DISSERTATION

ECONOMIC & SOCIAL DETERMINANTS OF CO_2 EMISSION TRENDS

Submitted by

Maged A. Hamed Elhemri

Graduate Degree Program in Ecology

In partial fulfillment of the requirements

For the Degree of Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

Spring 2021

Doctoral Committee:

Advisor: Robert W. Kling

Andrew F. Seidl
Gregory D. Graff
Marco Costanigro

ABSTRACT

ECONOMIC & SOCIAL DETERMINANTS OF CO_2 EMISSION TRENDS

The increase in the concentration of carbon dioxide caused by human activity is a major cause of climate change, which is the most prominent international environmental problem in recent decades. This research aims to study the relationship between economic growth and CO_2 emissions resulting from production-related fossil fuel burning, under the assumptions of the Environmental Kuznets Curve (EKC), with an emphasis on the impact of underlying variables which may affect CO_2 emissions through the "technique" variables (structure and technology). From our survey of the literature, we extract the general trends of the CO_2 EKC hypothesis, studies which mostly follow the traditional method of the standard regression model (with emissions as a quadratic function of GDP per capita). Many of those studies confirm the EKC hypothesis but find that the critical value, or turning point, is at a relatively high level of GDP. Generally speaking, those findings were confirmed in all three levels of our analysis.

In our Level 1 analysis, we develop a standard EKC regression model as a benchmark, using a panel data sample. The results confirm the EKC hypothesis, where CO_2 emissions have a positive relationship to the level of income before the EKC threshold and then a negative relationship beyond the threshold (at a relatively high level of GDP). Then a subsample analysis, on the basis of education quality, transparency, regulatory effort, and democracy, suggests that underlying variables may have a beneficial effect on emissions efficiency; on the other hand, the trade openness subsample analysis may indicate a detrimental effect on emissions efficiency,

though further study is needed to determine the effect of the scale factor and the technique factor that may tend to induce or inhibit the down-turning of the CO_2 EKC.

In our Level 2 analysis we break out the technique factor (structural and technological) from the scale factor and the result confirms the EKC hypothesis and supports the idea that a downturn is due to improved technology or emissions efficiency. The analysis contains additional information about the role of structural change in explaining the EKC. When countries become affluent, they start to demand proportionally more services, decreasing the pollution intensity of production, though with the possibility of two-way causality between industrial share and income.

The Level 3 analysis isolates the impact of each underlying variable on its own, *ceteris paribus*, to investigate which variables may tend to encourage or inhibit the down turning of the CO_2 EKC through the technique factor; the results confirm the EKC hypothesis. Moreover, we find that some underlying variables (Education, Trade Openness, and Regulatory Effort) affect the relationship between carbon dioxide emissions and income with beneficial impact on the emissions efficiency of production; others (Transparency and Democracy) may not have the same effect on emissions efficiency, while evidence is insufficient to confirm a negative impact of global free riding ability. By comparing the effects of the underlying variables both in terms of GDP elasticity effects on emissions and of the turning points, in both Levels 1 and 3, we find that Education and Regulatory Effort affect the income-emissions relationship with a beneficial impact on emissions. For Trade Openness, there is a detrimental impact but the net beneficial effect of high openness compared to low openness suggests a benefit from the composition effect relative to any scale effect; openness lessens the negative impact of affluence. Regarding Democracy and Transparency, there is a contradiction in the conclusions between Level 1 and 3, and results also contradict our expectation, which leads us to not draw any strong implications overall.

ACKNOWLEDGEMENTS

I praise the Almighty God for granting me the blessings, and strength, to complete my graduate studies successfully. It was a great journey at Colorado State University, which I had the honor to be a part of over the past years, starting with my second Master's degree in the Department of Agricultural Economics and Natural Resources, and ending with my PhD degree program in Ecology in collaboration with the Department of Economics. My great appreciation goes to my advisor Dr. Robert Kling for all his advice and assistance. I would like to express my sincere gratitude for his continuous support of my academic study, and my personal life, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all the time of research and writing of this dissertation. I also would like to thank the doctoral committee for their valuable suggestions to improve the dissertation. My thanks to all my teachers in every single course and all my graduate student colleagues from all over the world at CSU. Finally, I extend a big thank you to my family and friends for their support and encouragement, especially my wonderful wife Hana Gatlawi, who has endured many difficulties with me over the past years.

DEDICATION

To the memory of my adored father.

To my mother, my wife, my daughters, and my siblings.

TABLE OF CONTENTS

Chapter 1. Introduction

1.1 Background

Economic growth is linked to environmental degradation, which is the "depletion of resources such as air, water, and soil; the destruction of ecosystems and the extinction of wildlife; and pollution" (Johnson & et al, 1997). As the human species grows and thrives -- measured at least by population and material affluence -- it impacts its environment and other species, and is in turn impacted by those changes. A very important instance of these impacts and feedback loops involves the way human economic production affects the global climate via the emission of so-called "greenhouse gases" that absorb and emit radiant energy in the thermal infrared range, causing the greenhouse effect.

Through a variety of activities such as changes in land use including deforestation, burning of fossil fuels, agricultural processes, and industrialization, humans have pumped greenhouse gases (most notably carbon dioxide) into the atmosphere over the past two centuries, and that has led to raising their levels higher than they have been for thousands of years, lowering environmental quality and expanding pollution problems. The consequences of global warming such as the rise of sea levels, decrease in glacial mass, and more frequent extreme weather events have raised public concerns over environmental issues since they threaten the well-being of humankind.

At the same time that economic growth affects the climate, it creates dynamic trends internal to its own economic and socio-political systems regarding production technologies, valuation of the environment, political empowerment, and social priorities. This dissertation explores the interactions among economic affluence, CO_2 emissions, production technology, and a number of underlying socio-political variables. The goal is to identify social policy directions that offer the most promise of beneficially dampening the destructive impacts of human economies on the environment in which they operate.

Carbon dioxide has been claimed to be the gas most responsible for global warming, as its concentration is the highest as compared to the other greenhouse gases. Studies and future projections indicate an escalating growth in emissions linked to economic growth (Kaika & Zervas, 2011). The global average annual growth rate of CO_2 emissions was 2.9% over the first decade of the third millennium, but in 2012 the increase slowed to 1.1% (totaling 34.5 million metric tons), while the global economy grew by 3.5% in the same year (PBL Netherlands Environmental Assessment Agency, 2013). In 2012, a 'decoupling' of the growing CO_2 emissions from international economic growth (in GDP) occurred reflecting a shift from fossil-fuel intensive activities towards renewable energy intensive activities and increased energy saving (PBL Netherlands Environmental Assessment Agency, 2013).

In 2017, global CO_2 emissions from fuel combustion grew by 1.4% according to the International Energy Agency, which noted, "The increase in CO_2 emissions, however, was not universal. While most major economies saw a rise, some others experienced declines, including the United States, United Kingdom, Mexico and Japan. The biggest decline came from the United States, mainly because of higher deployment of renewables."

The accumulation of greenhouse gases in the atmosphere, especially carbon dioxide and the heavy impact it can have, has increased interest in human emission sources (anthropogenic sources) and ways to reduce those emissions. Reduction requires considerable changes in energy use and global production techniques in multiple activities such as agriculture, industry, and land-use. In addition, the level of future emissions is related to variables such as economic and population growth, and technological changes that are difficult to predict, which leads to uncertainties in expectations and strategies (Clarke et al., 2008).

There is a debate between many economists and ecologists about economic growth and environmental degradation relationship; while ecologists tend to think it is a detrimental relationship, (e.g., Meadows et al, 1972), many economists interpret it through the Environmental Kuznets Curve (EKC). The classic EKC has an inverted-U shape. As income in a country increases, the emission level grows at first until it reaches a peak and then begins declining after a threshold level of income has been crossed (Dinda, 2004). This is due to the combination of two main effects: the scale factor and the technique factor. At lower levels of economic development or per-capita GDP, the scale factor dominates. More production implies more pollution, particularly as societies move from a predominantly agricultural economy to a predominantly manufacturing economy. Subsequently, at higher levels of income (past the threshold level) and later stages of development, the technique factor tends to dominate: first, with more resources available for investment the economy moves toward more emphasis on the production of services and cleaner activities that are less resource-intensive (structural change); second, with basic needs met, citizens place more emphasis on demand for environmental quality as a basis for quality of life; third, better technology can be incorporated into production processes to create higher levels of efficiency and pollution abatement; and fourth, more education, increased environmental awareness, democracy, and transparency may allow environmental preferences to be effectively expressed and implemented through governmental enforcement of environmental regulations and higher environmental expenditures. All these factors encourage cleaner, greener production, so the technique factor can decrease emissions faster than the scale factor increases them.

The Kuznets curve is basically a graphic representation of economist Simon Kuznets' hypothesis of how stages of development (affluence) affect income inequality. According to Kuznets (1955) the relationship between individual income and income inequality is an inverted U-shaped curve. As per capita income increases, income inequality also increases in the beginning and then begins to decline after a turning point. Meaning that sustainable economic growth will lead to lower levels of inequality.In the nineties, this relationship was used in the field of environmental economics and known as the Environmental Kuznets Curve (EKC) to describe the relationship between the level of economic growth represented in GDP per capita, and various aspects of environmental degradation such as deforestation, biodiversity, and pollution, especially air pollution.

The early studies focused on supporting the hypothesis and did not include any extra control variables besides income (represented as GDP per capita). The empirical results showed an inverted-U shape, especially in local air pollutants such as sulfur dioxide, nitrogen oxide, particulates, and smoke, for which policymakers and social planners found an incentive for effective regulation, causing an EKC turning point at relatively low levels of average income (e.g., Grossman and Krueger, 1991; Holtz and Selon, 1992; Selon and Song, 1994). In contrast, for global environmental indicators such as CO_2, emissions either increase monotonically with income or have turning points at very high income levels.

Therefore, we see studies that show the relationship between CO_2 emissions and GDP to be monotonically increasing, or that are unable to provide enough evidence whether the hypothesis of EKC holds (e.g. Shafik and Bandyopadhyay, 1992; Roca et al., 2001; York et al., 2003; Azomahou et al., 2006; Huang, 2008; Akbostanci, 2009). Numerous studies have estimated a shape for the CO_2 EKC which, depending on the functional form, may imply a downward-sloping side to the curve by extrapolation (e.g., Cole et al. ,1997; Agras and Chapman ,1999; Galeotti and Lanza ,1999; Heil and Selden ,2001; Galeotti, 2003; Neumayer, 2004; Cole ,2004; and Galeotti et al., 2006; Choi, et al 2010). Some studies showed an inverted-U shape, with a turning point coinciding with the oil crisis of the 1970s (e.g. Moomaw &Unruh, 1997; Galeotti, 2003; He & Richard, 2010), which could be interpreted as an adjustment towards less polluting technology in response to more expensive oil. This is consistent with studies which found an N-shaped relationship, which implies that any delinking would be temporary, or with some single-country time series studies showing an inverted-U shape because of differences in economic structure and the neglect of the consumption side (e.g. Sengupta, 1996; Moomaw & Unruh, 1997; Friedl & Getzner, 2003; Martinez-Zarzoso & Bengochea-Morancho, 2004; Choi, et al 2010; Alwan & Al-Tarawneh, 2014).

Based on the foregoing, it is appropriate to examine the result of the Neumayer (2004) study, which found that the relationship between CO_2 and per capita income is monotonic and positive, and CO_2 emissions are increasing but at decreasing rate. Moreover, we think it's clear that the chosen functional form, specification, and data matter a lot in answering the question of the existence and significance of the EKC.

At the theoretical level, there are reasons to believe there are forces that inhibit the downturning of the curve. Perhaps the largest is that CO_2 and other "greenhouse gases" are global pollutants, rather than local or regional. For each county, the benefits of emissions are mostly internalized while the damage costs are mostly external and fall on others. Therefore, we have a global public externality, or alternatively a "global commons" problem, in which each country has a vastly diminished level of both ability to perceive the impacts of its own actions, and incentive to do anything about it. There is another form of free riding that can occur. As with other pollutants, one country’s evolution toward a cleaner output mix can be enabled by open trade, which allows the importation of goods whose dirty production occurs in other countries. In the case of some pollutants, that means the damage costs are mostly exported and borne by the producing country. However, in the case of global climate-change pollutants, some of those damage costs do “come back home” though in small enough proportion that the global free-rider factor still dominates incentives. Trade is a factor in the size of the “leakage” and “feedback” effects of a country’s consumption demand.

Many scholars have published EKC articles which include further explanatory variables in order to model underlying or proximate factors, such as ‘‘political freedom’’ (e.g., Torras & Boyce, 1998) or "output structure" (e.g., Panayotou, 1997), or "trade" (e.g., Suri & Chapman, 1998). But, Stern (2004) indicated that “testing different variables individually is however subject to the problem of potential omitted variables bias. Further, these studies do not report cointegration or other statistics that might tell us if omitted variables bias is likely to be a problem or not.”

1.2 Research objectives

Based on the foregoing, the variables that may affect the EKC relationship could be classified as:

- ***Proximate variables*** that include scale (income or production) and technique (structural and technological change);
- ***Underlying variables***, such as education and environmental awareness, institutional effects, trade, and free rider effect, which can only have an effect via the proximate variables through regulation and formal effort.

The aim of this research is to study the relationship between economic growth and production-related carbon dioxide emissions from fossil fuel burning, under the assumption of the Environmental Kuznets Curve. Therefore, we intend to investigate:

(1) Whether, and at what levels of income and emissions, the estimated EKC may turn downward;

(2) The impact of underlying variables that may tend to induce or inhibit the down-turning of the CO_2 EKC through the technique variables (structural and technological change).

(3) The extent to which we can hope that economic development, in combination with complementary policy strategies, will help rather than hurt global climate change.

Surveys of EKC studies have been conducted by Stern (2004) and others, including studies that incorporate additional explanatory variables, intended to model both underlying and proximate factors. We have tried to track the studies which concentrate on the CO_2 EKC.

So besides proximate variables, our econometric estimations of EKC effects will include the following underlying factors suggested by the surveys, elaborated below: human and social development indicators, trade openness, global free-rider ability, and formal regulatory effort.

Human and social development indicators

While GDP per capita is a key development indicator that affects both the scale and technique factors, the technique effect also is likely influenced by many other dimensions of development at both the individual and social levels. These include education and environmental awareness, and institutional factors (political freedom & transparency).

Education boosts an individual's' ability to receive, process, and understand information, and that information processing and interpretation influence learning and change behaviors (Nelson, 1966). Education is considered a vehicle for sustainable development and thus for the fight against pollution. Without education, people have little information about harmful risks, effects of the environmental damages in the long term and are only interested in the obvious impact. Additionally, they have little confidence in their own capacity to influence authorities. Education is an indirect explanatory factor in the EKC via technique, and theoretically, education contributes to changing consumer preferences towards a clean environment. In the absence of effective government policies, communities with high education take favorable actions to control or reduce emissions of pollution. Empirically, education in developing countries has more effect on Co_2 emission than developed countries (Romuald, 2010).

Institutional effects on emissions could be discussed through the impacts of democracy and the level of corruption using an accountability framework. Public participation has an effect on environmental decision making for environmental degradation abatement, and individuals' demand for environmental quality that could be expressed might be crucial for the environmental quality in a country.

Deacon (1999) said that non-democratic regimes are more likely to under-provide public goods, such as environmental quality, compared to regimes that are more democratic. In a system with a representative legislature, the role of interest groups is enhanced. If this effect is biased against environmentally unfriendly solutions, such as subsidies to energy-intensive industry, emissions could increase with political freedom. Carlsson & Lundström, (2001) found a negative relationship between democracy and environmental degradation, but they could not confirm the results for CO_2.

Transparency is a government's willingness/tendency to make its private information available, and it is a separate concept from political participation as a measurement of the level of democracy in the countries as a country can fulfill institutional requirements to be fully categorized as a democracy but have relatively low transparency score. Thus, there are variations of transparency scores among democracies as well as among dictatorships. Some studies find that transparency has a significant impact on emission. Increase in government transparency would negatively impact emission level as government's accountability increases Gani, (2012). As transparency increases, governments are more likely to make policies that would decrease emissions in order to gain political popularity and support. So, more transparent government is more likely to make policy progress available to be further evaluated by relevant political supporters as well as the international community and use emission reduction effort to remain in power.

Trade Openness

Trade indicators, particularly by sector if the data are available, can be used to estimate the degree to which both benefits and costs and can be imported or exported, affecting country capacity and incentives to reign in emissions.

Trade increases the size of the economy leading to an increase in pollution, therefore, it is considered the cause of environmental damage, *ceteris paribus*. But many scholars have long claimed that trade is not the primary cause of environmental degradation (Dinda, 2004). Nevertheless, free trade has opposing effects on the environment, both raising pollution levels and boosting reductions in it. Environmental quality could deteriorate through the scale effect as increasing the volume of trade, especially export, increases the economy size and consumption levels leading to an increase in pollution. In contrast, international trade can improve environmental quality through composition effect and/or technique effect. Previous research has shown that pollution transfer through trade flows can undermine environmental policies, particularly for global pollutants (Twerefou, et al., 2019). Peters & Hertwich (2007) monitored CO_2 emissions incorporated in international trade among 87 countries and the rates were rising.

Global free-rider ability

Consideration of the fact that CO_2 emissions are a "global" bad compared with most pollutants that are local or regional, and therefore there is a global public goods problem. Reducing CO_2 emissions does not have a direct impact at a local level, except the high costs of technological change. This becomes "a tragedy of the commons where it is most efficient for everyone to pollute and for no one to clean up, and everyone is worse as a result." (Yandle et al, 2002).

The size of the free-rider effect may be influenced by relative economic size, vulnerability to climate change damage, engagement with multilateral agreements, etc. The non-exclusiveness of public goods and absence of any global authority encourages free riding and emissions that increase with economics growth, but that could be solved by cooperative action dependent on reaching international agreement, which may encourage the down-turning of the CO_2 EKC. The essence of the free rider problem is that, independent of who may opt to bear the costs of providing transboundary environmental public goods, the benefits of the protected international ecosystem services accrue to many countries at a level that may not be internalized by whoever bears the costs. It should be noted that if one country (or a small group) is big enough to capture a significant portion of the total benefits, that agent may find it worthwhile to fix the problem on its own; but otherwise individual efforts are in vain (Montero, 2011).

Formal regulatory effort

Formal regulation plays an intermediary role between root causal factors, specifically between our "proximate" variables and our "underlying" variables. In less developed countries, regulatory institutions tend to be either weak or absent while in industrial economies, pollution tends to grow unless environmental regulation is enforced. In poor countries, pollution levels can be decreased if efforts concentrate on the dominant sources that are responsible for most of the pollution. Therefore, regulatory monitoring and enforcement on those key sources can notably reduce pollution, and empirical studies show that some poorer countries sometimes perform better than some wealthy countries in combatting environmental degradation. (Stern, 2004).

Usually, regulations aim to control both emission flows and stocks and, as we pointed out above, CO_2 emissions are a global issue and the absence of global regulations encourages free-riding and emissions that rise with economics growth, though that could be targeted by collective actions that ensure provision of global environmental public goods, which may encourage the down-turning of the CO_2 EKC.

The theory of groups or collective action theory by Mancur Olson was based on groups' composition of interests, so that group members get benefits and those who are outside incur the costs. This makes an incentive to get the benefits and avoid the costs or penalties. The logic of collective action is that "concentrated minor interests will be overrepresented and diffuse majority interests trumped, due to a free-rider problem that is stronger when a group becomes larger" (Olson, 2002). The group could consist of countries (maybe those directly affected by climate change) in the form of unions and official organizations to make agreements for concentrated interests or to assign penalties. The group also could be a combination of international or local not-for-profit associations that exercise social pressure, which gives variety and flexibility for collective action and consequently increases effectiveness. For example, government-mandated, and market-based approaches such as "emissions trading" or "cap and trade" to capping emissions provide economic incentives for attaining reductions in the emissions of pollutants like the

European Union Emissions Trading System. Imposing trade restrictions on countries exporting dirty industrial goods is an example of penalties.

Local regulations (which are different from country to another) should correspond to the global regulations, and in this context, Amigues, et al. (2009) stated: "Regulation of environmental externalities like global warming from the burning of fossil fuels (e.g., coal and oil) is often done by capping both emission flows and stocks. For example, the European Union and states in the Northeastern United States have introduced caps on flows of carbon emissions while the stated goal of the Intergovernmental Panel on Climate Change (IPCC) which provides the science behind the current global climate negotiations is to stabilize the atmospheric stock of carbon. Flow regulation is often local or regional in nature, while stock regulation is global."

1.3 Outline of the dissertation

Following this introductory Chapter 1, Chapter 2 will review the relevant CO_2 EKC literature. We have tried -- as much as possible -- to organize the present literature according to results and date of the publication. The last section will be the summary of the relevant literature reviews.

In Chapter 3, "Methodology," the theoretical framework will start with the basic IPAT model; then as a theoretical contribution, we will elaborate the identity by incorporating additional (proximate & underlying explanatory) variables. The second section of that chapter will provide the empirical model background by reviewing the relevant literature in EKC studies in general regardless of the source of pollution, and then will explain the econometric models by which the EKC hypothesis will be estimated in 3 stages:

(1) Level 1: Standard EKC regression model, estimating the relationship between emissions and income as a benchmark model;

(2) Level 2: Estimation of the Technique factor as a function of income or "affluence";

(3) Level 3: Estimation of the Technique factor as a function of underlying variables as well as affluence.

Chapter 4, "Data and Subsamples," will provide the definitions and measurement units of the variables represented in the data, as well as the data sources. In the second section of this chapter, we will identify subsamples based on levels of emissions, affluence, and underlying variables, where the comparison between subsamples raises interesting questions. Then we will present the summary statistics and trend data analysis.

In Chapter 5, "Results," we will present the results of the various model specifications detailed in the methodology chapter. The first section will present OLS estimation for the standard EKC regression model as a benchmark model using our panel data sample. The second section will estimate empirically (by OLS) the equation incorporating additional proximate explanatory variables (Industrial Share and Technology) as functions in Affluence, then will plug those equations into the IPAT identity to examine the implied EKC shape. The third section will incorporate underlying variables, by OLS estimation of the equations for the proximate variables Industrial Share and Technology, as functions of the underlying variables as well as Affluence, then plugging those functions into the IPAT identity to examine the implied EKC shape.

Finally, in Chapter 6, " Conclusions and Recommendations," we will discuss the results and propose some conclusions, as well as offering recommendations about policy applications

Chapter 2. Literature Review

EKC research started in the 1990s when researchers began estimating the relationship between various forms of local pollutants and per capita country income, which provided the backbone for subsequent studies. The social costs of global warming are shared across countries and generations, making issue more complex and unresolved for the case of carbon dioxide (CO_2).

The following is a survey of literature that has touched on our study subject, presented chronologically by date of publication as much as possible, followed by a table that is limited only to 42 studies that have directly tested the relationship between CO_2 and income.

2.1 Chronological development of the research literature

Shafik and Bandyopadhyay (1992) studied a variety of pollutants in their paper "Economic Growth and Environmental Quality: Time-Series and Cross-Country Evidence." For local pollutants, they found some empirical evidence of the EKC hypothesis, but results were less robust for CO_2 (as a global pollutant). On the other hand, trade, debt, technology, and other macroeconomic policy variables were tested as control variables and all were found to influence the environment except technology, in the CO_2 case.

Using global panel data, Holtz and Selden (1995) studied the relationship between economic development and carbon dioxide emissions, and despite the evidence supporting the EKC hypothesis, they found that the relationship in the foreseeable future will continue to be positive, as poor countries with increasing population growth rates have a high marginal propensity to emit.

Cole et al. (1997) used cross-country panel data to test the EKC hypothesis for several pollutants. While there was evidence supporting the existence of a meaningful EKC for local air pollutants, global air pollutants (e.g., CO_2) have turning points at per capita income levels higher than the sample mean, involving large standard errors.

Moomaw & Unruh (1997) compared EKC models to structural transition models of per capita CO_2 emissions and per capita GDP, and found that, "for the 16 countries which have undergone such a transition, the initiation of the transition correlates not with income levels but with historic events related to the oil price shocks of the 1970s and the policies that followed them."

Komen et al. (1997) examined the role of rising incomes in promoting development of new technologies directed toward environmental improvements in OECD countries. They found that "the income elasticity of public research and development funding for environmental protection is positive and may be close to unity. This finding suggests that emissions of at least some pollutants may decline with income after a threshold level of income is reached."

Roberts and Grimes (1997) used carbon dioxide intensity to study the EKC hypothesis. After taking the logarithm form of CO_2 intensity and GDP as input data for 147 countries, the authors applied a scatter-plot graphic examination of the 25 years of data (with a 5-year interval at 1965, 1970, 1975, 1980, 1985 and 1990) and used the OLS method to check for a linear relationship. The authors then divided the studied countries into three groups based on their per capita incomes. In general, the relationship between CO_2 intensity and level of economic development confirms an inverted-U shape, but the relationship differs from country to country, and the relationship changed from essentially linear in 1962 to strongly curvilinear in 1991. It should be noted the inverted-U curve reached statistical significance briefly in the early 1970s and increasingly since 1982. It was observed that for high-income countries, energy efficiency was improved after the 1973 and 1979 oil crises; on the other hand, there were no significant improvements for the low- or mid-income countries due to the transfer of polluting industries from developed to developing countries. Overall, what preserves the curvilinear relationship in the world economy is the imposition of dirtier technologies on poorer countries. Finally, the authors stressed that "the pollution-haven hypothesis has been validated by many researchers, and that an international environmental standard and promotion mechanism is required."

Agras and Chapman (1999) examine environmental degradation (a wide range of environmental indicators) and income in a quadratic function. For local air pollutants in the presence of energy price and trade variables, they did not find significant evidence for the existence of an EKC. Global environmental impact either increases monotonically with income or else has high turning points with large standard errors. Also, the trade variables were insignificant and of the wrong sign.

Heil and Selden (2001) estimated the relationship between carbon emissions and GDP using panel data to combine this relationship with plausible projections for GDP and population growth to construct a model that offers insights into the likely path of global emissions in the 21st century, and constructed country-by-country carbon emissions scenarios. The estimates indicate the continued accumulation of emissions (implying large increases in mean global surface temperature) accompanied by monotonic economic growth, and indicate that disengagement between income and emissions might occur at higher GDP levels.

Roca et al. (2001) aimed to analyze the relationship between income growth and nine atmospheric pollutants in Spain, adopting an input-output approach and using NAMEA data for the nine pollutants to estimate the emissions associated with the consumption patterns of different groups of households classified according to their level of expenditure. They found a weak relative delinking between economic growth and local emissions which can by no means be interpreted as an absolute delinking, and found, by contrast, that a delinking between economic growth and emission levels has not happened for CO_2 as the EKC hypothesis implies.

Carlsson & Lundström (2001) is the first cross-country study of the relationship between economic freedom and environmental quality. This paper investigated the effects of political and economic freedom on CO_2 emissions. They found: "The decreasing effect from increased use of markets is significant but non-robust, and increased freedom to trade does not have any significant effect. The effect of political freedom on CO_2 emissions is insignificant, most probably since CO_2 emissions is a global environmental problem and hence subject to free-riding by the individual countries."

Yandle et al. (2002) reviewed findings, methods, and policy implications. They revealed that "while there is no single relationship that fits all pollutants for all places and times, in many cases the inverted-U EKC best approximates the link between environmental change and income growth. Furthermore, the acceptance of the EKC hypothesis for select pollutants has important policy implications. Specifically, over time, policies that stimulate growth (trade liberalization, economic restructuring, and price reform) should be good for the environment." Improvement of the environment depends on government policies, social institutions, and the completeness and functioning of markets. "Because market forces will ultimately determine the price of environmental quality, policies that allow market forces to operate are expected to be unambiguously positive. The search for meaningful environmental protection is a search for ways to enhance property rights and markets."

Galeotti (2003) did not undertake an econometric estimation, but considered whether simple data analysis of variables like GDP, changes in the economic structure, and, energy prices can help to shed some light on motives that can rationalize the Environmental Kuznets Curve. This paper concluded that "after a certain level of income (which typically differs across pollutants) – the 'turning point' – pollution starts to decline as income further increases."

York et al. (2003) computed the ecological elasticities of population, affluence and other factors for cross-national emissions of CO_2. By refining the STIRPAT model through developing the concept of ecological elasticity (EE), their findings suggest that "affluence monotonically increases both CO_2 emissions and the energy footprint. However, for the energy footprint, the relationship between affluence and impact changes from inelastic to elastic as affluence increases, while for CO_2 emissions the relationship changes from elastic to inelastic."

Cole (2004) studied the US environmental load displacement (defined as emission embodied in imports minus those in exports) which led to structural changes in production or consumption over the period 1974-2001. It was found that the USA as a whole experienced environmental load displacement by increasing the scale of US trade, which became significantly cleaner over the period considered. In contrast, it was found that an increasing share of consumption is being met via imports that have grown more rapidly. That puts question marks on the downward-sloping side to the EKC, even if emissions were increasing at a decreasing rate.

Neumayer (2004) examined the role of geographical factors (hot climates, transportation requirements and the availability of renewable energy sources) as determinants of cross-country differences in per capita CO_2 emissions. He found that all these geographical factors are statistically significant determinants of emissions, but also the study found that the relationship between CO_2 and per capita income is monotonic and positive, and CO_2 emissions are increasing but at a decreasing rate, though theoretically, there exists a turning point beyond any currently existing per capita income level.

Galeotti and Lanza (2005) used an alternative functional form and panel data model for 110 countries, newly developed through previous work papers (1999, 2001), to estimate the relationship between CO_2 emissions and GDP. They found that the empirical relationship between carbon dioxide and income is well described by non-linear Gamma and Weibull specifications as opposed to more usual linear and log-linear functional forms, and the forecasts show that future global emissions will rise. The average world growth of CO_2 emissions between 2000 and 2020 was estimated at about 2.2% per year. So, emissions would be likely to reach a turning point at a higher but reasonable levels of GDP per capita, ranging between $13,260 and $21,757 depending on different specifications and samples.

Galeotti et al. (2006) reconsidered the evidence pointing to an inverted-U for the CO_2 EKC, by assessing how robust it is when the analysis is conducted in a different parametric setup and when using alternative emissions data, from the International Energy Agency instead of usual CDIAC data. The differing CO_2 data sources do not affect statistical robustness of the results in the EKC published studies that used traditional regression but when an alternative functional form is used, the statistical robustness can improve depending on the data sources.

Azomahou et al. (2006) examined the empirical relation between CO_2 emissions per capita and GDP per capita, relying on the non-parametric pool ability test using panel data of 100 countries, with country-specific effects to find evidence of the structural stability of the relationship. Results from standard parametric specifications frequently seem problematic. On one hand, linear models often support the EKC hypothesis, but with overall insignificant polynomial functional form; on the other hand, log-linear can be better in terms of econometric performance, "but not more encouraging in terms of estimated EKC." In contrast, alternative nonparametric specifications (such as Gamma and Weibull) have supported the EKC hypothesis and with statistical significance and reasonable turning points. These authors stressed the role of policy and pointed out that economic development is not enough: "Consequently, all countries should make an effort to reduce these emissions in order to reduce global warming."

Ang (2007) examined the dynamic relationship between CO_2 emissions, energy consumption, and output for France over the period 1960–2000 using cointegration and vector error-correction modelling techniques. Results of the study confirm the existence of the long-run relationship between CO_2 emissions, energy consumption and economic growth and support the EKC hypothesis with an inverted-U shape relationship between pollution and output. Subsequently, Mutascu et al. (2016) explored the causality between carbon emissions and economic growth in France, for the period 1983-2015. By following a wavelet approach, the study explores the causality between carbon emissions and GDP per capita for different periods of time under cyclical and anti-cyclical shocks. In the medium and long terms, the result supports the EKC hypothesis, but the hypothesis is not validated in the short term.

Peters & Hertwich (2007) concluded, "If countries take binding commitments as a part of a coalition, instead of as individual countries, then the impacts of trade can be substantially reduced. Adjusting emission inventories for trade gives a more consistent description of a country's environmental pressures and circumvents many trade-related issues. It also gives opportunities to exploit trade as a means of mitigating emissions."

Huang (2008) used single-country time series analysis for 75 countries to test the relationship between economic development represented by GDP, and GHG emissions. The results showed that "most of the countries do not possess evidence that supports the EKC hypothesis for GHG emissions and 38 industrialized countries are unable to meet their targets under the Kyoto Protocol within the specified period."

Atici (2009) examined the interactions between air pollution, energy usage and trade openness in Central and Eastern Europe over the period 1980-2002. Results of the study support the existence of the EKC hypothesis for Turkey, Hungary, Bulgaria and Romania and suggest that air pollution decreases when economic growth increases in the region.

For Turkey, Akbostanci et al. (2009) used time series and panel data analysis and, applying cointegration techniques, examined the relationship between environmental degradation and income. They found a monotonically increasing relationship between CO_2 and income based on time series analysis, supporting the results of Lise and Montfort (2007) and rejecting the EKC hypothesis for the case of Turkey. On the other hand, the EKC hypothesis was confirmed for the Turkish economy, by Ozturk and Acaravci (2013). And further, they investigated the relationship between financial development, trade, economic growth, energy consumption and CO_2 emissions, again using cointegration techniques. "The results show that an increase in foreign trade to GDP ratio results in an increase in per capita carbon emissions and financial development variable has no significant effect on per capita carbon emissions in the long-run." In a third study of Turkey, Shahbaz et al. (2013) examined the relationship between emissions, energy intensity, economic growth and globalization over the period 1970-2010 by applying unit root testing and cointegration methods under the existence of structural breaks; empirical findings confirmed the EKC hypothesis in Turkey and indicated bidirectional causality between CO_2 emissions and economic growth.

