benefits of policies in the absence of original data collection. It transfers mortality effect and VSL estimates from one or more already completed studies – often termed the study site – to predict the health and economic benefits from the mitigation of pollution at a different point in space, time or both – the policy site. Environmental analysts have increasingly used benefit transfer in cost benefit analyses, particularly those pertaining to non-market valuation (see for instance Boyle et al., 2009; Navrud and Ready, 2007; Pearce et al., 1994).

There are three major benefit transfer approaches used in eliciting WTP for fatal risk reductions: preference calibration, value transfer and meta-regression analysis. The preference calibration technique, which has only seen limited use, specifies a preference function and uses available benefit information to calibrate the function's parameters to match the existing benefit estimates (see Smith et al., 2002 for more details). The value transfer method transfers and calibrates either a point VSL estimate, a measure of central tendency from a group of original WTP studies – usually the mean – or administratively approved VSL estimates from a developed country, particularly the US (see for instance Rosenberger and Loomis, 2003). This is the most convenient benefit technique to transferring estimates from study sites to policy sites (Navrud

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[1] Acute effects associate short term changes in exposure to air pollution and mortality; and chronic effects evaluate the mortality effects across communities or neighbourhoods with different levels of air pollution over longer periods (see Pope, 2007 for details).

[2] Common approaches to estimating the VSL include stated preference surveys where respondents are asked to make trade-offs between mortality risk and monetary consequences, and revealed preference approaches such as through assessing workers' trade-offs between wages and job-related risks.

and Ready, 2007). The meta-regression analysis is a statistical method that combines the results of several VSL studies to provide a VSL prediction function, to be used for an out-of-sample approximation. The use of meta-regressions for function transfers is gaining growing popularity in environmental and health economics research (see for instance Nelson and Kennedy, 2009; Bellavance et al., 2009). Evidence from previous studies supports the stylised fact that meta-regressions (or more generally function transfers) lead to more accurate predictions than value transfers (see for instance Boyle et al., 2010; Kaul et al., 2012; Rosenberger and Loomis, 2003). Contrary to this fact, a majority of health and economic cost studies conducted in the developing world – and a handful of studies in the developed world too – employ the latter technique in estimating policy site VSL (see for instance Zhou and Tol, 2005; Quah and Boon, 2003; Chestnut et al., 1997; Larson et al., 1999; Pearce, 1996).

To the best of the authors' knowledge, this paper is the first study that monetises the mortality related benefits associated with improving air quality in a developing country employing a VSL estimate provided by the meta-regression method. In addition, this paper extends upon an earlier meta-regression by Miller (2000) in three ways. First, by including developing countries in the sample, this study has a better representation of these countries in its regressions. Second, this study explores the use of additional regressors and statistical tests in determining its most preferred VSL meta-regression prediction function. Third, in contrast to Miller (2000), we employ a consistent estimator for the expected value of the VSL from meta-regressions that use the log of VSL as the dependent variable. Accordingly, we improve on Miller's study by conducting this adjustment in the VSL prediction for Nigeria. Finally, and perhaps most importantly, the paper compares VSL estimates provided by both the value transfer and meta-regression approaches, investigating which of the two methods provides more reliable VSL approximations for developing countries. We find the latter to be the superior method. Thus, the paper recommends the use of the meta-regression benefit transfer approach in health risk analyses in developing countries, if much more expensive and time-consuming stated or revealed preference studies cannot be implemented.

1.2 Survey of Literature

1.2.1 A Roundup of Studies on the Value of Statistical Life and the Economic Cost of Particulate Pollution

Assessment of the economic costs of air pollution is a fairly new branch of research in the fields of environmental and health economics. While epidemiological studies have assessed the health costs of air pollution since the 1940s, it was not until the early 1990s that economists made an effort in assessing these costs. As earlier stated, the VSL is an individual's or society's WTP for fatal risk reductions, thus involving a money-risk trade-off. There are at least three generally accepted ways of eliciting this trade-off. The first is a wage-risk study. This measures WTP by estimating the compensation, in the form of wage premiums, demanded by workers for taking up riskier jobs. The second is consumer choice study which investigates individuals' market decisions that reveal implicit values embedded in behaviour to reduce mortal risk; such as decisions to buy smoke detectors, bicycle or motor-cycle helmets and so on (see Miller, 2000). These two methods – wage-risk and consumer choice – are generally termed revealed preference techniques, with the former and latter eliciting individuals' risk taking preferences in the labour and product markets respectively. The third approach is to use stated preference surveys, which directly or indirectly ask respondents to make contingent trade-offs between mortality risks and monetary consequences.

Several studies employed these three valuation methods in estimating the VSL. For instance, Viscusi (2004) and Garbacz (1989) employed the wage-risk and consumer choice methods in estimating the US VSL as \$5.9 million and \$3.0 million, respectively. Similarly Ortuzar et al. (2000) used the contingent valuation method in estimating Chile's VSL as \$0.63 million. However, most of the available studies are from developed countries, particularly the US and UK. These money-risk trade-off studies were virtually non-existent for developing countries and it is only recently that a few have cropped up in China, India, Malaysia, Taiwan, Chile, Mexico and Thailand. Data scarcity on WTP to avoid mortality or even on occupational risk and wages, and the huge costs involved in conducting these studies, plagues and constrains the emerging body of interesting work estimating the VSL in developing countries (Bowland and Beghin, 2001). Most of these studies used the wage-risk method and available estimates vary depending on the baseline and type of risk assessed, and the valuation method employed. Even in the face of identical risk reductions, these three valuation methods could lead to considerable variations in the money-risk trade-offs obtained. However, it is generally observed in the VSL literature that consumer choice studies tend to produce lower VSL estimates than the contingent valuation technique (see Bellavance et al., 2009; de Blaeij et al., 2003). Unlike the case of consumer choice and contingent valuation methods, there is no consensus on whether the contingent valuation technique provides higher or lower VSL estimates than the wage-risk method. However, Viscusi (2011) and Kochi et al. (2006) indicated the likelihood of the latter providing relatively higher estimates than the former.

Studies that estimated the benefits of air pollution control programs indicate that when monetary measurements for reductions in mortality effects are considered, the benefits of mitigation could be enormous (Chestnut et al., 1997). For instance, Quah and Boon (2003) estimate the mortality related welfare losses resulting from particulate pollution in Singapore for 1999. Employing the benefit transfer method via the transfer of dose response functions (DRFs) developed by Ostro (1994)[3] and a (value transfer) calibration of Singapore's VSL, the study estimates the total economic costs of particulate pollution as $3.7 billion.[4] This amount translates to about 4.3 percent of Singapore's GDP in 1999. Zhou and Tol (2005) employed similar benefit transfer techniques in estimating the mortality related welfare losses arising from particulate air pollution in Tianjin, China, for 2003. They estimate this as $1.1 billion, with mortality cost accounting for 80 percent of this amount and the remaining attributable to morbidity cost – such as cost of chronic bronchitis, asthma, and pneumonia amongst other particulate air pollution related diseases.[5] This amount represents 3.7 percent of Tianjin's GDP in 2003. Such substantial mortality related welfare losses to Singapore and Tianjin imply that the mitigation of particulate air pollution might yield substantial welfare gains that are equal to a significant percentage of these economies' GDPs. Consequently, this research suggests a need for these previously mentioned economies to incorporate environmental management into their developmental policies.

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[3] Dose response functions show a relationship between exposure to a given concentration of an air pollutant and the resulting mortality effect from that concentration level. See methodology section of paper for more details.

[4] Adopting the human capital and cost of illness approach, these economic costs could be interpreted as productivity losses brought about by pre-mature mortality resulting from air pollution. Consequently, this paper uses the terms economic cost and mortality related welfare losses interchangeably in its analysis of the monetised health costs of particulate pollution.

[5] The estimates for Singapore and Tianjin are in US 1999 and 2003 dollars respectively. Except otherwise stated, all monetary estimates presented in this paper are in US 2006 dollars.

1.2.2 Empirical Evidence on Mortality Effects of Particulate Air Pollution

Six decades ago, two devastating air pollution episodes sparked public awareness of the health impairing effects of outdoor particulate pollution, especially in highly polluted cities of the world. These were the toxic fogs in Donora, Pennsylvania (USA) between 25th and 31st October, 1948 and that of London between 5th and 8th December, 1952 that claimed 20 and 4000 lives respectively. These incidents drew global attention to the mortality effects of particulate pollution on human health (Pope and Dockery, 1994; Phalen, 2002).[6] In spite of the fact that historical accounts of air pollution exposures in cities and work places prior to the 1990s were rarely accompanied by quantitative pollution data, an increasing number of deaths and sicknesses during these two major pollution episodes made obvious the fact that an association between (particulate) pollution and mortality exists (see Phelan, 2004; Pope and Dockery, 1994 for instance). In a bid to provide more compelling evidence on the association between outdoor particulate pollution and mortality, these pollution incidents launched a plethora of time series studies that observed changes in daily death counts linked with short-term term changes in particulate pollution. Daily time series studies evaluate effects of short-term exposure to pollution by analysing associations between changes in daily mortality counts with day-to-day changes in ambient pollution concentrations. Further, these studies relate mortality to several days of abnormally high concentrations of air pollution, for example the Donora and London fog episodes (see for instance Pope, 2007; Schrenk et al., 1949). Pope (2007) interestingly posited that despite the fact that studies of short-term exposure to particulate pollution are associated with mortality effects, these same effects are generally larger with intermediate and longer-term time scales of exposure. This is undeniably a logical argument. As long as an association between exposure to particulate pollution and mortality exists, the mortality risks of short-term exposure should be less than those of the long-term.[7]

Subsequently, a handful of long-term (and intermediate) exposure studies investigate whether or not the mortality effect of short-term exposure to particulate pollution may be due to

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[6] There is uncertainty regarding the estimated deaths from these disasters, especially that of London because there was a concurrent influenza epidemic during that period. In addition, it is argued that other confounding factors such as the correlation between PM and other air pollutants, temperature and high humidity could have also been responsible for the deaths (Holland et al., 1979). Nevertheless, most estimates attribute at least 3,000 deaths to the London fog (see for instance Stern, 1977; Clayton, 1978).

[7] In his review of studies analysing time variations in response to exposure to particulate pollution, Pope (2007) found that incremental increases of a 20 $\mu g/m^3$ of PM_{10} are associated with approximately a 0.4 to 1.3 percent and a 6 to 17 percent increase in relative risk of mortality due to short-term and long-term exposures, respectively. Hence, the mortality effects of short-term exposure are glaringly less than those of the long-term.

a phenomenon called 'mortality displacement' or 'harvesting effect.[8] Dominici et al. (2003) set out to investigate this phenomenon using different timescales of variation in air pollution time series. This analysis found larger relative rates of mortality associated with particulate air pollution at longer timescale variations – 14 days to 20 months – than at shorter timescales – 1 to 4 days. Also, Schwartz (2000, 2001 and 2003) applied smoothing techniques to decompose data into different timescales and arrived at a similar conclusion as Dominici et al. (2003). Hence, recent epidemiological studies do not only confirm the association between particulate air pollution and mortality but also show that long-term exposure to particulate pollution is associated with larger mortality effects than short-term exposure. This evidence refutes the suggestion that mortality effects of short-term exposure are due to mortality displacement. Despite the fact that temporal proximity in exposure matters, with the latest exposure having the largest mortality effect, empirical evidence suggests that short-term exposure studies of particulate pollution only capture a fraction of the overall effects of long-term repeated exposure to particulate pollution. The overall epidemiological evidence suggests that mortality effects are dependent on both exposure concentrations and duration of exposure, and that long-term exposures have larger, more persistent cumulative effects than short-term exposures (Pope, 2007). Appraising these studies reveals that similar associations between particulate air pollution and mortality were found despite the differences in methodologies employed and samples investigated. Furthermore, the most recent studies appear to show similar associations with those of the great air pollution episodes despite the fact that average concentration of particulate pollution has been on the decline, especially in the developed nations (see for instance Pope et al., 1995; WHO, 2003).

1.3 Methodology and Data

1.3.1 The Value of Statistical Life

The huge costs – in terms of resource, expertise and time – associated with the direct elicitation of the VSL has limited the use of direct estimation in the developing world. Thus, there

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[8] Mortality displacement, in this context, refers to the temporal change in the mortality rate of a particular population usually attributable to short-term pollution episodes. For instance, during the 1952 London fog, an excess mortality rate – especially among the older and sick people – was recorded. This might therefore imply that the fog greatly affected those whose health was already impaired and would have died in the short-term anyway. Hence, the excess deaths after the fog episode would be accompanied by a short-term compensatory reduction in deaths.

is a need for an affordable and reliable means of estimating WTP for fatal risk reductions for the third world. This has led environmental researchers in these countries to increasingly use two major benefit transfer techniques – the value transfer method and meta-regression analysis – without costly direct estimations (Miller, 2000). Conventionally, the value transfer method simply calibrates a VSL estimate transferred from a developed country, particularly the US, based on income differences between the country undertaking the adjustment and that in which the estimate is transferred. Virtually all health and economic cost studies conducted in developing countries have employed this method in estimating the VSL. This technique obtains a VSL estimate for Nigeria using the following equation:

$$VSL_{NIG} = VSL_{US} * \left(\frac{Y_{NIG}}{Y_{US}}\right)^{e} , \qquad \text{(i)}$$

where VSL_{NIG} is Nigeria's VSL estimate to be obtained via calibration; VSL_{US} is the US VSL estimate to be transferred to Nigeria; Y_{NIG}/Y_{US} is the ratio of purchasing power parity (PPP)[9] of Nigeria's GNI per-capita to that of the US (at 2006 prices); and e is the elasticity of WTP for a marginal reduction in mortal risk with respect to income. This is assumed arbitrarily to be 1.0 in most empirical studies estimating the health related benefits associated with mitigating air pollution in developing countries (see for instance Zhang et al., 2008; Hainoun et al., 2010; Sakulniyomporn et al., 2010).[10]

The apparent simplicity renders the value transfer procedure an attractive approach but it is not without flaws. Although the income elasticity of marginal risk reduction has been (assumed to be) unity in most empirical studies, there is no consensus on the choice of this parameter in the literature. In practice, this parameter is not necessarily constant but can vary depending on the income level of the country under investigation. In fact, most empirical studies conducted in both the developed and developing worlds estimated e to lie between 0.46 and 2.3 (see Bellavance et al., 2009). With precise reference to Nigeria (and other countries with very low GNI per-capita), the choice of e is of prime importance in the calibration process because of the large income disparity between Nigeria, and the US. For instance, a low income elasticity – say 1.0 – will lead to a much higher VSL estimate for Nigeria than a high elasticity – say 2.0. In order to cover the uncertainty in the choice of this elasticity parameter, Robinson and Hammitt (2009) suggest the

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[9] The PPP measurement of GNI presents GNI based on the price of the market basket of goods and services in one country relative to the US, thus, equating the difference in the purchasing power of a dollar in all countries.

[10] It is worth nothing that the formula in equation (i) is typically used in obtaining VSL value transfer estimates (see for instance Quah and Boon, 2003; Zhang et al., 2008; Zhou and Tol, 2005). Thus, the same formula could be applied to another country by substituting Nigeria's GNI per-capita with that of the country being investigated.

use of three estimates – lower, central and higher respectively given by 1.0, 1.5 and 2.0 – in health risk analyses conducted in the third world. We incorporate this suggestion in our value transfer analysis. However, it is pertinent to note that very little empirical evidence exists regarding the accuracy of the value transfer method, and it still remains uncertain whether it yields a larger or smaller calibration relative to what would have been obtained if more rigorous VSL studies were conducted in countries employing the method (see for instance Chestnut et al., 1997).

More importantly, the value transfer technique implicitly assumes that income disparity between countries is the only factor responsible for differences in WTP for fatal risk reductions across national boundaries. In addition to income, which has been observed to be a major determinant of the VSL,[11] other factors are likely to affect VSL; for example mortality risks posed by air pollution and public awareness of the dangers of these risks and demographic factors such as life expectancy. The value transfer procedure fails to capture the importance of these (and other) factors in its VSL calibration. Employing meta-regression analysis, we incorporate these additional factors accounting for differences in WTP for fatal risk reductions between countries in obtaining a VSL prediction for Nigeria. We then compare the estimates derived from both the value transfer and meta-regression techniques to choose the most preferred estimate for monetising mortality cost in Nigeria.

The meta-analysis in this paper follows and advances Miller's (2000) study. In spite of the fact that the literature clearly identifies (fatal) risk and income as major determinants of VSL, Miller (2000) considered the latter variable only in his regressions. We extend Miller's (2000) framework by controlling for mortal risk and other exogenous factors that could potentially affect the VSL. The paper also controls for study type – consumer choice (CC), contingent valuation (CV) and wage-risk (WR) – to enable the impact of the estimation technique on VSL differentials to be analysed. In obtaining a VSL prediction function for Nigeria we use the VSL estimates primarily obtained from developed countries, and a few from developing countries. Further, to control for additional country characteristics and to test the importance of including developing countries' VSL estimates in the meta-regression sample on the differential in income elasticity of VSL between developed and developing countries, we define a binary variable "*d*"; where *d=1* and *d=0* for the former and the latter countries respectively. We then interact this variable with income; the coefficient for the interaction term gives the difference in income elasticity of VSL between

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[11] VSL and income have been observed to have a positive and significant relationship in virtually all studies that have explored the relationship between the two (see Miller, 2000; Viscusi and Aldy, 2003; Bowland and Beghin, 2001).

the two groups of countries. The paper's meta-regression analysis takes into account differences in income, fatal risk, educational level, development levels and demographics between countries (see for instance Wang and He, 2010). As a result, we assume the following regression equation:

$$\ln(VSL_i) = f(X_i) + \varepsilon_i \;, \qquad i = 1,2,\dots,n \qquad \text{(ii)}$$

where *ln(VSL) is* the logarithm of value of statistical life; *X* is a vector of regressors including GNI per-capita in PPP terms (*gnipc*), mortal risk (*risk*), education (*educ*), age (*age*), the study type binary variables – *CC*, *CV* and *WR* (with *CC* being the base group), *d* and *gnipcd* which are the developed country binary variable and its interaction with income respectively; *ε* is the random error term; *i* is an individual observation (study) and *n* is the total number of observations in the sample. We assume two different functional forms for *f(.)*, the double-log model and the semi-log model. For the double-log model we use a logarithmic transformation for the continuous regressors, while for the semi-log model the right-hand side variables are not logged. The use of the two functional forms broadens the range of benefit transfer models to be assessed (Miller, 2000).

We discuss in more detail the variables that are used to control for income, fatal risk, education and age. Firstly, GNI per-capita in 2006 PPP terms is used to capture income in equation (ii) as well as in the value transfer equation (i). Secondly, crude mortality rate is used as a proxy for risk. VSL estimates vary due to different baseline risks employed in VSL investigations. An increase in baseline risk assessed leads to an increase in VSL, ceteris paribus (Hammitt, 2000). The type of fatal risk assessed and the method of valuation employed in these assessments are also likely sources of variation in VSL estimates. It is therefore not a coincidence that the cross country VSL estimates in our sample have a considerable variation. These differences in baseline, types and methods of assessing risks and the unavailability of case specific risk data for Nigeria pose a systemic challenge for the use of one fatal risk variable that unifies all these differences. Thus, we aggregate the different risk concerns under the unifying heading "mortality risk" and employ the crude mortality rate of each country as a proxy for this.

Thirdly, the average years of education of individuals in each country in the sample, school life expectancy, is used to capture individuals' awareness of different kinds of mortal risk. The reasoning here is that the more aware of these dangers people are, the more likely they are to pay for a reduction in mortal risks and vice-versa. Fourthly, life expectancy at birth captures average age of individuals in each country. The VSL literature recently recognised the importance of individuals' life expectancy in explaining WTP for health risk reductions. Remaining life expectancy at older ages is lower than that of younger ages, hence, reducing the number of future years at risk as people age. Therefore, the benefit of a unit decrease in current period mortality risk declines overtime (Hammitt, 2000). This should reduce older individuals' WTP for fatal risk reduction than that of younger individuals, ceteris paribus. Conversely, the opportunity cost of spending on fatal risk reduction declines with age as individuals' savings accumulate, especially during the phase they earn comparably higher incomes in their career cycle (see for instance Muller and Mendelsohn, 2007; Hammitt, 2000). Similarly, many analysts would argue that a society would pay more for a regulation that saves a particular number of young people than one that saves the lives of the same number of senior citizens. It is worth noting that the literature dictates no consensus on the effect of age on WTP for risk reductions as various authors have found both positive and negative relationships between the two (see for instance Viscusi and Aldy, 2007; Hammitt, 2000).

While estimating the meta-regression function, we employ individual t-tests and F-tests of multiple exclusion restriction in determining which regressors can be excluded from the model. The preferred specification is premised on the model providing a VSL prediction with statistically significant regressors only. Afterwards, we employ the Davidson-Mackinnon test for non-nested models (see Wooldridge, 2008) in choosing which of the preferred specification under the two functional forms is more suitable for estimating Nigeria's VSL.

After estimation of the VSL prediction function, the Nigerian prediction is obtained by inputting the Nigerian values for the chosen regressors. The use of the three study type dummies provides three VSL estimates corresponding to the prediction provided by each of the study type. The coefficients of the *CV* and *WR* variables capture the differentials in VSL prediction provided by each of these two methods and the base group, the consumer choice method. To avoid a proliferation of VSL predictions emanating from these study variables, we report the mean from the data to obtain one estimate. Further, as the regressand is in log form, the prevalently used approach in obtaining a prediction – exponentiation of the log predicted value – is an inconsistent estimator that underestimates the expected value. To obtain a consistent prediction, we adjust the commonly used method by employing the Smearing Factor Approach (see for instance Manning and Mullahy, 2001; Wooldridge, 2008).[12] Miller (2000) did not incorporate this

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[12] This approach obtains a consistent prediction by multiplying the exponentiated log predicted value to the mean of the exponentiated OLS residuals from the regression (see for instance Wooldridge, 2008). It is pertinent to note that this adjustment does not rely on the OLS assumption of normally distributed errors because there is not much information available about the stochastic properties of the VSL estimates transferred to this study. Additionally, these estimates have been obtained by different researchers analysing different types of risk and at the same time using different specifications and techniques (Bowland and Beghin, 2001). See Manning and Mullahy (2001) and Wooldridge (2008) for details on other methods of conducting this adjustment with and without the normality assumption.

adjustment in his VSL prediction for countries of the world. As mentioned in the introductory section, this paper implements this retransformation in its VSL prediction for Nigeria. Consequently, we call this parameter the adjustment coefficient and the corrected VSL prediction obtained from this procedure the adjusted VSL (see details in the results for meta-regressions in results and discussions section).

1.3.2 Mortality and Economic Costs of Particulate Air Pollution

Assessment of the mortality costs and mortality related welfare losses arising from particulate air pollution starts with estimating mortality costs and then uses the results to compute its corresponding welfare losses. Like many earlier studies, this research closely adopts Ostro's (1994) DRF procedure in estimating the mortality cost of particulate pollution.[13] The method has been well worked out over time with many panel studies and large national surveys (see for instance Dixon et al., 1994; Pope et al., 1995).

Ostro (1994) presented one of the most carefully executed meta-analyses of epidemiological studies on particulate air pollution and developed dose response coefficients (DRCs) for mortality health effects. Recent health cost analyses have relied on Ostro's (1994) DRCs and these have been largely employed in assessing mortality costs of air pollution on a global scale (see for instance Zaim, 1999; Resosudarmo and Napitupulu, 2004; Quah and Boon, 2003). Hence, just like similar studies using the benefit transfer approach, we assume the transferability of DRCs largely obtained from studies in the US to investigate the mortality cost of particulate

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[13] As earlier noted, the DRF shows a relationship between exposure to a given concentration of an air pollutant – dose – and the respective health effect – mortality – of the pollutant. In other words and with particular reference to this study, DRFs show the expected change in mortality per unit change in PM_{10} concentration. A majority of epidemiological studies assume this relationship to be linear. The dose response relationship is often expressed as a percentage change in mortality due to a given change in a pollutant, PM_{10}. Recall that in the case of PM_{10}, the units of pollution are measured in $\mu g/m^3$ of air sampled. These are small amounts and the change in health outcome – mortality – is also very small per microgram change in pollution. Thus with an estimated dose response coefficient of 0.096 percent which is equal to a factor of 0.00096, this implies that a single microgram change in PM_{10} pollution will have a very small impact on crude mortality rate – the percent of population that dies each year.