Jalil and Mahmud (2009) studied the impact of international trade on the EKC in China (1975-2005). Results of the study revealed that there is a quadratic relationship between GDP and

CO_2 emissions which implies the EKC hypothesis applies to the Chinese economy. Also, trade showed a positive though statistically insignificant impact on CO_2 emissions.

Du et al. (2012) studied the interactions between carbon emissions, economic growth, industry structure, urbanization, energy usage, technological improvement, and trade openness for the case of China as well and, in contrast to Jalil and Mahmud (2009), found that "the inverted-U shape relationship between per capita CO_2 emissions and economic development level is not strongly supported by the estimation results." Also, the estimation results show "that economic development, technology progress, and industry structure are the most important factors affecting China's CO_2 emissions, while the impacts of energy consumption structure, trade openness, and urbanization level are negligible."

Choi, et al. (2010) investigated the existence of the environmental Kuznets curve (EKC) for CO_2 emissions in China, Korea, and Japan (1971-2006), and its causal relationships with economic growth and openness by using time series data. They found that "the CO_2 consequences according to openness and economic growth do not show uniform results across the countries. Depending on the national characteristics, the estimated EKC for China shows an N-shaped curve while for Japan it shows a U-shaped curve. Such dissimilarities are also found in the relationship between CO_2 emissions and openness. In the case of Korea and Japan it represents an inverted-U shape curve, while China shows a U-shaped curve. Also analysis of a variance decomposition shows evidence of large heterogeneity among the countries and variables impacts."

Amigues et al. (2009) tried to answer: "How do these multiple pollution control efforts interact when a nonrenewable resource creates pollution?" They review examples of the effectiveness of local efforts to serve a global goal and found "that local and global pollution control efforts, if uncoordinated, may exacerbate environmental externalities. For example, a stricter cap on emission flows may actually increase the global pollution stock and hasten the date when the global pollution cap is reached".

He & Richard (2010) used semiparametric and flexible nonlinear parametric modeling methods in an attempt to provide more robust inferences. They found that the relationship between CO_2 and income is monotonically increasing but at a decreasing rate over time. They observed that a temporary structural break seems to appear after the oil crisis and the increase in oil price of the 1970s, which has had an important impact on progress towards less polluting technology and production. Finally, the authors pointed out that “although emission efficiency seems to improve with time, thanks to the so-called technological progress, until now, we cannot yet observe an obvious decreasing trend for carbon pollution in Canada."

Romuald (2010) investigated the impact of education on environmental quality. He found for the whole sample of panel data, no relationship between education and growth of CO_2 per capita, but the result changed when he had sub-samples based on level of development. "While the effect remains insignificant in the developing countries sub-sample, education does matter for air pollution growth in the developed countries. More interestingly, when controlling for the quality of political institutions, the positive effect of education on air pollution growth is mitigated in the developed countries while being insignificant in the developing countries."

Lean and Smyth (2010) investigated the relationship between CO_2 emissions, electricity consumption as an energy consumption indicator, and economic growth, in a panel setting for five ASEAN countries over the period of 1980-2006. The results support the EKC hypothesis. Also, there is a positive relationship between electricity consumption and CO_2 emissions. Heidari et al. (2015) examined the EKC hypothesis by investigating the interactions between CO_2 emissions, economic growth and energy consumption for ASEAN countries over the period of 1980-2008.

Results of their study are consistent with the results of Lean and Smyth (2010), confirming the validity of the EKC for the case of five ASEAN countries.

Apergis and Ozturk (2015) investigated the validity of the EKC hypothesis for 14 Asian countries including controls for population density, land, industry shares in GDP, and four indicators that measure the quality of institutions for the period of 1990-2011, by adopting panel data methodology. The results support the existence of the inverted-U shaped relationship between CO_2 emissions and income per capita. Also, the rest of the estimates have the expected signs and are statistically significant, yielding empirical support to the presence of EKC.

Dong, et al. (2011) observe that "a substantial fraction of the growth in the developing countries satisfies the consumption in developed countries." Based on production-based accounting, North Korea shows an inverted-U shape EKC but it is monotonically increasing for South Korea. With consumption-based accounting of CO_2 emissions, they found that both North and South Korea's EKCs are monotonically increasing. This signals a displacement or leakage effect where dirty industries are displaced to less developed countries.

Jaunky (2011) tested the EKC hypothesis for 36 high-income countries, and found that "unidirectional causality running from real per capita GDP to per capita CO_2 emissions is uncovered in both the short-run and the long-run. The EKC is valid for the cases of Greece, Malta, Oman, Portugal, and the United Kingdom, and for the whole panel, it can be observed that a 1% increase in GDP generates an increase of 0.68% in CO_2 emissions in the short-run and 0.22% in the long-run. The lower long-run income elasticity does not provide evidence of an EKC, but does indicate that, over time, CO_2 emissions are stabilizing in the rich countries."

Nasir and Rehman (2011) studied the relationship between air pollution, energy consumption, economic growth and trade openness for the case of Pakistan, a developing country, for the period of 1972-2008. They suggest that "there is a quadratic long-run relationship between carbon emissions and income, confirming the existence of EKC. Energy consumption and foreign trade are found to have positive effects on emissions."

Onafowora and Owoye (2014) investigated the relationship between CO_2 emissions, energy consumption, trade openness, and population growth for the case of 8 countries in the EKC hypothesis context. Results of the study suggest that the EKC hypothesis exists in an inverted-U shape in Japan and South Korea, but for other countries the estimated relationship is N-shaped. The estimated turning points are much higher than the sample mean, moreover. Granger causality test results indicate that changes in energy usage causes changes in both CO_2 emissions and economic growth for all countries.

Grunewald & Zarzoso (2011) used a dynamic panel data model for the period 1960 to 2009. They analyzed the driving factors of CO_2 emissions to investigate to what extent emission reduction obligations from the Kyoto Protocol have had an effect on CO_2 emissions. The main results "indicate that obligations from the Kyoto Protocol have a reducing effect on CO_2 emissions."

Montero (2011) looked at the current state of the art on the science of strategic behavior and national treatment of different kinds of international environmental public good. He concluded that "many environmental public goods are managed through multilateral environmental agreements aimed at building consensus over time (social norms), others are not." Provision depends on the nature of the environmental public good and the necessity of cooperating with other countries, and coalitions of countries enhance provision of public goods and mitigation of global free-rider effects.

Gani (2012) examined the relationship between five dimensions of good governance (political stability, government effectiveness, regulatory quality, rule of law, and corruption) and CO_2 emissions in a cross-section of developing countries. The results provide confirmation that all those dimensions are negatively and statistically significantly correlated with CO_2 emissions. "The results also provide evidence in support of the EKC, but a turning point occurs at very high levels of per capita incomes and is out of the range of observations in the sample considered for the empirical work. Moreover, trade openness and the size of the industrial sector are other strong correlates of CO_2 emissions."

Dinh & Shih (2014) studied the "dynamic relationships" between CO_2 emissions, energy consumption, foreign direct investment and economic growth for Vietnam. They used cointegration and Granger causality tests before they ran the EKC regression, and the empirical results do not support the EKC theory in Vietnam. "However, the cointegration and Granger causality test results indicate a bidirectional relationship among CO_2 emissions, energy consumption, FDI and economic growth relationship among CO_2 emissions, energy consumption, FDI and economic growth." Also for Vietnam, Al-Mulali et al. (2015) examined the validity of the EKC for the period of 1981-2011. Results of the study indicate a positive relationship between air pollution and economic growth both in the short and the long run which means that the EKC hypothesis is not valid in Vietnam.

Alwan & Al-Tarawneh, (2014) used the ARDL bounds testing approach to apply a distributed lag regression model between economic growth and CO_2 emission (1980-2010) in Jordan. The results are consistent with the EKC hypotheses in the long run; also, they found bidirectional causality among variables in their CO_2 model.

Katircioglu (2014) examined the role of tourism in the relationship between development and air pollution under the EKC hypotheses in Singapore. The study confirmed the hypothesis and the contribution of the tourism sector positively on emission efficiency; with unidirectional causality to carbon emission growth in the long-term.

Shin et al. (2015) used data for 125 countries from 1980 to 2008, to examine the EKC hypotheses for carbon dioxide with government transparency and democracy as extra control variables. The results show the positive effect of institutional improvements on emission efficiency in relatively rich countries, and the negative effect on emission efficiency in poor countries "with income levels below certain thresholds."

Jula et al. (2015) tested the EKC hypothesis for the case of Romania (1960-2010). The CO_2 EKC hypothesis was confirmed using time series data, giving an inverted-N-shaped relationship in the long run.

Robalino-Lopez et al. (2015), in a case study of Venezuela (1980-2025), used time-series data and offering a predictive extrapolation. The result did not support the EKC hypothesis, but according to the predictions "stabilization in environmental degradation is expected in the medium term supported by increases in renewable energy usage due to economic growth."

Kasman and Duman (2015) used panel data for new EU member and candidate countries, for the period 1992-2010, to examine the carbon dioxide EKC hypotheses with energy usage, urbanization, and trade openness as extra control variables. The results support the hypothesis with an inverted-U shaped and short-run unidirectional panel causality among CO_2 and the control variables; and they confirmed that "trade openness, urbanization, energy usage, and economic growth are the determinants of CO_2 emissions in the long run."

The Cambodia case study by Ozturk and Al-Mulali (2015), for the period 1996-2012, used GMM and Two-Stage Least Squares to examine the carbon dioxide EKC hypotheses with better governance and corruption control, urbanization, energy consumption, and trade openness as extra control variables. The results did not support the EKC hypothesis, but the researchers confirmed "that GDP, urbanization, energy consumption, and trade openness increase CO_2 emission while the control of corruption and governance can reduce CO_2 emission."

Al-Mulali et al. (2015) used a Fully Modified OLS (FMOLS) model for Latin American and Caribbean countries (1980-2010) to examine the carbon dioxide EKC hypothesis with renewable energy consumption and financial development as extra control variables. The results support the hypothesis and, also, the researchers confirmed that "financial development can improve environmental quality by its negative long-run effect on CO_2, where renewable energy has no long-run effect on CO_2."

Omri et al. (2015) examined the EKC hypothesis with financial development and trade openness as extra control variables for MENA countries (1990-2011). The results support the hypothesis and the researchers also confirmed bidirectional relationships between carbon emissions and economic growth, and unidirectional causality running from trade openness to CO_2 emissions.

The Magazzino (2016) case study in Italy (1970-2006) examined the carbon dioxide EKC hypothesis with renewable energy consumption as an extra control variable. The results failed to support the hypothesis, but the Toda-Yamamato causality test confirmed two-way causality between CO_2 emissions and the control variables.

Elhemri (2019) tested whether an EKC relationship holds for CO_2 in Egypt and South Korea (1960-2014), using time-series data and GLS regression analysis. The empirical results suggest, in general, that the hypothesis applies for the 2 countries, but with four cautionary observations: (1) the critical value, or turning point, is at a relatively high level of GDP, which means those two economies are still on the upward side of the Environmental Kuznets Curve; (2) the S-curve result for South Korea is inconsistent with the EKC hypotheses, though it suggests that emissions have been increasing at a decreasing rate for most of the estimated curve, offering some hope of moderated environmental impact; (3) based on the high significance F-test of overall regression for all equations forms, the interpretations of the results are meaningful but there is a concern about accuracy in determining the level of income at the turning points, due to the insignificance of some coefficients; (4) there is an importance of the data timeframe and range -- with the current data range, there is a possibility that the fluctuation only caught a local maximum point rather than a global. Therefore the turning points are not truly the maximum point of the relationship between CO_2 emissions and income and we need to extend the data range.

Table 2-1 provides a summary comparison of 45 key studies relevant to the EKC hypothesis as it applies to CO_2.

Table 2-1: Summary of studies

	Study	Data	Extra Variables	Main Conclusion for CO_2	Equation form	Turning point $ GDP per capita
1	Shafik & Bandyopadhyay (1992)	-Time Series & Cross Country for 135 countries -GDP (PPP)	Trade, energy prices, debt, political and civil liberties and technology	1. CO_2 does not improve with rising incomesbecause the costs are born externally 2. Little empirical evidence to support the existence of EKC hypothesis in inverse U or mirror N shape	-Linear in logs -Quadratic in logs - Cubic in logs	NA $7 million NA
2	Holtz & Selden (1995)	-Global panel for 13 countries - Real GDP (1986 $)	-	The pace of economic development does not dramatically alter the future annual or cumulative flow of CO_2 emissions, despite evidence suggesting a diminishing marginal propensity to emit especially in lower-income nations.	-Quadratic in levels -Quadratic in logs	$35,428 $8 million
3	Cole et al. (1997)	-Panel data for 15 OECD members - Real GDP (1985 $)	-	Unlike local air pollutants, high turning points for CO_2, but large standard errors attach little confidence level.	-Quadratic in levels -Quadratic in logs	$25,100 $62,700
4	Moomaw & Unruh (1997)	- Time Series & panel data for 16 OECD members - Real GDP (1984 $)	-	Due to the impact on energy structure caused by the oil crisis, testing the standard EKC model supports the hypothesis iof inverse U for most individual countries and mirror N shape for the panel.	-Quadratic in levels -Cubic in levels	NA $12,813 and $18,333
5	Roberts and Grimes (1997)	- Panel for 147 countries, 5 years (1965, 1970, 1975, 1980, 1985 and 1990) - Real GDP (1987$)	National CO_2 emissions intensity (CO_2/GDP)	-Confirms the EKC hypothesis of inverse U-shape (linear in 1962 to strongly curvilinear in 1991) -For high-income countries, energy efficiency was improved after oil crises. -No significant improvement for low- or mid- income due to transferring polluting industries from developed to developing countries, and due to constraints on poorer countries the curvilinear relation is likely to persist in the world economy.	-Quadratic in logs	NA

6	Agras and Chapman (1999)	- Panel for 31 countries - Real GDP (1997 $)	Trade and energy prices	Global environmental impact either increases monotonically with income or else has higher turning points compared with the average. Trade variables were insignificant and of the wrong sign.	-Quadratic in logs	$13,630
7	Heil and Selden (2001)	- Global panel for 135 countries - Real GDP (1992 $)	-	Continued accumulation of emissions accompanied by monotonic economic growth; disengagement could occur at higher GDP levels.	-Quadratic in levels -Quadratic in logs	$36,044 $2.3 million
8	Roca et al. (2001)	NAMEA system (1995-2000) in Spain	-	Adopted an input-output approach; no delinking between economic growth and emission levels for CO_2.	-	-
9	York et al. (2003)	- Global panel for 138-145 countries - GDP ppp	Energy footprint	Affluence monotonically increases both CO_2 emissions and the energy footprint. However, for the energy footprint the relationship between affluence and impact changes from inelastic to elastic as affluence increases, while for CO_2 emissions the relationship changes from elastic to inelastic.	-Quadratic in levels	$61,000
10	Neumayer (2004)	- Global panel for 163 countries - GDP ppp	Geographical factors	Geographical factors are statistically significant determinants of emissions, but the relationship between CO_2 and per capita income is monotonic and positive, and CO_2 emissions are increasing but at decreasing rate, and theoretically there exists a turning point.	-Quadratic in logs with renewable energy share excluded -Quadratic in logs with renewable energy share included	$55,000 $90,000
11	Galeotti and Lanza (2006)	- Global panel for 100 countries - GDP ppp -CO_2 IEA & CDIAC	-	1. EKC evidence does not appear to depend upon the source of the data if polynomial relationship functions were used. 2. For non-OECD countries the EKC is basically increasing (slowly concave) according to IEA data and more bell-shaped in the case of CDIAC data if alternative functional forms were employed. (For OECD countries there is evidence of an inverted-U pattern, with reasonable turning point, regardless of the data set employed.)	IEA Data Weibull Not-Weibull CDIAC Data Weibull Not-Weibull	 $ 16,595 $ 26,491 $ 16,593 $ 15,600
12	Azomahou et al. (2006)	- Global panel for 100 countries - Real GDP (1985 $)	-	Using a nonparametric approach, found that the relationship between CO_2 emissions and GDP per capita is upward sloping, and rejects the usual polynomial functional form which leads to the Environmental Kuznets Curve.	- Cubic in levels - Nonparametric	NA -
13	Ang (2007)	-Time series for France (1960-2000) -Real GDP	Energy consumption	Confirmed long-run relationship between CO_2 emissions, energy consumption and economic growth and supported the EKC hypothesis of inverse U-shaped relationship between pollution and output.	- Quadratic in logs - Cointegration	-

14	Mutascu et al. (2016)	-Time series for France (1983Q2-2015Q2) - GDP ppp	-	Following a wavelet approach for different frequencies and sub-periods, revealed the lead-lag nexus between variables under cyclical and anti-cyclical stocks. EKC is not validated in short term, meaning there does not exist any influence of GDP per capita on carbon emissions.	-Wavelet approach	-
15	Huang (2008)	- Single-country time series for 75 countries - Real GDP (2000 $)	-	Most of the countries' EITs do not possess evidence that supports the EKC hypothesis for GHG emissions; the GDP and emissions relationship exhibits a hockey-stick curve trend.	-Levels -Logs	-
16	Atici (2009)	-Panel for Bulgaria, Hungary, Romania and, Turkey, 1980-2002 - Real GDP 1995 $)	Energy use Trade openness	Supported the existence of EKC hypothesis for the 4 counties and suggested that air pollution decreases when economic growth increases in the region, while trade openness has not generated higher emissions.	-Quadratic in logs	$ 2,077 to $ 3,156
17	Akbostanci et al. (2009)	- Panel data for 58 provinces in Turkey, 1968-2003 - Real GDP (2000 $)_	-	A monotonically increasing relationship between CO_2 and income according to time series analysis, so no existence for EKC.	-Quadratic in logs -Cointegration	-
18	Ozturk, and Acaravci (2013)	-Time series for Turkey, 1960-2007 - Real GDP (2000 $)	Trade openness and financial development	- Supported the validity of EKC hypothesis in the Turkish economy - An increase in foreign trade to GDP ratio results in an increase in per capita carbon emissions and the financial development variable has no significance.	-Quadratic in logs -Cointegration	NA
19	Shahbaz et al. (2013)	-Time series for Turkey, 1970-2010 -Real GDP, Turkish currency	Energy intensity, and globalization	Confirmed the existence of EKC hypothesis in Turkey and indicated bidirectional causality between CO_2 emissions and economic growth	-Quadratic in logs -Cointegration	NA
20	Jalil and Mahmud (2009)	Time series for China,1975-2005 -Real GDP	International trade	There is a quadratic relationship between GDP and CO_2 emissions which implies the validity of EKC hypothesis in China. Trade has a positive but statistically insignificant impact on CO_2 emissions.	-Quadratic in logs -Cointegration	NA
21	Du et al. (2012)	- China, provincial panel data set 1995- 2009 -Real GDP	Urbanization, energy usage, technological improvement and trade	-EKC hypothesis does not exist for the case of Chinese economy. -Economic development, technology progress and industry structure are the most important factors affecting China's CO_2 emissions, while the impacts of energy consumption structure, trade openness and urbanization level are negligible.	A series of static and dynamic panel data models	-

22	Choi, et al. (2010)	- Time series data from China, Korea, and Japan (1971-2006) --Real GDP	Trade openness	- "CO_2 consequences according to openness and economic growth do not show uniform results across the countries" For GDP: -China shows an N-shaped curve. -Japan has an inverse U-shaped curve. - Korea has U-shaped curve	China -Quadratic in logs Japan -Quadratic in logs Korea -Quadratic in logs	NA NA NA
23	He & Richard (2010)	- Time-series data for Canada, 1948-2004 -Real GDP.	-	1.Using polynomial model, found the relationship between CO_2 emission and GDP to be an inverted-U shape (GDP^3 insignificant). 2.Using semiparametric and flexible nonlinear parametric modeling methods, found little evidence in favor of the EKC hypothesis which could be interpreted as indicating that the oil shock of the 1970s has had an important impact on progress towards less polluting technology and production.	- Polynomial in levels -Nonlinear parametric	\$22,615 -
24	Lean and Smyth (2010)	- Panel data for ASEAN countries, 1980-2006. -Real GDP (2000 \$)	Electricity consumption	1. Supported the existence of EKC hypothesis 2. Found a positive relationship between electricity consumption and CO_2 emissions.	-Quadratic in levels -Cointegration	NA
25	Heidari et al. (2015)	- Panel data for ASEAN countries, 1980–2008. -Real GDP (2000 \$)	Energy consumption	1. Compliant with the results of Lean and Smyth (2010) which confirms the validity of EKC for the case of ASEAN countries. 2. There is a positive relationship between energy consumption and CO_2 emissions	-Quadratic in levels, Panel Smooth Transition Regression method	\$4,686
26	Apergis and Ozturk (2015)	-Panel data & time series data for 14 Asian countries - Real GDP (2005 \$)	Population, land, industry share in GDP, and four indicators that measure institution quality	1. Empirical support of the presence of EKC. 2. Rest of the estimates have the expected signs and are statistically significant, yielding empirical support to the presence of EKC.	Generalized method of moments (GMM) -Quadratic in logs	NA
27	Jaunky (2011)	-Panel data for 36 high-income countries, 1980-2005 - Real GDP	-	For the whole panel, a 1% increase in GDP generates an increase of 0.68% in CO_2 emissions in the short-run and 0.22% in the long-run. The lower long-run income elasticity does not provide evidence of an EKC, but does indicate that, over time, CO2 emissions are stabilizing in the rich countries.	Generalized method of moments (GMM) -Quadratic in logs	NA
28	Nasir and Rehman (2011)	- Time series data for Pakistan, 1972–2008 - Real GDP	Energy consumption, and trade openness	1. There is a quadratic long-run relationship between carbon emissions and income, confirming the existence of EKC.	-Quadratic in logs -Cointegration	NA

				2. Energy consumption and foreign trade are found to have positive effects on emissions		
29	Onafowora and Owoye (2014)	- Panel data & time series data for 8 countries	-Electricity consumption, trade openness, and population	1. Inverted U-shaped EKC hypothesis holds in **Japan** and **South Korea**. In the other **six** countries, the long-run relationship between GDP and CO_2 emissions follows an N-shape. 2. Estimated turning points are much higher than the sample mean	-Quadratic in logs -Cointegration	NA
30	Dinh & Shih (2014)	-Time series data for Vietnam, 1980-2010 - Real GDP	-Energy consumption, FDI	1. Empirical results do not support the EKC. 2. Bidirectional causality among variables of CO_2 model.	-Quadratic in logs -Cointegration	-
31	Al-Mulali et al. (2015)	-Time series data for Vietnam, 1981-2011 - Real GDP	-	- Positive relationship, which means that the EKC not valid	-Quadratic in levels with ARDL methodology	-
32	Alwan & Al-Tarawneh (2014)	-Time series data for Jordan, 1980-2010 - Real GDP (1994 JD)	-Energy consumption	1. The results are consistent with the EKC hypotheses in long run. 2. Bidirectional causality among variables of CO_2 model.	-Quadratic in logs -Cointegration	JD 1265 (This value was reached during 2003-04.)
33	Katircioglu (2014)	-Time series data for Singapore - Real GDP (2000 $)	-Tourism development -Energy consumption	1. A negative impact of tourism development on emissions with unidirectional causality to carbon emission growth in the long-term of the economy.	-Quadratic in logs -Cointegration	NA
34	Gani (2012)	- Cross-section of 99 developing countries for years 1998, 2000, 2002, 2003, 2004, 2005, 2006 and 2007 - Real GDP2000$	Political stability, government effectiveness, regulatory quality, rule of law, and corruption	1. Provided evidence in support of EKC, but turning point occurs at very high level incomes. 2. Political stability, rule of law, and control of corruption are negatively and statistically significantly correlated with CO_2 emissions	-Quadratic in levels	NA
35	Shin et al. (2015)	Panel data for 125 countries, 1980-2008 -Real GDP	Transparency, democracy	Institutional improvements decrease emissions in relatively developed countries. In poor countries with income levels below certain thresholds, CO_2 emissions may increase with improvements in government transparency and democratic political institutions.	-Quadratic in logs	NA
36	Jula et al. (2015)	Time series data for Romania, 1960-2010	Political and structural changes	Existence of the EKC hypothesis is confirmed in mirror N shaped relationship	-Quadratic in levels	NA
37	Robalino-Lopez et al. (2015)	-Time series data and projections	-	-EKC is not esupported but stabilization in environmental degradation is expected in the medium	-Quadratic in logs -Cointegration	-

		for Venezuela, 1980-2025		term by the help of increases in renewable energy usage due to economic growth.		
38	Kasman and Duman(2015)	-Panel data for EU members, 1992-2010.	Electricity consumption, trade openness, urbanization	1. Supports EKC hypothesis and indicates an inverted-U shaped relationship. 2. Short-run unidirectional panel causality running among variables of CO_2 model.	-Quadratic in levels -Cointegration	NA
39	Ozturk and Al-Mulali (2015)	- Time-series data for Cambodia, 1996-2012 Real GDP (2000 $)	Corruption, governance, urbanization, energy consumption, trade openness	1.EKC hypothesis is not present 2. GDP, urbanization, energy consumption, and trade openness increase CO_2 emission while the control of corruption and governance can reduce CO_2 emission	Generalized method of moments (GMM) -Quadratic in logs	-
40	Begum et al. (2015)	Time-series data for Malaysia, 1970-2009 -Real GDP	Electricity consumption, population	1. Invalidity of EKC hypothesis. 2. Economic growth and energy have positive effects on CO_2 emissions while population growth has no significant effect on emissions.	-Quadratic in levels ARDL	-
41	Al-Mulali et al. (2015)	- Panel data for18 Latin American and Caribbean countries, 1980-2010. -Real GDP	Renewable energy consumption, and financial development	1.EKC hypothesis is supported for this case. 2. Financial development has negative long-run effect on CO_2, where renewable energy has no long-run effect on CO_2.	-Quadratic in levels OLS (FMOLS)	NA
42	Omri et al. (2015)	- Panel data for 12 MENA countries (1990-2011) -Real GDP (2005 $)	Financial development, and trade	1. Confirmed the EKC hypothesis. 2. Bidirectional relationships are observed between carbon emissions, trade and economic growth.	-Quadratic in logs GMM	NA
43	Magazzino (2016)	Time-series data for Italy, 1970-2006 -Real GDP (2005 $)	Energy consumption	1. Failed to confirm EKC hypothesis 2. Feedback relationship between CO_2 emissions and economic growth and between CO_2 emissions and energy consumption	-Cointegration	-
44	Elhemri (2019)	Time-series data for Egypt and South Korea, 1960-2014 GDP (2005 US $)	-	Mixed support for the EKC hypothesis (monotonic concave for S Korea in the cubic model)	- Quadratic in levels Egypt South Korea - Cubic in levelss Egypt South Korea	 $ 4,450 $ 52,332 $ 1,646 NA

2.2 Summary Literature Review

Our survey of studies focused on research in this area shows that it has taken two directions: first, research that deals with the analysis of this relationship at the level of a single country and second, analysis at the level of multiple countries. In most of these studies, the interaction between environmental degradation and income was modeled in terms of quadratic or log quadratic functional form. This issue is elaborated in Chapter 3, Methodology. Based on these observations, the following points can be drawn as a summary review from the previous survey.

2.2.1 Studies grouped by sample type

Most of the past research focused on global or regional data, with relatively few studies on a single country. This reinforces our perception that CO_2 pollution is a "global bad" compared with many pollutants that are local, and local reduction of CO_2 emissions does not have a direct impact at a local level beyond the high costs of technological change. So we have a "tragedy of the commons," and it is noted that by increasing the size of the sample and its diversity, the opportunity to support the existence of the EKC hypothesis is increased; see e.g.Holtz & Selden (1995); Cole et al. (1997); Moomaw and Unruh (1997); Roberts and Grimes(1997);Schmalensee et al. (1998); Agras and Chapman (1999); Heil and Selden (2001) ;York et al. (2003) ;Galeotti and Lanza (2005); Azomahou et al. (2006); Galeotti and Lanza (2005); Huang (2008); Gani, (2012) Shin et al (2015); Kasman and Duman(2015).

However we may find studies of time series of individual countries, or panel data for a group of countries, that support the hypothesis because of the nature of the economic structure. e.g. Cole et al. (1997); Roca et al. (2001); Galeotti and Lanza (2006); Akbostanci et al. (2009); Ang (2007); Atici (2009), Choi, et al (2010)He & Richard (2010); Lean and Smyth (2010); Jaunky (2011); Nasir and Rehman (2011); Gani, (2012); Onafowora and Owoye (2014); Dinh and Shih (2014); Alwan & Al-Tarawneh (2014); Omri et al. (2015); Katircioglu (2014)Jula et al. (2015);

Heidari et al. (2015); Apergis and Ozturk (2015); Ozturk and Al-Mulali (2015); Begum et al. (2015); Al-Mulali et al.(2015); Apergis and Ozturk (2015); Shin et al (2015); Mutascu et al (2016).

2.2.2 Studies grouped by implied curve shape

Most of the studies that have estimated an inverted-U shaped relationship between CO_2 and GDP imply a downward-sloping side to the curve only by extrapolation -- a turning point at a higher level of GDP than the current range of data; see e.g. Cole et al. (1997); Choi, et al 2010; Shafik & Bandyopadhyay (1992); Holtz & Selden (1995); Cole et al. (1997); Agras and Chapman (1999); Heil and Selden (2001);York et al.(2003); Neumayer (2004); Galeotti and Lanza (2006). We note most of these studies used panel data. Other studies estimated the relationship between CO_2 emissions and GDP to be linear, or were unable to provide enough evidence whether the hypothesis of EKC holds, e.g., Roca et al. (2001); Akbostanci (2009); Du et al. (2012); Magazzino (2016).

As Dinda (2004) states, "The EKC may not hold even in the long run, and the economy can foresee a so-called N-shaped curve, which exhibits the inverted-U curve initially, but beyond a certain income level, the relationship between environmental pressure and income turns positive again." Some CO_2 studies showed an inverted-U shaped trend, with their turning point coinciding with the 1970s oil crisis, e.g. Cole et al. (1997); Choi, et al (2010); Gani (2012); Apergis and Ozturk (2015). This is consistent with studies finding an N-shaped relationship, which implies that any delinking is only temporary.

There is evidence of an inverted-U pattern with a reasonably close turning point for some time-series studies for single countries or panel data for a group of countries because of the nature of the economic structure e.g. Galeotti and Lanza (2006); Atici (2009); Choi, et al (2010); Dong, et al (2011); Alwan & Al-Tarawneh, (2014); Heidari et al. (2015).

Some studies have found that the relationship between CO_2 and per capita income is monotonic and positive; see e.g., Shafik & Bandyopadhyay (1992); Ang (2007); Huang (2008); Akbostanci et al. (2009); Du et al. (2012); Al-Mulali et al. (2015); Robalino-Lopez et al. (2015); Ozturk and Al-Mulali (2015); Begum et al.; (2015) Magazzino (2016)). Note, though, that Neumeier (2004) and Galeotti and Lanza (2006) found CO_2 emissions to be increasing but at a decreasing rate.

In general and as mentioned previously, most studies that imply turning points estimate a turning point at a higher level of GDP than the current range of data. It has been noted that as the sample size increases, the high turning point rises to a higher level of GDP, especially in panel data studies, and using rich country samples raises the high turning point rises even higher compared to poor countries. Also, with the use of linear methods, the high turning point rises even higher compared with nonlinear methods for the same sample; additionally, using logarithmic data raises the turning point to a higher level compared to non-logarithmic data for the same sample. See Table 2-1 for specifics.

2.2.3. Studies grouped by data source, type, and logarithmic treatment

The results of the EKC studies may vary based on the data, e.g., Galeotti and Lanza (2006) found that for non-OECD countries the EKC is basically increasing (slowly concave) according to the IEA data, but more bell-shaped in the case of CDIAC data. In addition, using consumption-based accounting of CO_2 emissions, Wang (2011) compared the EKCs in North and South Korea and found that both regions' EKCs are monotonically increasing, but North Korea shows an inverted U-shaped for the EKC with production-based accounting of CO_2 emissions.

Using natural logarithms for values which are mostly increasing, to deal with skewed data by log transformation, we can decrease the variability of data and make data conform more closely to the normal distribution (Changyong et al., 2014), and that is why Katircioglu (2010) uses natural logarithms to capture growth effects of regressors on the dependent variable. Also, by using logs, we set all variables to the same relative scale to show percent changes or multiplicative factors. Thus, comparing changes from the means is an apples-to-apples comparison. Using the logarithm does restrict the levels of regressors from being zero or negative, which is fitting for income and emissions (Stern, 2004), and using logarithms can help remove the appearance of heteroscedasticity if all variables are positive.

In terms of data type, the most common types of empirical CO_2 EKC studies, especially in the early stages to find evidence for the phenomenon, were panel or cross-section data since CO_2 is a global pollutant. But a number of empirical studies have used time-series data to test whether an EKC relationship holds for single countries, which may vary due to economic growth conditions.