Estimating a DRF requires a detailed measurement of exposure and damage and this process can be very costly – resource, expertise and time-wise (Glover, 2002; Zhang et al., 2008; Quah and Boon, 2003; Krupnick et al., 1993). The estimation procedure is undertaken in two ways; first, by following a given cohort of people through time and recording their health status. This is then related to a time series of pollution concentration data. Second, a cross-sectional technique is employed, for instance, correlating health data in different locations within or across cities with factors that are likely to explain variations in the health status and mortality. A majority of studies on AP related DRFs have been undertaken in the developed world, particularly the US and UK.

pollution in Nigeria. The unavailability of indigenous DRFs and the cost advantages in terms of time and resources in providing estimates of DRFs justify the assumption of transferable DRCs. Health effect studies are very expensive to conduct and it would take years to replicate and interpret them before they are accepted by the scientific community (Chestnut et al., 1997). In addition, with particular reference to particulate pollution, there appears to be a consensus in DRFs as related studies provide a converging estimate (Quah and Boon, 2003). The few studies on DRFs conducted in the developing world suggest very similar DRCs to those derived in the developed world (see Khatun, 1997; Krzyzanowski et al., 2002).

Given the assumption of transferable DRFs, the following steps are used in estimating the mortality cost of particulate pollution:

1. Establish the annual average level of ambient PM_{10} concentration for the year under consideration, 2006.
2. Relate the concentration to mortality using DRFs.
3. Relate the DRFs to the stock at risk; the Nigerian population in 2006.

The general form of Ostro's (1994) DRF in estimating mortality damage from particulate pollution is:

$$H_{mortality,PM_{10}} = b_{mortality,PM_{10}} * crude\ mortality\ rate * POP_i * dPM_{10}\ , \qquad \text{(iii)}$$

where $H_{mortality,PM10}$ is the number of mortality cases caused by particulate pollution; $b_{mortality,PM10}$ is the mortality DRC for particulate pollution; *crude mortality rate* is the number of deaths per 1000 individuals for the year 2006; POP_i is the population at risk of dying due to particulate pollution; and dPM_{10} is the change in the ambient concentration of PM_{10}, defined as the difference between an observed and a target level of PM_{10} concentration. We employ the WHO (2005) annual average PM_{10} air quality guideline of 20µg/m^3 in computing dPM_{10}.

Table 1 summarises PM_{10} DRCs for mortality cost analysis estimated by Ostro (1994). The table presents three coefficients – lower, central and upper – for mortality effect associated with PM_{10}. The use of these three estimates paves way for sensitivity analyses in mortality risk investigations. Given that these DRCs are mostly derived from studies conducted in the US, their transferability to the Nigerian investigation needs to incorporate factors that account for differences between the US and Nigeria. For instance, it would be rational to assume that the baseline health and medical care standard in the US is better than Nigeria's, hence, a greater susceptibility to the mortality effect of PM_{10} for the Nigerian population (see for instance Chestnut et al., 1997). Consequently, a given dose of PM_{10} concentration may pose more fatal hazards in Nigeria than the US. Incorporating this into our analysis, this paper transfers the central and upper coefficients of the DRCs presented in Table 1 as its lower and upper estimates respectively.[14]

Finally, to monetise the mortality cost estimate, we relate the most preferred VSL estimate – after comparing the estimate to be derived from the value transfer and meta-analytic techniques – to the mortality cost estimate to be obtained. Thus, mortality related welfare losses attributable to particulate pollution are estimated using the following equation:

$$TC_{mortality,PM_{10}} = VSL_{NIG} * H_{mortality,PM_{10}}, \qquad \text{(iv)}$$

where $TC_{mortality,PM10}$ is the total mortality welfare losses resulting from PM_{10} pollution and all other variables are as previously defined.

Table 1: PM_{10} Dose Response Coefficients for Mortality Health Effect ($b_{mortality,PM10}$)

Lower Coefficient	Central Coefficient	Upper Coefficient
0.062	0.096	0.13

1.3.3 Data Sources and Summary Statistics

First, for the value transfer calibrations we adopt the US Environmental Protection Agency (USEPA) administratively approved VSL of \$5.5 million (1999 dollars) for the analysis of reduced mortality from air regulations (USEPA, 2004). This estimate approximates to \$6.655 million in 2006 dollars. Additionally, we employ the US average VSL estimate of \$7.66 million from our sample (see Table 3) in exploring further insights on the application of the value transfer calibration. Data on GNI per-capita in PPP terms for both Nigeria and the US are obtained from the World Bank's World Development Indicators (WDI, September 2010 edition).

Second, for the meta-regression analysis, estimates of VSL for different countries are drawn from literature reviews in the works of Viscusi and Aldy (2003) and Miller (2000), and more

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[14] By implication, the lower estimate of the mortality DRC presented in Table 1 will not be transferred to this study due to the expected difference in baseline health and medical care standards between the US and Nigeria.

recent studies are obtained through key word searches using search engines such as Social Sciences Citation Index, ScienceDirect and Econ Lit.[15] The VSL observations are estimates transferred from 83 individual VSL studies spread across twenty countries. The consumer choice, contingent valuation and wage-risk methods account for 12, 21 and 50 VSL estimates in the sample, respectively. Given that the individual studies estimate VSLs for different samples in different countries, this paper assumes these individual study site estimates as independent (random) country-wide VSL draws across the countries the samples were investigated. This assumption allows matching these VSL estimates with the aggregate explanatory variables in our meta-regression model. More importantly, the assumption is needed given the objective of obtaining a meta-regression prediction for Nigeria's VSL. For all the countries in the sample, data on GNI per-capita in PPP (*gnipc*) and life expectancy at birth (*age*) are obtained from the World Bank's WDIs (September 2010 edition). Data for crude mortality rate (*risk*) and school life expectancy (*educ*) are respectively obtained from the World Bank (2010) and United Nations Statistics Division (2010).[16] The sample consists of 83 observations drawn from 20 countries, a very good proportion coming from the US (see Table 2 in appendix 1 for data used in the study's meta-regression analysis).

Additionally, for the health cost estimation, data on Nigeria's annual average PM_{10} concentration and population are obtained from the World Bank's WDI (September 2010 edition). Data on Nigeria's crude mortality rate is obtained from the World Bank (2010) and estimates of mortality DRCs are transferred from the epidemiological literature – precisely from Ostro's (1994) study – using the benefit transfer approach. All estimations are for the year 2006.

Table 3 summarises the VSL estimates transferred for this paper's meta-analysis. The mean VSL for the 83 observations is \$6.2 million with a standard deviation (s.d) of 6.1 million. The US accounts for 33 of these studies with a mean VSL of \$7.7 million and s.d of 6.4 million respectively. The respective means for the UK, Canada, Sweden, India, New Zealand, South Korea and Thailand are \$6.7 million, \$8.2 million, \$4.3 million, \$0.3 million, \$2.2 million, \$1.2 million and \$1.1 million.[17] The estimates for other countries in the sample may be less reliable as they are based on only two or less of such studies (Miller, 2000). This paper includes 12 VSL estimates from other developing countries in the sample, namely; China, Chile, India, Malaysia, Mexico and

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[15] A majority of these VSL estimates are presented in different dollar years in their original studies. These estimates are converted to US 2006 dollars using the US Bureau of Labour Statistics CPI inflation calculator available online at http://data.bls.gov/cgi-bin/cpicalc.pl

[16] These data are available at and http://data.worldbank.org/indicator/SP.DYN.CDRT.IN and http://unstats.un.org/unsd/demographic/products/socind/education.htm, respectively.

[17] These countries means have a respective s.d of 7 million, 6.7 million, 2.5 million, 0.1 million, 0.5 million, 0.5 million and 0.7 million.

Thailand. This inclusion ensures a better representation of developing countries in the data set. Therefore, this is an extension to Miller's (2000) paper that had no developing country VSL estimates in its sample.

Table 3: Summary of Value of Statistical Life Estimates by Country of Origin

Country	Number of Values	Mean Value	Standard Deviation
Australia	2	11,356,098	9,106,156
Austria	2	5,366,079	818,462
Canada	8	8,179,265	6,679,756
China	2	62,620	27,339
Chile	2	469,513	227,606
Denmark	1	14,158,299	–
France	1	14,717,858	–
India	3	295,059	121,672
Japan	1	11,356,098	–
Hong Kong	1	1,990,244	–
Malaysia	1	594,939	–
Mexico	1	313,774	–
New Zealand	3	2,150,047	544,144
Poland	1	2,720,982	–
South Korea	3	1,188,353	470,877
Sweden	4	4,306,819	2,530,969
Switzerland	2	12,208,692	4,930,996
Thailand	3	1,123,365	744,184
United Kingdom	9	6,713,427	7,001,068
United States	33	7,660,518	6,396,053
Total	83	6,203,952	6,142,585

1.4 Results and Discussions

1.4.1 Value Transfer and Meta-regressions

As earlier stated, this paper transfers the USEPA's approved estimate of $6.655 million as the US VSL for its value transfer calibrations. From our data sources, Y_{NIG} and Y_{US} are $1,790 and $44,820 respectively. Incorporating these into equation (i) gives:

$$VSL_{NIG} = \$6{,}655{,}000 * \left(\frac{1{,}790}{44{,}820}\right)^{e} = \$6{,}655{,}000 * 0.0399^{\,e} \qquad \text{(v)}$$

Thus, the ratio of Nigeria's GNI per-capita to that of the US in 2006 PPP is approximately 0.04. Employing an income elasticity of WTP for fatal risk reduction – *e* – of 1.0, 1.5 and 2.0 gives three calibrations of Nigeria's VSL as presented in Table 4. From the table, it is evident that the large income disparity between Nigeria and the US accentuates the importance of the choice of the income elasticity, *e*, in the value transfer calibration. Employing an elasticity of 1.0, 1.5 and 2.0 respectively gives a VSL_{NIG} estimate of approximately \$266,000, \$53,000 and \$11,000. The large disparity in the estimates provided by these three elasticities no doubt poses a problem on the choice of which estimate is to be employed for health risk analyses. Despite the reliance of a majority of the empirical literature on the choice of 1.0, there has not been any cogent justification for picking this elasticity value. A direct elicitation of this elasticity is likely to provide a value that lies within or outside the range of 1.0 to 2.0. However, this remains unknown until valuation studies are conducted in the country of interest.

Table 4: Nigeria's Value Transfer VSL Calibrations

	Income elasticity for fatal risk reduction		
	1.0	1.5	2.0
VSL_{NIG}	\$265,784	\$53,115	\$10,615

Table 5 presents the results of the meta-regressions. The columns labelled [1a] to [3a] and [1b] to [3b] contain the results for the double-log and semi-log functional forms, respectively. The first models in the two functional forms – [1a] and [1b] – are the unrestricted versions of the meta-regression model, while the other models – [2a], [2b], [3a] and [3b] – are the restricted versions. The parameter estimates for the double-log specifications present elasticities of VSL with respect to each of the regressors. Based on this functional form, the income elasticity of VSL for developing countries ranges from 1.10 to 1.41. The income variable is observed to have a positive and marginally insignificant effect on VSL in the unrestricted model, [1a]. However, this variable is significant at the one percent level in the restricted models. Additionally, risk is observed to have a positive and significant effect on VSL; this variable is significant at the five and one percent levels in [1a] and [2a] respectively.

Table 5: Summary of OLS Regression Results for Meta-regression Analysis and Predicted Value of Statistical Life for Nigeria Based on Estimated Coefficients (Robust Standard Errors in Parenthesis)

Dep Variable: *ln*(*VSL*) number of observations = 83

Explanatory Variables	[1a]	[2a]	[3a]
ln(gnipc)	*1.101 (0.687)*	1.295* (0.154)	1.409* (0.179)
ln(risk)	1.642** (0.670)	1.735* (0.399)	-
ln(educ)	1.622 (1.409)	-	-
ln(age)	-3.060 (5.193)	-	-
CV	0.997* (0.323)	0.920* (0.292)	0.987* (0.296)
WR	1.189* (0.271)	1.167* (0.262)	1.085* (0.259)
d	0.910 (7.575)	-	-
ln(gnipc)d	-0.052 (0.774)	-	-
intercept	7.907 (17.440)	-2.819 (1.730)	-0.408 (1.905)
R^2	0.620	0.609	0.562
F-stat	16.57	28.40	25.63
Adjustment Coefficient	1.346	1.352	1.406
Predicted $ln(VSL_{NIG})$	13.619	12.798	11.165
Adjusted VSL_{NIG}	$1,105,864	$488,740	$99,285

	[1b]	[2b]	[3b]
gnipc	0.0001511 (0.0001047)	0.0000722* (9.65e-06)	0.0000788* (9.40e-06)
risk	0.255* (0.095)	0.168* (0.063)	-
educ	0.110 (0.082)	-	-
age	-0.014 (0.063)	-	-
CV	0.952* (0.328)	1.111* (0.329)	1.242* (0.328)
WR	1.178* (0.270)	1.178* (0.291)	1.138* (0.292)
d	1.974 (1.549)	-	-
gnipcd	-0.0001183 (0.0001083)	-	-
intercept	8.462** (3.889)	10.203* (0.609)	11.290* (0.468)
R^2	0.617	0.556	0.536
F-stat	16.39	22.25	25.09
Adjustment Coefficient	1.355	1.406	1.435
Predicted $ln(VSL_{NIG})$	14.420	14.322	12.638
Adjusted VSL_{NIG}	$2,480,080	$2,333,194	$442,044

For all results, *, ** and *** denote significance at the one, five and ten percent levels, respectively.

Further, the R^2 of the double-log specifications indicates that 56.2 to 62.0 percent of the variation in ln(VSL) is explained by the regressors and F-statistics indicate that all the explanatory variables are jointly significant in each of the models. However, education, age, developed country binary variable and the interaction term are individually insignificant in the unrestricted model, [1a]. Despite being individually insignificant, the negative coefficient of the interaction term suggests that the income elasticity of VSL for developed countries is relatively lower than that for developing countries. As there is a non-zero correlation between the developed country dummy and the interaction variable by construction, an assessment of the importance of including developing countries' VSL estimates in the meta-regression sample on the differential in VSL income elasticity between developed and developing countries requires the use of joint tests in evaluating these variables. Employing an F-test of multiple exclusion restriction indicates that the two variables are jointly insignificant, which may be due to the low number of observations for developing countries in the sample. It is worth noting that the individually insignificant regressors in this model (education, age, the developed country binary variable and the interaction term) are jointly insignificant too.

A similar scenario occurs in the semi-log functional form as in the double-log specifications. Here, income is observed to have a positive and insignificant effect on VSL in the unrestricted model, [1b]. Again, this variable becomes significant at the one percent level in the restricted models, [2b] and [3b]. Risk has a positive and significant effect on VSL in both restricted and unrestricted models. The study type binary variables in the two functional forms (contingent valuation and wage risk) are positive and significant at the one percent level. This sheds light on the importance of estimation technique on VSL differentials. Particularly, a survey of the coefficients of these variables shows that the coefficients of contingent valuations are higher than those of consumer choice studies in all models. Thus, a holistic appraisal of these results shows that our finding moves in tandem with the well documented observation of VSL estimates produced by consumer choice studies being generally lower than those of the contingent valuation method in VSL literature. In a similar vein, the results confirm Kochi et al's (2006) suggestion that wage-risk VSL estimates could be higher than those of contingent valuation.

Additionally, the R^2 of the semi-log specifications indicates that 53.6 to 61.7 percent of the variation in ln(VSL) is explained by the regressors and F-statistics show that the explanatory variables are jointly significant in the three models. However, just as in the double-log functional form, education, age, developed country binary variable and the interaction term are individually insignificant in the unrestricted model, [1b]. Again, despite being insignificant, the negative coefficient of the interaction term suggests that the income elasticity of VSL for developed countries is relatively lower than that for developing countries. Applying an F-test of multiple exclusion restriction on the developed country dummy and interaction term shows that the two variables are jointly insignificant.[18] Table 5 also presents the predicted VSL_{NIG} provided by each of the three models under the two functional forms. From the double-log specifications, a holistic appraisal of these predictions reveals that Nigeria's VSL ranges from about $99,000 to $1.1 million, with the lower and upper values of this range given by [3a] and [1a] respectively. An analogous prediction by the semi-log functional form yields an estimate of about $442,000 to $2.48 million, given by [3b] and [1b] respectively. A comparison of the variation in VSL predictions by both functional forms shows that the estimates from the latter are relatively higher and have a larger variation compared to those from the former. A further scrutiny of the Nigerian predictions from both functional forms reveals that the predictions for the double-log functional form are closer to the VSL estimates available for developing countries in the meta-regression sample.

More importantly, a further elucidatory analysis on the use of individual t-tests and F-test of multiple exclusion restriction leads to the choice of [2a] as the preferred specification in the double-log functional form. For the purpose of comparison we will also consider the same specification [2b] with the semi-log functional form.[19] To determine which of these functional forms is superior, we employed the Davidson-MacKinnon test for non-nested models. Conducting this test reveals the following: (a) The test fails to reject the null hypothesis of [2a] against the alternative of [2b]; (b) The test rejects the null hypothesis of [2b] in favour of the alternative of [2a] at the one percent significance level. As a result, we present model [2a] as our most preferred meta-regression model; thus, giving further justification for the preference of the double-log over the semi-log functional form.[20] This model predicts VSL_{NIG} as $489,000. This prediction falls within Miller's (2000) prediction of $40,000 to $700,000 (in 1995 US dollars) for Nigeria's VSL. Additionally, had our prediction only exponentiated predicted $\ln(VSL_{NIG})$ and not incorporated the adjustment coefficient, this would have resulted in a Nigerian VSL estimation of about $361,000. Obviously, there is a considerable difference in predictions obtained with and without the adjustment. This difference indicates the importance of incorporating this

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[18] It is worth noting that the four individually insignificant variables in this model (education, age, the developed country dummy and interaction term) are jointly significant.

[19] Although the four variables excluded from model [1b] (in the semi-log functional form) are jointly significant, these variables are all individually insignificant as mentioned above. Since it is somewhat difficult to justify different specifications for the two functional forms or include insignificant variables for the double-log model, we decided to restrict our comparison to models [2a] and [2b]. Note that models [3a] and [3b] are only used for further analytical illustrations. See ensuing paragraphs for more details.

[20] Employing the same test in comparing the two unrestricted models, [1a] against [1b], leads to a non-rejection of either model. The same result is obtained comparing the restricted model [2a] against the unrestricted model [1b]. However, employing the adjusted R^2 of choosing between non-nested models leads to a rejection of [1b] in favour of both [1a] and [2a], since the former has a lower adjusted R^2 than the latter two. See Wooldridge (2008) for details on the use of adjusted R^2 for testing non-nested models.

retransformation in predictions employing regression functions with logged dependent variables.[21]

Next, a comparison of the VSL prediction from the most preferred meta-regression specification and the multiple calibrations provided by the use of three income elasticities by the value transfer method indicates that the latter benefit transfer technique leads to lower VSL estimates than the former.[22] Also, some analysts would argue in favour of the use of the US average VSL in the sample for value transfer estimations as opposed to using an individual VSL estimate, such as the estimate approved by USEPA. This does not affect the analysis as the use of the US mean VSL estimate of $7.66 million would lead to a Nigerian calibration of about $306,000, $61,000 and $12,000 given by an elasticity of 1.0, 1.5 and 2.0 respectively. Thus, our conclusion of value transfer calibrations leading to lower VSL estimates than the meta-regression predictions remains unchanged.

Finally, the meta-regression models restricting the vector of explanatory variables to only income and study type dummies ([3a] and [3b]) provide the lowest VSL predictions in the two functional forms explored. These estimates indicate the likelihood of underestimating the VSL by the meta-regression method as well when the analysis concentrates on income and neglects fatal risk and other important factors affecting the VSL. Thus, the weight of evidence in comparing the two benefit transfer techniques leads to the conclusion that the value transfer method is likely to lead to an underestimation of the VSL for developing countries as the method neglects important determinants of VSL in its benefit transfer application, especially mortality risk. Consequently, this paper presents $489,000 as its most preferred VSL estimate for Nigeria.

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[21] The use of the Smearing Factor approach may be biased in the presence of heteroscedasticity (Manning and Mullahy, 2001). However, we conducted both the White and Breusch-Pagan/Cook-Weisberg tests for heteroscedasticity for all of the specifications in Table 5. The two tests fail to reject the null hypothesis of homoscedasticity in all models. Thus, these results suggest that heteroscedasticity may not be a problem in our models and the retransformations of the log predicted VSL undertaken in the paper does not seem to be biased based on the use of the Smearing Factor approach.

[22] However, just as initially noted, the value transfer calibrations are highly dependent on the elasticity employed. Particularly, the elasticities provided by our meta-regression results raise doubts on the conventional practice of using an income elasticity of unity for developing countries. With precise reference to Robinson and Hammitt's (2009) suggestion about using an elasticity of 1.0 to 2.0 for developing countries, our results indicate that the lower tail of this range is not necessarily equal to one. In fact, our results suggest that the inclusion of more developing countries in the sample is likely to move this lower bound elasticity away from 1.0, thereby making it more elastic. Thus, it might be worth setting the lower bound of the value transfer (elasticity) range with the statistically estimated elasticity of 1.30 given by the most preferred meta-regression specification. It is worth nothing that this elasticity estimate of 1.30 is statistically different from one. However, incorporating this in our analysis does not change the major conclusions arrived at by comparing the two benefit transfer methods investigated, but it might be an important point to explore in similar applications.

1.4.2 Health and Economic Costs

We next use equation (iii) to estimate the mortality costs of PM_{10} in Nigeria. Based on data provided by the World Bank (WDI, September 2010 edition), Nigeria's 2006 average PM_{10} concentration and population are 44.99µg/m^3 and 142,721,843 people respectively. Its crude mortality rate in 2006 was 17 per 1000 people (World Bank, 2010) or 1.7 percent. From the DRFs transferred from the epidemiological literature, our lower and upper estimates of mortality DRCs are 0.096 and 0.13 percent (equal to a factor of 0.00096 and 0.0013, respectively). We denote the former $b_{lowerDRC,mortality}$ and the latter $b_{upperDRC,mortality}$. The use of the WHO PM_{10} annual air quality guideline of 20µg/m^3 gives dPM_{10} as 24.99µg/m^3. Incorporating these into equation (iii) gives the following transformation:

$$H_{mortality,PM_{10}} = b_i * 0.017 * 142{,}721{,}843 * dPM_{10} \ , \qquad \text{(vi)}$$

where $b_i = b_{lowerDRC,\ mortality}$ and $b_{upperDRC,\ mortality}$.

The results of these estimations are provided in Table 6. The table provides estimates of mortality cases emanating from particulate pollution in Nigeria. If particulate pollution in Nigeria was mitigated to the WHO standard, this would have led to a decrease in premature mortality by about 58,200 to 78,800 people in 2006. Since Nigeria's crude mortality rate and population estimates are respectively 1.7 percent and 142.7 million people, these mortality estimates are therefore approximately 2.2 percent and 3.3 percent of total (implied) deaths for 2006 – 2.4 million people.[23] Hence, these results imply significant benefits in the form of mortality reductions to be expected from the abatement of particulate pollution.

Table 6: Mortality Costs of PM_{10} Pollution in Nigeria

$dPM_{10,\ WHO\ target}$	
$b_{lowerDRC,\ mortality}$	$b_{upperDRC,\ mortality}$
58,207	78,822

Table 7 presents the mortality related welfare losses resulting from particulate pollution in Nigeria. These results imply a mortality related welfare loss of $28.46 billion to $38.54 billion

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[23] This (implied) death estimate is not too far from the country's 2004 recorded deaths of 2.2 million people (WHO, 2009).

given by the lower and upper coefficients of the PM_{10} DRFs respectively. This loss translates to 19.4 to 26.3 percent of the nation's 2006 GDP.[24] Put more succinctly, had the nation mitigated its particulate pollution to the WHO standards, it could have avoided at least 58,207 premature deaths and recorded an avoided mortality related welfare loss of $28.46 billion in 2006.

Table 7: Economic Costs of PM_{10} Pollution in Nigeria

	$dPM_{10,\ WHO\ target}$	
	$b_{lowerDRC,\ mortality}$	$b_{upperDRC,\ mortality}$
Economic Cost (billions of US $)	28.46	38.54
Economic cost as a percentage of GDP	19.4	26.3

1.5 Concluding Remarks

Assessment of the mortality and economic costs of air pollution amplifies the relevance of incorporating environmental management into economic policies. The unavailability of primary data from a policy site poses an obstacle to making informed decisions in analysing the potential welfare gains of mitigating air pollution. The value of statistical life is an essential parameter in ascribing monetary values to the mortality costs of air pollution. This lack of information has left researchers with the choice of employing one of two major benefit transfer techniques – value transfer or meta-regression – in their health risk analyses. We set forth to determine which of the two transfer methods better suits developing countries. Using Nigeria as a case study, a comparison of the two methods reveals the following: (a) the value transfer method does not incorporate many characteristics that vary from the study site to policy site; (b) the value transfer technique is likely to underestimate the value of statistical life for very low-income countries as it assumes that income is the only factor accounting for differences in value of statistical life between study site and policy site; (c) the value transfer application leaves much more to the judgment of the analyst, which leaves open the possibility of substantial error. Thus, we conclude that the meta-regression approach is likely to provide more accurate VSL predictions for very low-

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[24] Nigeria's 2006 GDP at current dollars is $146.88 billion (World Bank – WDI, September 2010 edition).

income countries. This method provides a prediction of $489,000 for Nigeria's value of statistical life. It is, however, worth noting that this finding may be sensitive to the data employed in the regressions because there is a low representation of developing countries in the sample. Hence, the paper could be improved by incorporating more developing country money-risk trade-off valuations, in anticipation of a rise in the number of these valuation studies in the future.

Employing the most preferred VSL estimate, $489,000, this paper provides the first approximation of the mortality related benefits associated with improving air quality in Nigeria. We found that if Nigeria had mitigated its 2006 particulate pollution to the WHO standards, this action would have prevented at least 58,000 premature deaths and recorded an avoided mortality related welfare loss of about $28 billion. This amount translates to 19 percent of Nigeria's GDP for that year. As a result, the nation bears massive human capital and welfare losses through its particulate pollution. While it is common knowledge that death is inevitable, it is also important for people to know that they can live healthier and more productive lives, thereby prolonging their life span. Thus, the mitigation of air pollution can mean significant benefits for the nation; in terms of a healthier and more productive labour force. Given that the costs of other air pollutants are not considered, the estimate presented by our paper is therefore a conservative one. Consequently, the potential benefits of mitigation may exceed those presented in this paper.

This study is limited by its choice of explanatory variables employed in the meta-regression analysis, especially the variables measuring information on different kinds of mortality risks, education and age. The results may have been improved by using a variable that only concentrates on information regarding the fatal dangers of air pollution in the sampled countries and not the use of country wide crude mortality rates, given that the study is on air pollution and many other factors are responsible for a country's mortality rate. Also, school life expectancy might be a weak representation of individuals' awareness of these fatal dangers. Similarly, life expectancy at birth might be difficult to justify given the contention on the effect of age on individuals' risk avoidance preferences. However, the inclusion of these variables (education and life expectancy) in our models sheds light on the fact that in addition to income and risk, there could be other important variables explaining individuals' risk avoidance preferences. Future studies could delve into improved ways of measuring these variables or explore other variables that could be significant determinants of money-risk trade-offs.

Another limitation of this and similar studies hinges on the transferability of dose response functions which are mainly estimated from the developed world and transferred to developing nations. As a result of the large differences in climatic, demographic and welfare conditions between the developed and developing world, there is uncertainty whether or not the transferability of these estimates leads to an overestimation or underestimation of the mortality costs of particulate pollution in Nigeria. Nevertheless, currently, the assumption of transferable dose response functions is indispensable in health risk analyses for Nigeria and a majority of other developing nations due to the unavailability of local estimates. However, the need for more credible health risk analyses should influence these countries to make conscious efforts in developing their own dose response functions. This could be achieved by working in collaboration with international organisations such as the World Bank and World Health Organisation or with developed nations such as the United States, United Kingdom, Canada and Sweden among others who are experienced in conducting health risk research.

1.A Appendix 1 - Table 2: Data

COUNTRY **Study**	VSL (2006 US $)	GNI PER-CAPITA, in $ 2006 PPP (*gnipc*) [a]	CRUDE MORTALITY RATE (*risk*) [c]	SCHOOL LIFE EXPECTANCY (*educ*) [b]	LIFE EXPEXTANCE AT BIRTH (*age*)[a]
AUSTRALIA					
Kneisner & Leeth (1991)	4,917,073	33,030	7	21	81.04
Miller, Mulvey & Norris (1997)	17,795,122	33,030	7	21	81.04
AUSTRIA					
Weiss, Maier & Gerking (1986)	5,944,819	35,690	9	15	79.9
Maier et al. (1989)	4,787,339	35,690	9	15	79.9
CANADA					
Cousineau (1992)	5,397,165	36,470	7	16	80.64
Cousineau, Lacroix & Girard (1992)	5,385,366	36,470	7	16	80.64
Lanoie, Pedro & Latour (1995)	24,175,610	36,470	7	16	80.64
Martinello & Meng (1992)	5,268,293	36,470	7	16	80.64
Meng (1989)	5,034,146	36,470	7	16	80.64
Meng & Smith (1990)	9,834,146	36,470	7	16	80.64
Meng & Smith (1999)	6,087,805	36,470	7	16	80.64
Vodden et al. (1993)	4,251,591	36,470	7	16	80.64
CHINA					
Guo & Hammitt (2009)	81,951	4,790	7	11	72.76
Wang & Mullahy (2006)	43,288	4,790	7	11	72.76
CHILE					
Ortuzar, Cifuentes & Williams (2000)	308,571	11,380	5	15	78.39
Ortuzar, Cifuentes & Williams (2000)	630,454	11,380	5	15	78.39
DENMARK					
Kidholm (1995)	14,158,299	36,410	10	17	78.35
FRANCE					
Desaigues & Rabl (1995)	14,717,858	32,170	8	16	80.81

INDIA					
Bhattacharya, Alberini, and Cropper (2007)	154,839	2,550	8	10	63.08
Madheswaran (2007)	372,778	2,550	8	10	63.08
Madheswaran (2007)	357,559	2,550	8	10	63.08
JAPAN					
Kneisner & Leeth (1991)	11,356,098	32,720	9	15	82.32
HONG KONG					
Siebert & Wei (1998)	1,990,244	39,910	6	14	82.38
MALAYSIA					
Melhuish, Ross, Goodge, et al. (2005)	594,939	12,240	4	12	73.94
MEXICO					
Hammitt & Ibarraran (2006)	313,774	13,550	5	14	74.47
NEW ZEALAND					
Miller & Guria (1991)	1,816,252	24,760	7	19	80.05
Miller & Guria (1991)	1,855,937	24,760	7	19	80.05
Guria et al. (1999)	2,777,953	24,760	7	19	80.05
POLAND					
Giergiczny (2008)	2,720,982	14,640	10	15	75.18
SOUTH KOREA					
Kim (1985)	1,731,591	24,340	5	17	78.97
Kim & Fishback (1993)	936,585	24,340	5	17	78.97
Kim & Fishback (1999)	896,882	24,340	5	17	78.97
SWEDEN					
Johannesson et al. (1997)	6,864,189	36,360	10	16	80.87
Persson & Caldervall (1991)	2,314,961	36,360	10	16	80.87
Persson et al. (1995)	6,091,654	36,360	10	16	80.87
Soderqvist (1994)	1,956,472	36,360	10	16	80.87
SWITZERLAND					
Schwab-Christe (1995)	15,695,433	42,870	8	15	81.66
Baranzini & Luzzi (2001)	8,721,951	42,870	8	15	81.66

THAILAND					
Vassanadumrongdee & Matsouka (2005)	1,446,261	6,970	9	12	68.55
Vassanadumrongdee & Matsouka (2005)	1,651,565	6,970	9	12	68.55
Gibson et al. (2007)	272,270	6,970	9	12	68.55
UNITED KINGDOM					
Arabsheibani & Marin (2000)	23,297,561	35,180	9	16	79.45
Ghosh et al. (1975)	2,254,110	35,180	9	16	79.45
Jones-Lee et al. (1983)	6,272,882	35,180	9	16	79.45
Jones-Lee et al. (1995)	3,694,677	35,180	9	16	79.45
Maclean (1979)	3,334,866	35,180	9	16	79.45
Marin & Psacharapoulos (1982)	5,278,110	35,180	9	16	79.45
Melinek (1974)	1,927,370	35,180	9	16	79.45
Melinek (1974)	2,127,118	35,180	9	16	79.45
Siebert & Wei (1994)	12,234,146	35,180	9	16	79.45
UNITED STATES					
Smith (1974)	10,770,732	44,820	8	16	77.99
Thaler & Ronson (1975)	1,170,732	44,820	8	16	77.99
Smith (1976)	6,907,317	44,820	8	16	77.99
Viscusi (1978a, 1979)	6,204,878	44,820	8	16	77.99
Blomquist (1979)	1,170,732	44,820	8	16	77.99
Brown (1980)	2,224,390	44,820	8	16	77.99
Dardis (1980)	901,463	44,820	8	16	77.99
Portney (1981)	1,205,854	44,820	8	16	77.99
Viscusi (1981)	9,717,073	44,820	8	16	77.99
Olson (1981)	7,843,902	44,820	8	16	77.99
Butler (1983)	1,521,951	44,820	8	16	77.99
Low & McPheters (1983)	1,639,024	44,820	8	16	77.99
Leigh & Folsom (1984)	13,697,561	44,820	8	16	77.99
Smith & Gilbert (1984, 1985)	1,053,659	44,820	8	16	77.99
Dillingham & Smith (1984)	7,258,537	44,820	8	16	77.99
Ippolito & Ippolito (1984)	1,053,659	44,820	8	16	77.99
Leigh (1987)	15,570,732	44,820	8	16	77.99
Moore & Viscusi (1988b)	11,356,098	44,820	8	16	77.99
Garen (1988)	20,253,659	44,820	8	16	77.99
Garbacz (1989)	2,997,073	44,820	8	16	77.99
Viscusi & Moore (1989)	11,707,317	44,820	8	16	77.99

Atkinson & Halvorsen (1990)	6,005,854	44,820	8	16	77.99
Herzog & Schlottman (1990)	13,697,561	44,820	8	16	77.99
Moore & Viscusi (1990b)	24,351,220	44,820	8	16	77.99
Carlin & Sandy (1991)	983,415	44,820	8	16	77.99
Kneisner & Leeth (1991)	819,512	44,820	8	16	77.99
Gegax, Gerking & Schulze (1991)	2,458,537	44,820	8	16	77.99
Leigh (1991)	13,112,195	44,820	8	16	77.99
Berger & Gabriel (1991)	11,414,634	44,820	8	16	77.99
Dreyfus & Viscusi (1995)	5,385,366	44,820	8	16	77.99
Leigh (1995)	14,576,610	44,820	8	16	77.99
Blomquist, Miller & Levy (1996)	6,790,244	44,820	8	16	77.99
Dorman & Hagstrom (1998)	16,975,610	44,820	8	16	77.99
NIGERIA	–	1,790	17	9	47.47

[a] Data on GNI per-capita based on purchasing power parity are obtained from the World Bank's World Development Indicators (Sept. 2010 Edition) available online at http://econ.worldbank.org/ Data on life expectancy (LE) at birth are also obtained from the same source.

[b] Data on school life expectancy are obtained from United Nations Statistics Division (2010) available online at http://unstats.un.org/unsd/demographic/products/socind/education.htm . The data provided by this source are not for the year 2006 alone but also for other close years; such as 2004, 2005, 2007 and 2008. Since these years are very close and school life expectancy is not expected to be too different, we use the estimates provided for 2006.

[c] Data on crude mortality rate (CMR) are obtained from the World Bank (2010) available at http://data.worldbank.org/indicator/SP.DYN.CDRT.IN/countries. In addition, it should not be surprising that CMR is higher in some developed countries than in their developing counterparts; for instance, in the table above the CMR in the US is 8 per 1000 people – or 0.8% – while it is only 5 per 1000 people – or 0.5% – in Chile. This is due to the fact that a country's CMR depends on both its age specific mortality rate and age distribution. Thus, the high CMR in some of the developed countries simply implies that these countries have an entirely different age distribution, characterised by a higher proportion of older people resulting from lower mortality rates and also lower recent birth rates. This therefore explains the reason some developed countries record a higher CMR than some of their developing counterparts despite life expectancy being higher in the former than the latter.

Notes on Value of Statistical Life Estimates in Table 2

1. For VSLs reported as a range of values in the original studies, this table reports the mid-point/mean of the range.

2. Viscusi and Aldy's (2003) paper presents 41 US and 23 non-US VSL estimates (in US 2000 dollars). Of these studies, this paper only employs 33 US and 16 non-US studies in its analysis due to the following reasons. First, Sandy and Elliot's (1996) study reports a mean UK VSL of $43.7 million. Similarly, Shanmugam (2001) reports a mean Indian VSL of $4.8 million. Compared to other estimates for these countries, these papers' estimates are too high. As a result, this paper drops them in its meta-analysis because it views them as outliers. Secondly, Moore and Viscusi (1990c) was dropped because it produces the same US VSL estimate, $20.8 million, as Moore and Viscusi (1990b). Third, the other studies were dropped because they provided more than one VSL estimate and at the same time, these were not in a range of values. Consequently, there was neither a clear cut nor an objective way of taking the mean of these estimates. These studies are: Arnold and Nicholas (1983); Dorsey and Walzer (1983); Dillingham (1985); Moore and Viscusi (1988a); Lott and Manning (2000); Gayer, Hamilton and Viscusi (2000); Jenkins, Owens and Wiggins (2001); Shanmugam (1996/1997 and 2000); and Sandy et al. (2001). Fourth, due to the unavailability of credible data for Taiwan's GNI per-capita, crude mortality rate, school life expectancy and life expectancy at birth (recall these variables serve as the regressors in the meta-regression models); four Taiwanese studies – two each from Viscusi and Aldy (2003) and Miller (2000) – were dropped from our analysis.

3. From Viscusi and Aldy (2003), this table reports the mean of the VSL for US residents and immigrants estimated in Berger and Gabriel (1991).

4. 21 non-US VSL estimates were transferred from Miller (2000). However, 7 of these 21 studies also appear in Viscusi and Aldy (2003). These are the estimates for: Australia (Kneiser and Leeth, 1991); Austria (Weiss, Maier, Gerking, 1986); Canada (Martinello and Meng, 1992: Meng, 1989; Meng and Smith, 1990); Japan (Kneisner and Leeth, 1991); and UK (Marin and Psacharapoulos, 1982).

5. 13 other non-US VSL estimates, mainly for developing countries, were obtained through a literature search. These are the estimates for: China (Guo and Hammitt, 2009: Wang and Mullahy, 2006); Chile (Ortuzar, Cifuentes and Williams, 2000 and 2000); India (Bhattacharya, Alberini and Cropper, 2007: Madheswaran, 2007 and 2007); Malaysia (Melhuish, Ross, Goodge et al., 2005); Mexico (Hammitt and Ibarraran, 2006); Poland (Giergiczny, 2008); and Thailand (Vassanadumrongdee and Matsouka, 2005 and 2005: Gibson et al., 2007).

6. Inflation/deflation from other dollar years, as presented in the original studies, to US 2006 dollars was done using the United States Bureau of Labour Statistics CPI Inflation Calculator available online at http://www.bls.gov/data/inflation_calculator.htm

CHAPTER TWO

The Environmental Kuznets Curve at Different Levels of Economic Development: A Counterfactual Quantile Regression Analysis for CO_2 Emissions

2.1 Introduction

The late 1950s ushered in a theory in development economics whose roots extended 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,[25] progress is then associated with declining 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 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. Empirical investigations of the theory typically employ per-capita estimates of income and emissions as indicators of economic progress and environmental depletion respectively.

The inception of the EKC theory stirred considerable debate about the ensuing policy implications of the income-emissions nexus in the environmental economics literature. As investigations confirming the theory may lead to recommendations that improving environmental quality is an associated product of rising incomes, it is not surprising for advocates to suggest that the only way to achieve good environmental standards is through a decent level of economic development (see for instance, 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,

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[25] This paper uses the terms economic development, growth and progress interchangeably. The paper does not distinguish between the three concepts.

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 views may be that developing countries are too poor to be green and 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 achieving environmental clean-ups.[26]

Considerations of environmental sustainability and the greenhouse effect of CO_2 emissions may lead to considerable scepticism about the aforementioned recommendation of advocates. Global warming and climate change, primarily caused by anthropogenic CO_2 emissions, are arguably the most worrying environmental challenge confronting the world. Meteorological data indicate that average global temperature is on the rise. Thirteen of the world's warmest years on record occurred in the last fifteen years (Australian Government Bureau of Meteorology, 2012). Leaving the current levels of CO_2 emissions and rising trend in temperatures uncontrolled could have serious implications on the ecosystem's carbon sequestration capacity and the economic and social livelihoods of the present and future generation. These problems lead to concerns about how the needs of the future generation's climate and environment could be sustainably catered for if we continued with business as usual emissions without meaningful efforts to mitigate current emissions. Essentially, can we 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 (unknown) point in time as the primary means of mitigating emissions? Thus, there is need for a critical evaluation of the CO_2 EKC. This may provide signals on the relevance of relying on the recommendations of advocates or complementing these with appropriately designed instruments for mitigating emissions.

Also, the customary econometric methods used in investigating the CO_2 income-emissions nexus have attracted considerable criticisms (see for instance Stern, 2004). Most empirical studies exploring the income-emissions nexus employ a panel dataset of countries and these studies rely almost exclusively on the use of conventional longitudinal econometric techniques, particularly the fixed and random effects methods. A major criticism stems from the methods' focus on

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[26] Moreover, if the recommendations of the advocates were indeed true, this would therefore imply that environmental protection would be experienced in the high income nations alone. However, according to Dasgupta et al. (2002), the regulation of pollution and enforcement of pollution mitigation policies increase with income but the greatest increases happen from low to middle income levels and increased regulation is expected to have diminishing returns. Accordingly, environmental regulation is likely to be enjoyed by the low income countries as well and these countries may exhibit the income-emissions relationship posited by the dictates of the EKC.

estimating the rate of change in the conditional mean of emissions (as a quadratic or cubic function of income). The focus on conditional mean estimations produces constant slope coefficients across heterogeneous countries thereby being incapable of capturing country level heterogeneity in Kuznets curve explorations. Moreover, transferring the stylised reasoning about the epidemiological relationship between outdoor concentrations of local pollutants and adverse human health to the Kuznets curve subject – being that higher concentrations of these pollutants, such as particulate matter and sulphur oxide, are more harmful to humans relative to lower concentration levels (see for instance Pope, 2007; Yaduma et al., 2013) – an analogous reasoning applies to the relationship between concentrations of CO_2 emissions and the greenhouse effect. This therefore implies that the use of estimation techniques that provide a constant income-emissions relationship, especially for a group of largely heterogeneous countries, may not provide useful information on country specific turning point incomes where the Kuznets curve exists.

Thus, investigating the income-emissions relationship at different regions of the conditional emissions distribution may be more informative about turning point incomes relative to estimations focusing on the conditional mean alone. A quantile form investigation of the relationship at the upper, median and lower tails of the emissions distribution corresponds to examining the relationship for the highest, median and least polluting countries in a panel sample. As the relationship for the mean or median polluting countries may not necessarily be the same for the highest and least polluting nations in a given emissions distribution, this form of investigation provides a means of capturing country level heterogeneity in Kuznets Curve explorations. In other words, the income regressors in EKC explorations may not only determine the mean but also other parameters of the conditional distribution of emissions (see, for instance, Mills and Waite, 2009; Halkos, 2011). Hence, the reliance of a majority of empirical studies on conditional mean estimations spurs the need for the application of alternative estimation techniques with a greater flexibility of capturing the heterogeneity of countries' emissions in Kuznets Curve investigations. This paper is particularly interested in capturing this form of distributional heterogeneity whilst exploring the Kuznets Curve theory.

Given this background, this article contributes to the growing empirical literature on the Environmental Kuznets Curve by investigating the validity of the CO_2 income-emissions nexus across different quantiles of the conditional distribution of emissions. We employ the quantile fixed effects method to provide empirical insights into the distributional heterogeneity of this relationship. This method corresponds to a random coefficients setup allowing for heterogeneous income-emissions relationships at different conditional quantiles of the emissions distribution.[27] The technique is capable of identifying various relationships that may be missed by the application of conventional mean regressions thereby providing an opportunity for a more comprehensive examination of the carbon EKC theory. To our knowledge, this paper is the first to comprehensively employ this technique to introduce (distributional) heterogeneity in investigating the CO_2 income-emissions nexus.[28] We empirically examine the relationship between per-capita measures of CO_2 emissions and GDP for the entire world and different sub-sets of countries – OECD, Non-OECD, West, East Europe, Latin America, East Asia, West Asia and African regions. An exploration of the EKC at different percentiles of the conditional distribution of emissions is necessary due to two main reasons. Foremost, the conditional median estimates – one of the percentiles covered by the conditional quantile method – are more robust to outliers on the dependent variable than estimates of the conditional mean (Koenker, 2004, 2005). Second, the conditional mean estimation only characterises the mean effect of income on emissions thereby failing to characterise the full distributional impact. The information gained by examining the effect of income on a measure of central tendency – mean or median – of a particular emissions distribution may not necessarily be informative for other quantiles except this effect is not different from those at the other regions (see for instance Huang et al., 2007; Flores et al., 2013). Thus, conditional quantile estimation provides an opportunity for a richer exploration of the CO_2 income-emissions nexus as it allows an assessment of the impact of income across the entire conditional distribution of emissions, thereby, extending beyond the conditional mean.

For an additional expository analysis whilst investigating the income-emissions relationship, it is worth exploring further the most important reasons accounting for differences in carbon emissions distribution from one economic group of countries 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, white and black workers or skilled and unskilled employment amongst other uses (see for example DiNardo et al., 1996; Hertz

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[27] The two techniques – quantile regression and random coefficients models – are related as they estimate flexible slope coefficients across quantiles or groups. However, the latter model assumes that parameters are independent and identically distributed (iid) – thus, independent of explanatory variables – while the former does not rely on this assumption (see Fox et al., 2011). Hence, in the Kuznets curve context, a quantile regression model does not require the coefficient of income to be independent of income. The assumption of iid parameters by random coefficients models may be restrictive in some applications.

[28] However, it is worth noting that Huang et al. (2007) employed the same method to investigate the original Kuznets relationship between income inequality and economic development. Also, Flores et al. (2013) used the technique in exploring the EKC for nitrogen and sulphur emissions at the US state level.

et al., 2008; Fortin et al., 2010). Its extension to the EKC framework provides an opportunity to decompose the gap in CO_2 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. This allows us to disentangle whether cross-group differences in CO_2 emissions 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. However, 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 previously alluded to. 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). This improvement moves in tandem with the quantile estimations of the CO_2 income-emissions nexus to be 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. As at the time of writing, this paper is the first to systematically employ the 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.

2.2 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 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 inferring from 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 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 produces 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 economies, respectively.[29] It is worth noting that the role of this industry-type migration as

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[29] In addition to the movement of these industries, there are technical transfers, particularly of advanced and cleaner production technologies, from the developed to developing countries. Consequently, the overall effect of pollution havens on the environmental quality of the developing countries is not a simple one-way relationship. Obviously, this also depends on whether the depletion effect of pollution havens outweighs the enhancement effect of technical transfers.