2.2.4. Studies grouped by econometric model

Most of the studies have used a standard CO_2 EKC model, which applies a quadratic (sometimes cubic) function of the levels of GDP per capita, but many CO_2 EKC studies have included additional explanatory variables such as trade (see Table 2-1), as well government transparency (Shin et al., 2015), while similar studies (such as He & Richard, 2010) have included a linear time trend to capture exogenous advances in technology. In addition, some studies have added energy consumption but there is no consensus on the direction of causality between economic growth and energy consumption (Alwan & Al-Tarawneh, 2014).

Education and democracy (political participation) were not among the variables that have been added to the CO_2 ECK studies -- at least according to our survey -- but some studies test their relationship with CO_2 separate from economic growth. Romuald (2010) studied the education effect on the CO_2 level where the result is different from country to country based on the level o f development. Carlsson & Lundström (2001) found the effect of political freedom on CO_2 emissions to be insignificant.

Some CO_2 EKC studies have used different methods, e.g., He & Richard (2010) used semiparametric and flexible nonlinear parametric modeling methods in an attempt to provide inferences that are more robust.

2.2.5 Studies grouped by endogeneity treatment

Studies using the reduced form model, in which environmental quality is a function of income (as explained more thoroughly in Chapter 3), are subject to an endogeneity criticism, as to whether there is a simultaneity bias introduced by possible reverse causality between income and environmental degradation, or from an omitted variable bias (Liscow, 2013). In response:

- Many studies have used a reduced-form model in a quadratic or cubic form, with an EKC diagram showing income on the horizontal axis and pollution on the vertical axis. That suggests one-way causation from income to emissions. Primarily, the endogeneity criticism is relevant to the case of local pollutants, and not to global pollutants like CO_2 where there is a one-way income-to-emissions causality because emissions impact is mostly extra-national. In any case these studies used their models for the purpose of finding an association relation, not for estimating the coefficients; e.g., see Holtz & Selden (1995) and others noted in Table 2-1. We note that in this survey the results of empirical studies that used the Granger test to determine the direction of causation have supported this hypothesis, especially in cases of expanded cross-country panel data; the results do differ in single countries or particular regions, consistent with (Coondoo & Dinda, 2002).

- Several studies have used a cointegration approach, e.g., Nasir and Rehman (2011); see Table 2-1. This approach has been raised in the most recent studies and involves correcting the error (residual) and revealing the unconditional relationship in the long run. Thus, it avoids any simultaneity bias introduced by reverse causality of income and environmental degradation.
- Among the CO_2 EKC studies in this survey, we find no CO_2 studies applying the instrumental variables approach, but many CO_2 EKC studies have included additional explanatory variables such as trade or government transparency, or have included a linear time trend to capture exogenous advances in technology (see Table 2-1).

Chapter 3. Research Methodology

3.1 Theoretical Framework

3.1.1 The basic IPAT Model

One of the theoretical roots of the Environmental Kuznets Curve (EKC) is the IPAT mathematical identity, formulated by Ehrlich and Holdren (1971), the name of which comes from the components of the equation:

$$I = P\left(\frac{Y}{P}\right)\left(\frac{I}{Y}\right) \tag{3-1}$$

where I is environmental impact, P is population, and Y is GDP, so the equation can be interpreted as

Impact = (Population) (Affluence) (Technology).

Technology is interpreted as the pollution intensity of production methods, with a higher value meaning "dirtier" and a lower value meaning "cleaner" production per dollar of GDP. Adapting the identity to a per-capita version, and applying it to CO_2 emissions, the relationship can be written as:

CO_2 emissions per capita = (Affluence) (Technology)

or

$$E = A\,T \tag{3-2}$$

thereby decomposing emissions per person into the affluence or "scale" effect and a technique effect. As an identity, the nature of the relationship is irrefutable, and implies that E will be linear in A given a level of T, with affluence always bringing proportionally more environmental impact if it were assumed that technique were fixed. The EKC can arise from this context, based on an understanding that A and T are not independent. In particular, it is easy to hypothesize that greater affluence encourages cleaner technologies, and in that case

$$E = [A][T(A)] \text{ with } T'(A) < 0. \tag{3-3}$$

Then the EKC slope is

$$\frac{dE}{dA} = T(A) + [A][T'(A)] \qquad \textit{(3-4)}$$

which involves a positive term and a negative term, so if the second term becomes negative enough at high levels of A, we can have $\frac{dE}{dA}$ change from positive to negative, generating the classic inverted-U shape of the EKC.

3.1.2 Elaborating the identity with additional proximate explanatory variables

The original identity can be elaborated to further decompose the T factor, to suggest what might underlie an expectation of $T'(A) < 0$. For example, it is broadly observed that as societies develop to high levels of affluence, the composition of their output mixes tends to become more service intensive, and services tend to have lower environmental impact than industrial production. Even if manufacturing itself does not decline in total activity, it usually falls as a proportion of GDP. This output composition effect, one example of a structural effect, can be incorporated into the identity as follows:

$$E = Y \left(\frac{N}{Y}\right) \left(\frac{E}{N}\right) \qquad (3\text{-}5)$$

where N is total manufacturing output, with the interpretation

CO2 emissions = (*Affluence*) (*Industrial Share*) (*Industrial Technology*)

or

$$E = A\, n\, t \qquad (3\text{-}6)$$

Where $n = \frac{N}{Y}$ and $t = \frac{I}{N}$ and A is a renaming of Y. Here *Share* and *Technology* together make a *Technique* effect focusing on the environmental dirtiness of manufacturing activity in particular. Variations of this sort of composition structure effect are possible, and the plausible interdependencies also multiply. For instance, we can incorporate functional dependencies as follows:

$$E = [A][n(A)][t(A)]. \tag{3-7}$$

This model makes a curvature of the EKC when $n'(A) < 0$ and possibly $t'(A) < 0$ for reasons beyond compositional change, perhaps "demand" for environmental protection, or higher political transparency. Such socio-political factors could enter the empirical modeling of the $t(A)$ function.

In a similar way, the critical role of energy use and source can be built into the identity. Setting industrial structure aside for now, consider an identity amended as follows:

$$E = \left(\frac{Y}{P}\right)\left(\frac{G}{Y}\right)\left(\frac{I}{G}\right) \tag{3-8}$$

where G is total energy use so the interpretation becomes

Carbon emissions = (Affluence) (Energy Intensity) (Energy Impactfulness)

and we can understand that $\frac{G}{Y}$ would be impacted by technology trends, demand factors, and regulatory efforts all varying by time and place and affecting energy efficiency. With specific reference to CO_2 emissions, the impact factor $\frac{I}{G}$ would largely be explained by energy source according to carbon content – coal, oil, natural gas, nuclear, renewables – which would be affected by costs, availability generally, regulatory effort, etc.

3.1.3 Incorporating underlying variables that affect the proximate variables

Either Equation (3-6) or Equation (3-8) could be alternatives to the basic identity Equation (3-2). Moving forward with the industrial share factoring expressed by Equation (3-6), the search for explanatory variables would depart from such mechanical, deterministic identities with unitary elasticities, and would explore the stochastic dependency of the proximate variables on a number of underlying variables. In this case if X is the vector of underlying explanatory variables, the system of equations in general form would be:

$$E = A\,n\,t \tag{3-9}$$

$$n = n(A, X) \tag{3-10}$$

$$t = t(A, X) \tag{3-11}$$

Based on the literature, we offer Figure 3-1 to describe the hypothesized direction of causality, from affluence and plausible socio-political factors to technique and finally emissions. So, we assume that underlying variables affect the proximate variable technique in interaction with affluence:

$$E = [A][n(A, X, AX)]\ [t(A, X, AX)]$$

thereby enriching the mechanisms by which affluence affects technique and ultimately emissions.

Plausible underlying variables include trade openness (both import penetration and export specialization), as well as education, democracy, transparency, and regulatory indicators.

3.1.4 Hypothesized direction of causality

The foregoing diagram explicitly describes the hypothesized directions of causality, among scale/affluence, social-economic-political descriptors of society, technique, and emissions. The main assumptions underlying the diagram, to be explored more thoroughly in the next section, are: (1) a country's affluence affects emissions directly and via technique, and technique does not affect that country's affluence; (2) the underlying variables affect technique in interaction with affluence.

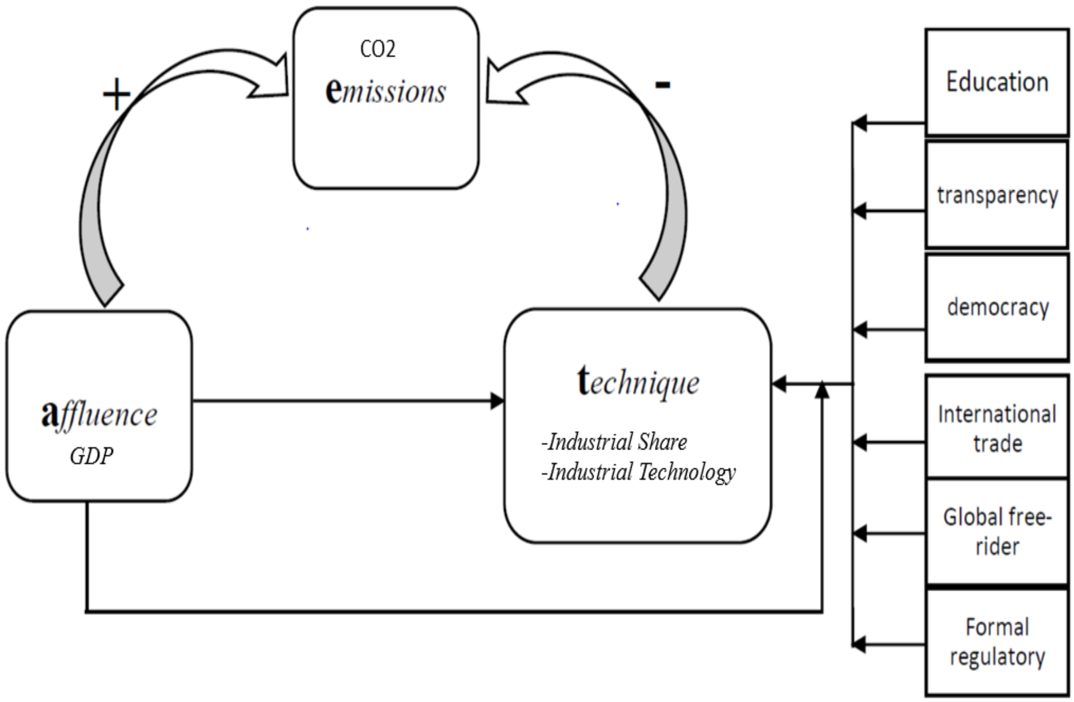

Figure 3-1: a schematic representation of the interdependencies

3.2 Empirical model background

The foregoing causality framework applies most directly to emissions of pollutants and can generate an inverted U-shape curve, but the result depends on the assumptions made and the values of particular parameters. Various studies make different simplifying assumptions about the economy. A first key assumption is that environmental damage does not reduce economic activity (Grossman & Krueger, 1994; Lopez, 1994; and Dinda, 2005) though income does explain changes in degradation. Studies using a reduced form model with environmental quality as a simple function of income are subject to an endogeneity criticism, whether via simultaneity bias introduced by the reverse causality of income and environmental degradation, or from an omitted variable bias. This issue was discussed in Chapter 2, and for CO_2 reverse causality is understood to be inconsequential at the country level since most of a country's emission costs are externalized.

As far as a broader level of causality issues, Selden and Song (1995) assume that pollution is generated by production and not by consumption. Though the level of emissions per capita may differ over countries at any particular income level, studies tend to assume the income elasticity is the same in all countries at a given income level (Stern, 2004). Several studies assume exogeneity of the independent variables (proximate & underlying) such as technology (Lopez, 1994), but Andreoni and Levinson (2001) argue that none of these special assumptions is needed and economies of scale in abatement are sufficient to generate the EKC. So, the standard EKC regression model is a quadratic function of the levels of Gross Domestic Product per capita (Grossman and Krueger, 1991; List and Gallet, 1999):

$$ln\, E_{it} = \alpha_i + \gamma_t + \beta_1\, ln\, GDP_{it} + \beta_2\, (ln\, GDP_{it})^2 + u_{it} \qquad (3\text{-}12)$$

where E_{it} is emissions per capita and the natural logarithm captures growth effects of regressors on the dependent variable (Katircioglu, 2010), and standardizes elasticities relative to scale. Also, Stern (2004) notes that the use of the logarithm does restrict the levels of regressors from being zero or negative, which is fitting for income and emissions. Usually the model is estimated using panel data for the i^{th} region and t^{th} year. Then α_i are region-specific intercepts and γ_t are year-specific intercepts, to catch time-varying or region-varying omitted variables effects. The fixed effects model treats α_i and γ_t as regression parameters. The random-effects model treats the α_i and γ_t components as random disturbance.

Under the assumption of exogeneity many EKC studies include additional explanatory variables, intended to model underlying and proximate factors, and that means implicitly the environmental damage does not affect the additional explanatory variables.

Panayotou (1997) modeled output structure as industry share in GDP and represents the structure or composition of economic activity. Ang (2007), Ozturk (2010), and some other studies include energy consumption as an exogenous parameter or explanatory variable, but there is no consensus on direction of causality between economic growth and energy consumption (Alwan & Al-Tarawneh, 2014). Also, He & Richard (2010) and others have included a linear time trend to capture exogenous advances in technology.

As underlying factors, government transparency and democracy (e.g., Torras & Boyce 1998; Krutilla & Shin 2015), trade (e.g., Suri & Chapman, 1998; Dong et al., 2011), and policy (e.g., Panayotou, 1997) have been modeled in several published papers. For education, Romuald (2010) investigates the impact of education on the growth of carbon dioxide emissions per capita.

In general, the included variables turn out to be significant at traditional significance levels. Stern (2014) reviews several of these and concludes "testing different variables individually is however subject to the problem of potential omitted variables bias. Further, these studies do not report cointegration or other statistics that might tell us if omitted variables bias is likely to be a problem or not" (p 1423).

Through the survey of the literature, we find most studies on this subject are based on estimating fully parametric quadratic or cubic regression models[1], but autocorrelation and

[1]Some studies used a different approach e.g., Holtz and Selden (1992) used sensitivity analyses; Roca et al. (2001) used input-output approach; York et al. (2003) computed the ecological elasticities; and He and Richard (2010) used

heteroscedasticity, calculating standard errors at the turning point level of income to indicate the reliability of estimates, are weaknesses associated with the estimation of EKCs outlined by Stern (2004).

On the other hand, we see in this survey that most studies use time series data for single countries, and panel data at the level of multiple countries, and we note that results show an inverted-U shape because of the nature of the economic structure and neglect of the consumption side (e.g. Sengupta, 1996; Moomaw & Unruh, 1997; Friedl & Getzner, 2003; Martinez-Zarzoso & Bengochea-Morancho, 2004; Choi, et al 2010; Alwan & Al-Tarawneh, 2014).

3.3 Econometric Models

Previously, we mentioned that the standard EKC regression model is a quadratic function of the level of Gross Domestic Product per capita. This is based on the explanatory power of GDP both in scale effect and influence on the technique. In our study we estimate the EKC hypotheses using model variations in 3 stages outlined in the next three subsections.

3.3.1 LEVEL 1: Standard EKC regression model

The first model is based on the literature review summarized in section 3.2, using a simple quadratic function

$$ln\, E_{it} = \alpha_i + \gamma_t + \beta_1\, ln\, GDP_{it} + \beta_2\, (ln\, GDP_{it})^2 + u_{it} \qquad \textit{(3-13)}$$

Where E is CO_2 emissions per capita and A is GDP per capita. This model will serve as a benchmark against which we can compare the results of our elaborated models.

semiparametric and flexible nonlinear parametric modeling methods. However, these papers were based in the standard theoretical context and yielded similar results; for more details see section 1.1 and Chapter 2.

3.3.2 LEVEL 2: EKC model with additional proximate explanatory variables

The second model, in two versions, is based on the IPAT-style identities that we had derived in Sections 3.1.1 and 3.1.2.

Version 1: Decomposition into Affluence (Scale) and Technique

From Equation (3) we have:

$$\text{Emissions} = \text{(Affluence) (Technique)} \quad \text{or} \quad E = A \;\; T(A).$$

Using available data, we will empirically estimate the equation for Technique as a function of Affluence, $T(A)$:

$$T_{it} = \theta_i + \delta_t + \eta_1 A_{it} + u_{it} \tag{3-14}$$

where $T = \frac{E}{Y}$ is the Technique factor, an inverse measure of *emissions efficiency* and A is GDP per capita. We will then plug that into the original $E = AT$ model to examine the implied shape.

$$E = A\, T(A) = A\,(c_1 + \eta_1 A) = (c_1 A + \eta_1 A^2) \tag{3-15}$$

Where c_1 (from equation (3-15)) is an intercept constructed from α_i and γ_t, giving a theoretically derived quadratic function of A.

Version 2: Decomposition into Affluence (Scale), Structure, and Technology

From Equation (7) we have:

$$\textit{Emissions} = \textit{(Affluence) (Industrial Share) (Industrial Technology)} \quad \text{or} \quad E = A\, n\, t.$$

Using available data, we will empirically estimate equations for Industrial Share and Technology as functions in Affluence, that is, $n = n(A)$ and$t = t(A)$:

$$n_{it} = \alpha_i + \gamma_t + \beta_1 A_{it} + \varepsilon_{it} \tag{3-16}$$

where $n = \frac{N}{Y}$ is Industrial Share (percent of GDP from manufacturing), and A is GDP per capita. And then:

$$t_{it} = \theta_i + \delta_t + \eta_1 A_{it} + u_{it} \tag{3-17}$$

where $t = \frac{I}{N}$ is the Industrial Technology factor, an inverse measure of emissions efficiency, and A is GDP per capita. We then will plug the estimated equations into the original $E = A\, n\, t$ identity to examine the implied shape.

$$E = A\,(c_1 + \beta_1 A)\,(c_2 + \eta_{1_1} A) \tag{3-18}$$

where c_1 and c_2 are the intercepts, and which generates a theoretically derived cubic equation. Those intercepts come from equations (3-16) and (3-17) respectively.

3.3.3 LEVEL 3: EKC model with underlying variables that affect the technique variables

In the third model, we explore the possible role of other variables that could underlie the results of the second model, using the E = A n t identity that we derived as Equation (7). Using available data, we will empirically estimate the equation of Industrial Share and Technology as functions of a vector X of underlying variables.

$$n = n(A, X)$$
$$t = t(A, X)$$

Where X is a vector of 6 plausible underlying variables including trade openness, education, democracy, transparency, global free riding, and formal regulation, assuming that the underlying variables affect the proximate variables, including possible interaction with affluence. We will estimate:

$$n_{it} = \alpha_i + \gamma_t + \beta_0 a_{it} + \beta_1 x1_{it} + \cdots + \beta_6 x6_{it} + \beta_7 A\, x1_{it} + \cdots + \varepsilon_{it} \quad (3\text{-}19)$$

$$t_{it} = \theta_i + \delta_t + \eta_0 a_{it} + \eta_1 x1_{it} + \cdots + \eta_6 x6_{it} + \eta_7 A\, x1_{it} + \cdots + u_{it} \quad (3\text{-}20)$$

Then we will plug the estimated equations into the original identity to examine the implied shape:

$$E = A\, n\, t = A\,(K_1)\,(K_2) \quad (3\text{-}21)$$

where K_1 comes from equation (3-19) and K_2 from equation (3-20).

3.4 Estimation Methods

3.4.1 Ordinary least squares

The OLS model will be applied to the three previous specifications (Levels 1, 2, and 3) to estimate the cross-country EKC from panel data samples. Also, to ensure the specifications and method have no critical econometric problems, diagnostic tests such as the Dickey–Fuller, Durbin Watson, and White tests will be applied.

3.4.2 Sub-sample analysis

For the Level 1 analysis, the EKC hypotheses will be tested on the full sample of 65 countries, as well as 10 pairs of sub-samples based on the proximate and underlying variables, which can raise interesting questions through sub-sample comparisons. Each sub-sample pair consists of 20 countries, representing the top 10 and bottom 10 countries as ranked based on the underlying variable in question.

Sub-samples based on emission level

The first sub-sample pair includes countries ranked by the total emissions in metric tons, and the second includes countries ranked according to per capita emissions.

Sub-samples based on GDP ppp

The first set includes countries ranked by gross domestic product, the second includes countries ranked according to domestic product per capita (GDP per capita), and third includes countries ranked by gross domestic product per emissions (income-producing efficiency).

Additional sub-samples

The same sub-sample approach will be applied using indices measuring the following 5 underlying variables:

- Education
- Transparency
- Democracy
- International trade
- Formal regulatory effort

The indices used for these variables are discussed in Chapter 4.

Chapter 4. Data

4.1 Data sources

In its most succinct form, the analysis includes 10 primary variables mentioned above, for 65 countries, from 1990 to 2011 unless otherwise noted below. These time series data are published on the Internet in various websites such as the United Nations, International Energy Agency (IEA), World Bank, World Integrated Trade Solution (WITS), Yale Center for Environmental Law and Policy, and Center for International Earth Science Information Network.

Emissions

Metric tons per capita of carbon dioxide (CO_2) emissions are those stemming from the burning of fossil fuel fuels during production processes. Data published by the World Bank, and calculated by the Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee, USA. Data are available for 268 countries and region from 1960 to 2013. The data are available at:

http://data.worldbank.org/indicator/EN.ATM.CO2E.PC

http://www.iea.org/statistics/

http://www.iea.org/statistics/relateddatabases/co2emissionsfromfuelcombustion/

http://edgar.jrc.ec.europa.eu/overview.php?v=CO2ts_pc1990-2014

Income

Gross domestic product (GDP) per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are published by the World Bank in current U.S. dollars and adjusted for purchasing power parity (PPP). The PPP GDP is gross domestic product converted to international dollars using purchasing power parity rates. An international dollar has the same purchasing power over GDP as the U.S. dollar has in the United States. Data are available for 268 countries and region from 1990 to 2015 at:

http://data.worldbank.org/indicator/NY.GDP.PCAP.CD

http://www.statista.com/statistics/205966/world-carbon-dioxide-emissions-by-region/

Education

The Education Index (EI) is published by the United Nations, and calculated from the *mean years of schooling index* and the *expected years of schooling index*. Data are available for 187 countries from 1980 to 2013 at:

http://databank.worldbank.org/data/reports.aspx?source=education-statistics-~-all-indicators&preview=on

http://hdr.undp.org/en/content/education-index

Transparency

We use a transparency measure constructed by Hollyer, Rosendorff, and Vreeland (HRV index). The HRV Index is designed to measure the technocratic capacity of the government to collect data as well as the government's willingness to disclose economic data, and the project provides observations for 125 countries from 1980 to 2011 at:

http://0001c70.wcomhost.com/wp2/download-data/

https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/24274

Democracy

The polity score from the Polity IV project is a commonly used measure of democracy. The variable ranges from 0 to 20. Annual Polity scores have been plotted for each of the 167 countries currently covered by the Polity IV data series for the period 1946-2013. The data are available at:

http://www.systemicpeace.org/polity/polity4.htm

http://www.nsd.uib.no/macrodataguide/set.html?id=32&sub=1

http://www.eiu.com/home.aspx#offer-ss-data

See also:

http://www.systemicpeace.org/polityproject.html

http://databank.worldbank.org/data/reports.aspx?source=worldwide-governance-indicators

https://www.hks.harvard.edu/fs/pnorris/Data/Data.htm

International trade

We use an "openness" index representing trade openness or trade dependence on foreign countries. The openness index, a measure of merchandise trade liberalization, is measured as the sum of merchandise exports and imports divided by the value of GDP, all in current U.S. dollars based on World Trade Organization data and World Bank GDP estimates. Data are available for 268 countries and region from 1960 to 2015 at:

http://wits.worldbank.org/

http://data.worldbank.org/indicator/NE.TRD.GNFS.ZS

http://www.iccwbo.org/global-influence/g20/reports-and-products/open-markets-index/

http://www.iccsaudiarabia.org.sa/arabic/News/Pages/201305022.aspx

Global free-rider ability

To create an indicator of countries' capacity to act as free riders on the public good of climate conservation, we generate dummy variables for signatory countries to the emission reduction agreement under the United Nations Framework Convention on Climate Change (UNFCCC). We use data for 65 countries from 1990 to 2011 that can be found at:

http://unfccc.int/kyoto_protocol/items/2830.php

We tracked the status of the sample countries starting from the signature of the agreement, in accordance with the following timeline:

- 1992: The initial date of signature of the Kyoto Protocol marks the start of mutual emissions reduction commitments, so for the two years preceding the signing of the agreement the dummy variable will take the value of 0 for all countries, indicating the lack of cooperation between the countries. Then as of 1992 in the event that a country signs the agreement its dummy variable changes to 1 starting that year, indicating the intention of cooperation and diminished freedom to act as a free rider.
- 1998: The beginning of ratification of the Kyoto Protocol by signatory countries serves as the next commitment threshold, so that the dummy variable takes the value of 0 if a country does not ratify the protocol, and continues a value of 1 in the event of ratification indicating the intention of continuing cooperation.
- 2005: As the Kyoto Protocol comes into force, the dummy variable will revert to 0 for a year if a country does not fulfill its obligation for that year.
- In the event of the withdrawal of a state from the treaty, the dummy variable will take the value of 0 for that year and thereafter.

Formal regulatory effort

There are several indicators available, including Environmental Indexes. The Environmental Performance Index (EPI) ranks countries' performances on high-priority environmental issues in two areas: protection of human health and protection of ecosystems. The EPI is a method of quantifying and numerically marking the environmental performance of a state's policies. This index was developed from the Environmental Sustainability Index (ESI), and both indexes were developed by Yale University (Yale Center for Environmental Law and Policy) and Columbia University (Center for International Earth Science Information Network) in collaboration with the World Economic Forum and the Joint Research Centre of the European Commission. The ESI was developed to evaluate environmental sustainability relative to the paths of other countries. Due to a shift in focus by the teams developing the ESI, the EPI uses outcome-oriented indicators, creating as a benchmark index that can be more easily used by policy makers, environmental scientists, advocates and the general public. The data are available at:

https://sedac.ciesin.columbia.edu/data/set/epi-environmental-performance-index-2018/data-download#

http://archive.epi.yale.edu/faqs

http://climatepositions.com/environmental-performance-index-2016-ranking-of-180-countries/

Industrial Share

We use manufacturing as a proportion of GDP, and it is calculated as $n = N/Y$ where N is the dollar value of industrial output and Y is total GDP. We use the industrial share percenteage data published by the World Bank. See:

http://data.worldbank.org/indicator/NV.IND.TOTL.ZS

http://www.tradingeconomics.com/

http://www.theglobaleconomy.com/rankings/industry_value_added/

http://www.indexmundi.com/facts/indicators/NV.IND.TOTL.ZS/compare#country=ae

Industrial Technology

This variable is emissions per dollar of industrial output, and is a measure of inverse emissions efficiency or industrial pollution intensity. We calculate it as $t = E/N$ where N = (n)(GDP) with n defined as above, and where E is total CO_2 emissions.

4.2 Sub-sample data

For the overall analysis, we use data for a sample of 65 countries, from which we draw 10 sub-sample pairs based on the proximate and underlying variables. Tables 4-1 to 4-7 list the Top 10 and Bottom 10 countries ranked for each of the indicated variables.

Table 4-1: Top 10 and Bottom 10 countries by CO_2 emissions

	Total CO_2 emissions	**Per capita CO_2 emissions**
	Top 10	***Top 10***
1	China	Kuwait
2	United States	United Arab Emirates
3	India	Oman
4	Russia	Australia
5	Japan	Saudi Arabia
6	Iran	United States
7	Korea, Rep.	Canada
8	Canada	Russia
9	Brazil	Korea
10	Saudi Arabia	Japan
	Bottom 10	***Bottom 10***
1	Oman	Nigeria
2	Romania	Pakistan
3	Chile	Philippines
4	Nigeria	India
5	Belgium	Indonesia
6	Philippines	Vietnam
7	Kuwait	Brazil
8	Iraq	Egypt
9	Algeria	Algeria
10	Netherlands	Romania

Source: (CDIAC, 2010).

Table 4-2: Top 10 and Bottom 10 countries by GDP

	GDP (PPP)	GDP (PPP) per capita	GDP per emissions
	Top 10	***Top 10***	***Top 10***
1	China	Singapore	Chad
2	USA	Kuwait	Mali
3	India	UAE	Switzerland
4	Japan	Norway	Norway
5	Russia	Switzerland	Sweden
6	Brazil	United States	Burkina Faso
7	Indonesia	Saudi Arabia	France
8	UK	Netherlands	Central Africa
9	France	Austria	Congo
10	Italy	Denmark	Denmark
	Bottom 10	***Bottom 10***	***Bottom 10***
1	Niger	Central African Rep	China
2	Guinea	DR Congo	Iran
3	Swaziland	Burundi	Zimbabwe
4	Togo	Malawi	Iraq
5	Sierra Leone	Liberia	Vietnam
6	Burundi	Niger	India
7	Liberia	Mozambique	South Africa
8	Central African	Guinea	Russia
9	Guinea-Bissau	Guinea-Bissau	Egypt
10	Burkina Faso	Togo	Liberia

Source: (World Bank, 2015)

Table 4-3: Top 10 and Bottom 10 countries by Education Quality

	Education Index	Education Index
	Top 10	***Bottom 10***
1	Norway	Niger
2	Australia	DR Congo
3	Switzerland	Central African Republic
4	Netherlands	Chad
5	United States	Sierra Leone
6	New Zealand	Burkina Faso
7	Canada	Burundi
8	Singapore	Guinea
9	Denmark	Mozambique
10	Sweden	Guinea-Bissau

Source: (United Nations, 2010)

Table 4-4 Top 10 and Bottom 10 countries by Transparency

	Corruption Perceptions Index	Corruption Perceptions Index
	Top 10	***Bottom 10***
1	Denmark	Sudan
2	Finland	Angola
3	Sweden	Libya
4	New Zealand	Iraq
5	Netherlands	Venezuela
6	Norway	Guinea-Bissau
7	Switzerland	Zimbabwe
8	Singapore	Burundi
9	Canada	DR Congo
10	Germany	Chad

Source: Transparency International (2015)

Table 4-5: Top 10 and Bottom 10 countries by Democracy

	Democracy Index	Democracy Index
	Top 10	***Bottom 10***
1	Norway	Chad
2	Sweden	Central African Republic
3	New Zealand	Saudi Arabia
4	Denmark	Guinea-Bissau
5	Canada	DR Congo
6	Ireland	Iran
7	Switzerland	Libya
8	Finland	Sudan
9	Australia	Burundi
10	Netherlands	UAE

Source: Economist Intelligence Unit (2015)

Table 4-6: Top 10 and Bottom 10 countries by Trade Openness

	Open-Markets-Index	Open-Markets-Index
	Top 10	***Bottom 10***
1	Singapore	Sudan
2	Belgium	Bangladesh
3	Netherlands	Venezuela
4	UAE	Uganda
5	Ireland	Pakistan
6	Switzerland	Algeria
7	Sweden	Liberia
8	Germany	Nigeria
9	Norway	Angola
10	Denmark	Tanzania

Source: World Bank (2010)

Table 4-7: Top 10 and bottom 10 countries by Environmental Performance

	EPI	EPI
	Top 10	***Bottom 10***
1	Finland	Uganda
2	Sweden	Central African Republic
3	Denmark	Chad
4	Spain	Congo, Dem. Rep.
5	Portugal	Burundi
6	France	Zimbabwe
7	New Zealand	Guinea-Bissau
8	United Kingdom	Venezuela
9	Australia	Iraq
10	Singapore	Angola

Source: Yale (2014)

4.3 Summary Statistics and trend data analysis

A summary of statistics for the annual panel data of 21 years (1990-2011) and 65 countries is presented in Table 4-8. The table presents the standard deviations for these varaibles and indicates how much of the variation is attributable to variation across countries and over time, respectively. The variation in the data is acceptable and that makes the regression analysis tractable. The variables vary substantially across countries (between), and over time (within), respectively, though variation is more marked across countries while relatively more stable over time within countries.