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 homogeneous 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 CO_2, Dijkgraaf and Vollebergh (2005) examined the hypothesis in a panel of 24 OECD countries. Applying the fixed effects technique to a data-set on CO_2 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 findings 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 questioned the practice of pooling various countries together in Kuznets Curve investigations. Additionally, they challenged the existence of an overall CO_2 EKC as a result of the flawed homogeneity assumption of traditional panel techniques. Thus, they suggested a further exploration of the CO_2 income-emissions relationship using more flexible panel methods that are capable of capturing the heterogeneity issues usually 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 CO_2 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 a group of 40 poorest countries in the analysis. Additionally, the authors conducted a preliminary test for the null of slope homogeneity using Swamy's (1970) chi-square test statistic. This null was strongly rejected.

Further, the study found that the EU but not the US, was mostly 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 our knowledge, the only exception is the recent study by Flores et al. (2013) who applied the conditional quantile fixed effects method to a US state level data-set spanning from 1929 to 1994 to investigate nitrogen oxide (NO_X) and sulphur oxide (SO_2) EKC. This method explains the income-emissions relationship at different percentiles of the conditional distribution of emissions, thereby being able to capture state level heterogeneity in the sample. Their study confirmed the EKC for all quantiles of the conditional distribution of NO_X considered. However, mixed results were found for the SO_2 scenario; both an EKC and a monotonically rising relationship were found. Most importantly, the study found that the traditional mean fixed effects method provides more optimistic turning point incomes relative to the quantile fixed effects method in the case of NO_X. 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 fixed effects technique influences the suggestion that progress is a panacea to pollution. To our knowledge, no study thus far has employed the quantile fixed effects technique in investigating the CO_2 income-emissions nexus. Our paper aims to fill this methodological gap.

2.3 Econometric Framework

2.3.1 Quantile Fixed Effects Model

Following the traditional EKC reduced form framework, this paper models per-capita CO_2 emissions as a cubic polynomial function of per-capita income as follows:

$$lnems_{it} = \alpha_i + \gamma_t + \beta_1 \ln inc_{it} + \beta_2 lninc_{it}^2 + \beta_3 lninc_{it}^3 + \varepsilon_{it}. \qquad \text{(vii)}$$[30]

Equation (vii) represents a conventional longitudinal fixed effects relationship where *lnems* is the log of per-capita CO_2 emissions; *lninc*, *lninc*^{2} and *lninc*^{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.

As mentioned earlier, the model above estimates a homogeneous income-emissions relationship for all countries in the sample, thus, not being able to capture the existing heterogeneity amongst countries to be investigated. To bridge this gap, this paper employs a quantile fixed effects version of equation (vii). The quantile transformation of this equation is:

$$Qlnems_{it}(\tau | lninc_{it}, \alpha_i, \gamma_t) = \alpha_i(\tau) + \gamma_t(\tau) + \beta_1 \ln inc_{it}(\tau) + \beta_2 \ln inc_{it}^2(\tau) + \beta_3 lninc_{it}^3(\tau) + \varepsilon_{it}(\tau), \qquad \text{(viii)}$$

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 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 (viii) 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.[31] This technique paves way for a comprehensive understanding of the varying income-emissions relationships in-built in a single EKC system.

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[30] It is worth noting that the traditional framework does not control for other possible determinants of emissions; for instance population density, energy use, income distribution within the country and trade openness amongst other factors. This is not to imply that this framework belittles the role of these factors. The choice of income (in its level, quadratic and cubic polynomials) is based on three main reasons: first, the EKC hypothesis is mostly concerned with the shape of the relationship between income and emissions but not obtaining best predictions for emissions in subsequent years; secondly, data limitations restrict the analysis to income and emissions. In this respect, the use of panel techniques that sweep cross country effects away enables us to control implicitly for any invariant determinants; thirdly, the framework allows comparability with similar studies (see Azomahou et al., 2006, for more details).

[31] The conventional fixed effects method estimates: $E(ems_{it} | inc_{it}) = \alpha_i + \gamma_t + \beta_1 inc_{it} + \beta_2 inc_{it}^2 + \beta_3 inc_{it}^3$, and the corresponding quantile fixed effects version estimates: $Q_\tau(ems_{it} | \alpha_i, \gamma_t, inc_{it}) = \alpha_i(\tau) + \gamma_t(\tau) + \beta_1 inc_{it}(\tau) + \beta_2 inc_{it}^2(\tau) + \beta_3 inc_{it}^3(\tau)$, where τ is a selected quantile. Consequently, the two functions represent different optimisation problems (see for instance Flores et al., 2013). The conventional fixed effects technique minimises the mean squared error given by: $\min_{\beta \in \Re^P} \sum_{i=1}^{N} (ems_{it} - \alpha_i - \gamma_t - \beta_1 inc_{it} - \beta_2 inc_{it}^2 - \beta_3 inc_{it}^3)^2$. Similarly, the quantile fixed effects method

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 are given 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 different from estimating a mean regression when we condition on data on the lower tail of the distribution. Thus, $Qems_{it}(0.25|lninc_{it})$ is not the same as $E(ems_{it}|ems_{it} < c, lninc_{it})$, 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).

2.3.2 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 endowment or explained effect and the latter 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 an important role in the paper’s decomposition analysis in the next section.

The Machado and Mata (2005) decomposition technique is based on the generation of a counterfactual distribution of (log) emissions for Non-OECD countries; the distribution of CO_2 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

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minimises an asymmetrically weighted sum of absolute residuals. The solution to the quantile fixed effects version of the minimisation problem is given by: $\min_{\alpha,\gamma,\beta} \sum_{k=1}^{q} \sum_{t=1}^{T} \sum_{i=1}^{N} \rho_{\tau_k} [ems_{it} - \alpha_i(\tau_k) - \gamma_t(\tau_k) - inc_{it}(\tau_k) - inc_{it}^2(\tau_k) - inc_{it}^3(\tau_k)]$, where $\rho_\tau(u) = \mu[\tau - 1(u > 0)]$ is called the check function. This is solved by linear programming techniques (see Koenker, 2004 for more details).

characteristics were 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 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:

$$Qlnems_{group}(\tau|X_{group}) = \beta_{group}(\tau)X_{group} \qquad \tau \in (0,1) \tag{ix}$$

Where X is a vector of the covariates (*income*, $income^2$, $income^3$ 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).[32] The Machado and Mata algorithm is outlined as follows:

a. Generate a random sample of size *m* from a uniform distribution U[0,1] to obtain τ_j for $j= 1,2,\ldots,m$. These are the quantile regression coefficients to be estimated; $\beta_{group}(\tau_j)$.
b. Use the OECD covariates to generate fitted values $ems^*_{Non\text{-}OECD}(\tau) = X_{OECD}\beta_{Non\text{-}OECD}(\tau_j)$.[33] For each τ_j this generates *N* Non-OECD fitted values, where *N* is the number of observations in the OECD sample.

We denote $f(lnems_{group})$ as an estimator of the marginal density of log emissions based on the observed sample and $f^*(lnems_{group})$ an estimator of the marginal density of emissions based on the generated sample. The counterfactual densities are denoted $f^*(lnems_{Non\text{-}OECD};X_{OECD})$ 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 covariates.[34] 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 $f(ems_{OECD})$ to $f(ems_{Non\text{-}OECD})$ at each quantile is decomposed as follows:

$$f(lnems_{OECD}) - f(lnems_{Non-OECD}) = [f^*(lnems_{Non-OECD}; X_{OECD}) - f(lnems_{Non-OECD})] + [f(lnems_{OECD}) - f^*(lnems_{Non-OECD}; X_{OECD})], \tag{x}$$

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[32] As in the left hand side variable, emissions, the income variables are measured in logs as well.

[33] Conversely, the Non-OECD covariates could be used to generate $ems^*_{OECD}(\tau)=X_{Non\text{-}OECD}\beta_{OECD}(\tau_j)$. Estimation results can be expected to differ. Given our research perspective, we prefer using the OECD sample as the "counterfactual".

[34] Again, a similar counterfactual density could be generated for the OECD group if necessary; $f^*(lnems_{OECD};X_{Non\text{-}ECD})$. That is, the OECD distribution of emissions if its covariates were distributed as in the Non-OECD group.

where *ln* denotes natural logs and all other variables are as previously defined.[35] The first term (in brackets) on the right-hand side of equation (x) measures the contribution of differences in endowments to the raw differential at the *τth* percentile; the explained effect. The second term measures the contribution attributable to differences in the coefficients to the emissions gap at the *τth* 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 into the EKC exploration. This decomposition exercise is not merely appealing for the extra econometric exposition it offers. It identifies the relevance of income and other factors in explaining the emissions differential between the two economic blocs. This could be informative in suggesting key factors to be targeted in minimising the differential thereby contributing to the formulation of appropriate mitigation policies.[36]

Table 8: Economic and Geographical Groupings and Countries Covered

Geographic/Economic Group	Countries Covered
OECD*	Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Japan, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, South Korea, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States.
West	Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States.
East Europe	Albania, Armenia, Azerbaijan, Belarus, Bosnia, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Macedonia, Moldova, Poland, Romania, Russian Federation, Slovakia, Slovenia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan.

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[35] Similarly, $f(lnems_{Non-OECD}) - f(lnems_{OECD}) = [f^*(lnems_{OECD}; X_{Non-OECD}) - f(lnems_{OECD})] + [f(lnems_{Non-OECD}) - f^*(lnems_{OECD}; X_{Non-OECD})]$.
Employing the original OB method, the emissions gap corresponding to equation (x) is: $\overline{lnems}_{OECD} - \overline{lnems}_{Non-OECD} = \hat{\beta}'_{OECD}(\bar{X}_{OECD} - \bar{X}_{Non-OECD}) + \bar{X}'_{Non-OECD}(\hat{\beta}_{OECD} - \hat{\beta}_{Non-OECD})$, where the first and second terms on the left hand side of the equation are the mean outcomes of the OECD and Non-OECD per-capita emissions respectively; the right hand side of the equation denotes the emissions gap, $\bar{X}_{OECD}$ and $\bar{X}_{Non-OECD}$, are vectors of explanatory variables evaluated at their means for the OECD and Non-OECD groups respectively; $\hat{\beta}_{OECD}$ and $\hat{\beta}_{Non-OECD}$ are the conforming vectors of estimated coefficients for OECD and Non-OECD groups. Thus, the first and second terms on the right hand side of the equation are the explained and unexplained components of the emissions gap respectively [see Oaxaca (1973) and Blinder (1973) for more details].

[36] We use Blaise Melly's publicly provided Stata code for this decomposition. For more details on this code, see http://www.econ.brown.edu/fac/Blaise_Melly/code_counter.html and http://www.econ.brown.edu/fac/Blaise_Melly/code_rqdeco.html.

Table 8 Contd.

Latin America	Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, México, Nicaragua, Panamá, Paraguay, Peru, Trinidad and Tobago, Uruguay, Venezuela.
East Asia	Afghanistan, Bangladesh, Cambodia, China, Hong Kong, India, Indonesia, Japan, Laos, Malaysia, Mongolia, Nepal, North Korea, Pakistan, Philippines, Singapore, South Korea, Sri Lanka, Thailand, Vietnam.
West Asia	Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, Turkey, United Arab Emirates, West Bank and Gaza, Yemen.
Africa	Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoro Islands, Congo "Brazzaville", Cote D'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea and Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Kenya, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Tunisia, Uganda, Zaire (Congo Kinshasa), Zambia, Zimbabwe.

* All countries in the full sample but not in the OECD group make up the Non-OECD group.

2.3.3 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 CO_2 emissions respectively. We employ data on annual per-capita GDP measured in 1990 International Geary-Khamis dollars obtained from the Maddison Dataset at www.ggdc.net/MADDISON/oriindex.htm. Data on annual CO_2 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 8 provides a list of all the countries in the sample based on their economic and geographical 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 9 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.

Table 9: **Data Summary**

Variables	Mean	Median	Min	Max	sd
	Geographical Regions				
	World				
Income	5168.96	2811.633	206.5366	42916.23	5913.922
Emissions	4.435729	1.606196	0.0005567	105.736	7.408073
	OECD				
Income	12531.48	12064.23	1226.389	31357.37	5942.79
Emissions	8.451581	7.89927	0.5016128	22.84792	4.385215
	Non-OECD				
Income	3222.562	1940.666	206.5366	42916.23	4094.912
Emissions	3.364123	0.900827	0 .0005567	105.736	7.677549
	West				
Income	14587.9	14324.2	2955.836	31357.37	5403.46
Emissions	9.097003	8.233196	0.9189601	22.84792	4.246003
	East Europe				
Income	5340.328	4901.829	820.2494	20565.96	2980.06
Emissions	6.751345	6.069122	0.453943	19.89363	4.292865

Table 9 Contd.

	Latin America				
Income	4329.301	3672.72	672.4241	20801.3	2678.374
Emissions	2.262891	1.391259	0.0389847	27.86173	3.145726
	East Asia				
Income	3771.399	1534.156	426.0661	31130.11	5401.565
Emissions	2.450627	0.7673387	0.004365	19.10338	3.474071
	West Asia				
Income	7593.584	4732.719	923.1468	42916.23	7277.61
Emissions	12.71124	4.025418	0.0175833	105.736	18.3873
	Africa				
Income	1628.09	1059.674	206.5366	20361.38	1692.942
Emissions	0.9010168	0.2309844	0.0005567	18.57901	1.977811

Conversely, the corresponding mean per-capita CO_2 emissions for the two economic groups and seven regions discussed in the preceding paragraph consecutively 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 emissions in absolute but not per-capita terms. As in the case of income, the mean per-capita emissions for the different groups are considerably higher than their corresponding median observations. Again, 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.

Table 10: Results of Conditional Quantile and Conditional Mean Estimations
(Bootstrapped Standard Errors in Parenthesis)

Dep Variable: lnemissions

WORLD

Variables	Quantiles (τ)					Mean
	0.1	0.25	0.5	0.75	0.9	
lnincome	-7.0239* (2.6733)	-5.8682** (2.4768)	-11.1366* (2.0548)	-13.3500* (1.6375)	-15.9845* (1.8473)	-10.3512* (1.4834)
lnincomesq	1.1420* (0.3247)	0.9800* (0.2982)	1.6084* (0.2428)	1.8537* (0.1964)	2.1333* (0.2207)	1.5235* (0.1850)
lnincomecb	-0.0538* (0.0131)	-0.0463* (0.0118)	-0.0709* (0.0095)	-0.0796* (0.0078)	-0.0893* (0.0087)	-0.0678* (0.0076)
intercept	7.4750 (7.1641)	6.1927 (6.6662)	21.2604* (5.7781)	28.1431* (4.5198)	36.3214* (5.1009)	18.4953* (3.9168)
Turning Point	$15,334	$18,253	$17,532	$19,127	$19,627	$17,603

OECD

Variables	Quantiles (τ)					Mean
	0.1	0.25	0.5	0.75	0.9	
lnincome	-9.8058** (4.9292)	-13.8399* (5.3143)	-18.0604* (5.1298)	-11.0752* (2.9860)	-10.5815* (4.0188)	-16.1587* (3.3245)
lnincomesq	1.4278** (0.5608)	1.9512* (0.6097)	2.4417* (0.5728)	1.6241* (0.3448)	1.5648* (0.4537)	2.2166* (0.37890)
lnincomecb	-0.0614* (0.0212)	-0.0834* (0.0233)	-0.1026* (0.0213)	-0.0709* (0.0133)	-0.0687* (0.0171)	-0.0935* (0.0144)
intercept	19.1826 (14.3835)	29.3655*** (15.3587)	41.8538* (15.2331)	22.2085* (8.6152)	21.0042*** (11.8720)	36.2507* (9.6867)
Turning Point	$31,548	$25,197	$21,990	$24,836	$24,440	$24,573

NON-OECD

Variables	Quantiles (τ)					Mean
	0.1	0.25	0.5	0.75	0.9	
lnincome	-0.9257 (3.4701)	0.7984 (2.1803)	-0.5908 (2.5657)	-3.7116 (2.2821)	-8.9209* (2.1446)	-5.8955* (1.8319)
lnincomesq	0.3108 (0.4288)	0.0871 (0.2640)	0.2199 (0.3083)	0.5863** (0.2772)	1.1885* (0.2723)	0.9038* (0.2337)
lnincomecb	-0.0164 (0.0176)	-0.0071 (0.0106)	-0.0109 (0.0121)	-0.0250** (0.0111)	-0.0480* (0.0114)	-0.0396* (0.0098)
intercept	-7.4332 (9.2550)	-10.3431*** (5.9517)	-5.1796 (7.0468)	3.9356 (6.1801)	18.8538* (5.5968)	7.8731*** (4.7348)
Turning Point	N/A	N/A	N/A	N/A	N/A	$35,939

Table 10 Contd.

WEST

Variables	Quantiles (τ)					Mean
	0.1	0.25	0.5	0.75	0.9	
lnincome	-49.7372* (18.3407)	-34.2193*** (19.0715)	-12.1094 (19.5596)	5.0830 (13.7072)	-0.8310 (10.7115)	-30.0443* (11.0665)
lnincomesq	6.0364* (2.0109)	4.3918** (2.0708)	1.9841 (2.1012)	0.0367 (1.4552)	0.6478 (1.1396)	3.9511* (1.1995)
lnincomecb	-0.2382* (0.0734)	-0.1796** (0.0749)	-0.0929 (0.0752)	-0.0194 (0.0515)	-0.0402 (0.0403)	-0.1644* (0.0433)
intercept	134.1021** (55.6693)	85.2296 (58.5279)	18.2759 (60.6719)	-32.1252 (43.0299)	-13.0735 (33.4814)	72.4936** (33.9666)
Turning Point	$17,539	$19,154	N/A	N/A	N/A	$18,237

EAST EUROPE

Variables	Quantiles (τ)					Mean
	0.1	0.25	0.5	0.75	0.9	
lnincome	6.7364 (8.7150)	0.7427 (9.4556)	17.5084** (7.2493)	12.8960* (4.7739)	15.8279* (5.6458)	-0.7769 (6.5778)
lnincomesq	-0.6084 (0.9764)	0.0951 (1.1073)	-1.8718** (0.8522)	-1.3590** (0.5682)	-1.7045** (0.6764)	0.3491 (0.7975)
lnincomecb	0.0193 (0.0368)	-0.0079 (0.0433)	0.0692** (0.0333)	0.0501** (0.0224)	0.0633** (0.0268)	-0.0195 (0.0320)
intercept	-25.2881 (26.0158)	-7.6514 (26.9973)	-54.9430* (20.5353)	-40.9444* (13.3106)	-49.0482* (15.6242)	-5.3512 (17.9898)
Turning Point	N/A	N/A	N/A	N/A	N/A	N/A

LATIN AMERICA

Variables	Quantiles (τ)					Mean
	0.1	0.25	0.5	0.75	0.9	
lnincome	24.6223 (15.4098)	24.5839** (12.1272)	-1.3467 (15.3070)	-18.0577 (12.1242)	-22.8847** (9.4057)	0.6525 (8.5446)
lnincomesq	-2.7748 (1.8677)	-2.8080*** (1.4427)	0.3412 (1.8574)	2.4065 (1.4954)	2.9065** (1.1563)	0.0927 (1.0374)
lnincomecb	0.1065 (0.0755)	0.1090*** (0.0573)	-0.0187 (0.0749)	-0.1029*** (0.0612)	-0.1195** (0.0471)	-0.0080 (0.0419)
intercept	-73.9574*** (42.3890)	-72.7212** (33.9805)	-0.9969 (41.8693)	43.6654 (32.6186)	58.6773** (25.3607)	-6.7217 (23.3900)
Turning Point	N/A	N/A	N/A	$10,891	$13,358	N/A

Table 10 Contd.

EAST ASIA

Variables	Quantiles (τ)					Mean
	0.1	0.25	0.5	0.75	0.9	
lnincome	-4.2758 (5.5423)	-5.4398 (3.7026)	-4.4984 (3.5529)	-8.4915** (3.5791)	-13.6720* (3.5583)	-2.2036 (2.8506)
lnincomesq	0.7408 (0.6741)	0.8976** (0.4461)	0.8188*** (0.4308)	1.2756* (0.4240)	1.8462* (0.4199)	0.5206 (0.3422)
lnincomecb	-0.0339 (0.0271)	-0.0408** (0.0178)	-0.0389** (0.0173)	-0.0566* (0.0167)	-0.0775* (0.0165)	-0.0261*** (0.0136)
intercept	1.2263 (14.8368)	5.4189 (10.1588)	2.7893 (9.6443)	14.5090 (9.9748)	30.0345* (9.9567)	-3.3146 (7.8170)
Turning Point	N/A	N/A	N/A	$22,922	$22,011	N/A

WEST ASIA

Variables	Quantiles (τ)					Mean
	0.1	0.25	0.5	0.75	0.9	
lnincome	-10.0156 (13.5672)	-3.9640 (10.2096)	-12.1607** (5.3383)	-9.5314 (7.9640)	-0.1769 (11.1039)	29.4900*** (16.6699)
lnincomesq	1.1346 (1.5465)	0.4313 (1.1544)	1.3514** (0.6191)	1.0535 (0.9389)	-0.0524 (1.3460)	-3.3486*** (1.9074)
lnincomecb	-0.0405 (0.0582)	-0.0132 (0.0433)	-0.0471** (0.0236)	-0.0359 (0.0365)	0.0073 (0.0539)	0.1277*** (0.0720)
intercept	28.1458 (39.2497)	12.1834 (30.1336)	36.9108** (15.4526)	29.3698 (22.2937)	3.4745 (30.2616)	-85.6641*** (48.2779)
Turning Point	N/A	N/A	N/A	N/A	NA	NA

AFRICA

Variables	Quantiles (τ)					Mean
	0.1	0.25	0.5	0.75	0.9	
lnincome	15.1533* (2.1850)	12.5700* (3.0021)	11.0233** (4.8699)	2.1953 (7.0959)	-5.1070 (3.7611)	4.9264 (3.2712)
lnincomesq	-2.0051* (0.3080)	-1.6369* (0.4001)	-1.4174** (0.6285)	-0.3141 (0.9216)	0.6393 (0.5080)	-0.6415 (0.4386)
lnincomecb	0.0927* (0.0140)	0.0757* (0.0175)	0.0654** (0.0268)	0.0201 (0.0395)	-0.0213 (0.0227)	0.0336*** (0.0193)
intercept	-40.9902* (5.0138)	-34.8052* (7.4288)	-30.4862** (12.5140)	-7.0430 (18.0216)	11.8111 (9.2379)	-15.3255*** (7.9792)
Turning Point	N/A	N/A	N/A	N/A	N/A	NA

NB: *, ** and *** denote significance at the one, five and ten percent levels respectively.

2.4 Results and Discussions

2.4.1 Quantile Fixed Effects Analysis

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 10. In this table, the estimated income coefficients (in level, quadratic and cubic terms) and intercept for each economic and geographical group and the five quantiles considered *(τ = 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.[37] 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 10 are complemented by the diagrams in figure 1, appendix 2. 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. 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 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 CO_2 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 turning point

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[37] It is worth noting that the table omits the numerous year and country fixed effects accompanying the income coefficients.

incomes of about $15,300 to $19,600 and $17,600 respectively (see table 10 and figure 1); these estimates are considerably higher than the global mean per-capita income, $5,169. The mean estimation therefore provides an optimistic turning point 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 also, 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; assuming 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.[38] In contrast, the conditional mean results depict a significant EKC relationship with a turning point income of $35,900. However, there is a significant disparity between this turning point income and the mean income of this group, $3,223. This raises considerable doubts on how countries in the group would attain the turning point income, considering that virtually all of them have per-capita incomes significantly less than that depicted by the turning point income. 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 at various quantiles of the conditional distribution of emissions.

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[38] As the income variable (in level) for the 0.75 quantile is marginally insignificant at the 10 percent level, this therefore makes the estimated relationship insignificant.