Table 4-8: Summary Statistics for 65 countries data

Variables		Mean	Min	Max	Standard deviation	
CO_2 pc	Gross domestic product per capita	5.726566	0.07	34.47	Over all	6.561611
					Between	6.489388
					Within	1.249578
GDP pc	Gross domestic product per capita	19003.99	246.6705	114518.8	Over all	20739.57
					Between	20467.08
					Within	4169.438
trade	Metric tons per capita of carbon dioxide	60.69808	0.0209992	986.6469	Over all	56.44709
					Between	45.62482
					Within	33.69333
EI	Education index	0.5169448	0.0167	0.9158	Over all	0.2274687
					Between	0.2225184
					Within	0.054362
HRV	Transparency index	1.76335	-3.043783	8.345117	Over all	2.545822
					Between	2.383209
					Within	0.9407385
Polity IV	Democracy Measure	2.702797	-10	10	Over all	7.025331
					Between	6.598199
					Within	2.541425
UNFCCC	Global free rigid ability	0.727972	0	1	Over all	0.4451599
					Between	0.1876708
					Within	0.4043076
EPI	Environmental performance index	69	1	180	Over all	51.55878
					Between	48.4652506
					Within	18.56116
n	Industrial share	32.00155	6.79107	91.75787	Over all	13.56241
					Between	12.63297
					Within	5.16646
t	Industrial technology	$9.22e^{-06}$	$5.86e^{-07}$	0.0004783	Over all	$6.08e^{-06}$
					Between	$4.82e^{-06}$
					Within	$3.76e^{-06}$
T	technology	0.000275369	2.52938E-05	0.001385	Over all	0.000174576
					Between	
					Within	

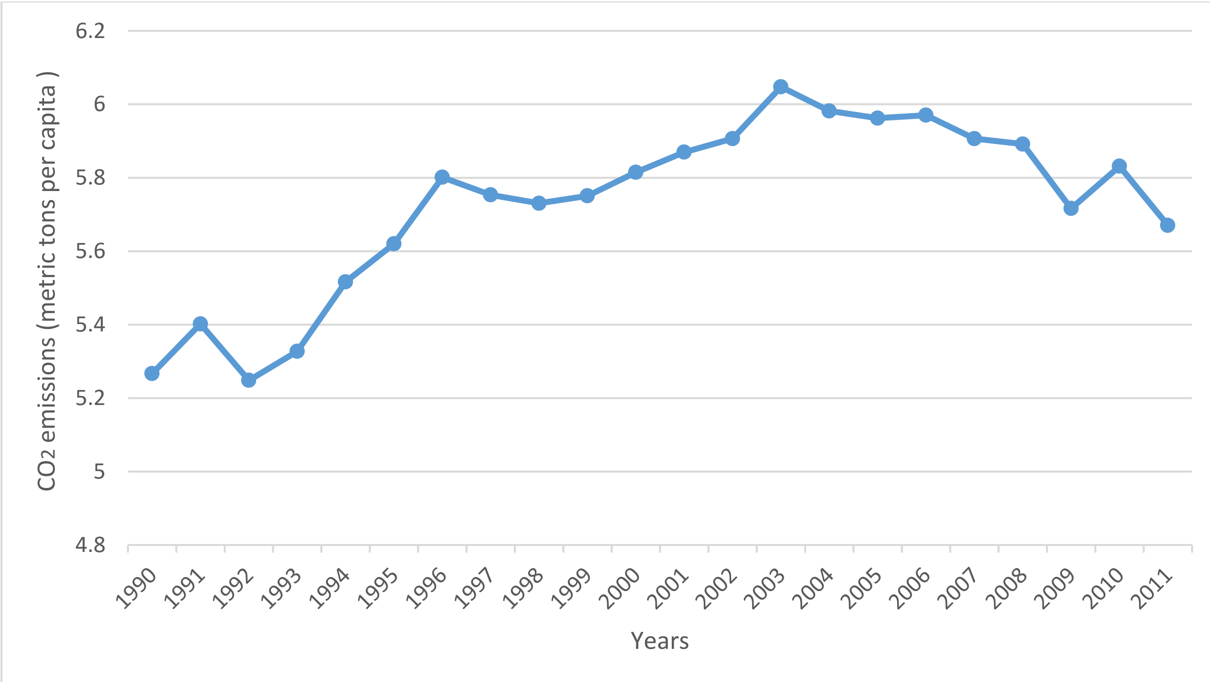

Figure 4-1A The development of the CO_2 pc level over time

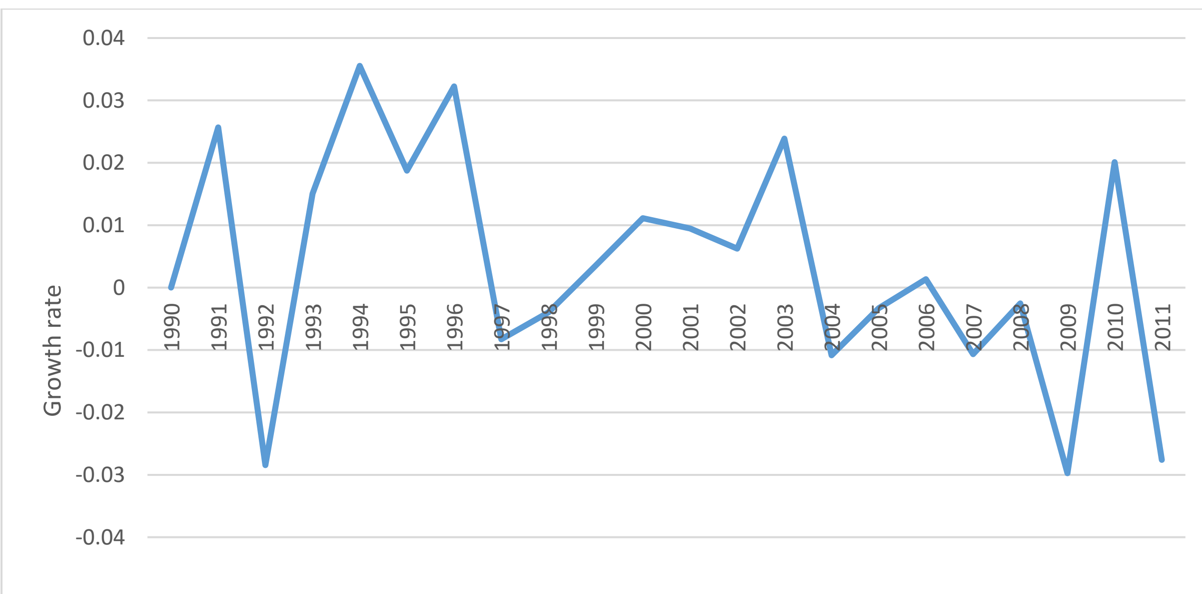

Fig 4-1B Trends in the growth rate of total CO_2 pc emissions normalized at 1990 values

The average of overall observations is 5.73 metric tons per year per capita through the years of the study. Emissions increased by 7.7% over the sample period with an annual average growth of 0.36%, although there has been a decline in total emissions from 2003. It should be noted, that we note that drop happened in, 2009 constant with the drop in GDP.

Figure 4-2A and 4-2B: The trends of GDP and its growth rate for the 65 countries 1990-2011.

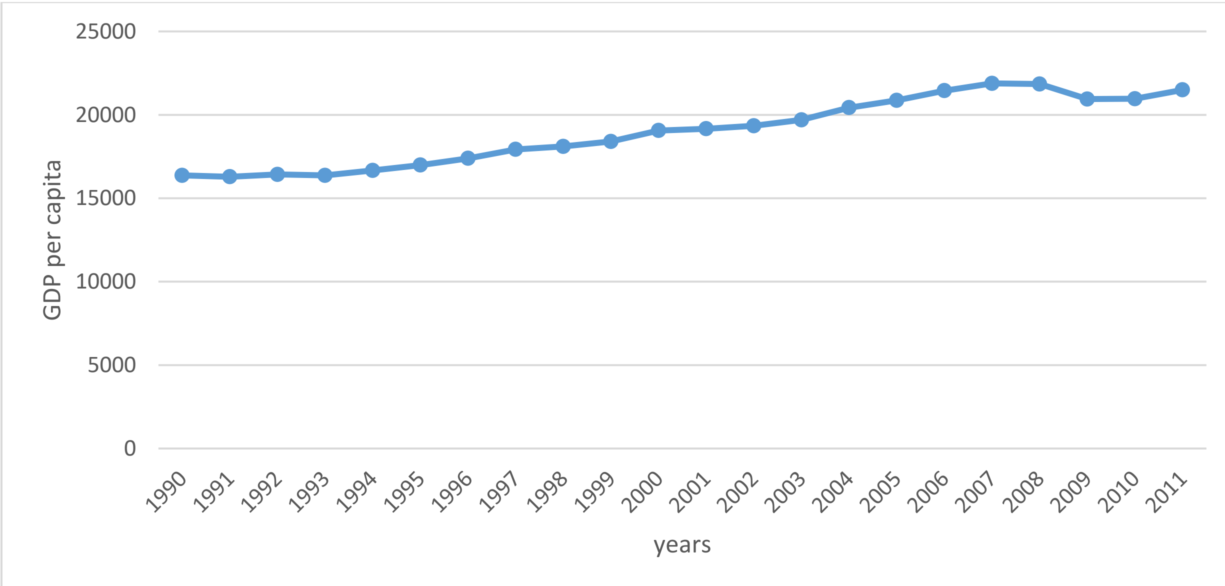

Fig 4-2A The development of GDP pc level over time

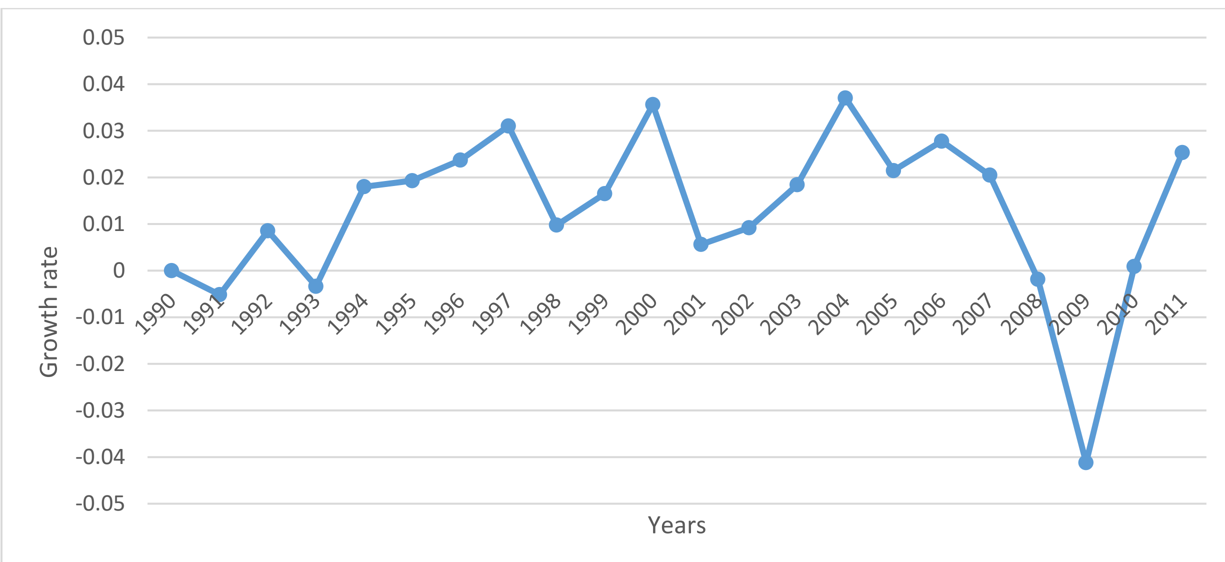

Fig 4-2B The trends in the growth rate of total GDP pc normalized at 1990 values

The average of overall observations is $19,004 per capita based on purchasing power parity through the years of the study. Emissions increased by 31.30% over the sample period with an annual average growth of 1.26%.

Chapter 5. Empirical Results

This chapter presents the econometric results and interpretations for the various models specified in Chapter 3, namely:

- Level 1: Standard EKC regression model
- Level 2: EKC model with additional proximate explanatory variables
- Level 3: EKC model with underlying variables that affect technique

5.1 Level 1: Standard EKC model

In all the regression models presented in this section, we present the results for the estimator with robust standard errors for a fixed-effect panel regression with serial correlation. The Hausman test supports the hypothesis of a fixed-effect model as the preferred approach. For both the full sample of 65 countries and all the 10-country subsample analyses, it is important to remember that the results only apply, and should be interpreted with respect to, the limited sample. Additionally, for all the models in this section, there is no use of decomposition or control variables that could help resolve issues of heterogeneity; those elaborations are introduced in Levels 2 and 3. In every case, the quadratic polynomial functional form is imposed, then assessed for fit with the sample data; this approach simply establishes benchmark results according to the traditional quadratic formulation.

Finally note that in this as well as in the subsequent sections, many of the regressions use logarithmic data, and then the figures show the curves transformed back into levels rather than logs. There are at least 3 implications:

- The curves become skewed. For a quadratic function in logs, which would in its own right have a symmetric parabolic graph, the graph becomes skewed to the left, as well as constrained to a positive domain.
- The transformation also affects the visual impression of how the data points are scattered around the estimated curve, giving the idea that it is not best fit, though it is best fit in logarithms.
- Finally, the transformation can change the convexity or concavity of the EKC. Note that for a log-log estimate of y as a function of x, the result would be $\ln y = f(\ln x)$ for some form of function f. Transformed, we have $y = e^{f(\ln x)}$, from which we can derive $\frac{dy}{df} = \left[e^{f(\ln x)} f'(\ln x)\right]/A$ and subsequently:

$$\frac{d^2 f}{dx^2} = e^{f(\ln x)}[f"(\ln x) + (f'(\ln x))^2 - f'(\ln x)]/x^2$$

Consequently, as in the case of results reported in Tables 5-9 and 5-10, and corresponding Figures 5-7 and 5-9, the estimated log-log function is convex, while the level-level graph is concave. Note the even when concavified, the nature of $\frac{dy}{df} = \left[e^{f(\ln x)} f'(\ln x)\right]/A$ means the transformed function f cannot reach a turning point, a peak, since f' will never reach zero for an increasing convex function.

5.1 Level 1: Standard EKC model

5.1.1 The relationship between emissions and income for 65 countries

Table 5-1 summarizes the regression results for our full sample of 65 countries. The regression is significant at a 99% level of confidence based on the F test which gives a *p*-value of 0.0002, and the individual regression slope coefficients are significant at the 95% confidence level based on *t* tests, with the exception of GDP-squared. We find $\beta_1 > 0$ and $\beta_2 < 0$, and for the 65-country sample the EKC is inverse U-shaped, but the estimated critical value, or turning point where GDP per capita and CO_2 emission level become negatively related, is \$3,917,640 and 7.185 metric tons. (The GDP turning point is calculated as the antilog of $-\frac{\beta_1}{2\beta_2} = 15.181$.) This result implies that all the 65 countries are still on the upsloping side of the Environmental Kuznets Curve, far below the turning point. See Figure 5-1.

Table 5-1: Standard EKC estimation for the sample of 65 countries

Constant	-5.7253 (0.021)
GDP	1.0140 (0.054)
GDP^2	-0.0333 (0.234)
R^2 within	0.2270
R^2 between	0.9285
R^2 overall	0.9144
P-value for F test	0.0002
Turning point	\$3,917,0640 7.19 mt

Note: P-values for t test are in parentheses. Country FE (yes), Year FE (no)

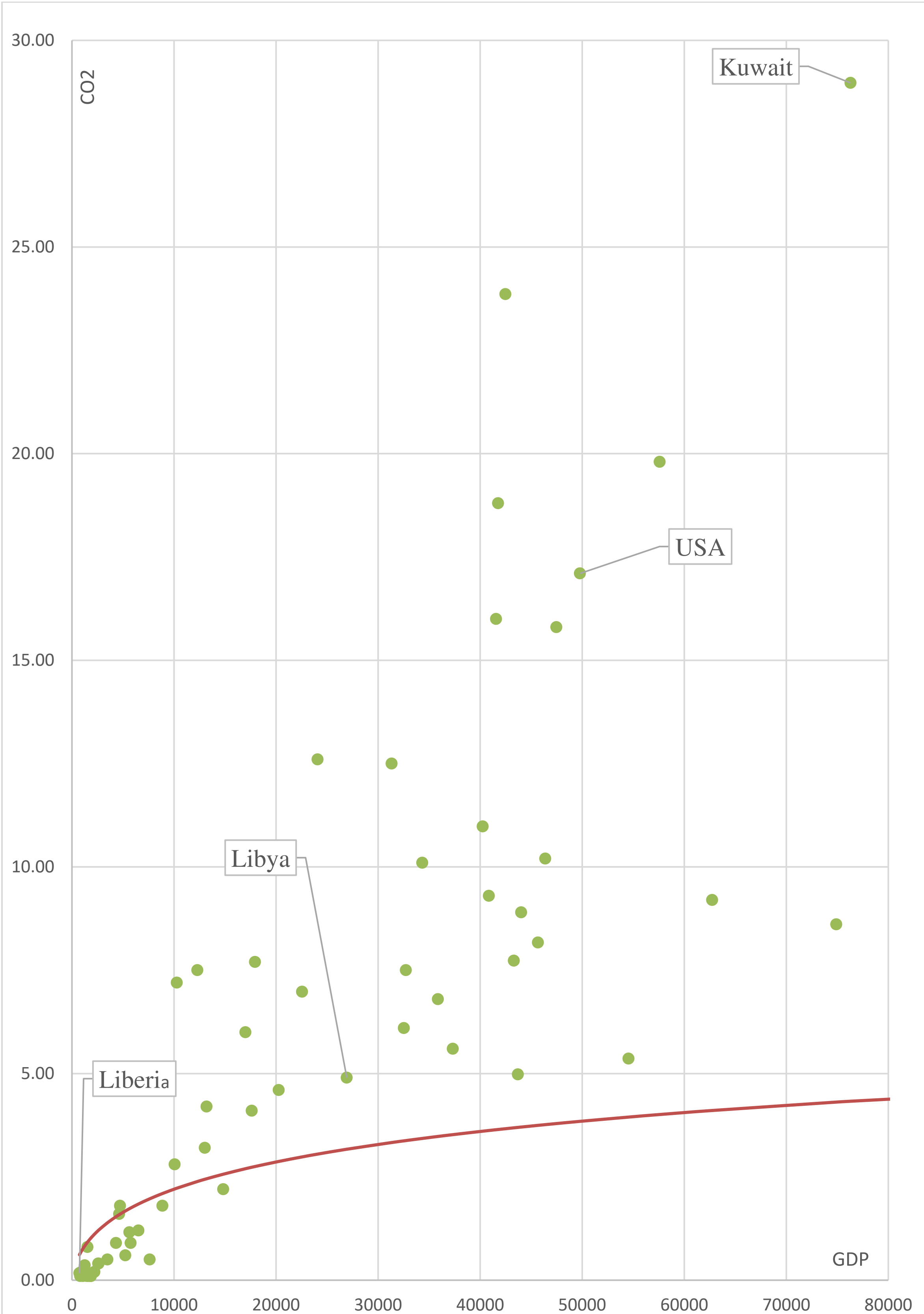

Figure 5-1: The inverted U-shaped EKC for 65 countries (standard EKC model)

5.1.2 Relationship between emissions and income for Underlying Variable subsamples

5.1.2.1 For subsamples based on Education Quality

Table 5-7 summarizes the regression results for two subsamples, the Top 10 and Bottom 10 countries based on Education Quality. Estimated curves are illustrated in Figures 5-2 and 5-3; note that in Figure 5-3 and a few figures to come later, an inset shows the section of curve where the actual data points are most relevant. In other later cases an inset is used to show critical points in context.

Table 5-7: Standard EKC for Top 10 and Bottom10 countries based on Education Quality

	Top 10 countries	Bottom10 countries
Constant	-46.39694 (0.162)	-5.791205 (0.028)
GDP	9.350228 (0.137)	0.926626 (0.211)
GDP^2	-0.4484235 (0.131)	- 0.0520713 (0.355)
R^2 within	0.1731	0.0951
R^2 between	0.0031	0.6017
R^2 overall	0.0009	0.5219
P-value for F test	0.1035	0.0211
Turning point	$33,791	$7,317

Note: P-values for t test are in parentheses. Country FE (yes), Year FE (no)\\\\

For the Top 10 sample[2] (the highest countries in terms of education quality), we find $\beta_1 > 0$ and $\beta_2 < 0$, and when transformed the implied EKC for these countries is inverse U-shaped and the estimated turning point is \$33,725, and 10.423 metric ton on average for these countries which means as rich countries all of the highest countries in terms of education quality have surpassed the turning point and are thus on the downside of the curve with the exception of New Zealand where the income level is very close to the tipping point income, and its emissions are already below the sample peak. The regression is not significant at a high level of confidence (though it was highly significant before application of the robust standard error approach for fixed effect panel regressions with serial correlation).

For the Bottom 10 sample[3] (the lowest countries in terms of education quality), the regression is significant at the 95% level, but not so for the individual regression slope coefficients. We find $\beta_1 > 0$ and $\beta_2 < 0$, and the implied EKC for these countries is inverse U-shaped, and the estimated turning point is \$7,317, and 0.1884 metric ton in average for these 10 countries which means as poor countries they are still on the upside side of the EKC before turning point.

Based on the Z test[4] result we fail to reject the null hypothesis that the true coefficients in two linear regressions are equal, which means the two sets of observations (two subsamples) could plausibly fit the same regression function.

[2] Norway, Australia, Switzerland, Netherlands, United States, New Zealand, Canada, Singapore, Sweden, Denmark.
[3] Niger, Congo D.R, Central African, Chad, Sierra Leone, Burkina Faso, Burundi, Guinea, Mozambique, Guinea-Bissau.
[4] This is a test of whether the true coefficients in two linear regressions on different data sets are equal. The test often is used to determine whether the independent variables have different impacts in different subgroups of the population. Drawing on the work of Clog et al. (1995), the formula for Z statistic should be:

$$Z = \frac{\text{the difference between two regression coefficients}}{\sqrt{SE1^2 + SE2^2}}$$

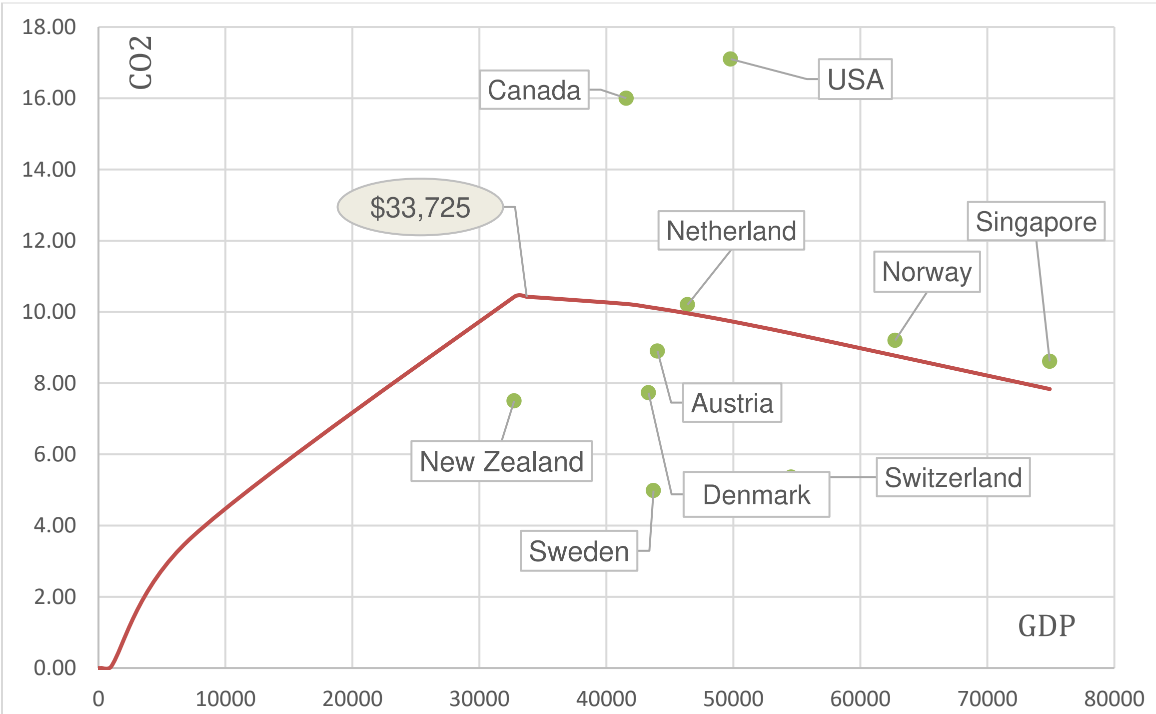

Figure 5-2: The inverted U-shaped EKC for Top 10 countries based on Education

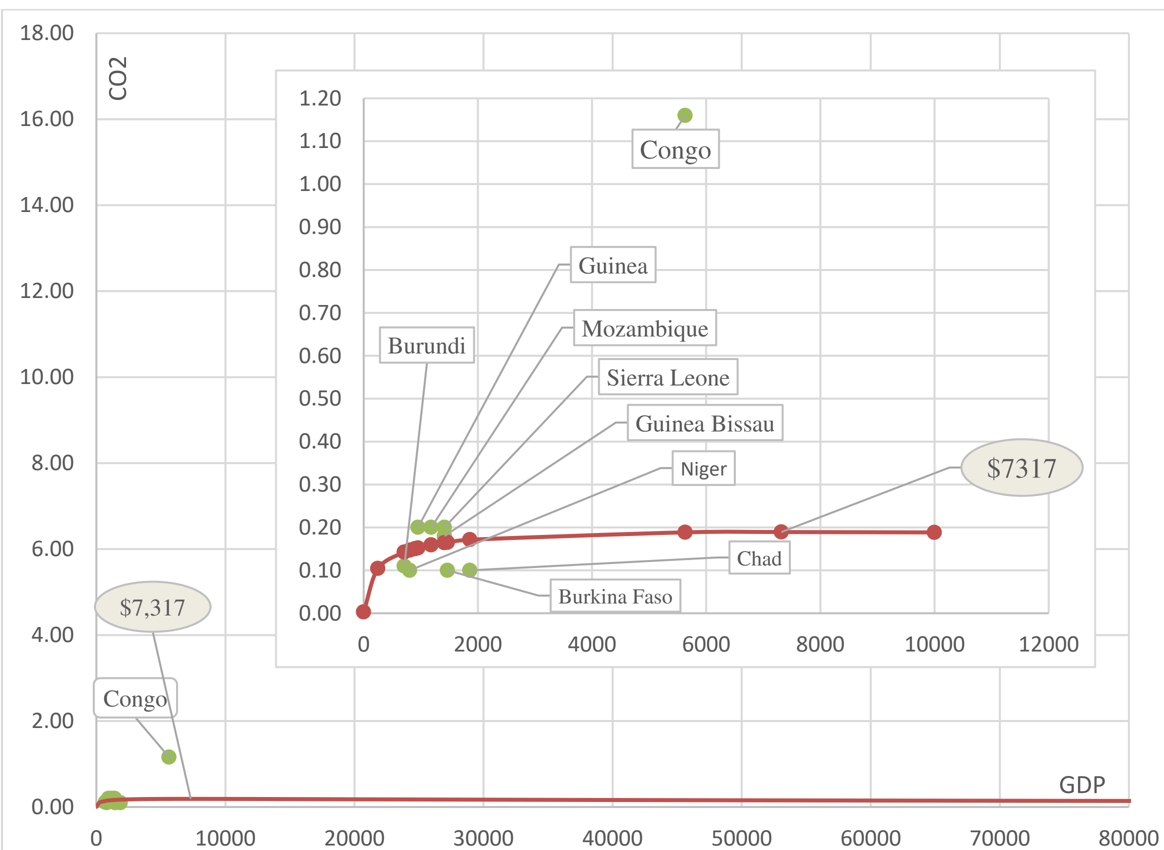

Figure 5-3: The inverted U-shaped EKC for Bottom 10 countries based on Education

5.1.2.2 For subsamples based on Transparency

Table 5-8 summarizes the regression results for two subsamples, the Top 10 and Bottom 10 countries based on Transparency. Estimated curves are shown in Figures 5-4 and 5-5.

For the Top 10 sample[5] (the highest countries in terms of Transparency), the regression is significant at a 90% level of confidence, but no individual regression slope coefficients are significant. We find $\beta_1 > 0$ and $\beta_2 < 0$, and when transformed the implied EKC for these countries is inverse U-shaped, and the estimated turning point is $30,394 and 10.0543 metric tons for these countries which means all of the highest countries in terms of Transparency have surpassed the turning point and are thus on the downside of the curve.

Table 5-8: Standard EKC estimation for Top and Bottom 10 based on Transparency

	Top 10 countries	Bottom10 countries
Constant	-37.51977 (0.209)	-13.01393 (0.091)
GDP	7.717329 (0.175)	2.887977 (0.101)
GDP^2	-0.3738384 (0.166)	-0.1591173 (0.111)
R^2 within	0.1752	0.1823
R^2 between	0.0022	0.6626
R^2 overall	0.0021	0.6256
P-value for F test	0.0816	0.2246
Turning point	$30,387	$8735

Note: P-values for t test are in parentheses. Country FE (yes), Year FE (no).

[5] Denmark, Finland, Sweden, New Zealand, Netherlands, Norway, Switzerland, Singapore, Canada, and UK.

For the Bottom 10 sample[6] (the lowest countries in terms of Transparency), $\beta_1 > 0$ and $\beta_2 < 0$, and the implied EKC for these countries is inverse U-shaped, and the estimated turning point is $8,735 and 0.6597 metric ton, so for most of these 10 countries that means they are still on the upside side of the EKC before turning point, with the exception of Libya, Iraq, and Venezuela which have large oil incomes. The overall regression is not significant at a high level of confidence (though it was highly significant before application of the robust standard errors approach for fixed effect panel regressions with serial correlation).

Based on the Z test we fail to reject the null hypothesis that the true coefficients in the two regressions are equal, so the two subsamples could plausibly fit the same regression function.

[6] Sudan, Angola, Libya, Iraq, Venezuela, Guinea-Bissau, Zimbabwe, Burundi, Congo, and Chad.

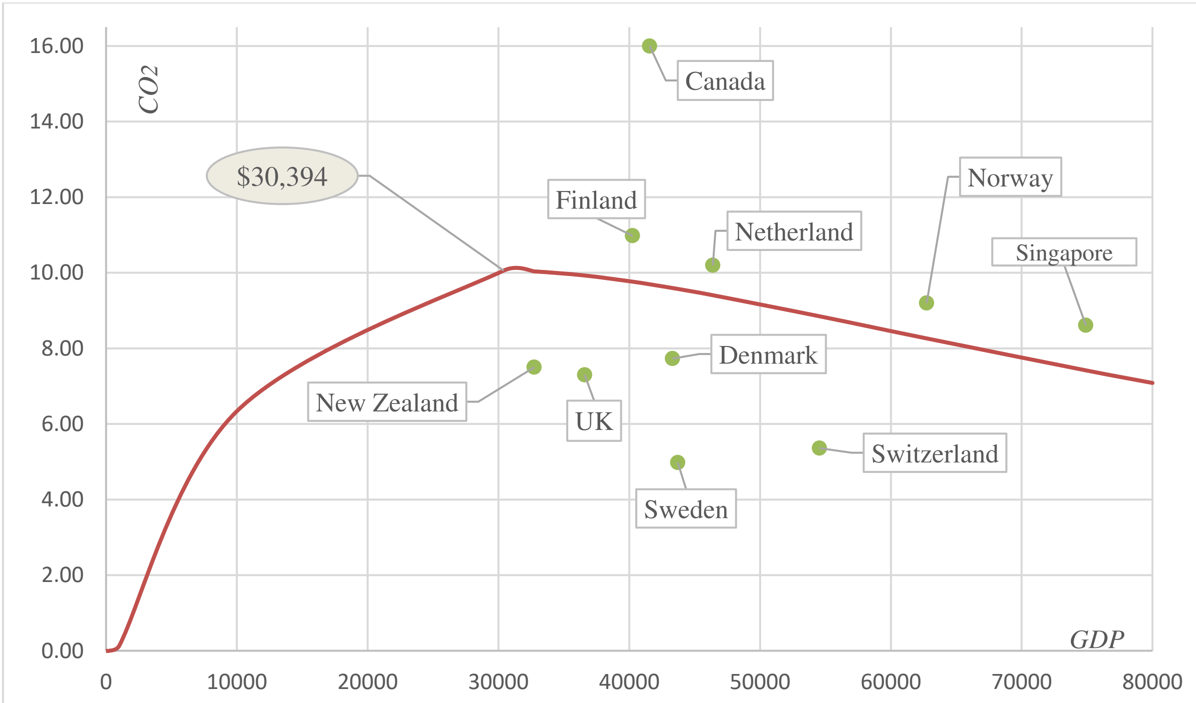

Figure 5-4: The inverted U-shaped EKC for Top 10 countries based on Transparency

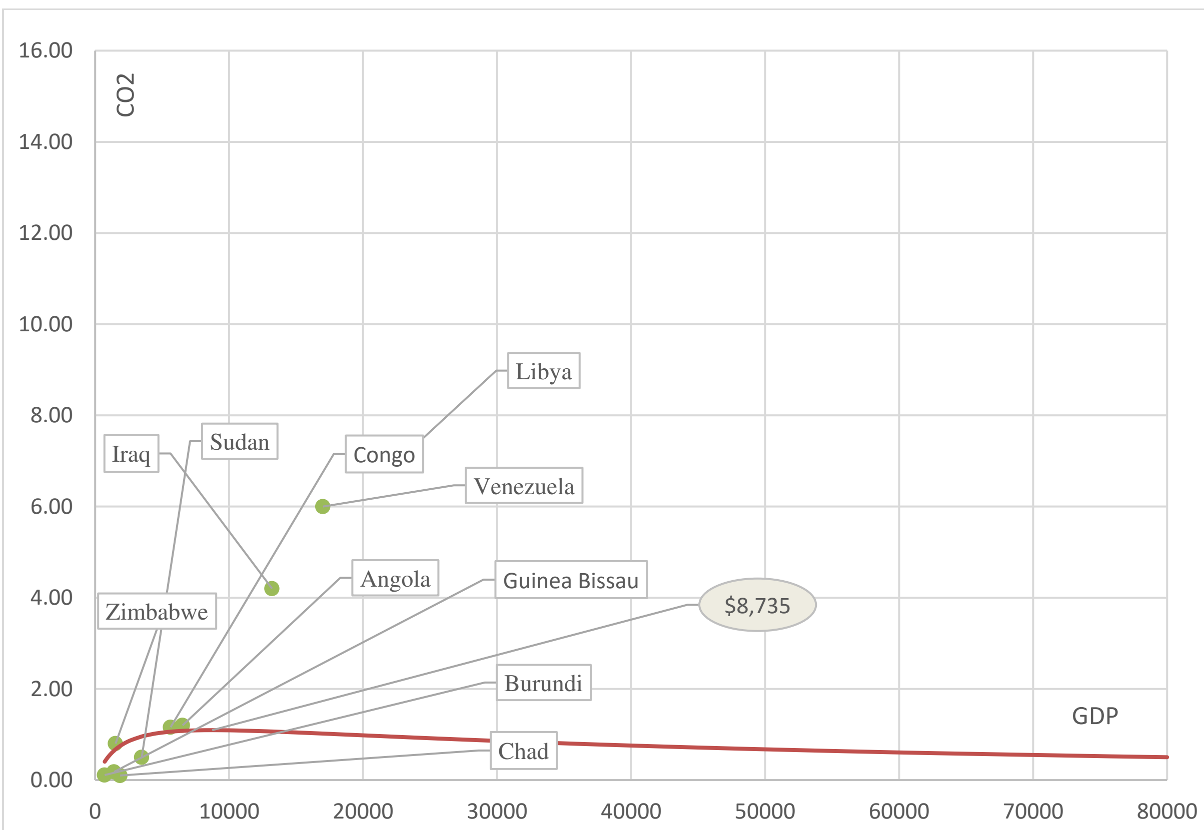

Figure 5-5: The inverted U-shaped EKC for Bottom 10 countries based on Transparency

5.1.2.3 For subsamples based on Democracy

Table 5-9 summarizes the regression results for two subsamples, the Top 10 and Bottom 10 countries based on Democracy, with illustrations in Figures 5-6 and 5-7.