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 for 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, the disparity between turning point and mean incomes in this geographical group is not as remarkable as in the global and OECD samples.

The overall result for the East European region shows 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 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 various forms of income-emissions relationship are obtained between different conditional quantiles and the conditional mean. The 0.10 and 0.25 quantiles show a monotonically rising income-emissions relationship, with the former relationship being insignificant. Also, the median and conditional mean results show a monotonic (but insignificant) income-emissions 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.[39] Again, these findings reiterate

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[39] Precisely, the income and incomesq variables are marginally insignificant at the 10 percent level for the 75th percentile. Also, theoretically, quantile curves are not expected to cross each other. However, it is not unusual to have crossings in empirical applications of the quantile regression method but these should not be too many (Koenker, 2005). In the Latin American sample, it is quite inconceivable to avoid these crossings especially in the presence of both the monotonic and inverted U-shaped relationships found in the sample.

the additional informational gains associated with the application of the conditional quantile over the conditional mean technique; the latter method may conceal 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 casts doubts on advocates' proposition that the achievement of economic development is the only solution to 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 those promoting economic development instead of relying on the latter policies alone for achieving environmental clean-ups.

For the East Asian region, the 0.75 and 0.90 quantiles show a significant EKC relationship (see table 10 and figure 1). The curves for the other quantiles and 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 point incomes are relatively higher than the mean income of the region, \$3,711. As in the Latin American scenario, the results for the East Asia 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) 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 suggestion of the EKC advocates that the only way to improve 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 median and lower tail 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. 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 rises 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 of emissions. As the conditional quantile method covers the entire distribution of the outcome 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 emissions observations on the emissions distribution.

2.4.2 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.[40] Table 11 presents the results of this estimation. The first, second and third columns in this table present the five percentiles at 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 percent confidence intervals respectively; the OECD estimated marginal density 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 point estimates of these effects.

In table 11, 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 (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 the same but the Non-OECD sample had the OECD's distribution of income, the former would pollute about 25.66 to 39.77 percent more CO_2 emissions 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.

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[40] For the purpose of computing bootstrapped standard errors, we bootstrapped the procedure 100 times.

Table 11: Quantile Decomposition of Changes in Emissions Distribution between OECD and Non-OECD Countries

Quantiles	Differential	95% Conf. Interval		Contributions					
				Covariates	95% Conf. Interval		Coefficients	95% Conf. Interval	
quant10	3.6859	3.5700	3.8018	39.7735 {52.43%}	0.7274	78.8196	-36.0876 {47.57%}	-75.1240	2.9488
	(0.0591)			(19.9218)			(19.9169)		
quant25	3.3446	3.2546	3.4346	37.3166 {52.35%}	-1.5449	76.1781	-33.9720 {47.65%}	-72.8350	4.8910
	(0.0459)			(19.8277)			(19.8284)		
quant50	2.3407	2.2755	2.4059	34.4338 {51.76%}	-4.0404	72.9079	-32.0931 {48.24%}	-70.5752	6.3891
	(0.0333)			(19.6300)			(19.6341)		
quant75	1.4074	1.3302	1.4846	30.1213 {51.20%}	-8.0670	68.3096	-28.7139 {48.80%}	-66.9079	9.4801
	(0.0394)			(19.4842)			(19.4871)		
quant90	0.6646	0.5707	0.7585	25.6562 {50.66%}	-11.8694	63.1817	-24.9916 {49.34%}	-62.5308	12.5477
	(0.0479)			(19.1460)			(19.1530)		

* Percentages in curly brackets are the contributions of the covariate and coefficient effects to the estimated raw differentials at the corresponding percentile.

Combining the decomposition results with those of the EKC estimations, this implies that even in the face of rising per-capita incomes in the Non-OECD countries, this development has generally not been promising for their environment. In spite of the slight dominance of the covariate over the returns effect in explaining the OECD-Non-OECD emissions gap, an extension of this result to the EKC analysis might imply that income differences between the two groups explains a significant amount of the differences in the shapes of the EKC curves for these economic blocs. However, other unexplained factors are accountable for an equally significant amount of these estimated curves as well. Thus, there is need for policy to target income and other important factors explaining the emissions differential – one of the probable major factors being the use of well-designed mitigation tools – to mitigate carbon emissions. A combination of policies enhancing economic development and pollution mitigation could be more beneficial to achieving cleaner environmental standards relative to policies promoting rising incomes alone.

2.5 Concluding Remarks

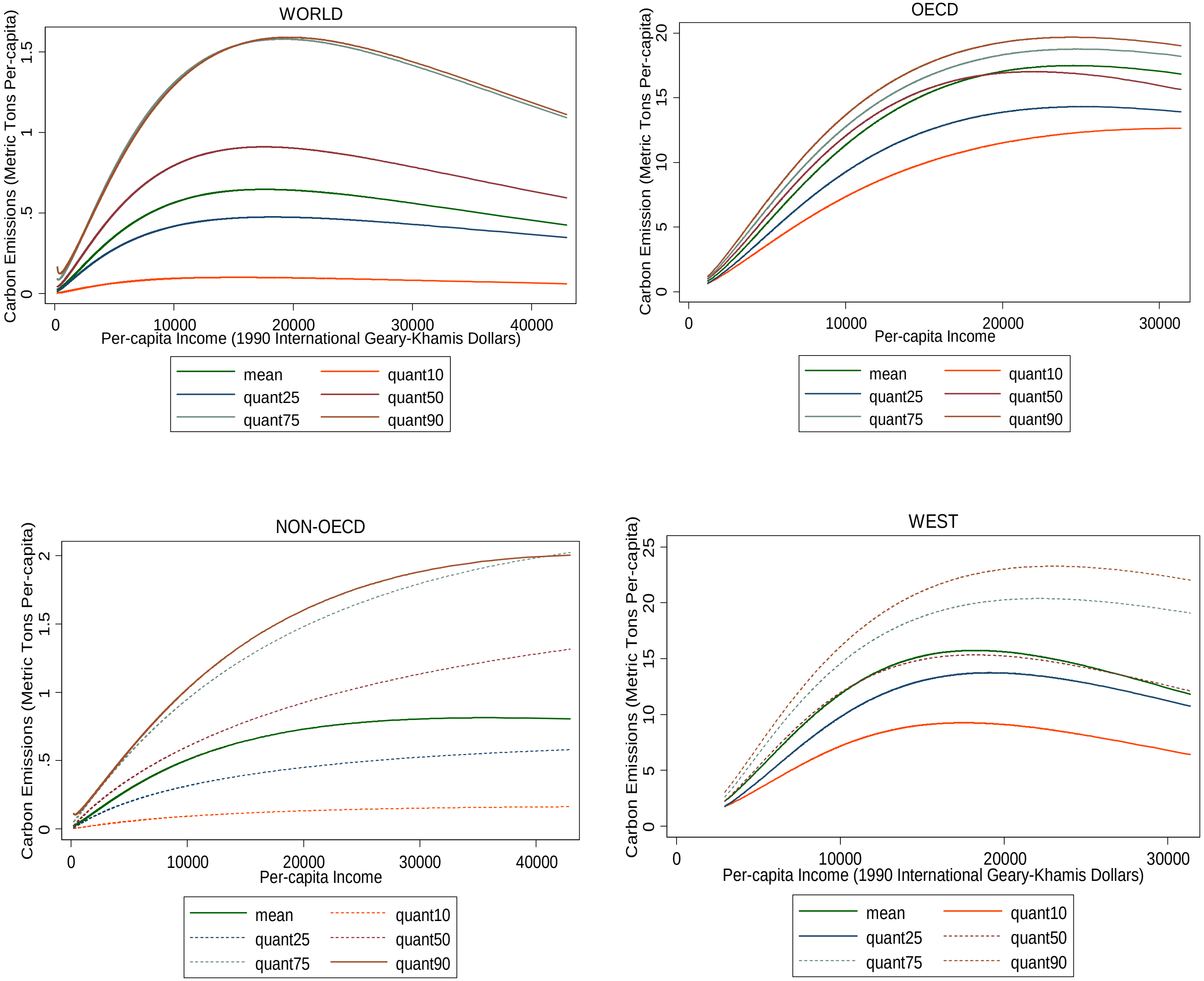
The EKC hypothesis posits that the early stages of economic progress are associated with increasing environmental damage. However, after the attainment of a threshold level of income, progress leads to environmental improvements. Graphically, this denotes an inverted U-shaped relationship between income 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. This suggestion may undermine 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.

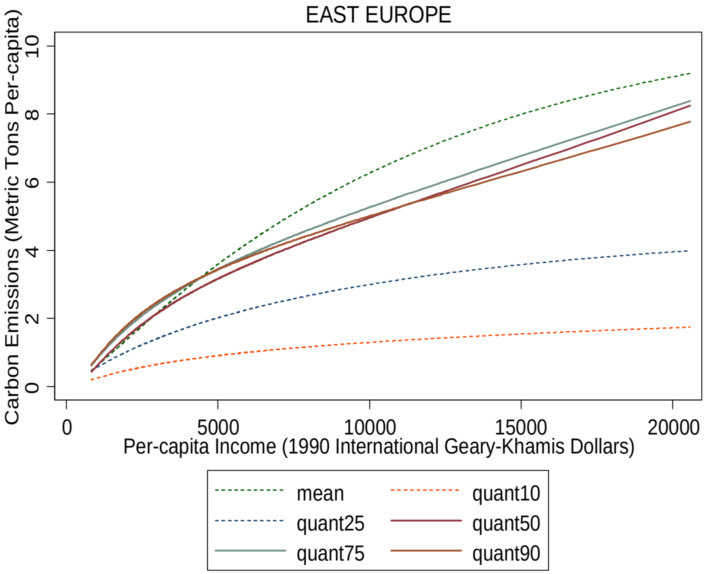
Deviating from conventional methods of EKC investigations, we applied the quantile fixed effects technique in exploring the CO_2 EKC within two groups of economic development (OECD and Non-OECD) and six geographical regions – West, East Europe, Latin America, East Asia, West Asia and Africa. A comparison 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 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 may conceal 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.

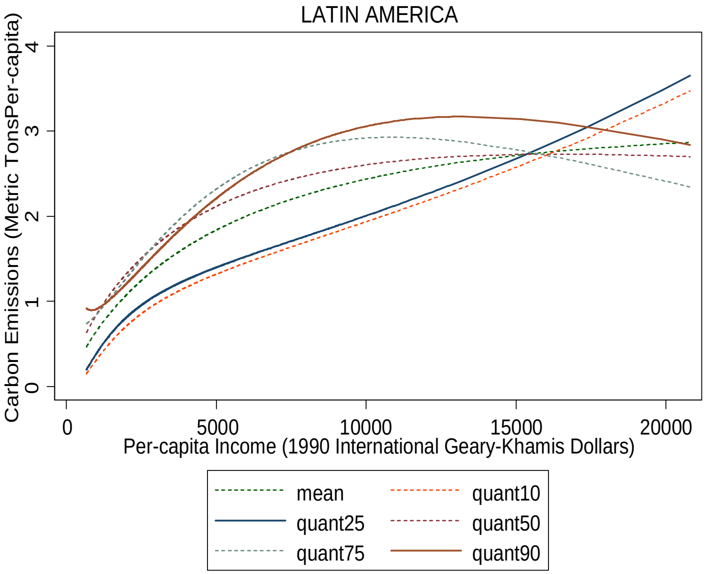
In whole, we confirmed existence of a significant EKC in the global, OECD and western samples. Interestingly, the hypothesis was confirmed in the Latin American and East Asian regions as well thereby reiterating Dasgupta et al.'s (2002) stance that environmental clean-ups are also achievable in developing countries. Thus, turning point incomes may not exist in developed countries alone, but in developing countries as well. Further, our study extended decomposition techniques largely used in labour economics to the EKC framework 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 CO_2 than its Non-OECD counterpart, depending on the quantile evaluated. Also, if the Non-OECD had the same incomes as the OECD group but every other thing remained the same, the former would pollute about 26 to 40 percent more than the latter. Moreover, we found that there may be 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 havens amongst others.

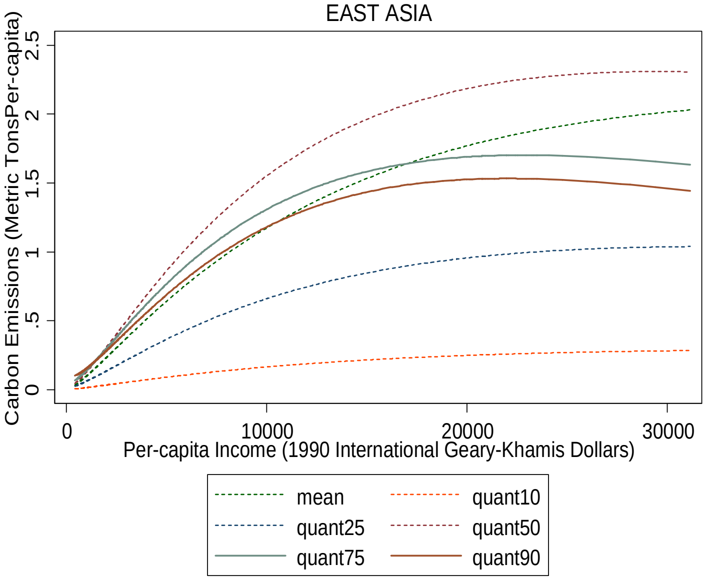
In sum, our exploration of the income-emissions nexus reaches the following clear-cut conclusions; first, no single income-emissions relationship fits all countries of the world; second and most importantly, although our paper finds evidence of the EKC across different levels of economic development, 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 may provide greater impetus for mitigating CO_2 emissions.

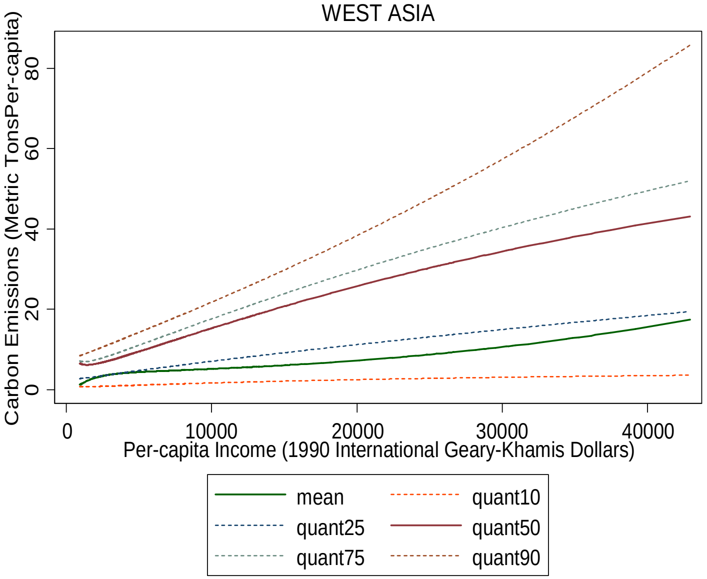
2.A **Appendix 2 - Figure 1:** Plots of Estimated Income-Emissions Relationships

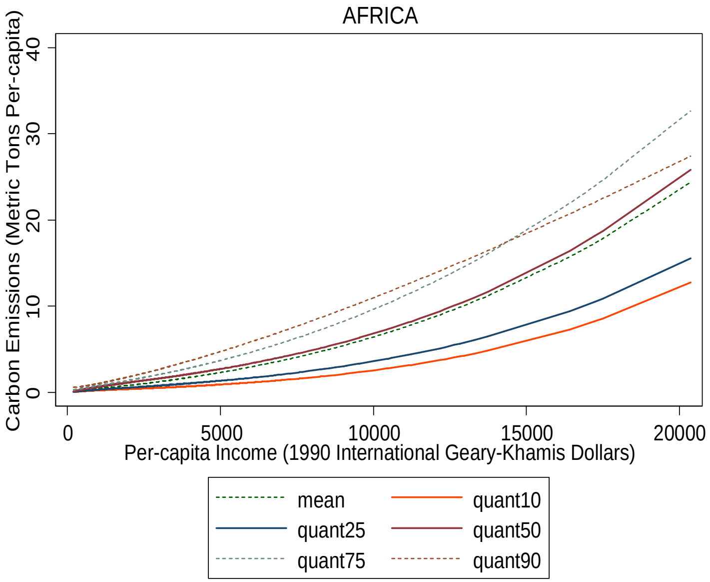



EAST EUROPE
Carbon Emissions (Metric Tons Per-capita)
0
2
4
6
8
10
0
5000
10000
15000
20000
Per-capita Income (1990 International Geary-Khamis Dollars)
mean
quant10
quant25
quant50
quant75
quant90


LATIN AMERICA
Carbon Emissions (Metric TonsPer-capita)
0
1
2
3
4
0
5000
10000
15000
20000
Per-capita Income (1990 International Geary-Khamis Dollars)
mean
quant10
quant25
quant50
quant75
quant90


EAST ASIA
Carbon Emissions (Metric TonsPer-capita)
0
.5
1
1.5
2
2.5
0
10000
20000
30000
Per-capita Income (1990 International Geary-Khamis Dollars)
mean
quant10
quant25
quant50
quant75
quant90


WEST ASIA
Carbon Emissions (Metric TonsPer-capita)
0
20
40
60
80
0
10000
20000
30000
40000
Per-capita Income (1990 International Geary-Khamis Dollars)
mean
quant10
quant25
quant50
quant75
quant90


AFRICA
Carbon Emissions (Metric Tons Per-capita)
0
10
20
30
40
0
5000
10000
15000
20000
Per-capita Income (1990 International Geary-Khamis Dollars)
mean
quant10
quant25
quant50
quant75
quant90

CHAPTER THREE

An Investigation of Oil Curse in OECD and Non-OECD Oil Exporting Economies Using Green Measures of Income

3.1 Introduction

Classical economic reasoning considers vast natural resource endowments as a driver for economic development. Sustainably managed natural resource rents could provide the finance needed for the development of various productive assets. However, a relatively new literature pioneered by Sachs and Warner (1995) assigns a somewhat paradoxical role to natural resource abundance, especially for economies richly endowed with exhaustible natural resources. This literature informs that resource scarce economies often outperform their resource rich counterparts with higher growth rates, thus, natural resource abundance inhibits growth. The paradoxical idea suggesting a shift from the classical conception of the growth enhancing effect of rich natural resource endowments is termed the 'Resource Curse' theory. The literature ascribes the Dutch disease, terms of trade effect, poor quality of institutions, civil conflict, rent seeking and corruption as likely mediums through which resource abundance hinders growth (see for instance Boos and Holm-Muller, 2012; Brunnschweiler and Bulte, 2008; Alexeev and Conrad, 2009).

As with most theoretical postulations, the resource curse theory spurred a considerable volume of empirical studies with the objective of validating the propositions raised by its authors. A great deal of studies exploring the subject employs the growth rate of real GDP in its aggregate or per-capita terms as the indicator of economic progress. The choice of these income indicators ensues from the format in which traditional national accounts presents information on aggregate economic activity. However, the use of GDP measures in resource curse investigations is questionable for two main reasons. First, it treats the depreciation of physical capital during the accounting year as a positive contribution to national income.[41] Thus, net domestic or net national

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[41] The popularity of GDP measurements without correcting for this depreciation might be attributed to the following: first, there is no straightforward and objective accounting method of computing physical capital depreciation; secondly, the incorporation of this depreciation estimate into national income

product is a better measure of income as it correctly adjusts for physical capital depreciation. Second and more importantly, GDP measures of output do not portray the ‘true incomes’ of resource intensive economies as standard national income accounting procedures are inconsistent with green accounting procedures.[42] The former system of national accounts treats natural resource rents as a positive contribution to GDP without making a corresponding adjustment to the depleted natural capital stock. This accounting method fails to consider that the depletion of a natural resource stock is essentially the liquidation of an asset, thus, natural resource extraction should not be treated as a positive contribution to GDP (Hamilton and Clemens, 1999). Therefore, an accounting procedure consistent with sustainability requires a prudential treatment of natural capital depletion in national income accounts; this should net the sum of the value of natural resources extracted (and any external costs associated with extraction) from the rents. Such an adjustment could considerably reduce GDP estimates especially for resource intensive economies (Neumayer, 2004).

The adjustment of traditional national income measures to green income measures is inextricably linked to sustainability considerations. Conceptualising sustainability as non-declining capital stock, production possibilities, welfare or consumption overtime, Hartwick (1977) prescribed that natural resource rents must be profitably invested in other forms of capital for development to be sustainable. This prescription, generally referred to as the ‘Hartwick Rule’, is considered the rule of thumb for sustainable development especially for economies with an intensive extraction of exhaustible natural resources (Solow, 1986). Conceptually, the Hartwick rule may be more applicable to the non-declining capital stock notion of sustainability but the prescription is not far-fetched from the other notions as well. A non-declining capital base serves as the bedrock for non-declining production opportunities, welfare and consumption. Thus, sustainability entails a judicious management of an economy’s capital stock ensuring that this remains at least constant overtime. Strict adherence to the Hartwick rule is paramount to achieving sustainable development. It is pertinent to note that our discussion of sustainability in this paper connotes the weak but not the strong form of sustainable development, where natural

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accounting does not considerably alter the GDP estimates for most countries thereby leading to very little and quite often negligible bias in GDP accounting (see for instance, Neumayer, 2004).

We distinguish between four types of capital: (a) Natural Capital – ecosystem, mineral, oil and gas resources and scenic views amongst others. (b) Human Capital – learned skills, health, and education amongst others. (c) Physical Capital – plant and machinery, buildings, roads and other productive infrastructure. (d) Intellectual Capital – a society’s culture and institutions not necessarily embodied in people and infrastructures, for instance, legal structures that pave way for an efficient utilisation of the other forms of capital. These can further be categorised into two major groups; natural and man-made capital, the latter consisting of human, physical and intellectual capital.

[42] It is worth noting that our mention of the term “resource intensity” implies countries with a relatively high share of natural resource rents in GDP.

capital is almost perfectly substitutable with man-made capital. Strong sustainability assumes only limited substitution possibilities between the two forms of capital. We concentrate on the former in presenting a simple analysis of the relationship between the resource curse and sustainable development using green measures of income.

Given this background, our paper contributes to the existing empirical literature on the resource curse in three ways. First, we investigate the curse for the most important energy resource; crude oil. Aside the prominent role played by crude oil as an important source of energy in a great deal of economic activities, our emphasis on this resource is not far-fetched given that it is the most articulated to be associated with the curse (see for instance, Bjorvatn et al., 2012; Neumayer, 2004; Frankel, 2010). We investigate the oil curse for major OECD and Non-OECD oil producing countries. Second, diverging from a vast majority of the empirical literature, we complement our analysis of the curse by investigating a two-fold relationship; we investigate the (traditional) relationship between standard measures of economic output and oil intensity on one hand, and, the relationship between measures of sustainable development and oil intensity on the other hand. We employ the World Bank's green measure of income – the genuine income – as our indicator of sustainable development. Genuine income is computationally defined as GNI less physical and natural capital depreciation.[43] It is worth noting that our paper is not the first to use this green measure of income for investigating the curse. To our knowledge, Neumayer (2004) is probably the first and only paper to directly employ genuine income in investigating the curse. While our paper follows Neumayer (2004) in investigating whether or not the curse holds for genuine income measures, we employ two competing measures of resource intensity to test the robustness of our findings. Thus, we explore the curse using both the share of oil rents in GDP and per-capita oil reserves as the measures of resource intensity in our explorations. The two measures effectively translate to measures of oil dependence and abundance, respectively. The former is analogous to Neumayer (2004) and a wide range of other studies in the resource curse literature, for instance, Bjorvatn et al. 2012; Dietz and Neumayer 2012; Sala-i-Martin and Subramanian, 2003. The latter is in line with Brunnschweiler and Bulte (2008) who argue for the use of stock-based measures in resource curse investigations.

Third, our paper contributes to the existing empirical literature by applying the Arellano-Bond generalised method of moments (GMM) technique. Earlier resource curse studies often relied on cross-country regressions and panel econometric methods (especially fixed and random effects methods) for their investigations (see for instance Papyrakis and Gerlagh, 2004; and

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[43] Genuine income is termed adjusted net national income in the World Bank's books (see the World Bank, 2011, 2012).

Neumayer, 2004). These estimation techniques are prone to endogeneity problems thereby generating considerable scepticism on the findings arising from the use of the methods. A primary source of endogeneity from these estimation techniques is automatically generated from the traditional dependent variable used for the investigations, GDP. Income follows a dynamic process where its contemporaneous observations are partly determined by their past realisations. Again, the autoregressive term (usually defined as lagged income in growth regressions) is systematically correlated with the errors thereby violating the OLS Gauss-Markov assumption of zero conditional mean.[44] Hence, this leads to endogeneity in resource curse models. The same problem ensues in the presence of simultaneity, a situation where there is bi-directional causality between one or more regressors and the dependent variable in a model. This is particularly the case where the most commonly used measure of resource intensity, share of natural resource rents in GDP, is already scaled by an income metric thereby automatically generating simultaneity with the income based dependent variable. We follow Dietz et al. (2007) and Bjorvatn et al. (2012) in addressing this problem by employing the Arellano and Bond (1991) difference GMM approach for our estimations. The method generates a set of (weakly) exogenous regressors by instrumenting endogenous variables with their lags (see Roodman, 2009; Arellano and Bond, 1991).

The rest of the paper is organised as follows. Section two reviews literature on the use of a savings parallel of genuine income, the genuine savings measure, in assessing sustainability. Section three presents the method and data for our estimations. The fourth section discusses the results, and, the final section is dedicated to concluding remarks.

3.2 A Literature Survey of the Links between Genuine Savings, Genuine Income and the Resource Curse in Assessments of Sustainable Development

The objective of attaining non-declining wealth overtime essentially makes sustainability a choice between present consumption and building a healthy capital base for the future generation through strategic investments. Strict adherence to the Hartwick rule prescribing the investment of natural resource rents in man-made capital is conceived a substantial step towards

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[44] This assumption posits that the errors have an expected value of zero conditional on the regressors (see for instance Wooldridge, 2008).

sustainability of resource intensive economies (see for instance Solow, 1992; Hartwick, 2009). Satisfying this rule therefore revolves around savings and investment decisions undertaken by resource rich economies. As in GDP accounting, empirical resource curse assessments of the links between savings and sustainable development are also not free from a major computational criticism. Traditional national income accounts measures do not include natural capital depreciation in computations of economic savings. For instance, an economy's net savings is conventionally estimated by deducting only the depreciation of physical capital from gross savings estimates. As savings is an economy's source of investment, and investment in turn determines the future productive base, a more accurate estimate of savings that takes into consideration the depletion of natural resources is required for better accounting and planning purposes. Thus, an assessment of a country's performance towards achieving sustainable development requires the use of green savings measures; a measure incorporating natural capital depreciation and external costs of economic activity into savings estimates of national income accounts. Amongst other reasons, this led the World Bank (1997) to introduce the Genuine Savings measure.[45] Analytically, consistently positive genuine savings estimates indicate development may be sustainable.[46] Conversely, consistently negative genuine savings rates imply an unsustainable development path resulting in a decline in society's wealth overtime. This indicator is more widely employed than genuine income in assessing countries' sustainable states. Thus, the ensuing discussion reviews a collection of studies largely employing the genuine savings indicator for sustainability assessments of oil rich countries in particular.

Kellenberg (1996) applied the genuine savings measure in investigating Ecuador's sustainability from 1970 to 2004. Using standard savings computations for the investigated period, Ecuador's savings rate was consistently more than 20 percent, with a peak of slightly greater than 30 percent in the early 1990s. However, an inclusion of Ecuador's oil extraction and environmental damages for estimating its genuine savings moves the true savings rate very close to zero or even negative in some years. This implies that a shift from conventional savings calculation to genuine savings may lead to a considerable decline in the true savings rate of resource rich countries, as in the case of Ecuador. Ecuador had negative genuine savings rates

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[45] Again, it is worth noting that genuine savings is presented as adjusted net savings in the World Bank's publications and dataset. This measure is scaled by GDP thereby giving a ratio. The ratio is further transformed into a percentage called genuine savings rate. Hence, the mention of genuine savings in this article automatically translates to genuine savings rate and vice-versa.

[46] Caution must be applied in making sustainability inferences arising from positive genuine savings rates. Positive genuine savings may not always imply a sustainable development outcome as there are certain methodological shortcomings in genuine savings computations. Also, there are likely complications arising from the uncertain effects of population growth and technical changes on genuine savings (see Arrow et al., 2004, for more details).

from 1974-1990. Further, the study found that a good proportion of the rents garnered from the exploitation of Ecuador's oil resources (especially in the 1970s and 1980s) has not been profitably invested in man-made capital but used to increase consumption through various subsidy and tax-reduction policies. This finding essentially translates to the resource curse, thus, implying an unsustainable management of Ecuador's oil rents when true measures of savings, and probably income, are incorporated in analysing its management of oil rents.

Similarly, Hamilton et al. (2006) developed a Hartwick rule counterfactual framework to investigate the amount of physical capital resource rich countries would have accumulated by 2000 if these countries had followed the Hartwick prescription since 1970. The study employed data on investments, income and resources rents from the World Bank for its computations and analyses. Concentrating on the results for two countries principally cited as suffering from the oil curse, Nigeria and Venezuela, the study finds that the countries could have accumulated five and four times as much produced capital respectively if they had satisfied the Hartwick rule. By implication, these countries have spent a significant amount of their oil rents on other avenues, especially boosting current consumption, other than accumulating physical or human capital.[47] Further, the paper suggests that if Nigeria had adhered to the Hartwick rule since 1970, oil exports would not have been as relevant as it is to the Nigerian economy today, with likely beneficial impacts on policies diversifying the economy to other sectors.

Additionally, Hamilton and Clemens (1999) computed empirical estimates of genuine savings rates for a wide range of countries from 1970 to 1993. The authors conceived genuine savings as net savings plus investments in human capital less the value of natural capital depreciation and environmental depletion. Largely employing data from the World Bank, the study finds persistently negative genuine savings rates for a good proportion of developing countries. Not surprisingly, the study finds negative genuine savings rate for the major oil producing developing countries in the sample; for example, Bolivia, Ecuador, Trinidad and Tobago, Venezuela, Algeria, Bahrain, Iran (Islamic Rep. of), Saudi Arabia, Syrian Arab Republic, and Nigeria amongst others. The authors indicate that persistently negative genuine savings rates must eventually lead to declining wellbeing overtime. Thus, they suggest that the link between genuine savings rates and sustainability implies there is a wide range of policy interventions needed to attain a sustainable allocation of resource rents, from the macroeconomic to the purely environmental.

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[47] Closely tied to this consumption pattern is an example cited by Carbonnier and Wagner (2011) suggesting that the construction of lavish presidential palaces and government houses often characteristic of resource rich countries may have contributed to GDP but not to sustainable development.

An enquiry into probable policy measures that could be used for a sustainable management of natural resource rents led Atkinson and Hamilton (2003) to investigate the links between resource curse, economic growth, genuine savings and governance in a sample of 91 countries (from different regions of the world). Applying cross-country regressions to a dataset spanning from 1980-1995 largely obtained from the World Bank, the paper regressed growth rate of GDP per-capita on initial income (measured as 1980 GDP per-capita) to capture conditional convergence,[48] resource abundance (conceived as the share of mineral, energy and forest resources rents in GDP), a measure of human capital (captured by average years of educational attainment of people over 25 years) and binary variables to control for regional factors amongst other explanatory variables. The paper finds evidence of the curse; a ten percent increase in resource abundance reduces the growth rate of GDP by about 0.5 percent ceteris paribus. To provide an understanding of the probable underlying factors explaining the curse, the authors interact the resource variable with three policy variables; share of government investment in GDP, share of government consumption in GDP, and share of public sector wages and salaries in government expenditure. Most importantly, this investigation found that resource abundant countries with a high share of government consumption in GDP on average have lower growth rates. A further analysis found that resource rich countries that have suffered from the curse are primarily those with low or negative genuine savings rates. Thus, the paper recommends a shift from the dissipation of resource rents from financing current consumption to prudent investments in man-made capital as a key policy action towards avoiding the curse. This should gear resource intensive economies towards sustainable development.

Moreover, Dietz et al. (2007) investigated whether improving the quality of political and bureaucratic institutions mitigates the growth impairing effect of resource dependence. The paper employed the commonly used fixed effects estimation method complemented by the Arellano-Bond difference GMM technique to capture the dynamic process of the outcome variable – genuine savings – and correct for probable endogeneity bias in the estimations. However, the endogeneity concerns embedded in the former method led the study to draw its major findings and conclusions from the results produced by the latter. To investigate the role of improved institutions in mitigating the curse, the authors regressed genuine savings rate on its lagged term, a variable capturing resource dependence (share of fossil fuels and mineral exports in total exports), measures of institutional quality (lack of corruption, bureaucratic quality and rule of law), and an interaction between resource dependence and institutional quality amongst

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[48] Conditional convergence is a general idea in growth regressions that a country will enjoy faster growth rates the further it is from its steady-state output (Barro and Sala-i-Martin, 1995).

other regressors. Most importantly, the paper's two-step difference GMM estimation finds evidence of the curse in genuine savings. However, this curse is mitigated by the positive effect of the interaction between resource intensity and low levels of corruption. In other words, the growth mitigating effect of resource dependence on genuine savings is reduced with lower levels of corruption. In a similar study, Barbier (2010) confirmed that corruption plays a greater role than resource dependence in explaining the inability of resource intensive countries (especially sub-Saharan African countries) to prudently invest natural resource rents into man-made capital. Thus, the papers suggest the adoption of anti-corruption measures by resource rich economies as a way of escaping the curse. Such measures could also play a vital role in promoting a transition from an unsustainable to a sustainable investment of resource rents.

In a related study, Tsui (2011) explored variations in the timing and size of oil discoveries to identify the impact of oil wealth on democracy. Employing an instrumental variable method of estimation, the paper estimates the effect of oil discovery on long-term democratic development in a sample of the top 65 oil producing economies. The investigation finds that on average, discovering 100 billion barrels of oil pushes an economy's level of democracy about 20 percentage points below existing levels after three decades. This effect is higher for oil fields with relatively higher quality of oil and lower extraction and exploration costs. However, this finding is particularly applicable to undemocratic countries as the paper finds oil discovery to have a negligible effect in democratic economies. Hence, oil discovery and the development of democratic governance are related and the development of democratic institutions could play a role in achieving a sustainable management of oil rents. In other words, the development of democratic governance could be a medium of avoiding the curse especially in countries with undemocratic structures of government.

Further, Arrow et al. (2004) employed genuine savings to investigate whether or not some countries consume too much. This study uses two criteria in its assessment of excessive consumption; the maximum principle and sustainability criteria (see Arrow et al., 2004 for details). Our review dwells on the sustainability criterion given its direct relevance to the prevailing discussion. The sustainability criterion investigates if investments in man-made capital are sufficient to offset the depletion of natural capital. A positive genuine savings rate satisfies this criterion and implies that the investigated economy is sustainable and not consuming too much. The reverse is the case with a negative genuine savings rate. This study finds that sub-Saharan Africa, Middle East and North Africa have negative genuine savings rates, hence, these regions consume too much and by implication not sustainable. Essentially, investments in man-made capital are not sufficient to meet the level of natural resource depletion and environmental pollution in these regions. Further, the study recommends the use of regulations, taxes or the establishment of clearer or more secure property rights systems to help prices of natural and environmental resources better approximate the external costs associated with the extraction of these resources.[49] These price corrective measures could prevent excessive depletion of natural resources thereby boosting genuine savings computations.

Also, a recent paper by Arrow et al. (2012) presented and applied a framework for analysing whether a given economy satisfies a predefined criterion for sustainability. In addition to the World Bank's inclusion of natural resource depletion and environmental externality in adjusting for savings and income, this paper incorporated human capital, technical changes and population growth in their adjustments for analysing sustainability. The authors define sustainable development as an increase in the potential wellbeing of the average person across generations. Investigating the sustainability of five economies – US, China, India, Brazil and Venezuela – between 1995 to 2000, the paper finds that all the countries satisfy the sustainability criterion, with Venezuela being the only exception. Venezuela falls short of this criterion primarily due to its vast exploitation of oil resources and negative total factor productivity growth. The study also finds that investment in human capital is the key contributor to the increases in per-capita wealth experienced by the US and India. In China, investment in reproducible capital is the key driver to the growth in per-capita wealth.

Finally, a need for the use of green national income measures in investigating the resource curse prompted Neumayer (2004) to explore whether or not the curse holds for growth in genuine income. If so, is the growth impairing effect of resource intensity over or underestimated by erroneously examining the growth in GDP? Employing cross-country growth regressions over a large group of countries covering the period 1970-1998, the paper regressed the average annual growth rate of GDP on initial GDP per-capita, natural resource intensity (defined as share of exports of primary products – agricultural, minerals and energy products – in GNP), a measure of trade openness, rule of law and external terms of trade amongst other regressors. Interestingly, the investigation found evidence of the curse for both measures of genuine income and GDP growth rates, thereby, reinforcing the resource curse theory. For

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[49] It is common knowledge that market failures lead to a divergence between the price of natural resources and the external costs resulting from resource extraction. For instance, the extraction of crude oil may lead to oil spillages thereby further leading to land or water pollution. However, the price of crude is almost exclusively determined by the demand and supply of the product in the international market, paying little or no consideration to the external costs associated with its production. Thus, there is need for policy to make the price of crude reflect its social costs through the use of regulations, fines, taxes and other pollution control instruments.

instance, one of the models used in comparing the effect of resource intensity on GDP and genuine income growth rates found that a ten percent increase in resource intensity leads to a 0.56 and a 0.50 percent fall in the former and latter measures of income respectively. Interestingly, the paper further finds that the growth impairing effect of natural resource intensity is slightly weaker in terms of growth in genuine income than growth in GDP in all models estimated. However, there is inconclusive evidence on the equality of coefficients of the effect of resource intensity on the two measures of income employed as tests confirm a difference of coefficients in some of the models at the 10 percent level but not at the 5 percent level. This paper is particularly relevant to our investigations as it spurred an interest for the use of green income measures in contributing to the resource curse literature.

3.3 Econometric Specification

3.3.1 Oil Curse Model

We employ a dynamic panel growth regression model in our investigation of the oil curse. This follows Solow's (1956) idea of conditional convergence in incomes; implying growth depends on the initial stock of capital thus richer economies (with a stronger capital base) should grow slower than poorer ones, ceteris paribus. In the empirical growth literature, initial capital stock is measured by lagged income (see for instance Barro, 2003). Amongst other explanatory variables, the dependent variable also depends on its own past realisations, thus explaining the dynamic nature of the framework. Even where the estimates of the lagged dependent variable may not be of direct interest as in our application, allowing for dynamics in the underlying process may be crucial for obtaining consistent estimates of other parameters (Bond, 2002). However, dynamic panel models are by construction embedded with econometric problems of omitted variable bias and endogeneity. We apply the GMM procedure initialised by Holtz-Eakin et al. (1988) and further developed by Arellano and Bond (1991) to control for these econometric problems. The method is generally referred to as difference or Arellano-Bond GMM technique. Our structural model starts from:

$$y_{i,t} = \varphi y_{i,t-1} + \beta' x_{i,t} + \mu_i + \varepsilon_{i,t}, \qquad i = 1, .., N \; and \; t = 2, \dots, T \qquad \text{(xi)}$$

where *i* and *t* represent country and time periods respectively; $y_{i,t}$ and $y_{i,t-1}$ are the contemporaneous and lagged realisations of the dependent variable, respectively; Φ is the autoregressive parameter; β' is a vector of slope parameters to be estimated; $x_{i,t}$ is a vector of both exogenous and endogenous growth regressors; μ_i is the unobserved country specific time invariant effect; and $\varepsilon_{i,t}$ is a random error term. Since μ_i is not observed, standard OLS techniques often include this into the residual term, thereby generating a composite error term given as:

$$y_{i,t} = \varphi y_{i,t-1} + \beta' x_{i,t} + v_{i,t}, \qquad where\ v_{i,t} = \mu_i + \varepsilon_{i,t}. \tag{xii}$$

The first problem of the model in equation (xii) is that it violates the OLS assumption of strict exogeneity. That is it assumes that

$$E(v_{i,t}|x_{i,t}, y_{i,t-1}) = 0, \tag{xiii}$$

which is not actually right since μ_i is part of the process that generates $y_{i,t-1}$ in equation (xii). To show this:

$$y_{i,t-1} = \varphi y_{i,t-2} + \beta' x_{i,t-1} + v_{i,t-1}, \qquad where\ v_{i,t-1} = \mu_i + \varepsilon_{i,t-1}. \tag{xiv}$$

Substituting equation (xiv) into (xii), it is obvious that,

$$E(v_{i,t}|y_{i,t-1}) \neq 0.^{50} \tag{xv}$$

Thus, the lagged dependent variable is structurally correlated with the fixed unobserved country effects and the lagged error term. Further, if the errors are serially correlated, the lagged dependent variable will also be correlated with contemporaneous (and future) realisations of the error term. Resultantly, the lagged dependent variable is endogenous in equations (xi) and (xii). The same problem occurs in the presence of simultaneity in a model. The use of standard OLS and panel techniques without correcting for these econometric problems may lead to biased and inconsistent estimates.[51] The difference GMM technique proposes two steps to comprehensively deal with the problems of omitted variable bias and endogeneity.

First, the method differences the variables in equations (xi) and (xii) to expunge the time invariant country specific effects. [52] Differencing either of the two equations yields:

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[50] The assumption of strict exogeneity is rejected whether or not the unobserved heterogeneity is included in the random error term. Note, $y_{i,t-1} = \varphi y_{i,t-2} + \beta' x_{i,t-1} + \mu_i + \varepsilon_{i,t-1} = \varphi y_{i,t-2} + \beta' x_{i,t-1} + v_{i,t-1}$.

[51] The use of fixed effects approach which sweeps out the unobserved effects via a within panel transformation provides only a partial solution to these problems in the presence of serially correlated errors.

[52] It is worth noting that this corrective measure expunges any time invariant regressors as well.

$$\Delta y_{i,t} = \varphi \Delta y_{i,t-1} + \beta' \Delta x_{i,t} + \Delta \varepsilon_{i,t} \qquad \text{(xvi)}$$

This transformation is identical to the difference-in-difference method of correcting for unobserved heterogeneity in time-series cross-sectional econometric analyses. However, the transformation still violates the assumption of strict exogeneity. To circumvent this concern, Arellano and Bond (1991) propose the use of $y_{i,t-2}$ as an instrument for the lagged dependent variable in the differenced equation. As a result, the method assumes:

$$E(\Delta \varepsilon_{i,t} | y_{i,t-2}) = 0\,, \qquad t \geq 3, \dots, T. \qquad \text{(xvii)}$$

Since, $y_{i,t-2}$ is mathematically related to $\Delta y_{i,t-1}$, this assumption holds as long as the errors are not serially correlated and the regressors are weakly exogenous.[53] Thus, the second lag of the (lagged) dependent variable in levels is a valid instrument for $\Delta y_{i,t-1}$ in the difference equation, equation (xvi). In general, the difference GMM technique instruments the endogenous variables in the differenced equation with their appropriate lags in levels as a corrective measure for endogeneity bias. Generalising equation (xvii), this therefore implies that:

$$E(\Delta \varepsilon_{i,t} | x_{i,t-2}) = 0\,, \qquad t \geq 3, \dots, T. \qquad \text{(xviii)}$$

Thus, the method assumes that the instruments are to be derived from within the dataset. However, it does not rule out the inclusion of external instruments.

We use the Stata command '*xtabond2*' provided by Roodman (2009) for our estimations. As a rule of thumb, difference GMM method requires the number of instruments used for estimations to be less than the number of cross-sectional units in the dataset (see for instance, Roodman, 2009). To keep the instrument count below the number of units, we utilise the collapse and lag limit options of *xtabond2*. The collapse option generates one instrument for each variable and lag distance instead of the default of one instrument for all variables, time periods and lag distances available in the data generation process. In a similar vein, we restrict the lag range used in generating the instruments to 5 lags. Further, difference GMM has one and two-step variants. Though the two-step variant is asymptotically more efficient and it automatically produces standard errors that are robust to heteroscedasticity, these standard errors are typically downward biased (Arellano and Bond, 1991). With the '*twostep*' and '*robust*' options, *xtabond2* makes available a finite sample correction for the two step covariance matrix derived by

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[53] It may be worth noting that weak exogeneity implies the assumption that the regressors have a zero correlation with future realisations of the random error term. On the other hand, strict exogeneity implies the regressors are not correlated with the contemporaneous and past realisations of the random error term.

Windmeijer (2005). Our estimations utilise these options to provide a corrected version of the two-step robust standard errors.

One of the key assumptions for the validity of the difference GMM method is that the (internally generated) instruments are valid. This assumption is tested using the Hansen J-test of over-identifying restrictions for the validity of the full instrument set. *Xtabond2* automatically produces the results of this test. The null hypothesis states that the instruments are jointly valid. Thus, evidence against the null implies that the instruments are invalid. *Xtabond2* also reports the results of first and second order tests of serial correlation in the differenced residuals. By construction, first order serial correlation is expected and evidence of this is uninformative; $\Delta\varepsilon_{i,t}$ is mathematically related to $\Delta\varepsilon_{i,t-1}$ through the shared $\varepsilon_{i,t-1}$ term. Thus, we investigate second order serial correlation in the differenced residuals to test for first order serial correlation in levels on the expectation this will detect the relationship between $\varepsilon_{i,t-1}$ in $\Delta\varepsilon_{i,t}$ and $\varepsilon_{i,t-2}$ in $\Delta\varepsilon_{i,t-1}$ (see Roodman, 2009). The presence of second order autocorrelation in differenced residuals renders the first lag of the endogenous lag dependent variable, $y_{i,t-2}$, an invalid instrument. Thus, higher order lags should be considered for instrumenting this variable. A satisfaction of the Hansen and serial correlation diagnostic tests gives credence to the adequacy of our instruments.

3.3.2 Explanatory Variables and Data Description

Our sample comprises an unbalanced panel of yearly observations covering 49 major oil producing countries, with time-series dimension spanning from 1980-2007. Of these countries, 13 are OECD and the rest are Non-OECD. Table 12 gives the list of countries covered in our paper.[54]

Table 12: Countries Covered Based on Economic Groupings

Economic Group	Countries Covered
OECD	Australia, Canada, Denmark, France, Germany, Hungary, Italy, Netherlands, New Zealand, Norway, Turkey, United Kingdom, United States.
Non-OECD	Albania, Algeria, Angola, Argentina, Azerbaijan, Bahrain, Bolivia, Brazil, Brunei, Cameroon, China, Colombia, Republic of Congo, Ecuador, Egypt, Gabon, India, Indonesia, Iran, Kazakhstan, Kuwait, Libya, Malaysia, Mexico, Oman, Peru, Qatar, Romania, Russia, Saudi Arabia, Syrian Arab Republic, Thailand, Trinidad and Tobago, Tunisia, Venezuela and Yemen.

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[54] It might be noticed from this table that the country list does not include other major oil producers, notably United Arab Emirates, Nigeria, Chile and Iraq. These countries are dropped due to unavailability of data on one or more of the covariates mentioned above.

In investigating the oil curse using the commonly employed indicator of national income and its associated green measure, GDP and genuine income respectively, we extend our analysis to the parallel per-capita measures of these two indicators; per-capita GDP and per-capita genuine income. Thus, the dependent variable ($y_{i,t}$) comprises four income measures; two from conventional national income accounts and the other two from green income accounts. Data on GDP, GDP per-capita and genuine income (all in constant 2000 US dollars) are obtained from the World Bank's World Development Indicators (WDI) [April, 2012 Edition]. The per-capita measure of genuine income was computed by dividing genuine income with the population estimate corresponding to the year and country under consideration. The WDI is also the source of these population data.