Table 5-9: Standard EKC estimation for Top & Bottom 10 based on Democracy

	Top 10 countries	Bottom10 countries
Constant	-41.76099 (0.249)	-1.846979 (0.714)
GDP	8.389211 (0.230)	-0.137487 (0.894)
GDP^2	-0.3995213 (0.233)	0.0400842 (0.457)
R^2 within	0.0633	0.2865
R^2 between	0.0131	0.9569
R^2 overall	0.0168	0.9494
P-value for F test	0.3657	0.0668
Turning point	$36,282	$5.56

Note: P-values for t test are in parentheses. Country FE (time), Year FE (no).

For the Top 10 sample[7] (the highest countries in terms of Democracy), the regression is not significant at any high level of confidence (though it was highly significant before application of the robustness estimator). We find $\beta_1 > 0$ and $\beta_2 < 0$ and when transformed the implied EKC for these countries is inverse U-shaped, and the estimated turning point is $36,280 and 9.767 metric tons for these countries, which means all of the highest countries in terms of democracy have

[7] Norway, Sweden, New Zealand, Denmark, Canada, Ireland, Switzerland, Finland, Australia, and Netherlands.

surpassed the turning point and are thus on the downside of the curve with the exception of New Zealand where the income level is close to the tipping point income, and it's emissions already below the tipping point emission.

For the Bottom 10 sample[8] (the lowest countries in terms of democracy), the regression is significant at a 90% level of confidence, but not so for the individual regression slope coefficients. Since $\beta_1 < 0$ and $\beta_2 > 0$, the log-log function is U-shaped, but this is a case where transformation to levels for the purposes of graphing the EKC makes the EKC concave and monotonically increasing as shown in Figure 5-7.

Based on Z test result we fail to reject the null hypothesis that the true coefficients in the two linear regressions are equal. Even though each subsample generated its own estimates, they are not inconsistent with the other subsample's estimates.

[8] Chad, Central African, Saudi Arabia, Guinea-Bissau, Congo, Iran, Libya, Sudan, Burundi, and UAE.

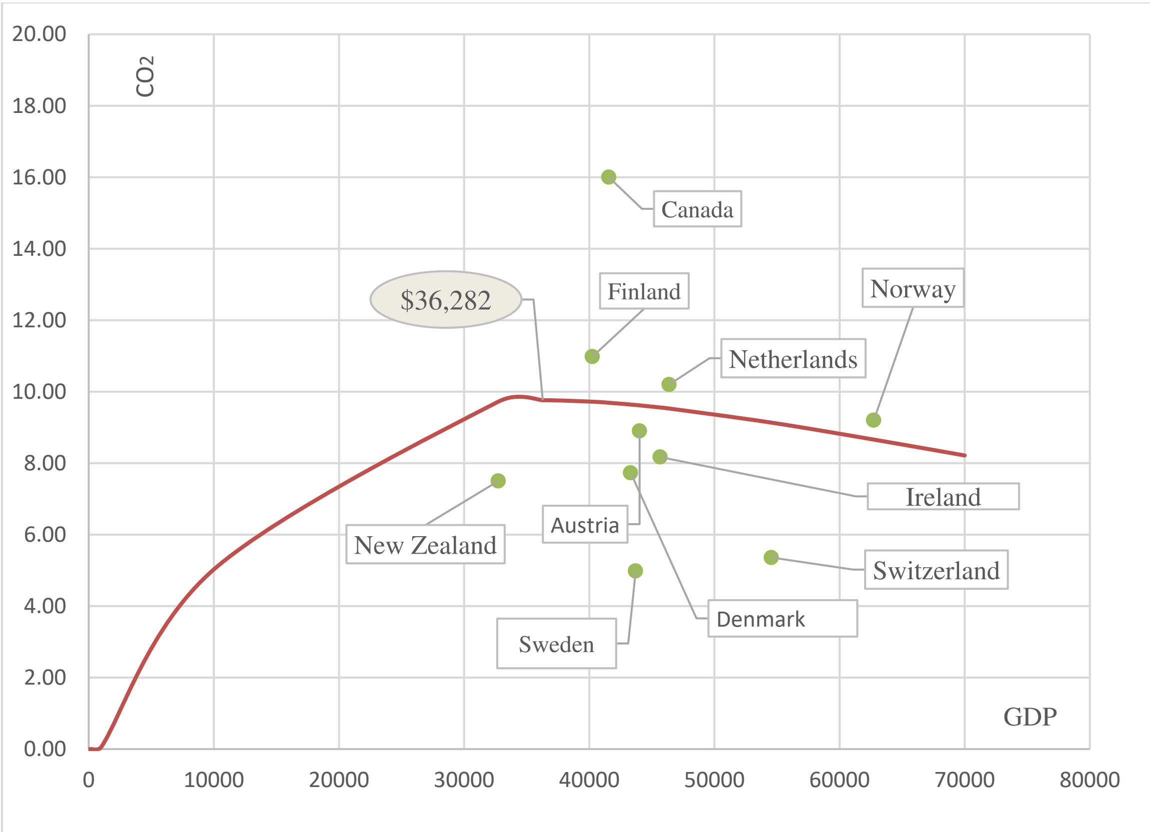

Figure 5-6: Inverted U-shaped EKC for Top 10 countries based on Democracy

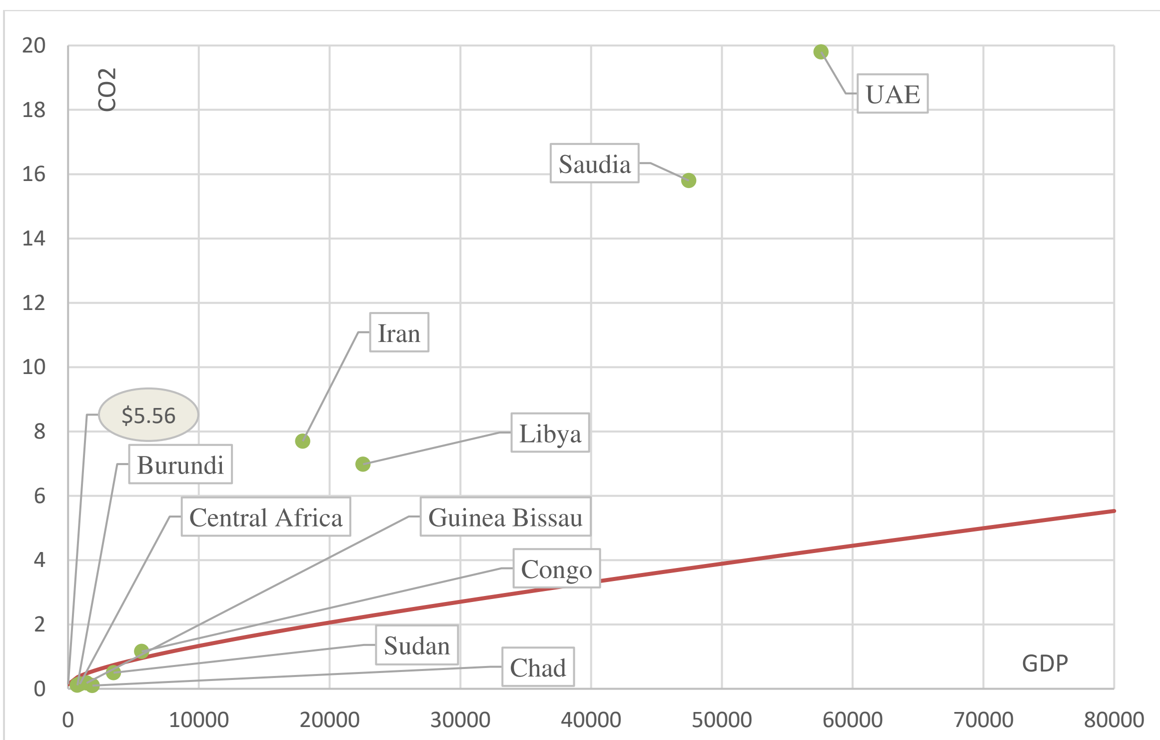

Figure 5-7: The Monotonic Increasing EKC for Bottom 10 countries based on Democracy

5.1.2.4 For subsamples based on Trade Openness

Table 5-10 summarizes the regression results for 2 samples of Top 10 and Bottom 10 countries based on Trade Openness, graphed in Figures 5-8 and 5-9.

Table 5-10: Standard EKC estimation for Top 10 & Bottom 10 based on Trade Openness

	Top 10 countries	Bottom 10 countries
Constant	30.23899 (0.375)	-2.755464 (0.461)
GDP	-5.24414 (0.413)	0.1333397 (0.906)
GDP^2	0.2460917 (0.414)	0.0155002 (0.856)
R^2 within	0.0704	0.1418
R^2 between	0.7013	0.9143
R^2 overall	0.5285	0.8722
P-value for F test	0.6982	0.2495
Turning point	42,404	-

Note: P-values for t test are in parentheses. Country FE (yes), Year FE (no).

For the top 10 sample[9] (the most open countries in terms of trade openness), the regression is not significant. We find $\beta_1 < 0$ and $\beta_2 > 0$, and the implied EKC for these countries is U-shaped. The estimated turning point, in this case a minimum point where GDP per capita and CO_2 emission level become positively related, is $42,404, and 9.985 metric ton in average which means that these countries are on the upside of the EKC, after the turning point with the exception of Belgium where the income level is very close to the turning point.

[9] Singapore, Belgium, Netherlands, UAE, Ireland, Switzerland, Sweden, Norway, Denmark, and Austria.

For the bottom 10 sample[10] (the most closed countries in terms of trade openness), the regression is again not significant. Hypothetically, since $\beta_1 > 0$ and $\beta_2 > 0$, the log-log relationship between CO_2 emission and GDP per capita for these countries is monotonic and increasing at an increasing rate, while Figure 5-9 shows that when transformed from logs to levels, the curve has CO_2 increasing at a decreasing rate.

Though the Z test result means the two subsamples could fit the same regression function, the non-significant overall regression values makes it difficult to tell a story based on the results.

[10] Sudan, Bangladesh, Venezuela, Uganda, Pakistan, Algeria, Liberia, Nigeria, Angola, and Tanzania.

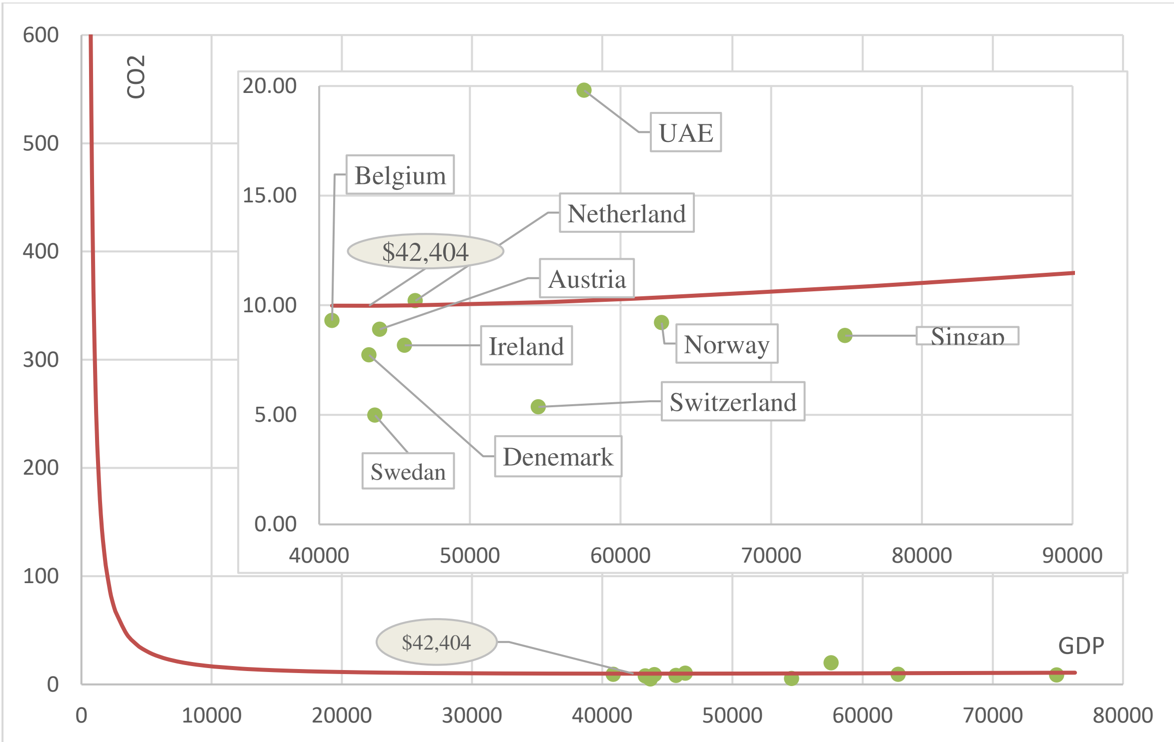

Figure 5-8: The U-shaped EKC for top 10 countries based on Trade Openness.

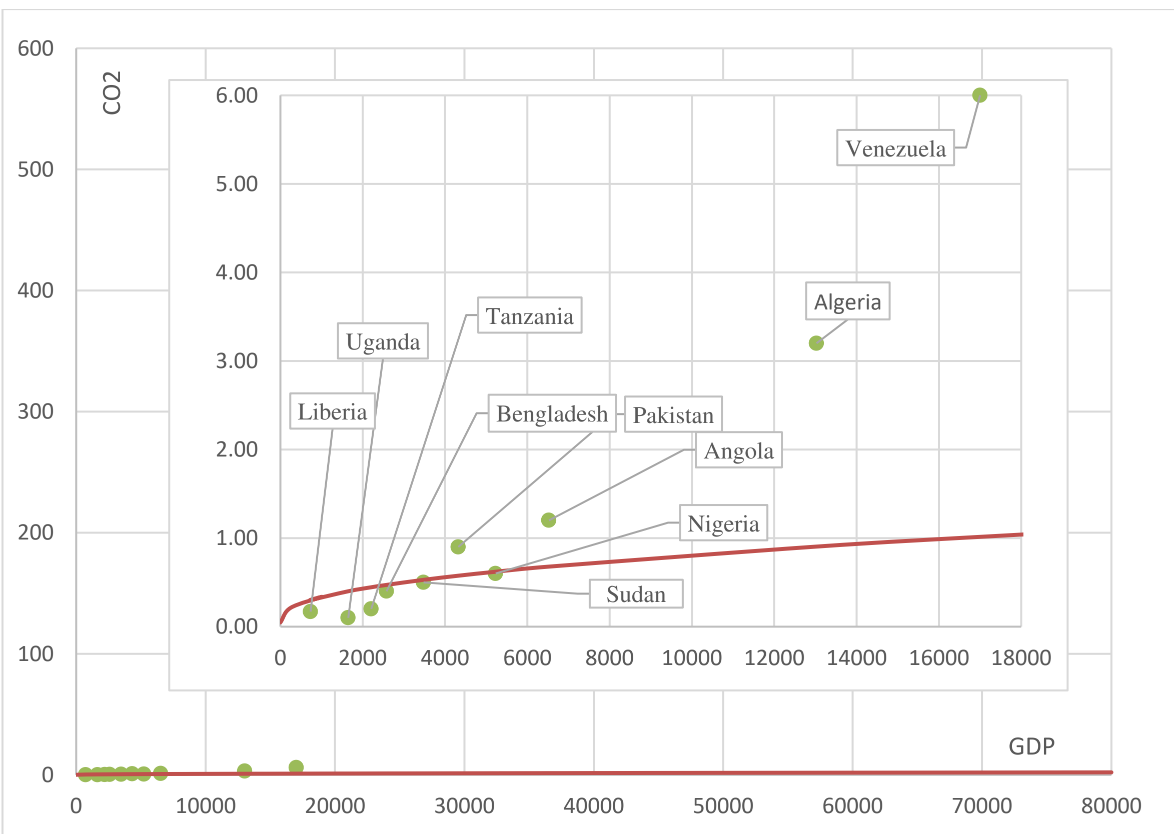

Figure 5-9: The Monotonic Increasing EKC for Bottom 10 countries based on Democracy

5.1.2.5 For subsamples based on Regulatory Effort

Table 11 summarizes the regression results for the Top 10 and Bottom 10 countries based on environmental performance as an indicator of formal regulatory effort.

For the top 10 sample[11] (the highest Regulatory Effort countries), the regression is significant at 95% level of confidant, but not the individual regression slope coefficients. Hypothetically, the transformed EKC for these countries is inverse U-shaped and the estimated critical value is $34,961, and 9.229 metric tons which mean most of the highest countries in terms of regulatory effort have surpassed the turning point based and are thus on the downside of the curve, where the income level of the rest of the countries is very close to the tipping point income, with their emissions already below the tipping point emission.

Table 5-11: Standard EKC estimation for Top 10 & Bottom 10 countries based on Formal Regulatory Effort

	Top 10 countries	Bottom10 countries
Constant	-88.21962 (0.001)	-8.459172 (0.174)
GDP	17.29007 (0.001)	1.844944 (0.206)
GDP^2	-0.8263461 (0.001)	-0.1077065 (0.205)
R^2 within	0.2838	0.0964
R^2 between	0.0130	0.5828
R^2 overall	0.0359	0.5299
P-value for F test	0.0033	0.4274
Turning point	$34,962	$5,245

Note: P-values for t test are in parentheses. Country FE (yes), Year FE (no).

[11] Finland, Sweden, Denmark, Spain, Portugal, France, New Zealand, United Kingdom, Australia, and Singapore.

For the bottom 10 sample[12] (the lowest countries in terms of Regulatory Effort), the regression is not significant at any high level of confidence (though it was highly significant before the robustness estimation). Hypothetically, though, we have $\beta_1 > 0$ and $\beta_2 < 0$, and the implied EKC for these countries is inverse U-shaped and the estimated turning point is $5,245 and 0.572 metric ton for these 10 countries which means they are still on the upside side of the EKC before the turning point, with the exception of Congo and Angola which very close to the tipping point; also Iraq, and Venezuela which have large oil incomes.

Based on Z test result we fail to reject the null hypothesis (the true coefficients in two linear regressions are equal) which means the two sets of observations (two subsamples) could plausibly fit the same regression function. See Figures 5-10 and 5-11.

[12] Uganda, Central Africa, Chad, Congo, Burundi, Zimbabwe, Guinea-Bissau, Venezuela, Iraq, and Angola.

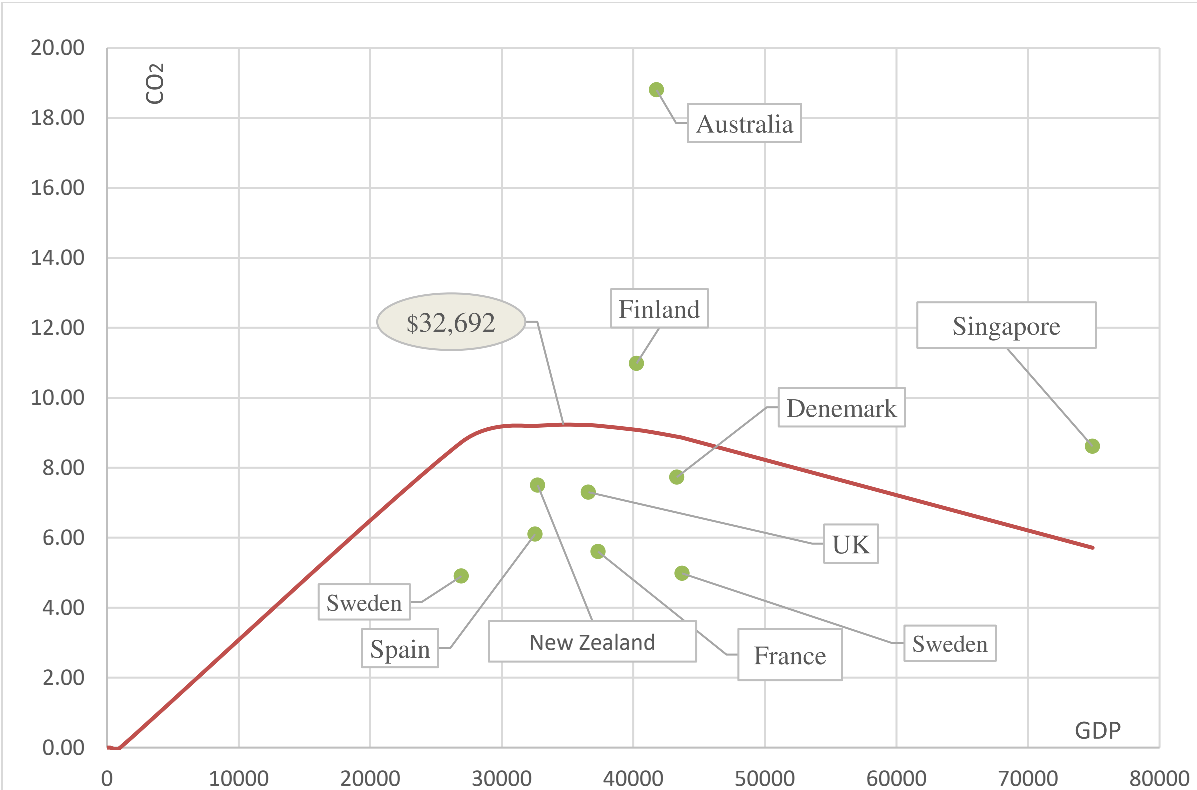

Figure 5-10: Inverted U-shaped EKC for top 10 countries based on Regulatory Effort

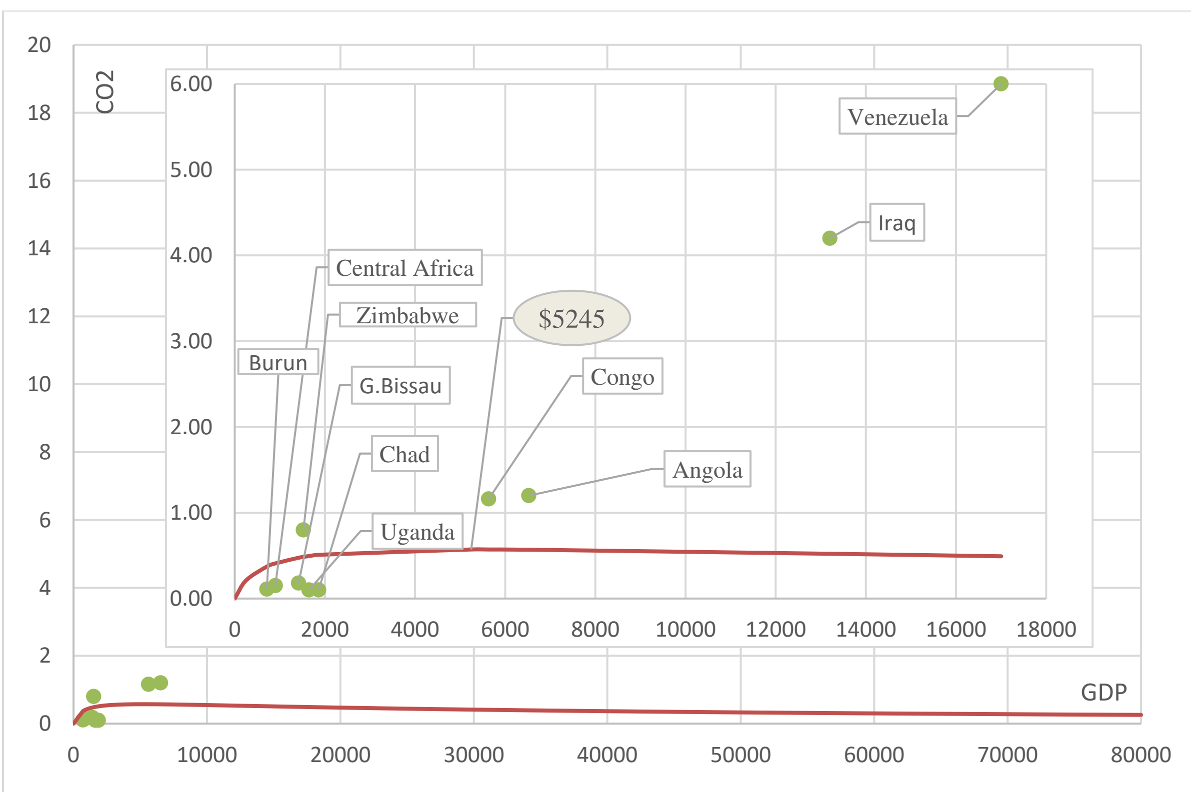

Figure 5-11: Inverted U-shaped EKC for Bottom 10 countries based on Regulatory Effort

5.1.3 Qualitative comparison of subsample results

Table 5-12 compiles and compares the qualitative implications of the Level 1 regression results. For the subsamples based on emissions and GDP, though some subsamples are estimated as U-shaped and others as inverted-U, most countries are on the upsloping side of the estimated curve. So the difference in results is mostly about curvature (concave or convex) and not about categorical differences in the environmental impact of GDP growth. For the subsamples based on the underlying variables, the evidence is more mixed and provides further motivation for the Level 3 analysis presented later.

Table 5-12: Comparison of subsample results

		F-stat significant?	t-stats significant?	Implied shape	Sample relative to turning point
Full sample, 65 countries		Yes	Mixed	Inv U	All on left up-sloping side
Underlying variable subsamples					
Education	Top 10	Yes	Yes	Inv U	All on right down-sloping
	Bottom 10	No	Yes	Inv U	All on left up-sloping side
Transparency	Top 10	Yes	No	Inv U	All on right down-sloping
	Bottom 10	No	Marginally	Inv U	Most on left up-sloping side
Democracy	Top 10	No	No	Inv U	All on right down-sloping
	Bottom 10	Yes	No	Increasing	Curve is monotonic increasing
Trade Openness	Top 10	No	No	U	All on right up-sloping side
	Bottom 10	No	No	Increasing	Curve is monotonic increasing
Regulatory Effort	Top 10	Yes	Yes	Inv U	All on right down-sloping
	Bottom 10	No	No	Inv U	All on left up-sloping side

5.1.4 Comparing GDP impact elasticities

One way to explore the effect of the underlying variables is to compare the Top 10 and Bottom 10 subsamples in those cases, as far as the elasticity of GDP impact on emissions. In this Level 1 we imposed the quadratic functional form for the sake of comparison to a long line of studies using that approach. Therefore, the elasticity is:

$$\varepsilon = \frac{d \ln CO_2}{d \ln GDP} = \beta_1 + 2\,\beta_2 \ln GDP$$

For instance, in the case of Education as an underlying variable, for the Top 10 we have β_1 = 9.35 and β_2 = - 0.45, while for the Bottom 10 we have β_1 = 0.93 and β_2 = - 0.05. Calculating the elasticities at the 2011 mean ln GDP of the subsamples, we have ε_{Top} = -0.37 (a negative elasticity, indicating that an increase in GDP by 1% will lead to a decrease in emissions by 0.37%), and ε_{Bottom} = 0.20 (a positive elasticity, telling that an increase in GDP by 1% will lead to an increase in emissions by 0.20%), thus, we see that low-education economies are associated with detrimental GDP impact, though that conclusion may be complicated by other unidentified aspects of the two subsamples. So, alternatively, using the 2011 mean GDP for the full sample of 65 countries, i.e., examining the difference that high and low education would make for the "typical" country, *ceteris paribus*, we have ε_{High} = 0.36 and ε_{Low} = -0.07. Here we see that it is the high-education economies that are associated with detrimental GDP impact.

Table 5-13 presents these elasticity comparisons for all five underlying variables. When the elasticities are applied to the full sample of 65 countries, in each case we use the 2011 mean GDP per capita of $21,495, which has a logarithm of 9.98.

Except for Trade Openness the rest of the underlying variables, if the elasticities are applied within the subsamples means, the Bottom 10 countries' positive elasticities are notably higher in magnitude than the Top 10 countries' negative elasticities, suggesting that countries ranked lower in terms of education quality, transparency, democracy, and formal regulatory effort, are associated with higher GDP impact; but by applying the estimates to the mean of the full sample, we get the opposite.

Table 5-13. Elasticities of GDP impact on CO_2 emissions, using 2011 GDP means

Underlying variable		β_1	β_2	*Mean GDP per capita (2011)*	*Ln of mean GDP*	*ε at subsample mean*	*ε at full sample mean*
Education	Top 10	9.35	-0.45	48,885	10.80	-0.37	0.37
	Bottom 10	0.93	-0.05	1,560	7.35	0.20	-0.07
Transparency	Top 10	7.72	-0.37	44,649	10.71	-0.21	0.33
	Bottom 10	2.89	-0.16	4,205	8.34	0.22	-0.30
Democracy	Top 10	8.39	-0.40	45,495	10.73	-0.19	0.41
	Bottom 10	-0.14	0 .04	15,958	9.68	0.63	0.66
Trade Openness	Top 10	-5.24	0.25	51,376	10.85	0.19	-0.25
	Bottom 10	0.13	0.02	5,675	8.64	-0.48	0.53
Regulatory Effort	Top 10	17.29	-0.83	41,006	10.62	-0.34	0.72
	Bottom 10	1.845	-0.11	5,043	5.53	0.63	-0.35

For Trade Openness, the Top 10 countries' positive elasticities are notably higher in magnitude than the Bottom 10 countries' negative elasticities, suggesting that countries ranked higher in terms of Trade Openness, are associated with higher GDP impact; but by applying coefficients with the mean of the full sample, we find the opposite.

All Top 10 countries' sub-samples (except the Trade Openness subsample) have surpassed the turning point and are thus on the downside of the inverse-U shape of the EKC, where the technique effect has started to dominate, while all Bottom 10 countries' sub-samples (except the trade openness' sub-sample) are still on the upside of the curve before the turning point, where scale effect still dominates. It should be noted that some countries in the Transparency sub-sample have passed the turning point, and also the EKC of the Democracy subsample is U-shaped but that will not change the conclusion.

In the Trade Openness subsamples, the Top 10 countries have surpassed the turning point of the U-shaped EKC and are thus on the upside; as well the Bottom 10 countries are on the upslope of an estimated monotonic relationship between CO_2 and GDP. So the Top 10 are associated with higher GDP impact compared with the Bottom10 countries, with a detrimental impact on CO_2 and consistent with a convex function.

We conclude from the previous analysis that underlying variables (education quality, transparency, democracy, and formal regulatory effort) may have a beneficial effect on emissions efficiency (the relationship between GDP and CO_2 will be negative and EKC will turn down), while trade openness may have a detrimental effect (the relationship between GDP and CO_2 will be positive).

5.1.5 Summary of Level 1 results

In this Level 1 analysis, we pursued a traditional EKC estimation with per capita GDP as the only independent variable, to establish a benchmark model applying our data to a simple quadratic functional form (with endogeneity concerns having been addressed in Chapters 2 and 3). We also explored possible differences between certain subsamples segregated according to a few variables of interest, including our underlying variables. The key results are as follows:

- For the full sample of 65 countries, a quadratic polynomial relationship plausibly exists between CO_2 and per capita GDP (giving an inverse U-shaped EKC), but the critical value, or turning point, is at a relatively high level of GDP, which means the world's economies are still on the upside side of the Environmental Kuznets Curve. This is consistent with several studies, e.g., Cole et al., 1997; Choi, et al. 2010; Shafik & Bandyopadhyay, 1992; Holtz & Selden, 1995; Cole et al., 1997; Agras and Chapman 1999; Heil and Selden, 2001; York et al., 2003; Neumayer, 2004; Galeotti and Lanza 2006.