Table 13: Data Summary

Variables	**OECD**				**Non-OECD**			
	Mean	Min	Max	sd	Mean	Min	Max	sd
Gen. inc.	1.01e+12	2.50e+10	1.00e+13	1.90e+12	1.14e+11	3.10e+08	2.00e+12	2.07e+11
Per-cap gen. inc.	15921.8	2857.49	34081.7	7009.39	2284.49	99.2533	16737.2	2495.973
GDP	1.14e+12	3.20e+10	1.20e+13	2.13e+12	1.19e+11	1.70e+09	2.50e+12	2.26e+11
Per-cap. GDP	18941.33	2540.36	41904.2	8768.407	4066.077	186.44	34380.2	5355.232
Oil share of GDP	1.357723	0.007091	15.6331	2.604386	17.80939	0.00893	80.2375	16.67073
Per-cap oil reserve	2.16e-07	7.20e-10	3.50e-06	5.77e-07	2.79e-06	8.80e-10	0.000059	8.35e-06
ipolity2	9.442982	2	10	1.439928	4.183007	0	9.75	3.028421
Trade openness	60.40693	17.0891	161.718	27.6245	69.60739	11.5457	251.139	39.83551
Govt exp.	19.56031	7.51559	28.3754	4.155963	15.35444	2.97554	76.2221	6.621791
Investment	25.77406	13.0931	39.3144	4.13076	18.65066	1.8459	60.4758	10.51251
Inflation	8.862133	-9.62854	110.173	16.32811	85.47915	-11.6861	11749.6	561.5613

Further, we follow Mehlum et al. (2006) supporting the role of institutions in explaining the resource curse theory to investigate the theme in a split sample of OECD and Non-OECD economies. Vast natural resource rents put institutional arrangements to a resource management test, hence, it is expected that the curse is more likely to appear in economies with poor quality institutions where rent seeking and sustainable management of rents into productive investments are competing activities. For instance, Norway and the US are commonly referred to as economies whose good quality of institutions – low level of corruption, good bureaucratic quality, well defined property rights regulations etc – have a positive feedback on their impressive economic performances (see Mehlum et al., 2006; David and Wright, 1997). Conversely, Tornell and Lane (1999) attribute the poor management of oil rents by Nigeria, Venezuela and Mexico to dysfunctional institutions that invite rent grabbing. Thus, we assume OECD economies have good quality of institutions relative to Non-OECD economies and we proxy institutional quality with OECD membership. This assumption essentially implies that the former bloc of economies, OECD countries, generally has institutions that promote the investment of oil rents into productive assets while rent seeking and productive investments are competing activities in the latter. We therefore define a binary explanatory variable '*OECD*' to control for the two levels of economic development prevailing in our sample – OECD and Non-OECD countries – as well as the assumed quality of institutions in these economies. 'OECD' equals one and zero for the former and latter economic groups respectively. More importantly, to test the oil curse between the OECD and Non-OECD blocks of major oil producing countries, we interact this binary variable with the regressors capturing oil intensity (oil rents as shares of GDP and per-capita oil reserves). Thus, the coefficient of the resource variable in question serves as an indicator of oil curse for the Non-OECD block. On the other hand, the coefficient of the interaction term gives the slope differential of the curse between the two groups.[55] Data on resource rents as shares of GDP and proved crude oil reserves (in billion barrels) are obtained from the World Bank's WDI and US Energy Information Administration, respectively. The per-capita measure of oil reserves is obtained by dividing the total reserves by the population figures obtained from the World Bank's WDI (April, 2012 Edition).[56]

Consistent with the growth literature, other controls include trade openness defined as sum of imports and exports as a percentage of GDP; government expenditure (a proxy for government size and distortions in the economy) defined as general government final consumption expenditure as a percentage of GDP; investment defined as domestic investments as a percentage of GDP; inflation rate (to capture macroeconomic instability) defined as inflation in consumer prices (annual percentage); and a democracy index '*ipolity2*' ranging from 0 to 10, with lower and higher values indicating least and most democratic economies respectively (see for instance, Bjorvatn et al., 2012; Brunnschweiler and Bulte, 2008; Carbonnier and Wagner, 2011). Investment and *ipolity2* are obtained from the University of Gothenburg Quality of Government Standard Dataset available at http://www.qog.pol.gu.se/data/. The other variables are obtained

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[55] It is worth noting that the difference transformation adopted by the difference GMM procedure, as explained in equation (xvi), sweeps out the OECD binary variable (in level) as it is time invariant. However, the time varying interaction term remains. We are particularly interested in the coefficient of the interaction term capturing the curse differential between the OECD and Non-OECD economies instead of the coefficient of the OECD binary variable merely capturing the difference in intercepts between the two groups. The latter coefficient might be important if the model was built for predictive reasons but this is not the case in this paper.

[56] Oil reserves data are obtained from http://www.eia.gov/.

from the World Bank's WDI (April, 2012 Edition). Hence, in addition to the lagged dependent variable arising from the dynamic nature of our data generation process, our set of covariates includes the two key variables measuring oil intensity – oil rents as shares of GDP and per-capita oil reserves, – the OECD binary variable and its interactions with the resource variables, ipolity2, trade openness, government expenditure, investment and inflation rate. We treat all of these variables as endogenous. Thus, we generate instruments for them as standard in the Arellano-Bond GMM method using all their available lags for each time period in levels (see Roodman, 2009). However, we restrict the lag-range to 5 lags to avoid instrument proliferation as previously alluded to.[57]

All of the variables used for the estimations (both right and left hand side) are measured in logs, with the exception of inflation rate. Table 13 provides summary statistics for the variables employed for the paper's estimations, separated by the two economic groups covered. The table presents the mean, standard deviation (sd), minimum and maximum values of the variables. From the table, it is not surprising that the OECD group has a relatively higher mean genuine income and GDP estimates (in both aggregate and per-capita terms) than the Non-OECD group. Conversely, the OECD bloc has a relatively lower mean estimate of oil rents as a share of GDP than the Non-OECD bloc; 1.36 percent compared to 17.81 percent for the former and latter, respectively. Also, the Non-OECD group has a much higher mean per-capita oil reserve estimate than its OECD counterparts – 2,790 barrels compared to 216 barrels.[58] Further, the OECD bloc has a remarkably higher degree of democratisation and macroeconomic stability (measured by the mean values of ipolity2 and inflation) than the Non-OECD bloc. In fact, the latter bloc has a below average democratisation score and a very high macroeconomic instability.

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[57] Virtually all the covariates have a GDP or population metric. Thus, it is very probable that there is bi-directional causality between each of the control variables and the dependent variables. This informs our choice for treating all the right hand side variables as endogenous. Even if any of the variables was exogenous, there should not be any bias arising from this assumption as long as the instruments used are related to the variables they stand for and they satisfy the diagnostic tests.

[58] Note crude oil reserves are measured in billion barrels.

Table 14: Results of Arellano-Bond Two-step Dynamic Panel GMM Estimations (Windmeijer's Robust and Corrected Standard Errors in Parenthesis)

	Dependent Variables							
	ln(GDP)	ln(Gen Inc.)	ln(GDP)	ln(Gen. Inc.)	ln(GDP Per-cap)	ln(Gen. Inc. Per-cap)	ln(GDP Per-cap)	ln(Gen. Inc. Per-cap)
	[1a]	[1b]	[2a]	[2b]	[3a]	[3b]	[4a]	[4b]
Explanatory Variables:								
lagged dependent variable	1.0178*	0.9993*	1.0232*	0.9752*	1.0018*	0.9140*	0.9868*	0.9561*
	(0.0297)	(0.0763)	(0.0331)	(0.0546)	(0.0435)	(0.0927)	(0.0506)	(0.0995)
ln(oil share of GDP)	-0.0071	-0.0734**	–	–	-0.0119	-0.0864**	–	–
	(0.0217)	(0.0336)			(0.0239)	(0.0407)		
ln(oil share of GDP) *OECD	0.0142	0.0968**	–	–	0.0137	0.0936**	–	–
	(0.0240)	(0.0427)			(0.0263)	(0.0467)		
ln(per-capita oil reserves)	–	–	-0.0269	-0.1540**	–	–	-0.0441	-0.2024***
			(0.0447)	(0.0815)			(0.0390)	(0.1030)
ln(per-capita oil reserves) *OECD	–	–	0.0617	0.2112**	–	–	0.0755	0.2766***
			(0.0571)	(0.1010)			(0.0506)	(0.1531)
ln(ipolity2)	0.0009	0.0126	-0.0025	0.0386	0.0016	0.0349	0.0093	0.0402
	(0.0364)	(0.0685)	(0.0319)	(0.0633)	(0.0398)	(0.0620)	(0.0242)	(0.0588)
ln(trade openness)	0.0012	0.0051	0.0157	0.0685	0.0285	0.1005	0.0658	0.0889
	(0.0374)	(0.1115)	(0.0478)	(0.0695)	(0.0452)	(0.1049)	(0.0445)	(0.0796)
ln(govt. exp. as shares of GDP)	-0.0870***	-0.1876*	-0.1027*	-0.1608*	-0.1261*	-0.1739*	-0.0786***	-0.1361**
	(0.0507)	(0.0514)	(0.0323)	(0.0525)	(0.0420)	(0.0630)	(0.0406)	(0.0609)
ln(investment as shares of GDP)	0.0613**	0.2245*	0.0463	0.1967*	0.0624**	0.2361*	0.0531**	0.2200*
	(0.0270)	(0.0450)	(0.0300)	(0.0558)	(0.0273)	(0.0442)	(0.0254)	(0.0552)
inflation	-0.000021**	-5.62e-06	-0.000016**	-7.38e-06	-0.000021***	-3.42e-06	-0.000016**	-6.60e-06
	(0.000011)	(8.90e-06)	(7.79e-06)	(9.12e-06)	(0.000011)	(8.99e-06)	(7.53e-06)	(9.06e-06)
No. of Obs	982	890	963	872	979	890	962	872
No. of Groups	49	44	49	44	49	44	49	44
No. of Instruments	40	40	40	40	40	40	40	40
AR(1) Test P-Value	0.000	0.007	0.000	0.002	0.000	0.008	0.000	0.003
AR(2) Test P-Value	0.373	0.306	0.280	0.689	0.285	0.329	0.397	0.805
Hansen P-Value	0.194	0.186	0.111	0.364	0.151	0.200	0.187	0.439

NB: AR(1) and AR(2) test p-values are the reported p-values for the first and second order tests of serial correlation in the differenced residuals.
*, ** and *** denote significance at the one, five and ten percent levels respectively.

3.4 Results and Discussions

Table 14 presents the results of the Arellano-Bond difference GMM estimations. The table is divided into two sections. The first section employs the aggregate measures of GDP and genuine income as its left hand side variables. Then, the alternating pair of columns labelled ‘a’ and ‘b’ denote the use of GDP and genuine income as the dependent variables, respectively. Also, the first and last sets of columns in this section, ‘[1a] and [1b]’ and ‘[2a] and [2b]’, employ oil rents as shares of GDP and per-capita oil reserves as their measures of oil intensity respectively. The second section of the table presents an analogous representation of the results using the per-capita measures of GDP and genuine income as its dependent variables. In the table, the prefix before variable names “*ln*” indicates natural log of the variables. Further, the bottom of the table presents: (a) the number of observations, groups and instruments used in the estimation of all models ([1a], [1b],…,[4b]); (b) the p-values for the first and second order tests of serial correlation in the differenced residuals; (c) the Hansen test of over-identifying restrictions examining the joint validity of instruments.

Concentrating on the most important variables to our investigation, the results in the first section of the table employing the aggregate measures of GDP and genuine income as its regressands (models [1a], [1b], [2a], and [2b]) show evidence of an inverse relationship between income and the resource variables irrespective of the indicator of oil intensity considered. Foremost, the coefficients of oil share of GDP and per-capita oil reserve variables in models [1a] and [2a] show that a ten percent increase in oil intensity of the Non-OECD bloc leads to a 0.07 percent and 0.27 percent decrease in GDP, respectively. Analogously, the results in [1b] and [2b] show that a ten percent increase in oil rents as a share of GDP and per-capita oil reserves leads to a 0.73 percent and 1.54 percent decrease in genuine income of the Non-OECD group, respectively. These findings therefore suggest an existence of the curse in the Non-OECD bloc of oil producing economies. Also, the results indicate that the curse may be stronger for the genuine income measure of sustainable economic progress relative to the GDP indicator. However, it is worth noting that our finding of a negative association between oil intensity and income whilst employing the GDP indicator is not backed by statistical tests of significance, thus, making the curse somewhat inconclusive for this standard measure of income. Nevertheless, an appraisal of the results arising from the use of the genuine income measure for the estimations still indicates that the Non-OECD oil producing countries have not been successful in investing their oil rents in other forms of capital. Conversely, oil resources are a blessing to the OECD oil producing economies. The coefficients of the variables capturing the oil curse differential between the OECD and Non-OECD groups (that is, the interaction terms between oil intensity variables and OECD binary variable) are positive and they offset the negative slope for the Non-OECD group. In particular, the significant interaction terms given by models [1b] and [2b] show that a ten percent increase in oil share of GDP and per-capita oil reserves leads to a 0.23 percent and 0.57 percent increase in the genuine incomes of the OECD bloc, respectively.[59] The resource and interaction variables in these models – [1b] and [2b] – are jointly significant at the five and ten percent levels respectively. Thus, the OECD bloc experiences an 'oil blessing' using genuine income measures in appraising their management of oil rents. These countries may be classified as sustainable as they have satisfied the Hartwick rule whilst extracting their oil resources.

Similar results are obtained in the second section of the table employing the per-capita measures of GDP and genuine income as its left hand side variables. Again, the negative correlation between oil intensity and income is validated for both measures of income. Models [3a] and [4a] indicate that a ten percent increase in oil rents as a share of GDP and per-capita oil reserves is associated with a 0.12 and 0.44 percent fall in per-capita GDP of the Non-OECD oil exporting countries, respectively. The corresponding models employing green measures of per-capita income show that a ten percent increase in oil share of GDP and per-capita oil reserves leads to a 0.86 and 2.02 percent decrease in per-capita genuine income of the Non-OECD group, respectively. Once more, it may seem that this negative association is stronger for per-capita measure of genuine income relative to per-capita GDP indicator but we refrain from making such a conclusion as the results for the latter indicator of income are not statistically significant. Thus, as in aggregate genuine income, the oil curse is also confirmed in per-capita genuine income. Conversely, oil rents is reconfirmed to be a blessing to the OECD bloc employing the per-capita measure of genuine income in evaluating their adherence to the Hartwick rule. The interaction terms in models [3b] and [4b] indicate that a ten percent increase in oil rents as shares of GDP and per-capita oil reserves leads to a 0.07 percent and 0.74 percent rise in the per-capita genuine incomes of the OECD bloc, respectively. Also, an F-test of joint significance indicates that the resource and interaction variables in model [3b] are jointly significant at the ten percent level. In model [4b], a joint test on the resource and interaction variables confirms they are marginally insignificant at the ten percent level but the two variables are individually significant at the ten percent level.

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[59] The marginal effects of these two indicators of resource intensity for the OECD bloc are obtained by summing the slope of the resource variable under consideration with the slope of its corresponding interaction term.

Our confirmation of the oil curse in genuine income but not GDP indicators of economic output is in line with earlier studies that have explored the natural resource curse theory. Mickesell (1997) suggested that if GDP was adjusted for natural capital depreciation, the curse would be stronger in adjusted income. Also, we explored suggestions in the literature review section of the paper that Ecuador, Nigeria and Venezuela may be suffering from the oil curse as these economies dissipate a good proportion of their oil rents on boosting consumption through various subsidy and tax reduction policies (see Kellenberg, 1996; Hamilton et al., 2006). In line with these suggestions, Atkinson and Hamilton (2003) recommend a shift from the dissipation of resource rents for financing current consumption to prudent investments in man-made capital as one of the avenues of avoiding the curse. This recommendation conforms to the Hartwick rule for sustainable management of natural resource rents. Thus, our paper provides additional evidence to the suggestion that if the unsustainable component of income was adjusted for natural capital depreciation, then the oil curse in genuine income may be stronger than the curse in GDP in the presence of a significant evidence of the curse in the latter. A reliance on our finding of a statistically insignificant negative association between GDP and oil intensity may generate suggestions that the curse may not be a serious resource management issue that requires concerted effort for the implementation of policies aimed at achieving sustainable resource management. On the other hand, our finding of the curse in adjusted measures of income indicates the gravity of natural resource mis-management in Non-OECD economies thereby providing signals for the need of appropriate measures to sustainably manage natural resource rents in these economies.

A further appraisal of the results in table 14 leads to two important findings. First, the curse is stronger for the per-capita measure of genuine income relative to the aggregate indicator given a measure of resource intensity used in the investigations. For instance, a comparison of models [1b] and [3b] employing oil share of GDP as their measure of oil intensity shows the curse to be weaker in the former model using an aggregate measure of genuine income as its dependent variable; the resource variable turns up an impairing elasticity of 0.07 percent in [1b] compared to 0.09 percent in [3b]. A comparison of [2b] and [4b] amounts to the same finding using per-capita oil reserves as the measure of oil intensity.[60] Speculatively, this result may be an indication that the relatively high population growth rates usually recorded by developing countries might be an obstacle to their sustainable development. And as such, it suggests that population control measures may be an avenue of achieving sustainability in these countries.

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[60] This also applies to the aggregate and per-capita measures of GDP but we do not pay much attention to this given that the ascertained growth impairing effects of resource intensity are not significant.

Second, we find the curse to be stronger for per-capita oil reserves measure of oil intensity relative to share of oil rents in GDP given an indicator of genuine income employed for the exploration. For example, a comparison of the elasticities of oil rents as shares of GDP in model [1b] and per-capita oil reserves in [2b] shows the former model to have a weaker impairing effect on genuine income than the latter; 0.07 percent in [1b] compared to 0.15 percent in [2b]. The same finding applies to a comparison of [3b] and [4b] employing per-capita genuine income as their outcome variable.[61]

Despite the estimates of the lagged dependent variable not being particularly important to our investigations, these autoregressive parameters are significant and approximately 1.0 in all models. This implies the outcome variables (aggregate and per-capita measures of GDP and genuine income) are highly persistent with a high predictive power; essentially, the contemporaneous values of the dependent variables are highly dependent on their past realisations, thus, justifying the adoption of a dynamic framework in our analyses. Additionally, we find government expenditure as shares of GDP and inflation to exert a negative effect on both aggregate and per-capita measures of GDP and genuine income while investment as shares of GDP exerts a positive effect on the outcome variables. These findings are consistent with the following: Barro (1991), Bjorvatn et al. (2012) and Afonso and Furceri (2010) find that government size exerts a negative effect on growth,[62] and, Neumayer (2004) and Bjorvatn et al. (2012) find investment to exert a positive effect on growth. The other regressors capturing the degree of democratisation and trade openness generally turn up a positive effect on the outcome variables but this relationship is not significant.

Finally, the results in the bottom of the table indicate that our estimations satisfy the specification tests of the Arellano-Bond difference GMM method. First, the number of instruments is less than the number of groups in all models. Second, as it is expected, the p-values

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[61] It is worth noting that our investigation of the curse employs the levels but not the growth rates of the dependent variables. However, employing the growth rates of the variables only affects the magnitudes of the effects of the explanatory variables and the major findings of the paper remain unchanged. Essentially, the following results remain unchanged using the growth rates of the variables: there is still inconclusive evidence of the curse in GDP and per-capita GDP as the negative slopes of the resource variables are not significant; the oil curse and blessing in aggregate and per-capita genuine income is still confirmed for Non-OECD and OECD economies respectively; the curse is stronger in per-capita relative to aggregate genuine income; and the curse is stronger in per-capita oil reserves relative to share of oil rents in GDP.

[62] It is worth noting that there is no consensus on the effect of government size on growth in the development economics literature. Inasmuch as there are ‘negative proponents’ of this effect, there are ‘positive proponents’ as well. The former argue that a larger government size crowds out private investment and leads to economic inefficiencies thereby inhibiting growth. However, we do not delve much on this debate in this paper given that government size is not one of our major variables of interest.

of AR(1) indicate the presence of first order serial correlation in the differenced residuals. However, the AR(2) p-values reject this serial correlation for the second order form. Thus, the residuals in the levels equation are not serially correlated. Thirdly, the Hansen test of joint validity of instruments fails to reject the null hypothesis that the set of instruments employed for the estimations are valid. Thus, the instruments generated are adequate for the estimations.[63]

3.5 Concluding Remarks

The conception of the resource curse theory generated a considerable change in the classical reasoning that vast natural resource endowments serve as a driver for economic progress. Instead, the theory prescribed a paradoxical role for natural resource abundance; economies with vast natural resource endowments, particularly exhaustible resources, often record lower growth rates than resource scarce economies. Obviously, this is not an all-embracing theory as there are a few exempt countries that have successfully converted their natural resource rents into considerable levels of economic development. Norway and Botswana are prime examples of countries that have successfully converted their oil and diamond rents into remarkable levels of economic progress. Contrary to the paradoxical term 'resource curse', these countries experience a 'resource blessing'. On the other hand, Venezuela and Nigeria are often cited as prime victims of the oil curse. These countries have been unable to satisfy the Hartwick rule in managing their oil rents.

Existing studies investigating the curse mostly employ cross-country and panel growth regressions for their analyses. As these techniques are subject to endogeneity concerns, the use of alternative methods that correct these problems is needed. Also, a significant amount of these studies regress an income measure, GDP in its aggregate or per-capita terms, on a measure of resource intensity (particularly the share of natural resource rents in GDP) and other factors that are thought to affect economic growth. However, the use of standard GDP measures for investigating the curse does not depict the true incomes of resource intensive economies. Traditional national income accounts records rents from natural resource extraction as a positive contribution to income without making a corresponding correction for the value of depleted

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[63] It is worth mentioning that this test marginally rejects the null at the ten percent level in model [2a]. Extending the restricted lag limits for this model from five to six lags turns up a Hansen p-value of 0.223. This brings the instrument count to 48, which is still below the number of groups, 49. At the same time, the coefficients in the model remain largely unchanged but the investment variable now becomes significant at the ten percent level.

natural resource stock. This system of national accounts is inconsistent with green accounting practices and it leads to a positive bias in the national income computations of resource intensive economies. Thus, this shortcoming of standard income measures requires the application of greener and more sustainable measures of national income in resource curse explorations.

We employ the Arellano-Bond dynamic panel difference GMM method to control for endogeneity bias in our investigations of the oil curse in major OECD and Non-OECD oil producing economies. In addition to investigating the curse in standard income measures (GDP and per-capita GDP), we explore the curse in genuine income measures as well. Also, our investigation employs two competing measures of resource intensity: share of oil rents in GDP and per-capita oil reserves. We confirm the oil curse in Non-OECD countries employing both aggregate and per-capita measures of genuine income. However, the curse is stronger in the per-capita measure of genuine income. Given that aggregate genuine income is scaled by population estimates to arrive at its corresponding per-capita measure, this finding generates a speculation that the relatively high population growth rates usually recorded by developing countries may be a medium through which resource abundance translates to lower economic progress. Further, we find the curse to be stronger for the per-capita oil reserves measure of oil intensity relative to the share of oil rents in GDP. Again, this reiterates the speculation of high population growth rates in oil rich Non-OECD countries to be growth impairing. There is considerable evidence in the literature that resource intensive countries have been unable to escape the curse due to the conspicuous consumption pattern, high corruption and rent seeking associated with vast natural resource endowments. Thus, a good blend of sound investment decisions (to satisfy the Hartwick rule), population control and anti-corruption measures by the Non-OECD countries should generate impetus for escaping the curse. Though we find a negative association between oil intensity and GDP measures of economic performance, this correlation remains inconclusive as the results are not statistically significant. Conversely, we find the two measures of oil intensity considered (share oil rents in GDP and per-capita oil reserves) to exert a positive effect on the genuine incomes of OECD oil producing economies. Thus, the OECD countries experience an ‘oil blessing’ and they may be classified as sustainable based on the management of their oil rents.

This paper is restrictive in its coverage of natural resources in the investigations. Though our focus on oil is dictated by an objective to explore the oil curse, future studies could investigate the curse for other mineral, agricultural or forest resources. Also, the analysis could be extended by employing the genuine savings (and probably other green measures of income) for the investigations. Another important area of further research is the likely mechanisms explaining the curse, especially the role of political and bureaucratic factors (level of corruption, rule of law, quality of institutions, property rights enforcement etc). A deeper insight into these mechanisms could provide a basis for recommending the most important policies needed for escaping the natural resource curse.

Overall Conclusion

This thesis primarily seeks to contribute to a better understanding of the inter-relation between economic and environmental sustainability as well as sustainable management by public authorities of natural resource rents in low-income countries. To achieve this, the thesis adopts a paper format comprising three separate articles or chapters. These articles seek to achieve the following secondary objectives: a) To estimate and monetise the mortality related benefits associated with mitigating outdoor particulate air pollution in developing economies using Nigeria as a case study, b) To empirically explore the validity of the popular Environmental Kuznets Curve theory for carbon emissions across a collection of geographical and economic bloc of countries, and c) To empirically investigate the oil curse theory between OECD and Non-OECD economic blocs of oil exporting economies. Though the chapters investigate different research problems, they are all related to the thesis' main objective of contributing to a better understanding of the inter-relation between management of (air) pollution externalities and a judicious management of natural resource rents especially in developing economies. This section summarises the major findings of the chapters and pools them into a coherent research piece. It also reflects on the policy implications of the findings and provides a critical appraisal of the methods used in achieving the three secondary objectives covered in the thesis.

The first article investigated the mortality related benefits associated with improving air quality in developing economies, the first secondary objective of the thesis. By doing so, this paper contributes to the general literature on the valuation of non-market goods and services associated with estimating health and economic costs of air pollution by being the first study to employ a meta-regression benefit transfer technique in monetising the mortality related benefits of mitigating particulate pollution in low-income economies. We proceeded by comparing the two major benefit transfer techniques used in monetising a quantified health effect of air pollution – the value transfer method and meta-regression analysis. The former method is more attractive to most researchers investigating developing economies because it has a simpler and more straightforward benefit transfer application compared to the latter. However, this computational ease may lead to considerable errors in the value of statistical life estimates provided by the method. A comparison of the two methods leads to the finding that the meta-regression technique may be more reliable in estimating money-risk trade-offs for developing economies due to the following reasons. First, the method incorporates more characteristics or factors that vary between study sites and the policy site in its benefit transfer application. Second, the value transfer application leaves much more to the judgment of the analyst, which leaves open the possibility of substantial error. This finding is backed by evidence from previous studies supporting the stylised facts that meta-regressions generally lead to more accurate predictions than value transfers (see for instance Boyle et al., 2010; Kaul et al., 2012; and Rosenberger and Loomis, 2003). Using the meta-regression method, we estimate Nigeria's VSL as \$489,000. It is worth noting that this estimate falls within Miller's (2000) prediction of \$40,000 to \$700,000 for Nigeria's VSL. This VSL estimate is tied with dose response functions from the epidemiological literature to arrive at the paper's major finding that mitigating Nigeria's particulate pollution to the WHO standards would have prevented at least about 58,000 premature deaths and the economy would have recorded an avoided mortality related welfare loss of about \$28 billion or 19 percent of the economy's 2006 GDP.

Assuming benefits of mitigation exceed costs, a first glance at this result may seem dramatic as it connotes a mind blowing benefit of 19 percent of 2006 GDP for mitigating particulate pollution. Probable questions that come to mind after a glance at this result are how much is the reduction in mortality risk associated with mitigating particulate pollution to WHO standards, how much is the total amount of pollution to be mitigated and how could this target be achieved, and, how could the mitigation action be funded? We reflect on these questions examining the major reasons accounting for this seemingly dramatic result and we summarise probable real life implications of an attempt to provide answers to the questions. Foremost, the economy's 2006 average PM_{10} concentration is $44.99 \mu g/m^3$ and the WHO PM_{10} air quality standard employed for the health cost estimations is $20 \mu g/m^3$.This implies that the targeted mitigation analysed in this paper is $24.99 \mu g/m^3$ or roughly 55.5 percent of observed particulate pollution in 2006. As the economy stands to reap a benefit of at least \$28 billion from mitigating $24.99 \mu g/m^3$ of particulate pollution, this result translates to a benefit of about \$1.12 billion for mitigating a single $\mu g/m^3$ on average or 0.76 percent of the economy's 2006 GDP.

Then, how could a program geared towards mitigating this amount of pollution be funded and what is the total reduction in mortality risk resulting from mitigating PM_{10} pollution to the WHO standard? The economy's crude death rate is 1.7 percent and this is inclusive of deaths caused by PM_{10}. Employing dose response functions, we estimate PM_{10} to cause about 68,500 premature deaths.[64] The difference of this estimate from the total population – 142.7 million people – implies that the crude death rate exempt of particulate pollution is approximately 1.65 percent. Thus, particulate pollution increases mortality rate by about 0.05 percent. By implication,

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[64] This estimate is obtained by taking the mean of the estimates of premature deaths provided by the lower and upper coefficients of the PM_{10} DRF. See table 6 for more details.

if 2000 Nigerians were sampled, the life of an anonymous one would be saved by mitigating PM_{10} pollution. Given an estimated value of statistical life of about $489,000 and if government was to fund the analysed mitigation through taxes, this result further implies that on average, these Nigerians would be required to pay about $245 for a 0.05 percent reduction in mortality risk. This amount, which is over 10 percent of an average Nigerian's income, seems inconceivable given the acute poverty levels in the country. It would be expected that average Nigerians would have more pressing needs to attend to relative to doling out roughly 10 percent of their income for mitigating pollution. However, a deeper consideration of the funding for the suggested mitigation action reveals the following.

Foremost, the initial assumption of achieving a mere 0.05 percent reduction in mortality risk may be valid but the total amount of mitigation to be achieved – $24.99\mu g/m^3$ or roughly 55.5 percent of the observed PM_{10} concentration in 2006 – may seem substantial. In fact, it might be considered an overambitious target for a low-income country like Nigeria to mitigate 55.5 percent of its 2006 particulate pollution in a single year. As any amount of mitigation in a specific year is expected to lead to improved health conditions in forthcoming years, it therefore makes economic sense to spread costs of mitigation action over several years. If mitigation was targeted for say an average of $3.57\mu g/m^3$ for seven years – which some may still consider an optimistic target for Nigeria – this aforementioned sample of 2000 Nigerian's would be required to pay $35 each per year for the targeted seven years to mitigate 55.5 percent of the economy's 2006 particulate pollution. Over time, the positive spill-over benefits resulting from this mitigation could yield considerable health benefits, especially to individuals with cardiovascular diseases.

Also, there are concerns in the epidemiological literature about the accuracy of dose response functions used in quantifying mortality effects, particularly the use acute studies investigating the effect of short term exposure to air pollution in quantifying health effect. For instance, Koop and Tole (2004) suggested that the use of OLS techniques commonly employed in investigating acute effects of particulate pollution on mortality generally leads to the finding of a positive and significant association between pollution and mortality. However, when measures of model and variable uncertainty considering which models out of a myriad of possible models to be chosen from in estimating health effect are accounted for in the investigation, this could considerably change the findings. The paper particularly finds that accounting for model and variable uncertainty may lead to very large standard errors relative to point estimates of the mortality effect of particulate pollution. This generates scepticism about the statistical robustness of the estimated correlation coefficients between pollution and mortality usually reported in the literature. Thus, the point estimates may be over-estimates of the mortality effect of particulate pollution. This concern is particular to acute effects of air pollution regressing daily death counts on daily concentrations of air pollutants and other factors that affect mortality, such as temperature and humidity. However, the concern is alleviated in the case of longitudinal studies of chronic effects analysing the mortality effect across communities with different levels of air pollution over longer time periods. The dose response functions used in this paper may not suffer much concerns of being over-estimates as Ostro (1994) combined both acute and chronic mortality effect studies in his meta-regression for producing the mortality effect dose response coefficients transferred to this as well as other studies. On a flip side of the argument, it could be possible that the dose response coefficients transferred to Nigeria may be underestimates. Hence, it is expected that the use of lower and upper limits of dose-response functions which generates room for sensitivity analyses of the mortality effect of particulate pollution in this paper might have accounted for these concerns. This issue was discussed in the conclusion of chapter one suggesting that there is uncertainty whether or not the transfer of dose response functions leads to an overestimation or underestimation of the mortality costs of particulate pollution in Nigeria. Nevertheless, currently, the assumption of transferable dose response functions is indispensable in health risk analyses for Nigeria and a majority of other developing nations due to the unavailability of local estimates.

Related to the aforementioned concern, the primary value of statistical life estimates used for the meta-regression analysis are highly based on US studies and this could (considerably) affect the predictions for developing countries. To control for this, we classified the meta-regression sample into two major groups – developed and developing economies – and defined a developed country binary variable. This is interacted with the income variable to capture the differential in the income elasticity of willingness to pay for fatal risk reduction between developed and developing economies. This interaction moves in tandem with one of the paper’s objectives of obtaining a value of statistical life prediction function for developing countries. Another method to control for the relatively high number of US studies in the meta-regression sample is to weight the different value of statistical life estimates transferred to this study depending on how important they are considered to the investigation. It is expected that this form of weighting would ascribe relatively higher and lower weights to estimates transferred from developing and developed economies respectively. However, the answer to the question of how important is each study site’s estimate employed for the benefit transfer valuation exercise – which would determine the weights to be employed – is subjective and this could generate considerably different weights depending on the judgments of various analysts.

It is also worth noting that it is not an unusual practise to weight primary observations transferred for meta-regression analyses by their inverse variance or sample size to correct for probable heteroscedasticity arising from the use of different sample sizes, estimation procedures etc for the primary studies (Nelson and Kennedy, 2010). Often these primary study variances are not known and this applies to our case. The wide-spread lack of knowledge of variances and sample sizes is accentuated in Nelson and Kennedy (2010), where 111 out of 140 meta-analyses surveyed did not incorporate any knowledge of these parameters used in weighting the primary observations of interest. Most importantly, our paper reports robust estimates of standard errors to account for any probable heteroscedasticity in statistical inference. Additionally, we conducted tests of heteroscedasticity. The homoscedasticity of the residual terms in our meta-regression models gives credence for our choice of not weighting individual VSL estimates in the meta-regression analysis.

The second article examined the validity of the famous Environmental Kuznets Curve theory for CO_2 emissions across a collection of geographical and economic bloc of countries with the aim of accounting for distributional heterogeneity in our exploration. Most empirical studies exploring the income-emissions nexus employ a panel dataset of countries and these studies rely almost exclusively on the use of conventional longitudinal econometric techniques especially fixed and random effects methods. A major criticism of these methods stems from their focus on estimating the rate of change in the conditional mean of emissions (as a quadratic or cubic function of income) thereby estimating constant slope coefficients across heterogeneous countries. However, estimating constant slope coefficients across heterogeneous nations implies that the procedures are incapable of capturing country level heterogeneity in Kuznets curve explorations. Thus, our paper contributes to the growing empirical literature on the Environmental Kuznets Curve by exploring the validity of the CO_2 income-emissions nexus across different quantiles of the conditional distribution of emissions. The chapter employed the quantile fixed effects method to provide empirical insights into the distributional heterogeneity of this relationship. We empirically examined the relationship between per-capita measures of CO_2 emissions and GDP for the entire world and different sub-sets of countries – OECD, Non-OECD, West, East Europe, Latin America, East Asia, West Asia and African regions. We innovate also by extending the Machado and Mata (2005) decomposition procedures to explore the most important explanations accounting for CO_2 emissions differential between OECD and Non-OECD economies.

Our exploration confirmed the EKC relationship for the entire world, OECD and Western samples across all conditional quantiles of emissions considered – 0.1, 0.25, 0.5, 0.75 and 0.9 –

and the conditional mean as well. By implication, the conditional mean method provides roughly the same information about the prevailing income-emissions relationships at different percentiles of the conditional distribution of emissions in these samples. However, this method provides less information in other samples. For instance, the conditional quantile method estimates a monotonic and an inverted U-shaped income-emissions nexus for the 0.25 and 0.90 quantiles in the Latin American sample respectively. On the other hand, the conditional mean method estimates a monotonic relationship. This implies that the latter technique is able to capture the relationship for countries with emissions at the lower tail of the emissions distribution – 0.25 quantile – but it misses the inverted U-shaped relationship at the 90th percentile. A similar scenario occurs in the East Asian sample where the conditional mean method is able to approximate the monotonic income-emissions relationship prevailing in the median and lower tail distributions but it misses the inverted U-shaped relationship at the upper tail percentiles. These results therefore indicate that the quantile fixed effects method is more informative about the prevailing income-emissions relationships at different conditional distributions and it provides room for a more comprehensive scrutiny of the income-emissions nexus relative to the conditional mean technique.

Our confirmation of the Kuznets Curve relationship in the Latin American and East Asian samples by the conditional quantile technique provides a signal that developing economies may be capable of achieving environmental clean-ups as well without necessarily recording the relatively high incomes displayed by their developed counterparts. Also, the decomposition results indicate that income difference between OECD and Non-OECD economies is an important factor attributing to the emissions differential between the two groups. However, other important factors are equally significant for explaining this differential. If the goal of policy was to minimise this differential between the two blocs, a redistribution of emissions consistent with environmental sustainability and climate change mitigation would require a combination of mitigation efforts by both blocs but the OECD bloc may be expected to abate more considering historical levels of emissions and other equity concerns. These considerations are characteristic of Kyoto Protocol's procedures for mitigating global carbon emissions. Hence, a combination of the findings from the quantile regression and decomposition analysis implies that there is need for policy to target income and other important factors explaining the emissions differential – one of the possible major factors being the use of well-designed mitigation tools – to mitigate carbon emissions. A combination of policies enhancing economic development and pollution mitigation could be more beneficial to achieving cleaner environmental standards relative to a reliance on policies promoting rising incomes alone.

Though the quantile fixed effects procedure employed in this chapter effectively captured distributional heterogeneity of country level emissions in our exploration of the income-emissions nexus, the method is not without flaws. First, as the reduced form model employed for the estimations does not control for other possible determinants of emissions which may be correlated with income – such as energy use, population density and trade openness – this may reduce the reliability of any interpretation of the causal effect of income on emissions in the analysis. More importantly, the model may be prone to endogeneity bias, especially bias arising from bi-directional causality. This precludes causal form interpretations in the exploration. For instance, an increase in economic activity could translate to a rise in carbon emissions via the scale effect. The greenhouse effect of a prolonged increase in emissions could affect regional temperatures. This in turn could lead to an increase or decrease in agricultural productivity, thereby affecting economic output, depending on the region considered. This bi-directional causality may be more pronounced in the case of a local pollutant. For instance, higher concentrations of particulate emissions brought about by increased economic activity is expected to cause greater damage to human health, ceteris-paribus. This may in turn lead to reduced labour productivity. Most studies investigating the income-emissions nexus for local and global pollutants might suffer from endogeneity bias (see for instance Stern, 2004).

Thus, it may be necessary to include other important determinants of emissions in the EKC model and employ methods that control for endogeneity bias – such as instrumental variable and generalised method of moments approaches – to be in a position to make causal effect interpretations in the analysis. This may be particularly important to scenario based forecasts of carbon emissions for analysing different paths of mitigating emissions based on assumed growth in emissions from different sectors of the economy in energy-economic modelling. Future research could extend the quantile fixed effects or random coefficients methods to instrumental variable and generalised method of moments techniques to capture country or regional level heterogeneity and control for endogeneity bias in Kuznets curve investigations. Also, the more apparent bi-directional causality depicted by local pollutants relative to carbon emissions may mean that the conditional quantile method employed in this paper may be more appropriate for examining the dynamics of local pollutants. However, our application of this technique to studying the dynamics of carbon emissions is based on the central problem of climate change to a sustainable global environment and the availability of richer country-level data for carbon emissions relative to local pollutants. Recorded series of observations of carbon emissions for most countries at major data-bases are considerably longer than series for local pollutants. Moreover, the relevance of panel data methods for investigating the income-emissions relationship for local pollutants might be reduced if the series were rich enough for individual country analyses.

The third chapter investigated the natural resource curse theory for crude oil in major OECD and Non-OECD oil producing economies. This theory posits that economies with vast natural resource endowments often record lower growth rates than resource scarce economies. Thus, natural resource abundance inhibits growth. The literature ascribes the Dutch disease, poor quality of institutions, rent seeking and corruption as mediums through which resource abundance translates to slower growth. The investigation of the curse employed in this paper was spurred by two major issues with the empirical literature. Foremost, existing empirical studies investigating the theory regress a measure of economic output, GDP in its aggregate or per-capita term, on a variable capturing natural resource intensity and other factors that affect economic progress. However, traditional national income accounts records natural resource rents as a positive contribution to GDP without making a corresponding adjustment to depleted natural capital stock. This system of national accounts fails to consider that the depletion of a natural capital stock is essentially the liquidation of an asset, thus, natural resource extraction should not be treated as a positive contribution to GDP (Hamilton and Clemens, 1999). As a result, traditional national accounting procedures lead to a positive bias in GDP computations of resource intensive economies. This shortcoming of standard GDP measures of income therefore requires the application of greener and more sustainable indicators of economic progress in resource curse investigations. Second, a majority of empirical studies investigating the curse employ standard panel and cross-country estimation techniques subject to endogeneity bias. Given these issues, our paper contributes to the existing empirical literature in two ways. First, we investigate the oil curse in major OECD and Non-OECD oil producing economies using genuine income measures of economic output. This indicator provides a closer approximation of the ‘true incomes’ of resource intensive economies relative to standard GDP measures as it accounts for natural capital depreciation in its national income accounting. Second, we deviate from a majority of the empirical literature by employing the difference GMM estimation technique to control for endogeneity bias. Also, our paper employs two competing measures of oil intensity for the investigations: share of oil rents in GDP and per-capita oil reserves. The former and latter translate to measures of oil dependence and abundance respectively.

We confirmed the oil curse in aggregate and per-capita genuine income indicators for the Non-OECD bloc. Also, we find that the negative association between oil intensity and genuine income is stronger in per-capita oil reserves measure of resource intensity relative to share of oil rents in GDP. Our confirmation of the oil curse in genuine incomes of Non-OECD oil producing countries indicates the gravity of natural resource mis-management in these economies. Thus, there is need for the implementation of appropriate measures to promote sustainable management of oil rents in these economies. There is considerable evidence in the literature that resource intensive economies have been unable to avoid the curse due to the conspicuous consumption pattern, poor quality of institutions, high level of corruption and rent seeking characterised by these economies. An investigation of the mediums through which oil intensity leads to the curse in genuine incomes of Non-OECD economies is a subject worth exploring to proffer appropriate recommendations for the most important mediums of avoiding the curse. Recommendations from this investigation in conjunction with sound investment decisions to satisfy the Hartwick rule should inform the formulation of policies for avoiding the curse. Conversely, our investigation finds oil resources to exert a positive effect on the genuine incomes of the OECD bloc of countries. Resultantly, oil resources are a blessing to these economies.

The difference GMM method employed for this chapter’s investigations was appropriate to control for endogeneity bias but the technique is not free from criticism. For instance, the OECD binary variable in the resource curse model ought to be jointly estimated with the other regressors in the model. Technically, this variable is included in the level equation of the oil curse model but the differencing transformation adopted by the method as outlined in equation (xvi) expunges it. Though our investigation is primarily interested in the coefficient of the interaction term capturing the curse differential between OECD and Non-OECD economies, it is possible that the sweeping out of this variable may affect the estimates of other regressors. This concern might be more worrying if the model was meant for predictive purposes where the coefficient of the expunged variable would stand for the intercept of the Non-OECD bloc of countries. On the other hand, it could be the case that there might not be any meaningful changes to the estimates of other regressors resulting from the procedural sweeping out of this variable as the method controls for all time invariant variables including the OECD dummy. As it stands, any probable estimation bias resulting from the sweeping out of this variable is unknown.

Second, the difference GMM technique estimates the effects of the regressors on the conditional mean of genuine income. Thus, the method is incapable of capturing heterogeneous effects of resource intensity on progress in the two economic blocs considered. For instance, we find that there is an oil curse in the conditional mean of genuine income for Non-OECD economies but this does not necessarily imply that some of the economies in this bloc are not suffering from the curse. It could be that Venezuela, Ecuador and other countries are driving the curse in the Non-OECD economies. In the same vein, the blessing in the OECD bloc does not necessarily imply that all the economies in this bloc experience an oil blessing. Norway and Canada could be driving the blessing in this economic group. Thus, future investigations may explore the use of a combined quantile regression or random coefficients methods with GMM or instrumental variable approaches to control for both heterogeneity and endogeneity bias in resource curse investigations.

Despite their individual shortcomings, the three major techniques used for the thesis' estimations were suitable for the various reasons they were employed. The meta-regression technique successfully provided a value of statistical life prediction function for low-income economies in the first chapter. Analogously, the quantile fixed effects and difference GMM methods appropriately captured distributional heterogeneity and controlled for endogeneity bias whilst investigating the CO_2 Kuznets curve and oil curse theories in the second and third chapters respectively. An application of these three methods in their respective areas of investigation served as a deviation from the commonly used approaches. This denotes a contribution to the methodological tool-set employed for understanding the inter-relation between sustainable management of pollution externalities and a judicious management by public authorities of natural resource rents in developing economies.

Collating the key findings of the three chapters of the thesis, the three major findings of the thesis could be summed up as: a) developing economies stand to gain significant health and economic benefits from the mitigation of particulate pollution, b) these economies could achieve decent environmental standards via a planned action geared towards abating carbon emissions despite their relatively low income levels, and 3) avoiding the oil curse (in genuine income) is undeniably a resource management problem that warrants more attention by oil rich developing economies. Synthesising these findings therefore implies that an appropriate mix of policies targeting rising incomes and cleaner environmental standards could be beneficial to the economic and environmental sustainability of developing economies. Given the prevalent poverty levels in these economies, it is not surprising rising incomes is one of their key macroeconomic objectives. Poverty considerations may serve as a constraint to internal funding of pollution abatement programs. However, the first two chapters of the thesis indicate the control of environmental pollution as another important area these economies have to give more attention to. These chapters provide evidence that developing economies could also achieve decent environmental standards through a planned abatement of both local and global pollutants. An appropriately planned mitigation action could be beneficial to their environmental quality and economic prosperity. We provide evidence that the goals of economic and environmental sustainability are interwoven. This contributes to one of many perspectives of considering the inter-relation between the management of environmental pollution and economic progress.

As found in the thesis, the mitigation of the most dangerous local pollutants generates significant health benefits to low-income economies. A healthier population implies more economic savings from the costs of treatment of sicknesses associated with (air) pollution. This also connotes an increased labour force productivity, ceteris paribus. Combining the association of the first two chapters with the explorations of the third, the thesis informs that profitable investments of natural resource rents by resource rich developing economies could stimulate economic activity, thereby, serving as a driver for economic progress. However, substantial effort is needed by these economies (especially those rich in oil resources) to reap the growth enhancing benefits of sustainably managed natural resource rents. Policies promoting economic diversification, control of corruption and rent seeking could serve as avenues for ensuring sustainable investments of resource rents. This consideration promotes an understanding of the inter-relation between prudent management of natural resource rents and economic progress. In a nutshell, this thesis specifically provides evidence that the mitigation of particulate and carbon emissions as well as profitable investments by public authorities of oil rents could generate significant health, economic and environmental benefits to developing economies. Thus, the findings give credence to the recommendation that an abatement of the most dangerous local and global pollutants as well as a prudent investment of natural resource rents are important avenues to improving human health and stimulating economic and environmental sustainability. The goals of economic growth and environmental clean-up are closely inter-related, hence, policies aimed at promoting economic sustainability should be set hand-in-hand with those promoting environmental sustainability. This involves an appropriate mix of policies promoting industrialisation, human capital development, improved institutional quality and the use of various instruments for mitigating pollution.

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