- The comparison of the rich country subsamples compared to poor countries subsamples shows a higher turning point for rich countries, consistent with Shafik & Bandyopadhyay (1992)); Stern (2004) and other studies. Although the use of the PPP measure of GDP may reduce the gap between environmental Kuznets curves in developed and developing countries (Elhemri, 2019), this phenomenon can be explained by:
    - Differing standards of living from one country to another that may affect the turning point; in developed countries, the standard of living is higher, and achieving perceived "basic needs" requires higher income levels before demand for a clean environment starts having its effect.
    - Developing countries benefitting from technology transfer from developed countries and achieving environmental improvement at earlier stages.
- Consistent with the conclusion from the literature review, as the sample size increases, the turning point rises to a higher level of GDP. This phenomenon may be because, even if we use a fixed effect approach to allow for country differences, larger samples tend to have larger variation, while smaller mostly homogeneous samples are isolated with respect to those differences, from the rest of the countries and their behaviors. The estimation results in turning points for these samples only (assuming the rest of the factors are fixed), and this will be far from the global reality.
- The subsample analysis for 4 underlying variables, namely education quality, transparency, regulatory effort, and democracy, shows that all Top 10 countries are on the downside of an inverse-U shaped EKC, while the Bottom 10 countries are still on the upside of the curve (though some sub-sample regressions which likely involve significant heterogeneity are not very highly significant after application of the robustness estimator); also, the elasticity

analysis shows negative elasticities, and thus a negative impact of GDP on CO_2 emissions in the Top 10 countries. All the above indicated underlying variables may have a beneficial effect on emission efficiency; on the other hand, the trade openness subsample analysis may indicate a detrimental effect on emission efficiency, though further study is needed to determine the effect of the scale factor and the technique factor that may tend to induce or inhibit the down-turning of the CO_2 EKC. Consequently, in our Level 2 analysis we will break out the structural and technological factors from the scale factor; and in the Level 3 analysis, we will more thoroughly examine the role of the underlying variables.

- Some subsample pair comparisons suggest differing curve shapes (e.g., U-shape versus inverted-U shape), even though a Z-test indicates that the subsamples are not inconsistent with each other's estimates. That motivates us: (1) to test functional forms other than the quadratic polynomial relationship, such as the cubic form, which may allow differing EKC curvatures in different ranges of affluence, as well as (2) to explicitly include the underlying variables as explanatory variables that may affect the EKC intercepts, slopes, curvatures, and turning points.

5.2 Level 2: EKC model with additional proximate explanatory variable

5.2.1 Industrial Share (n) and Technology (t) as functions of Affluence

Table 5-14 summarizes the regression results for Technology *t* (total emissions relative to industrial output) and Industrial Share *n* (manufacturing output relative to total GDP) as functions of GDP using the estimator for robust standard errors in fixed-effect panel regressions. We estimated linear, quadratic, and cubic functional forms, for both logarithmic and non-logarithmic transformations of the data. The results from the non-log models are not statistically significant, so here we will discuss only the results from the log models.

In the log models for Technology, the regressions are significant at high levels of confidence (by the *F*-test) and judging by the *t*-tests for the individual regression slope coefficients they too are significant, except for the cubic form. The results, illustrated in Figures 5-12, 5-13, and 5-14, indicate:

- First, for the linear-in-logs model, there is a negative mathematical relationship, implying a positive environmental impact relationship, between Technology (inverse emissions efficiency) and Affluence (or GDP). It indicates that for the 65-country sample a change of 1% in GDP per capita will lead to a change of 0.67% in emissions efficiency.
- We find that $\beta_1 < 0$ and $\beta_2 > 0$ in the quadratic-in-logs model, and for this sample there is a quadratic polynomial relationship with a U-shape suggesting that emissions efficiency will improve as GDP increases, up to a turning point where it starts growing worse, at the point (36.936, -21) in logarithms, converting to \$1.09926141e^{16} and 0.8e^{-9} metric tons per dollar). The absurdly high turning point level of income suggests this relationship is down-sloping and linear for all practical purposes.

Table 5-14a: Estimation results for Technology (*t*) as function of GDP for the full sample

	Non-log model			Log model		
	Linear	Quadratic	Cubic	Linear	Quadratic	Cubic
Constant	0.0000128 (0.000)	0.0000176 (0.000)	26.47306 (0.000)	-5.724755 (0.000)	-4.892196 (0.037)	3.921113 (0.718)
GDP	-1.88e-10 (0.010)	-6.12e-10 (0.006)	0.0007304 (0.338)	-0.6703368 (0.000)	-0.872082 (0.078)	-4.138203 (0.327)
GDP^2	-	4.06e-15 (0.020)	-1.49e-08 (0.304)	-	0.011805 4 (0.066)	0.4025832 (0.433)
GDP^3	-	-	7.69e-14 (0.323)	-	-	-0.0151483 (0.446)
R^2 within	0.0434	0.0919	0.0169	0.2515	0.2522	0.2568
R^2 between	0.0004	0.0022	0.0828	0.0166	0.0163	0.0135
R^2 overall	0.0017	0.0001	0.0732	0.0072	0.0069	0.0050
F-value	.	.	.	25.32 (0.000)	12.65 (0.000)	25.40 (0.000)
rho	0.7245534	0.8578429	0. 8417985	0. 96399985	0.963487	0.9602629

Note: P-values for t test and F test are in parentheses. Country FE (yes), Year FE (no).

Table 5-14b: Estimation results for Industrial Share (*n*) as function of GDP for the full sample

	Non-log model			Log model		
	Linear	Quadratic	Cubic	Linear	Quadratic	Cubic
Constant	32.86666 (0.000)	30.70997 (0.000)	26.47306 (0.000)	2.353544 (0.002)	-0.833233 (0.557)	7.4189 (0.265)
GDP	-0.0000455 (0.516)	0.0001432 (0.660)	0.0007304 (0.338)	0.1139309 (0.169)	0 .886147 (0.005)	-2.172008 (0.396)
GDP^2	-	-1.81e-09 (0.267)	-1.49e-08 (0.304)	-	-0. 045187 (0.011)	0 .3207081 (0.301)
GDP^3	-	-	7.69e-14 (0.323)	-	-	-0.0141837 (0.233)
R^2 within	0.0013	0.0064	0.1353	0.0158	0.0360	0.0449
R^2 between	0.1203	0.0118	0.0068	0.3321	0.4561	0.4034
R^2 overall	0.0969	0.0110	0.0014	0.2768	0.3803	0.3408
F-value	0.43 (0.5161)	2.55 (0.0862)	.	1.93 (0.1692)	4.46 (0.0154)	4.22 (0.0087)
rho	0.8579174	0.8501310	0. 8417985	0. 7620287	0. 746552	0. 74381431

Note: P-values for t test and F test are in parentheses. Country FE (yes), Year FE (no).

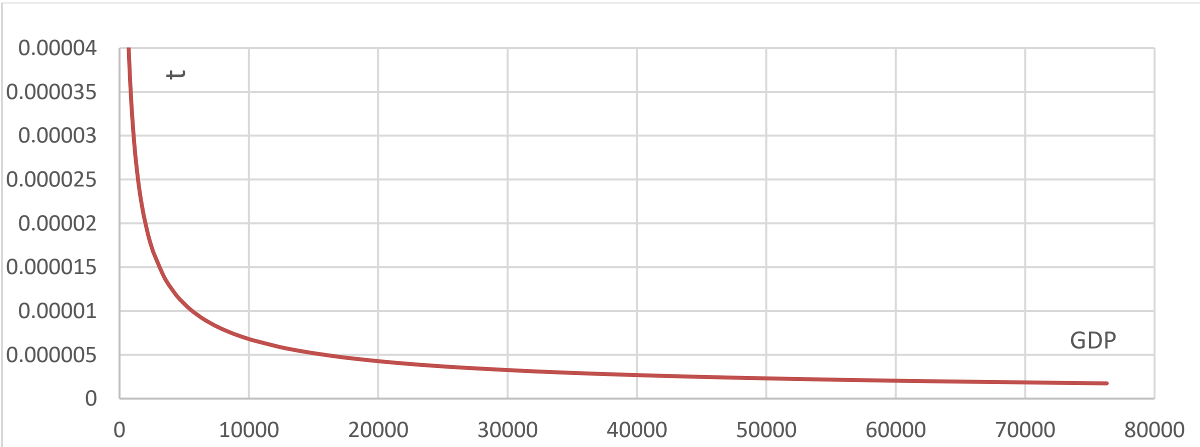

Figure 5-12: The linear t Curve (linear-log model) for 65 countries

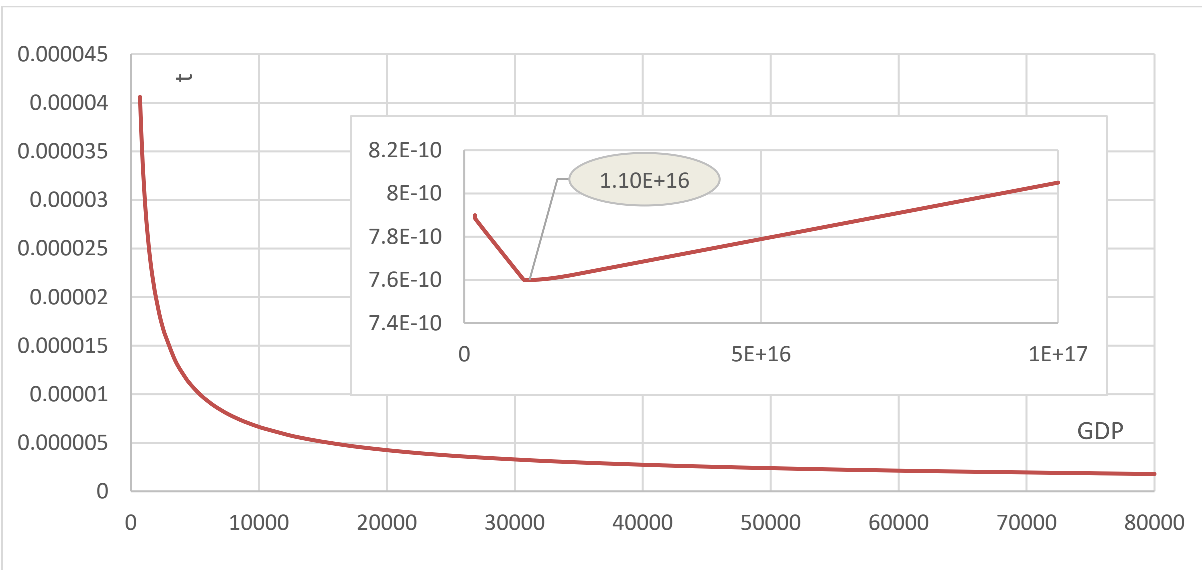

Figure 5-13: The U-shaped t Curve (quadratic-log model) for 65 countries

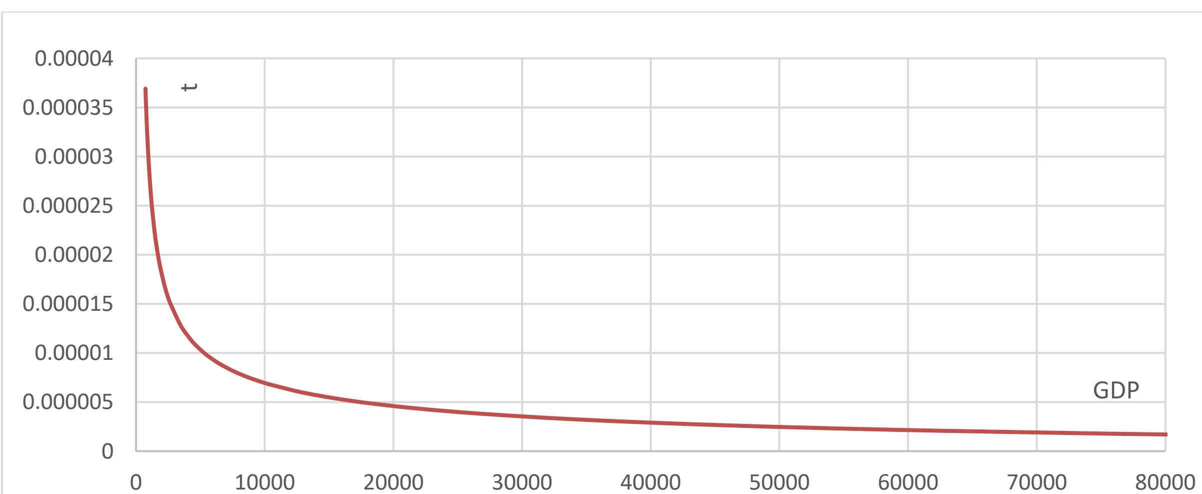

Figure 5-14: The Mirror-S shaped t Curve (cubic-log model) for 65 countries

- In the cubic model, the curve has a monotonically decreasing S-shape, but over the relevant income range shows a monotonically decreasing convex section. Either way, none of the coefficients are significantly different from zero, so little value can be taken from results.
- Noting that the natural logarithm of $1 million is about 13.8, all the function forms give a similar monotonically decreasing curve, over the relevant range of incomes. Overall, by its F-value, the p-values for the coefficient estimates, and its simplicity, the linear-in-logs model is the most reasonable fit to take forward to next stages.

On the other hand, for Industrial Share (with graphs in Figures 5-15, 5-16, and 5-17):

- The linear form shows a positive relationship between GDP and industrial portion of GDP, specifically that a change of 1% in GDP per capita will lead to an increase of 0.114% in industrial share (proportion of Industrial income from GDP). This model has a weak F value, which is consistent with *a priori* expectations that the relationship would <u>not</u> be linear and monotonic.
- For the quadratic form, we have $\beta_1 > 0$ and $\beta_2 < 0$, and there is a quadratic polynomial relationship with inverse U-shape, meaning that the proportion of industrial income from GDP will increase as GDP increases until a turning point where the industrial share of GDP will start to decline, at the point (9.805, 3.511) in logarithms or ($18,124, 33.5 % of GDP).
- The curve becomes mirror N-shaped in the cubic form with the GDP-cubed coefficient being negative ($\beta_3 < 0$) so we can conclude that there is a cubic polynomial relationship for our sample of 65 countries. Turning points respectively (5.137, 2.802) and (9.937, 3.586) or ($170.21, 16.5 % of GDP) and ($ 20,682, 36.1 % of GDP).
- The concave section of the cubic curve coincides very closely with the quadratic curve, both of them reaching a peak of about 35% at around $20,000.

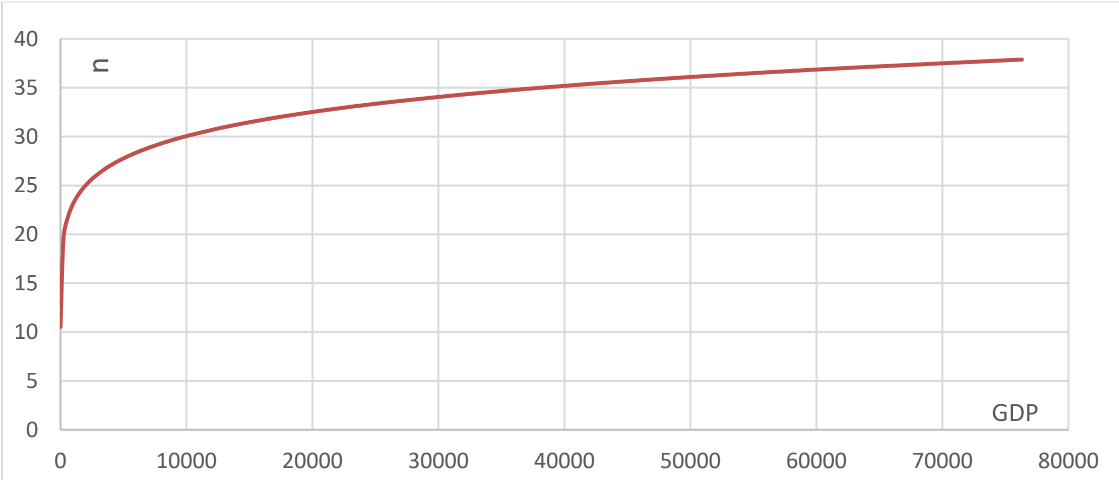

Figure 5-15: The linear n Curve (linear-log model) for 65 countries

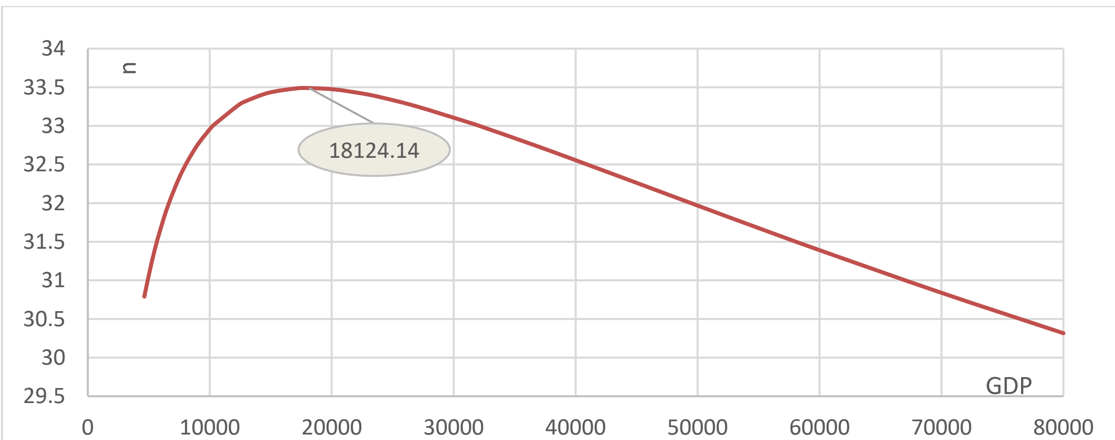

Figure 5-16: The inverse U-shaped n Curve (quadratic-log model) for 65 countries

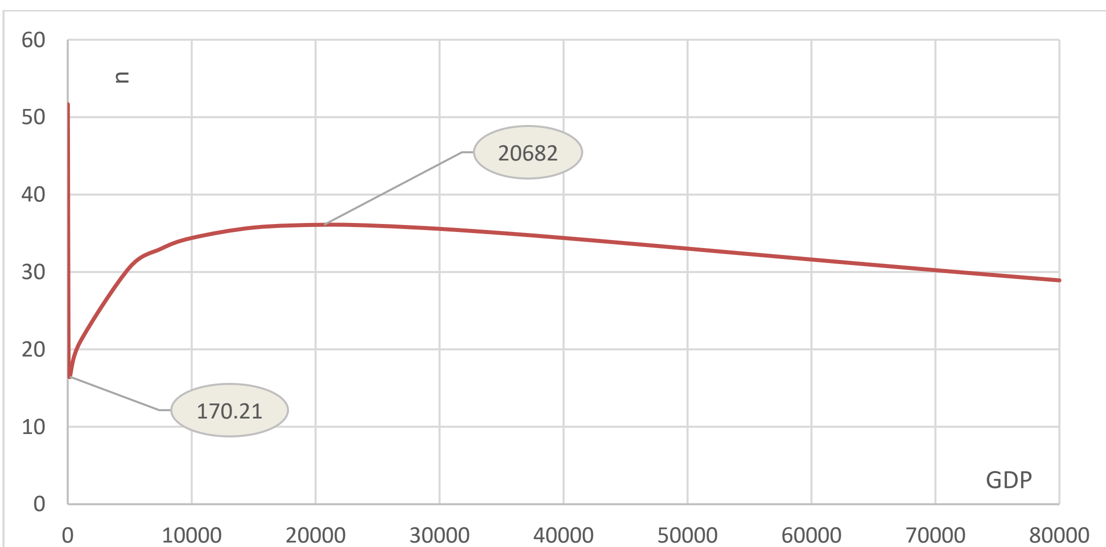

Figure 5-17: The mirror N-shaped n Curve (cubic-log) for 65 countries

5.2.2 Recomposition of the EKC using t and n (log model)

From the equation $E = A\,n\,t$ derived from the original IPAT model (equation 3-9), we have $\ln E = \ln A + \ln t + \ln n$, and by inserting the logarithmic model results from Table 5-19 we can reconstitute the full EKC. The various models summarized in Table 5-19 offer various paths. For instance, the simplest model would be to use the linear models for $t(a)$ and $n(a)$. In this case:

$$\ln E = \alpha_0 + \beta_0 + (\alpha_1 + \beta_1 + 1)\ln A = -3.371211 + 0.4435941\, ln\, A \qquad (5.1)$$

Unsurprisingly, this version implies the relationship between CO_2 emission and GDP per capita is monotonic and positive, with CO_2 emissions increasing though at decreasing rate. This version suffers from the weakness of relying on the non-significant linear estimation for $n(A)$.

Alternatively, if we take the most significant and reasonable models from the discussion above, the linear form for $t(A)$ and the quadratic form for $n(A)$, we get a different result. In this case:

$$\ln E = -6.558 + 1.216 \ln A - 0.045(\ln A)^2 \qquad (5.2)$$

After transformation of equation (5.2) from logs to levels, we can see in Figure 5-18 that the implied EKC for 65 countries is inverse U-shaped, and the turning point where GDP per capita and CO_2 emissions become negatively related is 13.511 in logarithms or $737,485 as a dollar income level. That is far higher than the incomes of all the sample countries, with the implication that all the countries are still on the upsloping side of the EKC, where more affluence brings more environmental deterioration.

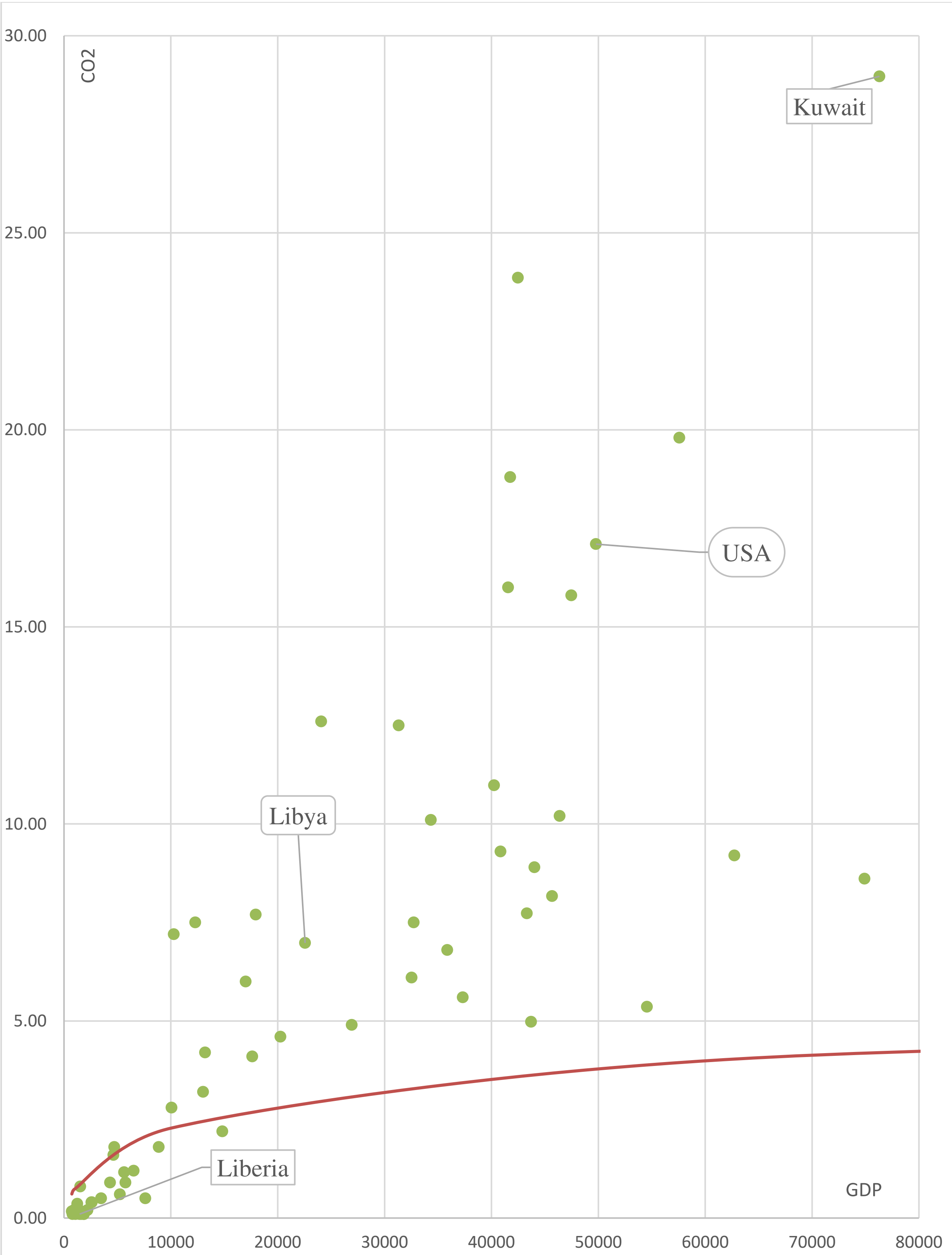

Figure 5-18: The inverted U-shaped Environmental Kuznets Curve for 65 countries (Log-linear model for Technology and log-quadratic for Industrial Share)

A possible complication could be endogeneity between n (manufacturing share of GDP) and GDP, which could lead to biased estimates though at least we get some benefit if we focus on correlation rather than causality, in order to insert the $n(A)$ relationship into the identity to get the EKC. As we know, a normal part of development is that moving from agriculture into manufacturing brings more income, so n would increase GDP. But in the other direction, we also think GDP affects n. When countries become affluent, they start to demand proportionally more services, which would decrease n; also, since affluence likely goes with higher wages, it might be that more manufacturing relocates abroad, which also would decrease n. So, there could be two-way causality: n increases GDP, and GDP decreases n. This is associated with the first part and the second part of the EKC, respectively, but both effects probably happen on both sides of the EKC.[13]

In contrast, we do not have the same issue with t, which is emissions divided by manufacturing output, E/N, a proxy for the dirtiness of manufacturing technology. We can think that as society becomes more affluent, it might demand environmental quality, so GDP might decrease t (though maybe not for CO_2). But for reasons discussed earlier, we think there will be little domestic in-country impact of t on GDP; the "dirtiness" will not come home to affect production. This argument holds for both Same for both $t = E/N$ and $T = E/GDP$.

So, here we can solve the endogeneity problem by going to the starting point in the analysis based on the IPAT identity that allows decomposition in the following way:

Emissions / Population = (GDP / Population) (Emissions / GDP)

[13]We could not find an econometric solution to the endogeneity problem such as an appropriate instrumental variable

i.e. $E = A\,T$ where A is affluence and T is inverse emissions efficiency or the technology dirtiness factor from all production not just from manufacturing. We know that n and t represent in detail two parts of the technique effect, manufacturing share and technology, but n and t can be incorporated together into T which represents the overall technique effect. In this way, we can without econometric bias determine at what levels of income and emissions the estimated EKC may turn downward. We explore this approach in the next section.

5.2.3 Technique (T) as a function of Affluence

Defining Technique as $T = E/GDP$ and estimating T as a function of GDP, Table 5-15 summarizes the regression results using the estimator for robust standard errors in fixed effect panel regressions.

Table 5-15: Estimation results for Technique (T) as function of GDP for 65 countries

	Non log- Model			Log- Model		
	(1) Linear	(2) Quadratic	(3) Cubic	(4) Linear	(5) Quadratic	(6) Cubic
Constant	0.000398 (0.001)	0.00053 (0.000)	0.000656 (0.000)	-3.371208 (0.001)	-5.725425 (0.021)	11.33995 (0.121)
GDP	-6.45e-09 (0.000)	-1.80e-08 (0.000)	-3.55e-08 (0.001)	-0.5564063 (0.000)	0.0140653 (0.978)	-6.310187 (0.031)
GDP^2	-	1.11e-13 (0.000)	5.00e-13 (0.008)	-	-0.033382 (0.234)	0.7232884 (0.048)
GDP^3	-	-	-2.29e-18 (0.022)	-	-	-0.0293319 (0.045)
R^2 within	0.1783	0.3036	0.3642	0.3036	0.3124	0.3428
R^2 between	0.0337	0.0559	0.0784	0.2448	0.2319	0.2047
R^2 overall	0.0186	0.0348	0.0533	0.1953	0.1847	0.1566
F-value	13.10 (0.006)	.	.	29.46 (0.000)	19.95 (0.000)	26.80 (0.000)
rho	0.937241	0.970061	0.981964	0.9819072	0.982693	0.9804362

Note: P-values for t test and F test are in parentheses. . Country FE (yes), Year FE (no).

Using non-log data, the linear regression (1) is significant at a high level of confidence (by the F-test), but not the quadratic and cubic forms, and judging by the t-tests for the individual regression slope coefficients they are all significant.

- In the linear model, there is a negative mathematical relationship, implying a beneficial environmental impact relationship, between Affluence A and Technique T (inverse emissions efficiency) indicating that for these 65 countries a change by $1 in GDP per capita will lead to an improvement of 6.45e-09 in emissions efficiency. This result has statistical significance but very minor material impact.
- In the quadratic model, we find $\beta_1 < 0$ and $\beta_2 > 0$, and after transformation there is an inverted U-shape with a turning point at $81,081 and -0.0002 metric tons per dollar, so in actuality it is decreasing for all the positive range of GDP.
- In the cubic form, the curve becomes S-shaped and monotonically decreasing.
- All three estimations give a monotonically decreasing curve, over the relevant range of incomes.

The three non-log models are shown in Figures 5-19, 5-20, and 5-21.

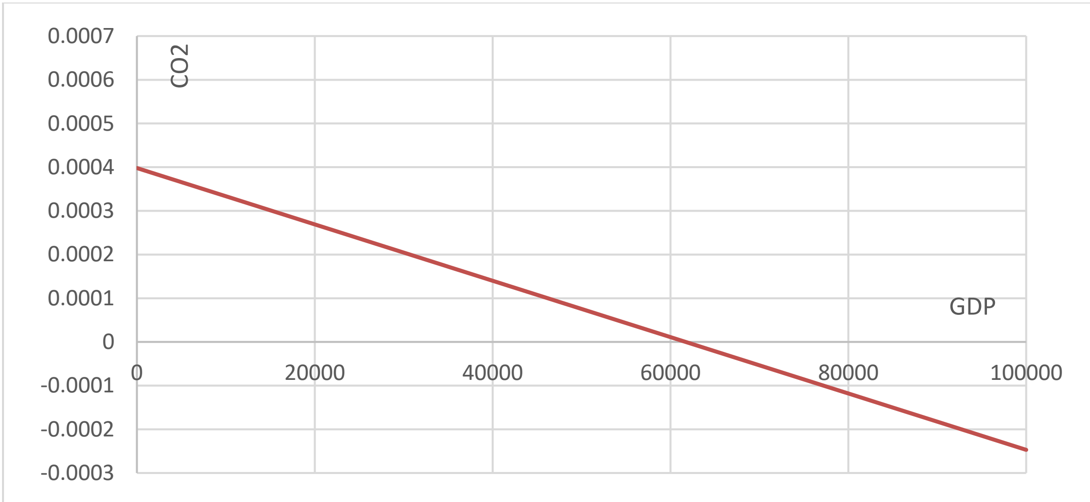

Figure 5-19: The linear T Curve (linear non-log model) for 65 countries

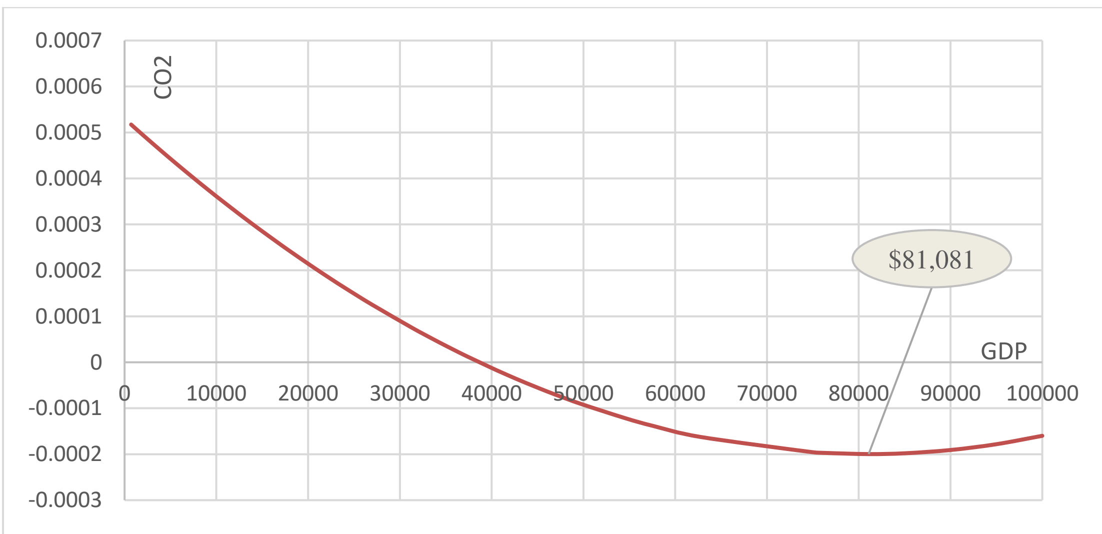

Figure 5-20: The U-shaped T Curve (quadratic non-log model) for 65 countries

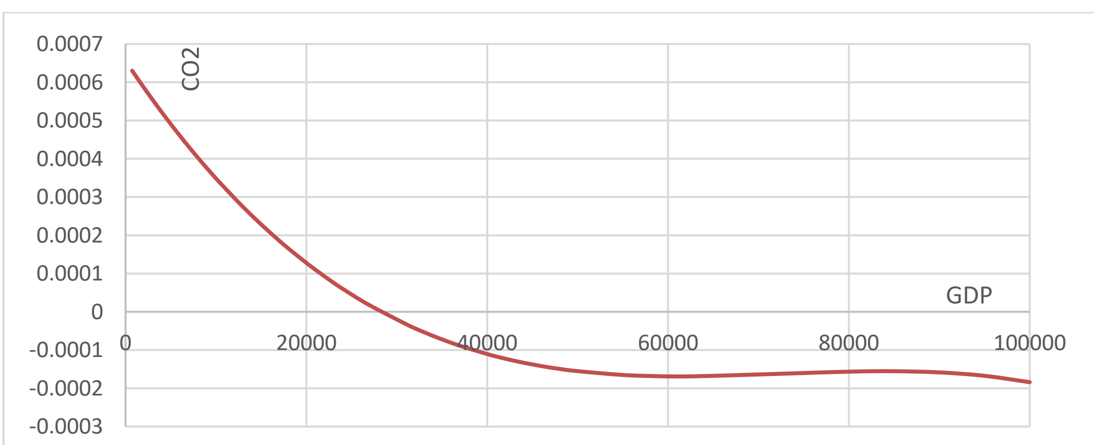

Figure 5-21: The S-shaped T curve (cubic non-log model) for 65 countries

In the log models for Technique, the regressions are significant at a high level of confidence (by the F-test), and judging by the t-tests for the individual regression slope coefficients they too are significant, except the quadratic form. The estimation results indicate:

- There is a beneficial relationship between Technique or emissions efficiency, and Affluence or GDP, shown in the linear model (4), with a change of 1% in GDP per capita leading to change of 0.556% in emissions efficiency.
- Since $\beta_1 > 0$ and $\beta_2 < 0$ in model (5), there is a log-log quadratic polynomial relationship with inverse U-shape, which might imply the emissions efficiency will grow worse as GDP increases until a turning point where it will start to improve. However, the turning point is very near zero GDP, so in fact the curve is decreasing (implying environmental benefit), over the range of positive GDP values.
- In the cubic model (6), the curve has a monotonically decreasing S-shape, with $\beta_1 < 0$, $\beta_2 > 0$ and $\beta_3 < 0$, but in the relevant income range shows a monotonically decreasing inverse U-shape section.

The three log models are shown in Figures 5-22, 5-23, and 5-24.

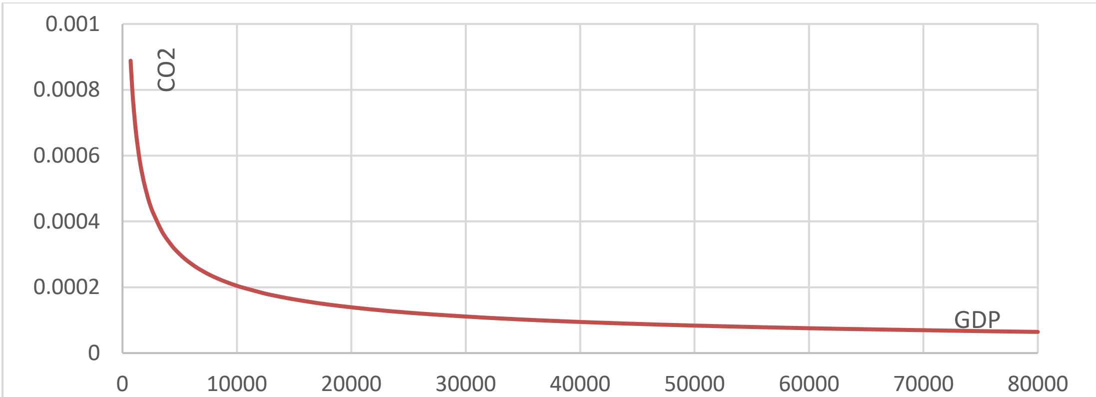

Figure 5-22: The linear T Curve (linear-log model) for 65 countries

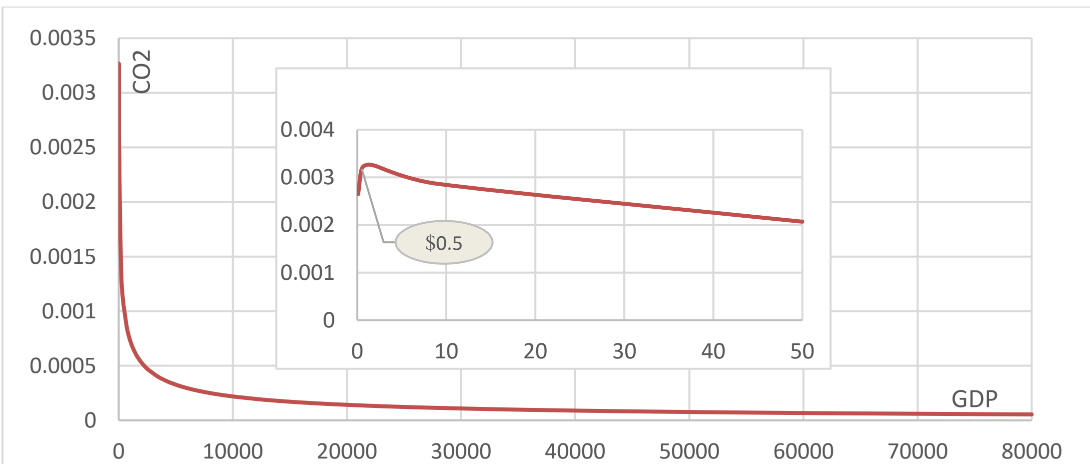

Figure 5-23: The inverted u-shaped T Curve (quadratic-log model) for 65 countries

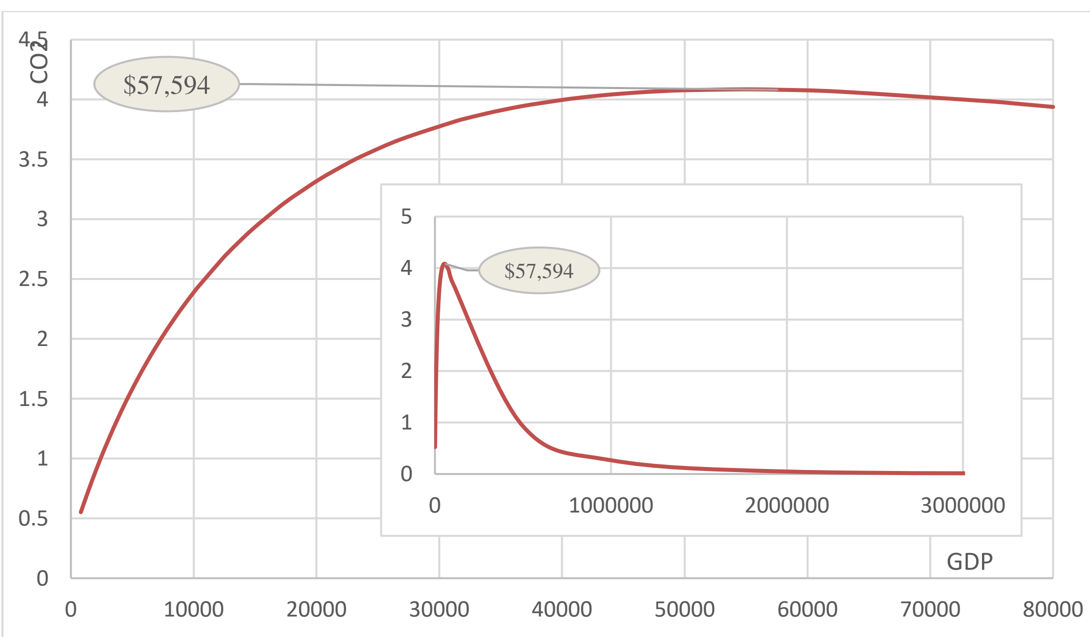

Figure 5-24: The N-shaped T Curve (cubic-log model) for 65 countries

5.2.4 Recomposition of the EKC using $T(A)$

We present the recomposition for the 4 models that have some significance.

Linear non-log model. By plugging the coefficients from model (1) into the original EKC equation we obtain:

$$E = A\,[T(A)] = A\,(\beta_0 + \beta_1 A) = 0.000398A - 6.45e^{-09}\,A^2 \qquad (5.3)$$

and Figure 5-25 shows the curve graphically.

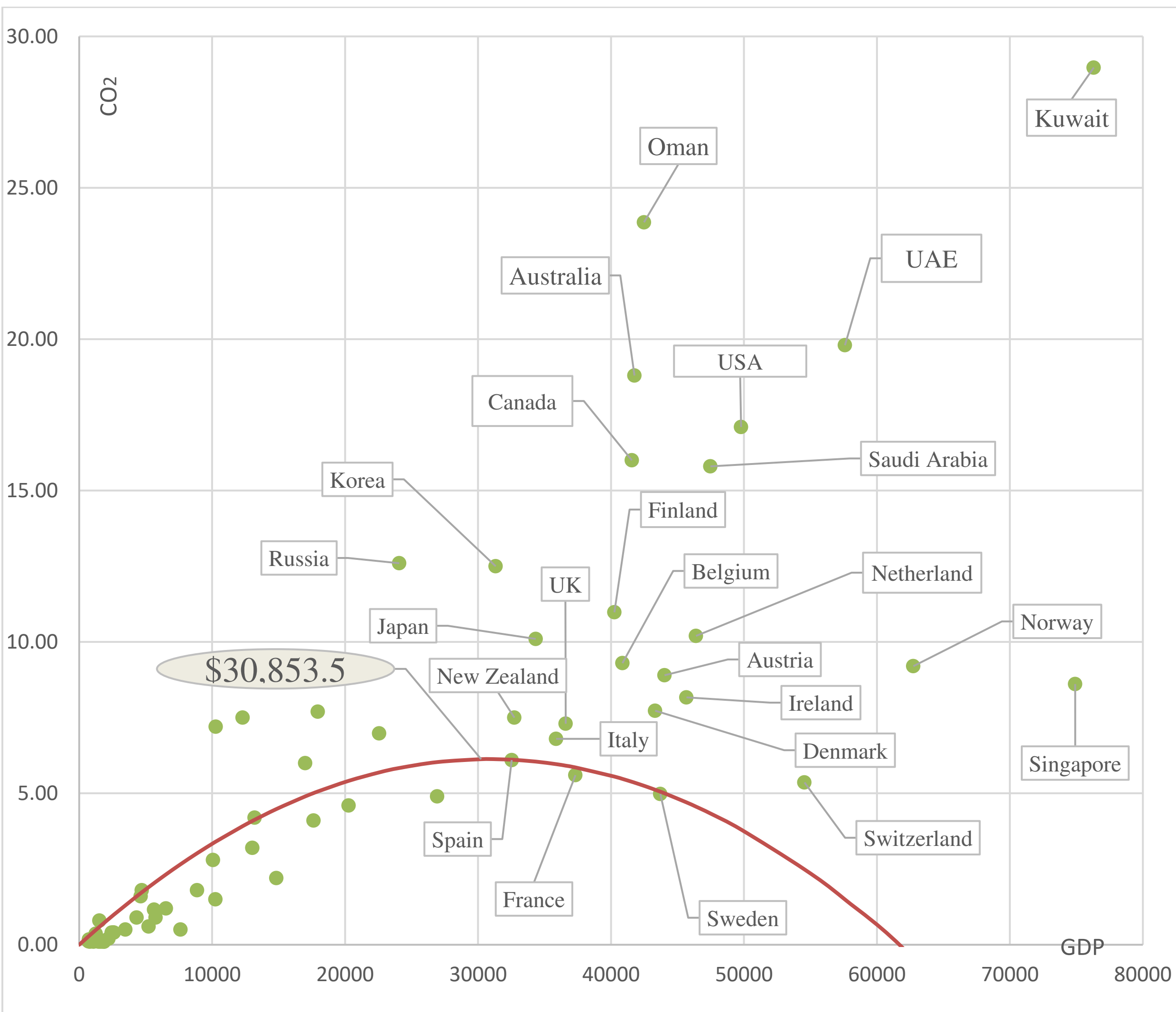

Figure 5-25: The inverted U-shaped EKC for 65 countries (with Technique as a function of Affluence, non-log linear form)

Based on equation (5.3) we can see that the implied EKC for these 65 countries is inverse U-shaped and the estimated turning point where GDP per capita and CO_2 emission level become negatively related is \$30,853. That is higher than the mean and median for the sample countries. Although some high-income countries are beyond the turning point, most countries are still on the upside of the EKC (where income growth brings environmental deterioration). The estimated curve does suggest the prospect of many countries moving to the downward sloped part of the curve, *ceteris paribus*, when their incomes rise past \$30,853.

Linear log model**.** By plugging the coefficients from model (4) into the EKC equation we obtain:

$$\ln E = \ln A + \ln T(A) = \beta_0 + (\beta_1 + 1)\ln A = -3.371208 + 0.4435937 \ln A \qquad (5.4)$$

Equation (5.4) suggests that the relationship between CO_2 emission and GDP per capita for 65 countries is monotonic and positive, and CO_2 emissions are increasing but at a decreasing rate,

Quadratic log model. Using the estimated coefficients from the quadratic model (5), we have:

$$\ln E = \ln A + \ln T(A) = \beta_0 + (\beta_1 + 1)\ln A + \beta_2(\ln A)^2$$
$$= -5.725425 + 1.0140653 \ln A - 0.033382\,(\ln A)^2 \qquad (5.5)$$

After transforming, equation (5.5) indicates that the EKC for 65 countries is inverse U-shaped (quadratic polynomial relationship), and the estimated critical value, or turning point where GDP per capita and CO_2 emission level become negatively related is at (15.189, 1.976) in logarithmic terms, or at \$3,948,332 and 7.214 metric tons which is far higher than the average of the study sample. The curve is shown in Figure 5-26. By this estimation the relationship between emission and income is monotonically increasing up to far beyond the relevant range of income levels.

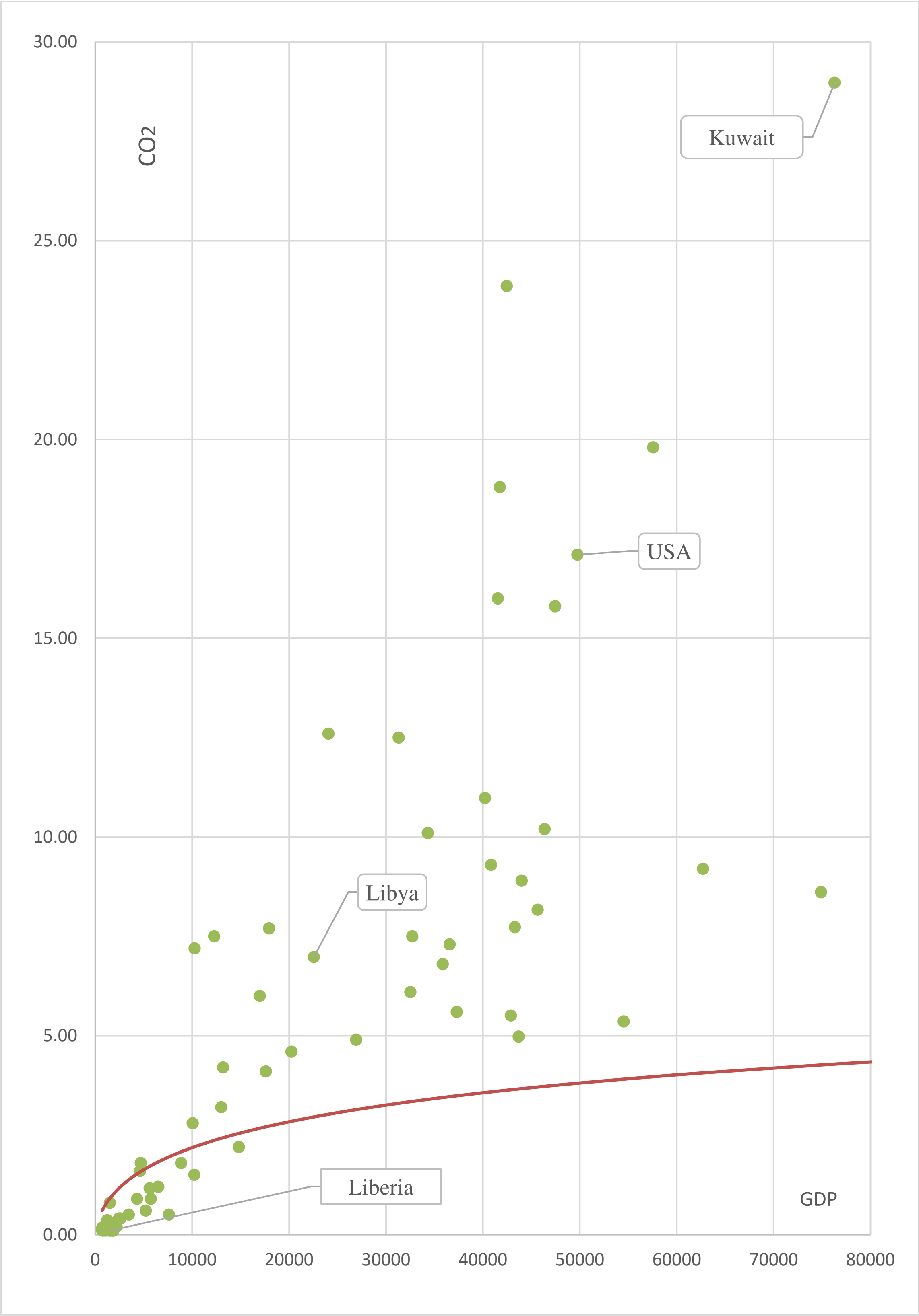

Figure 5-26: The inverted U-shaped EKC for 65 countries (with Technique as function of Affluence, quadratic-log form)

Cubic log model. Using the coefficients from the cubic log model (6), we get:

$$\ln E = \beta_0 + (\beta_1 + 1)\ln A + \beta_2 (\ln A)^2 + \beta_3 (\ln A)^3$$

$$= 11.33995 - 5.31018 \ln A + 0.7232884 (\ln A)^2 - 0.0293319 (\ln A)^3 \quad (5.6)$$

In this case the curve is a mirror-N shape with estimated critical values or turning points at (5.535, -0.871) and (10.904, 1.4) in logarithmic terms, the latter point being at $54,394 and 4.055 metric tons. That income level is marginally higher than, but near, the top of the sample range of incomes. That implies that all countries are still on the upsloping side of the EKC, where more affluence brings more environmental deterioration. The first turning point has little relevance. See Figure 5-27.

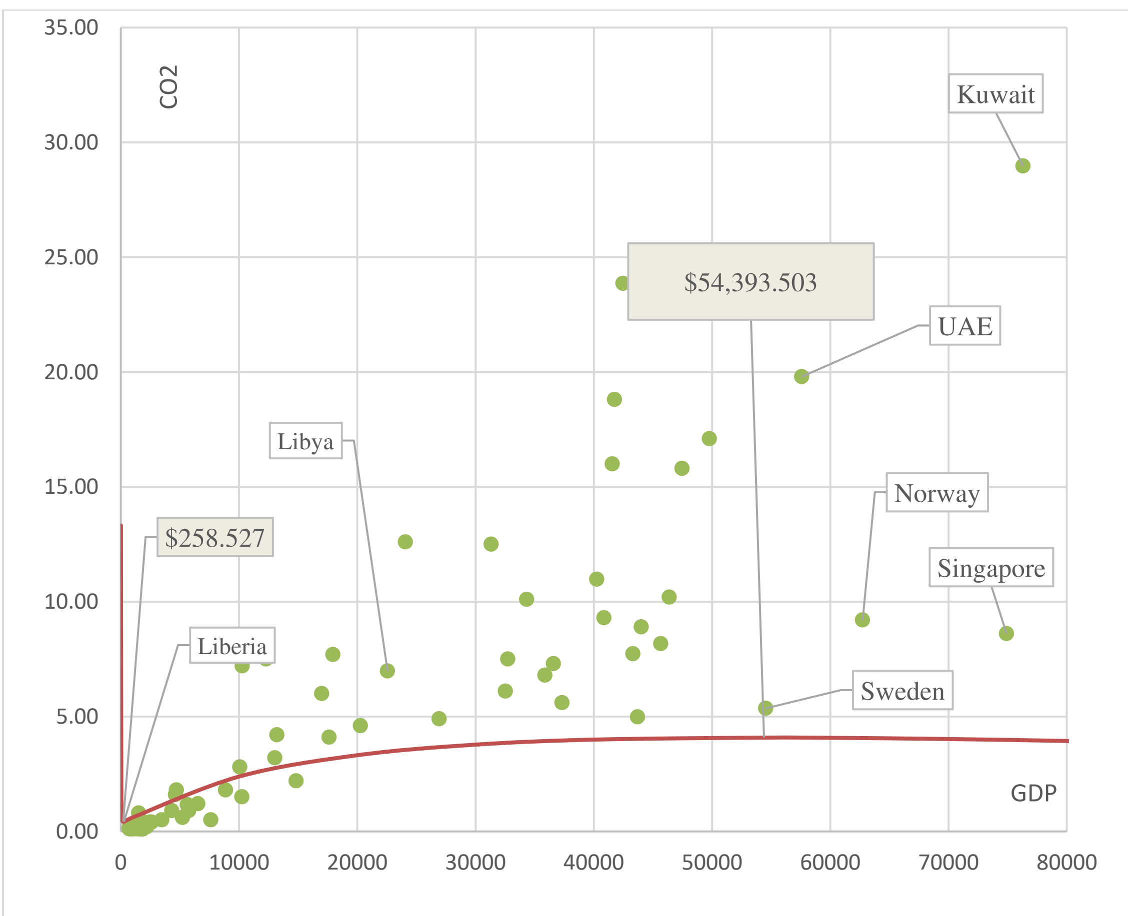

Figure 5-27: Mirror N-shaped EKC for 65 countries
(with Technique as function of Affluenc, cubic-log form)

5.2.5 Summary of Level 2 results

In this Level 2 analysis we break out the structural and technological factors from the scale factor:

- The overall conclusion is that a quadratic polynomial relationship exists between CO_2 and per capita GDP (giving an inverse U-shaped EKC), but the critical value, or turning point, is at a relatively high level of GDP, which means the world's economies are still on the upside side of the Environmental Kuznets Curve. This conclusion is consistent with the results of the Level 1 analysis.
- The result from analysis using Technique (T) as an additional proximate explanatory variable confirms the EKC hypothesis for the 65 countries, where CO_2 emissions have a positive relationship with the level of income before the EKC threshold and then a negative relationship beyond the threshold, and this can be explained by improved technology or emission efficiency. This is consistent with some studies, e.g., He & Richard (2010) have included a linear time trend to capture exogenous advances in technology. We find the linear form of the non-log model, and all forms of the log model, to be significant in estimating the Technique equation. So, they are more suitable to examine the implied shape in the original model of EKC using the original IPAT formulation. Although, we prefer the non-log linear form because it confirms the EKC hypothesis without inserting the quadratic or cubic term in the Identity.
- Despite the variance in the turning point levels between the log and non-log models, the points are very high in log models, and that is consistent with previous studies (see Chapter 2). But as Stern (2004) noted, the use of logarithms restricts the unlogged levels of the indicators (CO_2 in this case) from being zero or negative, which is appropriate and can push the estimated function to higher values.

- The result from the decomposition into Industrial Share (n) and Industrial Technology (t) as additional proximate explanatory variables offers additional information about structural change to explain the EKC. When countries become affluent, they start to demand proportionally more services, which would decrease the most polluting share of income, and this is consistent with some studies, e.g. Panayotou (1997) who modeled output structure as industry share in GDP and represents the structure or composition of economic activity. There is, however, a suspicion of endogeneity (two-way causality) when we estimate Industrial Share as a function of per capita GDP. Our subsequent analysis will use Technique (T) as the additional proximate explanatory variable, and it implicitly includes Industrial Share while reflecting emissions efficiency from total GDP, not just what is associated with industrial income.
- We find the log models (linear and quadratic forms) to be more statistically significant for estimating the equations for of Technology t and Industrial Share n. So, they are more suitable to examination of the implied shape in the original model of EKC.

5.3 Level 3: EKC model with underlying variables that affect the proximate variables

5.3.1 Technique as a function of Affluence and underlying variables

In this section we define Technique as $T = E/GDP$ (inverse emissions efficiency) and we estimate T as a function of GDP, Trade Openness (X_1), Education (X_2), Transparency (X_3), Democracy (X_4), Free rider freedom (X_5), and Formal regulatory effort (X_6). Table 5-16 summarizes the regression results using the estimator with robust standard errors in fixed effect panel regressions.

Models (1) to (3), using non-logged data, do not result in statistically significant regressions by the F test, so we focus on models (4) to (6). Note that the Free Rider indicator (X_5) is omitted from those models due to a collinearity issue.

In the log models, the regressions are significant at a high level of confidence (by the F-test), and the t-test indicates significance of most of the individual coefficient estimates.

- In the linear model, there is a negative mathematical relationship, implying a beneficial environmental impact relationship, between Affluence (A) and Technique (T).

- In the quadratic form, there is a quadratic polynomial relationship between Affluence (A) and Technique (T) with an inverse U-shape which means the emissions efficiency worsens as GDP increases until a turning point where emissions efficiency starts to improve.

- The cubic form gives a mirror N-shaped function indicating that emission efficiency is improved as GDP increases until the first turning point and then it reverses back until the second turning point where emissions efficiency is improved again as GDP increases.

Table 5-16: Estimation of Technique (T) as a function of underlying variables

	Non-log Models			Log Models		
	(1) Linear	(2) Quadratic	(3) Cubic	(4) Linear	(5) Quadratic	(6) Cubic
Constant	0 .0004983 (0.008)	0.0006194 (0.000)	0.0006411 (0.000)	7.234385 (0.074)	-1.109925 (0.887)	56.90697 (0.015)
GDP	-1.06e-08 (0.008)	-3.54e-08 (0.000)	-4.64e-08 (0.001)	-1.548603 (0.001)	0.4268198 (0.777)	-18.3336 (0.013)
GDP^2	-	1.95e-13 (0.000)	6.33e-13 (0.003)	-	-0.1135729 (0.151)	1.856852 (0.016)
GDP^3	-	-	-2.83e-18 (0.015)	-	-	-0.067555 (0.012)
X_1	2.44e-07 (0.109)	2.32e-07 (0.056)	2.79e-0 (0.005)	0.6746641 (0.216)	0.2306316 (0.703)	0.9893769 (0.081)
X_2	-0.000174 (0.200)	0.0001097 (0.344)	0.002486 (0.058)	3.025076 (0.003)	1.647895 (0.235)	3.556881 (0.011)
X_3	- 0.0000106 (0.235)	-0.000206 (0032)	0.000016 (0.075)	-0.4997207 (0.073)	-0.3984956 (0.094	-0.371405 (0.128)
X_4	7.10e-07 (0.655)	-1.81e-06 (0.295)	-1.63e-06 (0.300)	-3.263663 (0.057)	-3.972902 (0.019)	-4.490561 (0.012)
X_5	2.24e-06 (0.714)	4.94e-06 (0.420)	4.63e-06 (0.449)	-	-	-
X_6	-1.56e-08 (0.796)	-6.74e-08 (0.187)	-1.03e-07 (0.050)	-0.6389103 (0.031)	-0.5834927 (0.048)	-0.211261 (0.528)
GDP X_1	-9.31e-12 (0.200)	-1.17e-12 (0.794)	-1.46e-11 (0.009)	-0.0699796 (0.230))	-0.0251192 (0.693)	-0.100298 (0.089)
GDP X_2	6.64e-09 (0.073)	7.65e-09 (0.010)	8.14e-10 (0.824)	-0.3067919 (0.005)	-0.1578043 (0.291)	-0.359485 (0.018)
GDP X_3	2.62e-10 (0.293))	6.56e-10 (0.024)	5.21e-10 (0.049)	0.0560523 (0.053)	0.0463357 (0.063)	0.0427919 (0.091)
GDP X_4	-3.79e-10 (0.000)	5.07e-11 (0.651)	-4.47e-11 (0.607)	0.3270574 (0.061)	0.390444 (0.021)	0.4486623 (0.014)
GDP X_5	1.92e-10 (0.425)	2.25e-10 (0.329)	3.67e-10 (0.143)	-	-	-
GDP X_6	9.45e-12 (0.130)	7.19e-12 (0.310)	1.29e-11 (0.062)	0.0642085 (0.023)	0.058493 (0.038)	0.0237136 (0.459)
R^2 within	0.2551	0.4093	0.4486	0.6051	0.6141	0.6306
R^2 between	0.0505	0.0589	0.0633	0.0331	0.0001	0.0362
R^2 overall	0.0301	0.0382	0.0413	0.0050	0.0050	0.0042
F-value	.	.	.	16.67 (0.000)	21.18 (0.000)	23.75 (0.000)
rho	0.9579425	0.98465568	0.98717227	0.9839903	0.982693	0.9858840

Note: P-values for t test and F test are in parentheses. Country FE (yes), Year FE (no).

- The net effect of each underlying variable on T is not immediately evident, and requires more examination due to the interaction effects. We explore this issue later in this section.

5.3.2 Recomposition of the EKC using T (log model)

Linear log model. Plugging the estimated coefficients from the linear log-model (4) into the EKC equation we obtain:

$$\begin{aligned}\ln E &= \ln A + \ln T(A, X) \\ &= \beta_0 + (\beta_1 + 1)\ln A + \beta_2 \ln X_1 + \beta_3 \ln X_2 + \beta_4 \ln X_3 + \beta_5 \ln X_4 + \beta_6 \ln X_5 \\ &+ \beta_7 \ln X_6 + \beta_8 \ln A \ln X_1 + \beta_9 \ln A \ln X_2 + \beta_{10} \ln A \ln X_3 + \beta_{11} \ln A \ln X_4 \\ &+ \beta_{12} \ln A \ln X_5 + \beta_{13} \ln A \ln X_6\end{aligned}$$

Inserting the mean values for the underlying variables gives:

$$\ln E = 4.027175992 + 0.120663362 \ln A \qquad (5\text{-}7)$$

The elasticity given by the slope coefficient in equation 5-8 indicates that (calculated at the mean values of the sample) an increase in GDP by 1% will induce CO_2 emissions to increase by 0.12%. That means the relationship between CO_2 emissions and GDP per capita for this sample is monotonic and positive, with CO_2 emissions increasing but at a decreasing rate.

Quadratic log model. Using the estimated coefficients from the quadratic model (5), we have:

$$\begin{aligned}\ln E = \beta_0 &+ (\beta_1 + 1)\ln A + \beta_2 (\ln A)^2 + \beta_3 \ln X_1 + \beta_4 \ln X_2 + \beta_5 \ln X_3 + \beta_6 \ln X_4 + \beta_7 \ln X_5 \\ &+ \beta_8 \ln X_6 + \beta_9 \ln A \ln X_1 + \beta_{10} \ln A \ln X_2 + \beta_{11} \ln A \ln X_3 + \beta_{12} \ln A \ln X_4 \\ &+ \beta_{13} \ln A \ln X_5 + \beta_{14} \ln A \ln X_6\end{aligned}$$

Inserting the mean values for the underlying variables gives:

$$\ln E = -7.9 + 2.09 \ln A - 0.11\, (\ln A)^2 \qquad (5\text{-}8)$$

Figure 5-228: The inverted U-shaped EKC for 65 countries (with Technique as function of underlying variables, -log quadratic model)

Transforming equation (5-8) to levels, we can see that EKC for our full sample is inverse U-shaped (quadratic polynomial relationship), and the estimated critical value, or turning point where GDP per capita and CO_2 emission level become negatively related is $13,360, and 7.591 metric tons. This result implies that most of the developing countries are still on the upsloping side of the EKC, below the turning point, with the exception of countries which large oil incomes. All the developed democracies have also surpassed the turning point and are thus on the downside of the curve.

Cubic log model. Using the coefficients from the cubic log model (6), we get:

$$\ln E = \beta_0 + (\beta_1 + 1)\ln A + \beta_2 (\ln A)^2 + \beta_3 (\ln A)^3 + \beta_4 \ln X_1 + \beta_5 \ln X_2 + \beta_6 \ln X_3 + \beta_7 \ln X_4 + \beta_8 \ln X_5 + \beta_9 \ln X_6 + \beta_{10} \ln A \ln X_1 + \beta_{11} \ln A \ln X_2 + \beta_{12} \ln A \ln X_3 + \beta_{13} \ln A \ln X_4 + \beta_{14} \ln A \ln X_5 + \beta_{15} \ln A \ln X_6$$

Inserting the mean values for the underlying variables gives:

$$\ln E = 53.07 - 18.951 \ln A + 1.86 (\ln A)^2 - 0.68 (\ln A)^3 \quad (5\text{-}9)$$

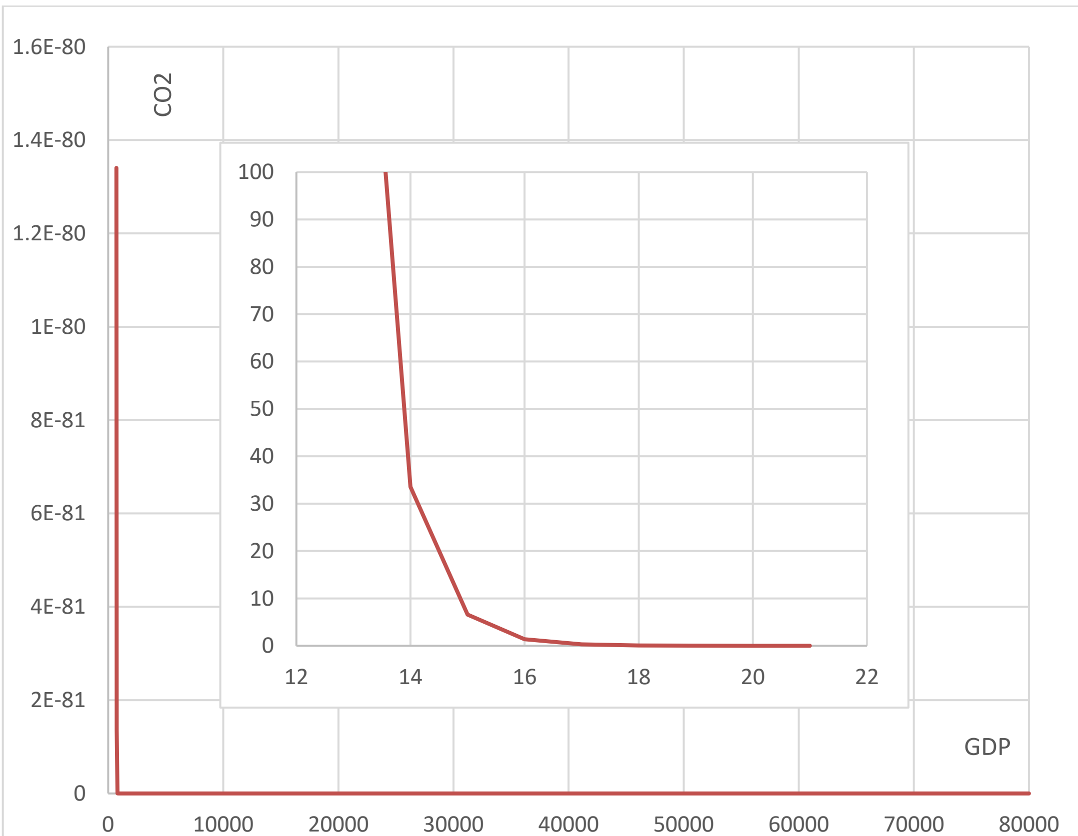

Figure 5-29: The S-shaped EKC for 65 countries
(with Technique as a function of underlying variables,log cubic form)

Equation 5-9 describes a log-log function that is monotonic decreasing and S-shaped. After transformation, as shown in Figure 5-29 we see that the EKC is a sharp L-shape, and is monotonically decreasing but essentially flat after a few dollars of GDP.

5.3.3 Underlying variable effects on the EKC

In this section, we explore the underlying variables' effects by comparing the GDP effect on CO_2 at the mean underlying variable value for each Top 10 and Bottom 10 subsample in turn, with all other variables at the full sample means.

Education impacts

Linear log model**.** Using the estimated coefficients from the linear model (4), setting all the X variables at the full sample means except for Education, which is set alternatively at the Top 10 mean and Bottom 10 mean, we find the following EKC equations:

Top 10 for Education: $\ln E = -0.53579 + 0.218179 \ln A$

Bottom 10 for Education: $\ln E = -4.84035 + 0.65858 \ln A$

Quadratic log model. Applying the same method to the quadratic model (5), we find:

Top 10 for Education: $\ln E = -11.382 + 2.44016 \ln A - 0.11 \ln A^2$

Bottom 10 for Education: $\ln E = -13.7261 + 2.66464 \ln A - 0.11 \ln A^2$

These different quadratic EKC curves generated by high and low Education levels are shown in Figures 5-30 and 5-31.

Transparency impacts

Linear log model**.** Using the same method as above, but for Transparency, we obtain:

Top 10 for Transparency: $\ln E = -2.43451 + 0.416857 \ln A$

Bottom 10 for Transparency: $\ln E = -1.38603 + 0.291039 \ln A$

Quadratic log model. Applying the same method to the quadratic model (5), we find:

Top 10 for Transparency: $\ln E = -12.4798 + 2.557209 \ln A - 0.11 \ln A^2$

Bottom 10 for Transparency: $\ln E = -11.641 + 2.432391 \ln A - 0.11 \ln A^2$

These different quadratic EKC curves generated by high and low Transparency levels are shown in Figures 5-32 and 5-33.

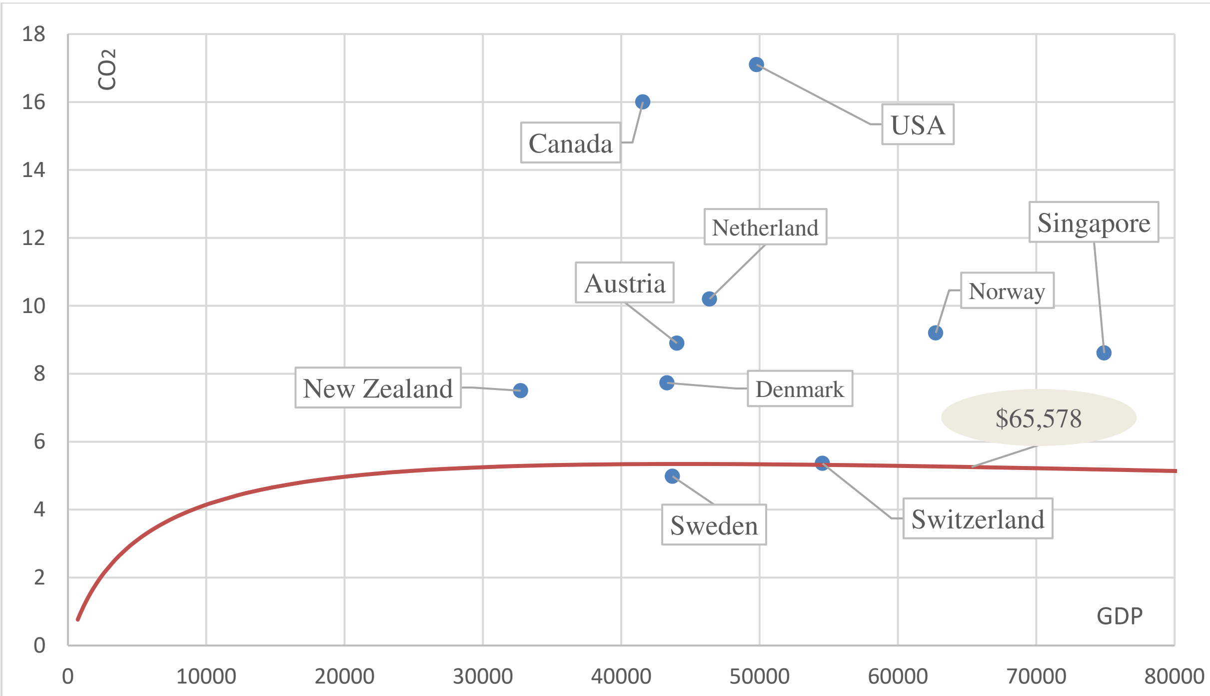

Figure 5-30: The Inverted U-shaped EKC for top 10 Education Countries (with Technique as function of underlying variables – log quadratic form)

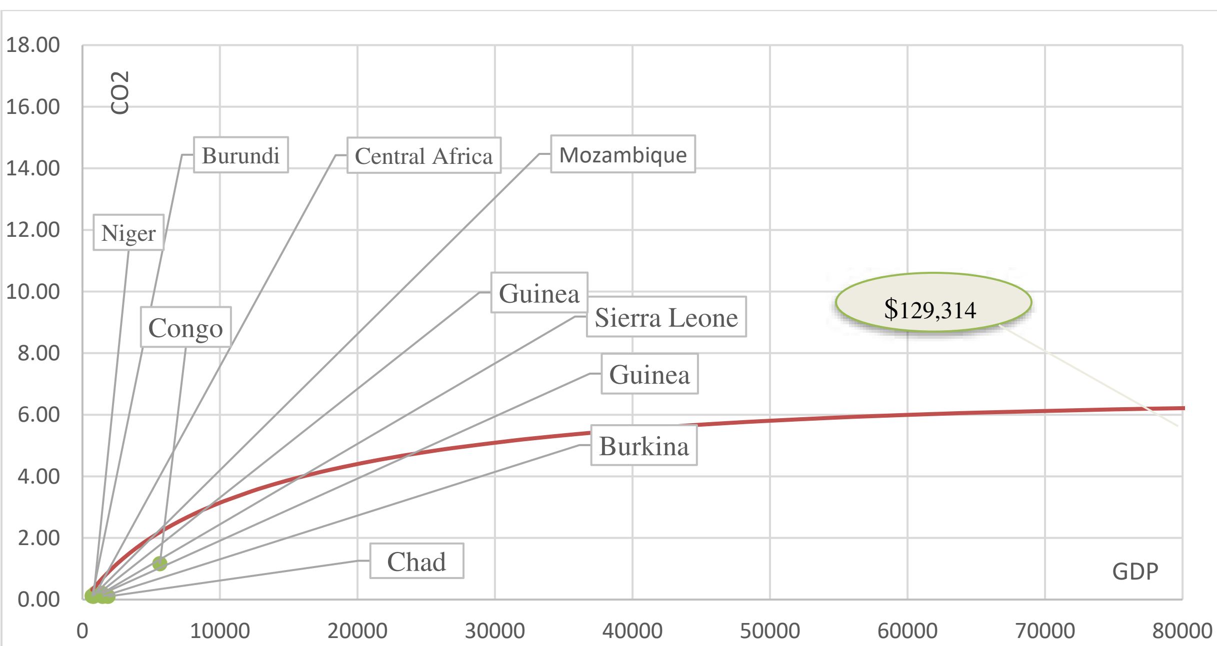

Figure 5-31: The Inverted U-shaped EKC for bottom 10 Education Countries (with Technique as function of underlying variables – log quadratic form)

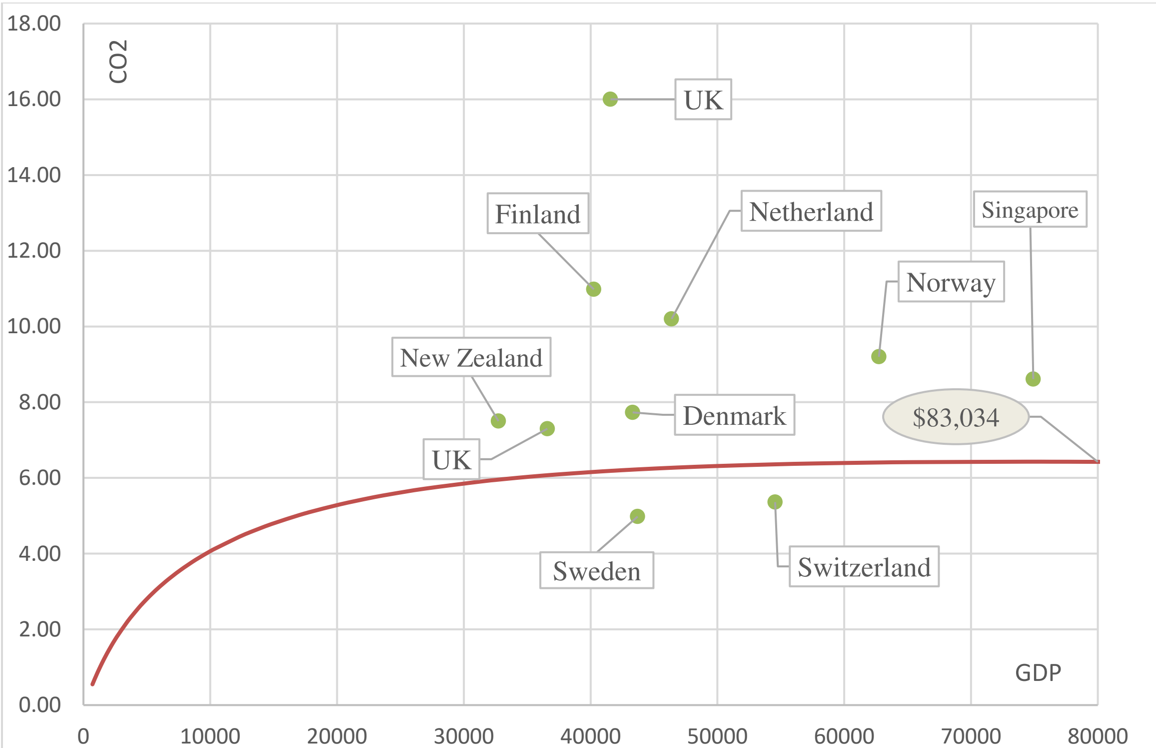

Figure 5-32: Inverted U-shaped EKC for top 10 Transparency Countries (with Technique as function of underlying variables – log quadratic form)

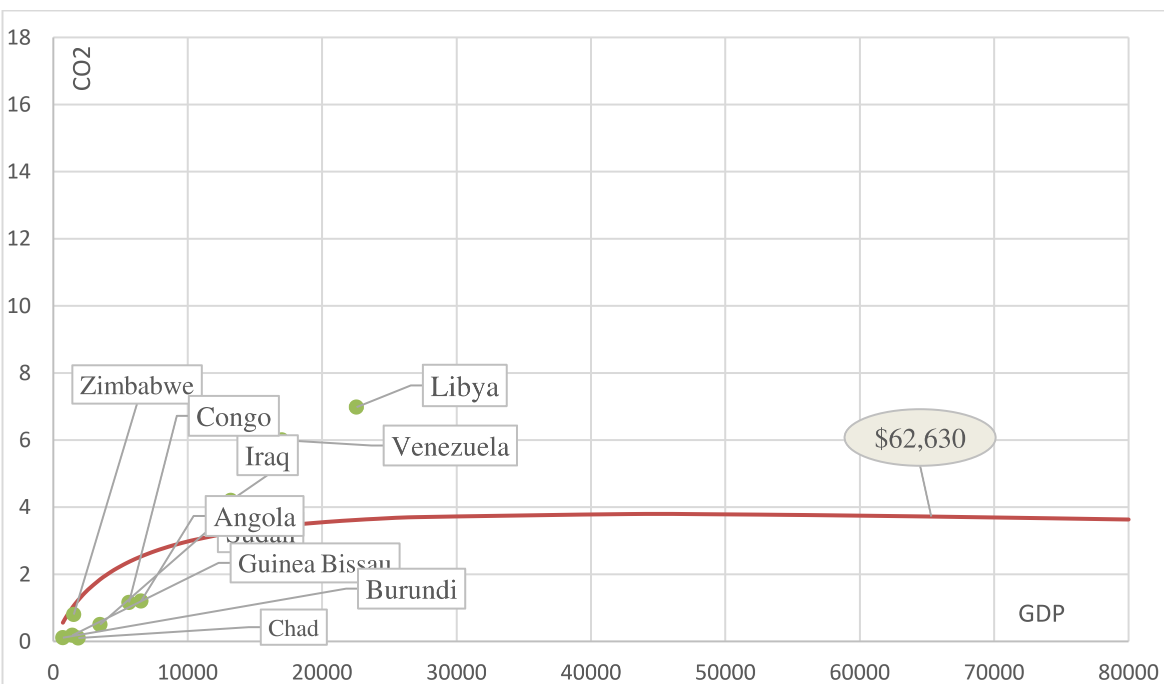

Figure 5-33: The Inverted U-shaped EKC for bottom 10 Countries Transparency (with Technique as function of underlying variables – log quadratic form)

Democracy impacts

Linear log model**.** Using the same method as above, but for Democracy, we obtain:

Top 10 for Democracy: $\ln E = -3.008 + 0.470263 \ln A$

Bottom 10 for Democracy: $\ln E = -0.54765 + 0.221166 \ln A$

Quadratic log model. Applying the same method to the quadratic model (5), we find:

Top 10 for Democracy: $\ln E = -13.2831 + 2.625776 \ln A - 0.11 \ln A^2$

Bottom 10 for Democracy: $\ln E = -10.2864 + 2.566156 \ln A - 0.11 \ln A^2$

These different quadratic EKC curves generated by high and low Democracy levels are shown in Figures 5-34 and 5-35.

Formal regulation impacts

Linear log model**.** Using the same method as above, but for Formal regulation, we obtain:

Top 10 for Formal regulation: $\ln E = -1.57015 + 0.329266 \ln A$

Bottom 10 for Formal regulation: $\ln E = - 0.31502 + 0.431363 \ln A$

Quadratic log model. Applying the same method to the quadratic model (5), we find:

Top 10 for Formal regulation: $\ln E = -11.723 + 2.4696 \ln A - 0.11 \ln A^2$

Bottom 10 for Formal regulation: $\ln E = -22.5913 + 2.7521 \ln A - 0.11 \ln A^2$

These different quadratic EKC curves generated by high and low Formal Regulation levels are shown in Figures 5-36 and 5-37.

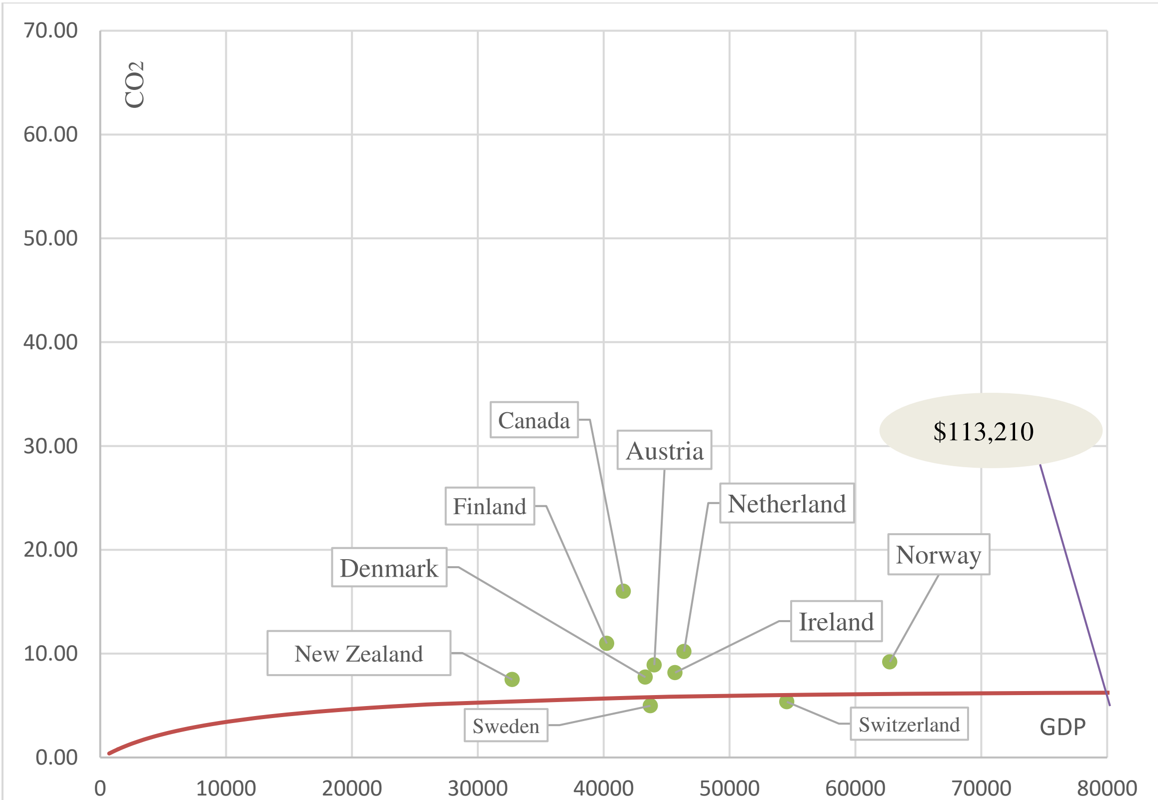

Figure 5-34: The Inverted U-shaped EKC for top 10 Democracy Countries (with Technique as function of underlying variables – log quadratic form)

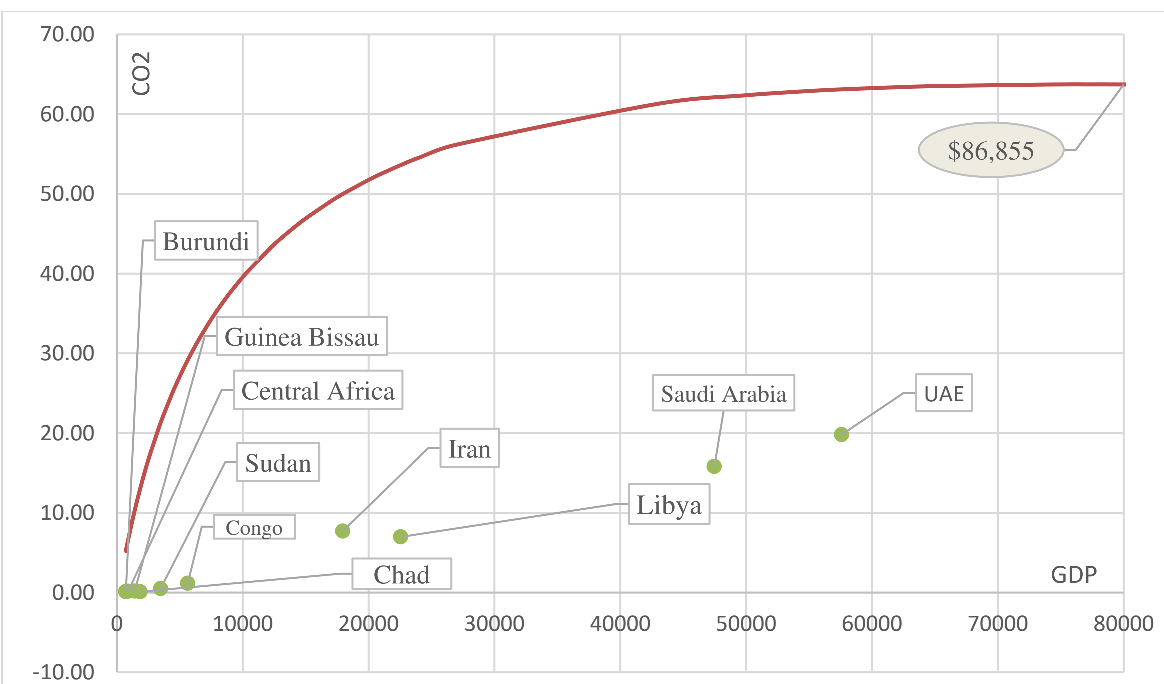

Figure 5-35: The Inverted U-shaped EKC for bottom 10 Democracy Countries (with Technique as function of underlying variables – log quadratic form)

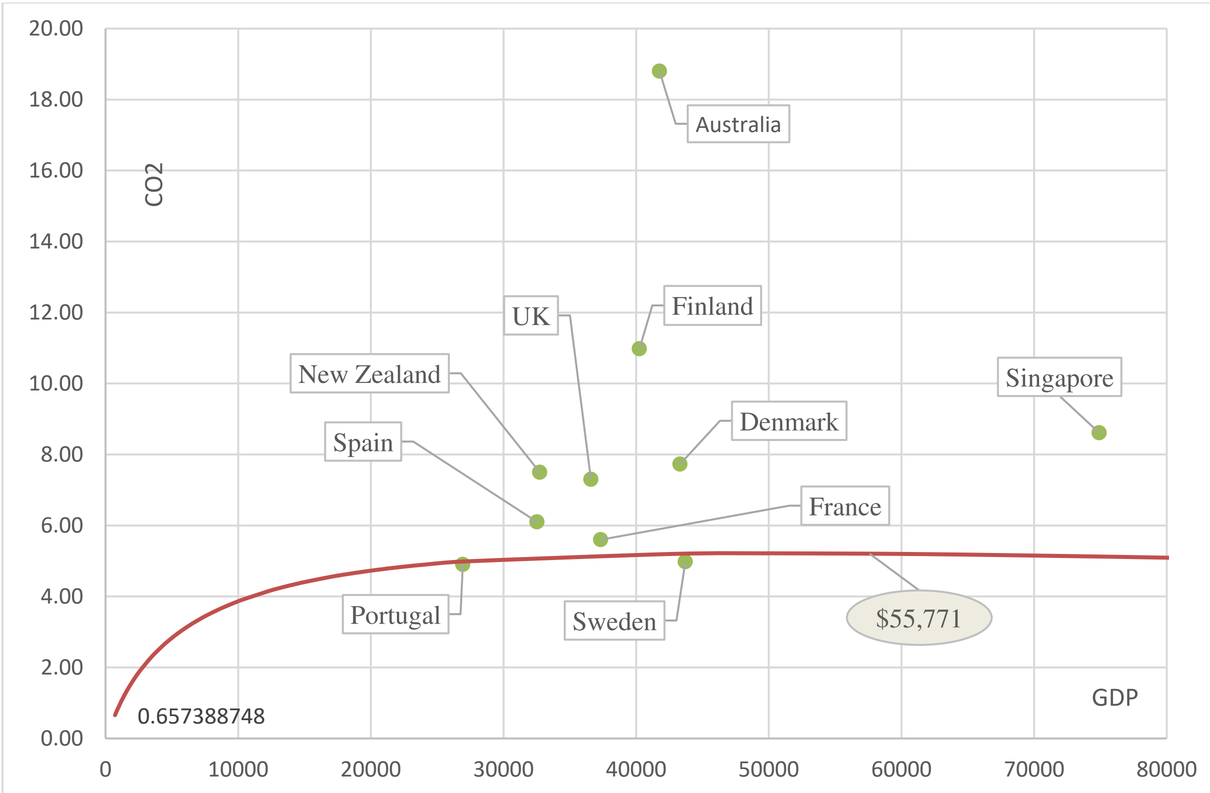

Figure 5-36: The Inverted U-shaped EKC for top 10 Regulation Countries (with Technique as function of underlying variables – log quadratic form)

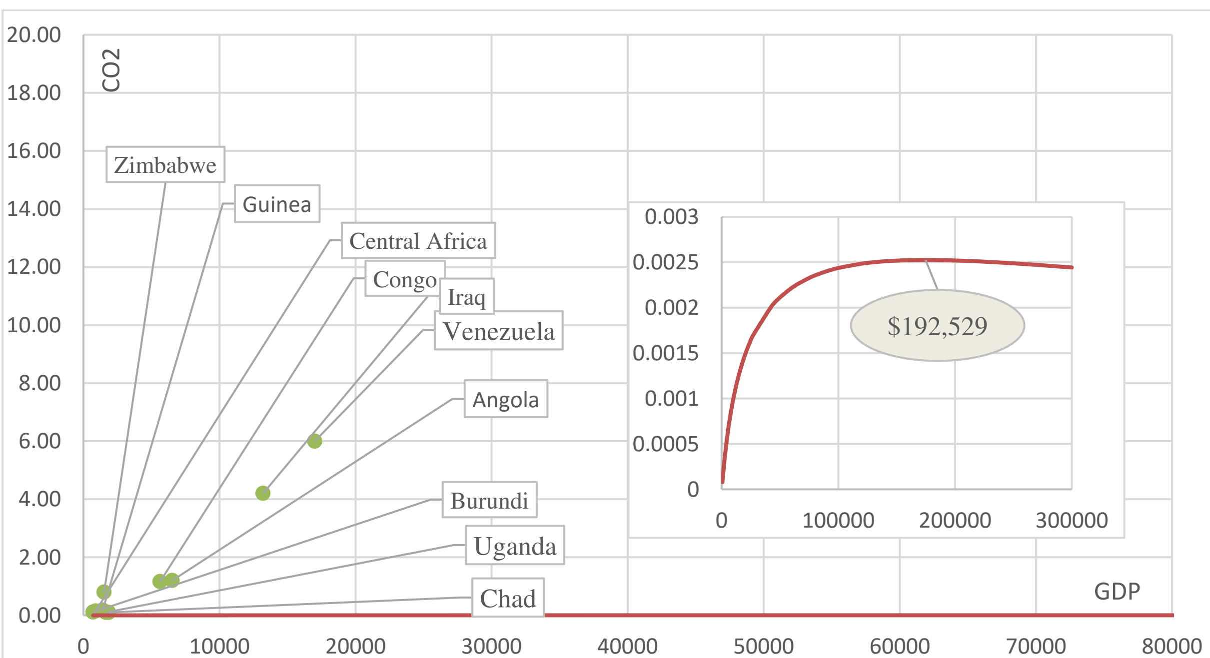

Figure 5-37: The Inverted U-shaped EKC for bottom 10 Regulation Countries (with Technique as function of underlying variables – log quadratic form)

Trade Openness impacts

Linear log model. Using the same method as above, but for Formal regulation, we obtain:

Top 10 for Trade Openness: $\ln E = -1.81007 + 0.347739 \ln A$

Bottom 10 for Trade Openness: $\ln E = -2.2332 + 0.391947 \ln A$

Quadratic log model. Applying the same method to the quadratic model (5), we find:

Top 10 for Trade Openness: $\ln E = -12.1514 + 2.510457 \ln A - 0.11 \ln A^2$

Bottom 10 for Trade Openness: $\ln E = -12.297 + 2.52940 \ln A - 0.11 \ln A^2$

These different quadratic EKC curves generated by high and low Trade Openness levels are shown in Figures 5-38 and 5-39.

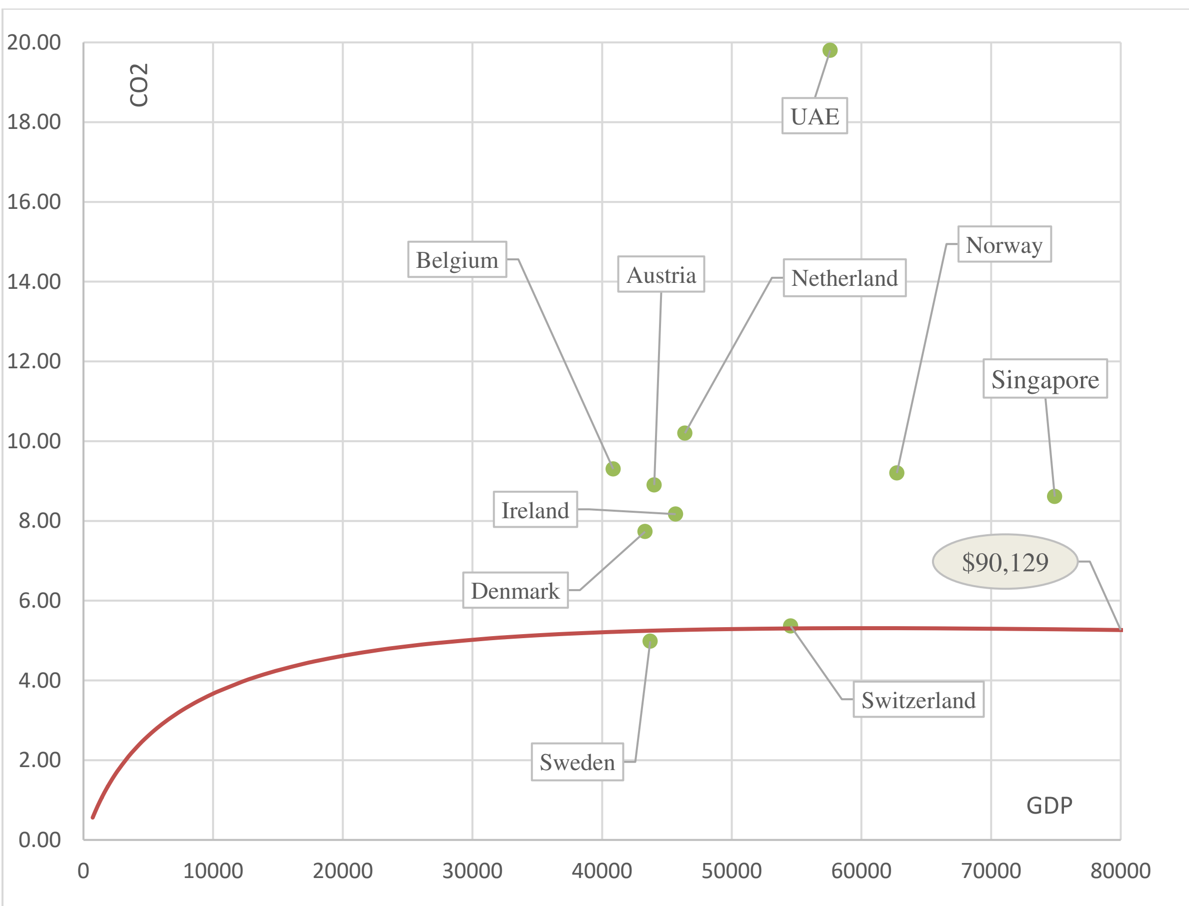

Figure 5-38: The Inverted U-shaped EKC for top 10 Trade Openness Countries (with Technique as function of underlying variables – log quadratic form)

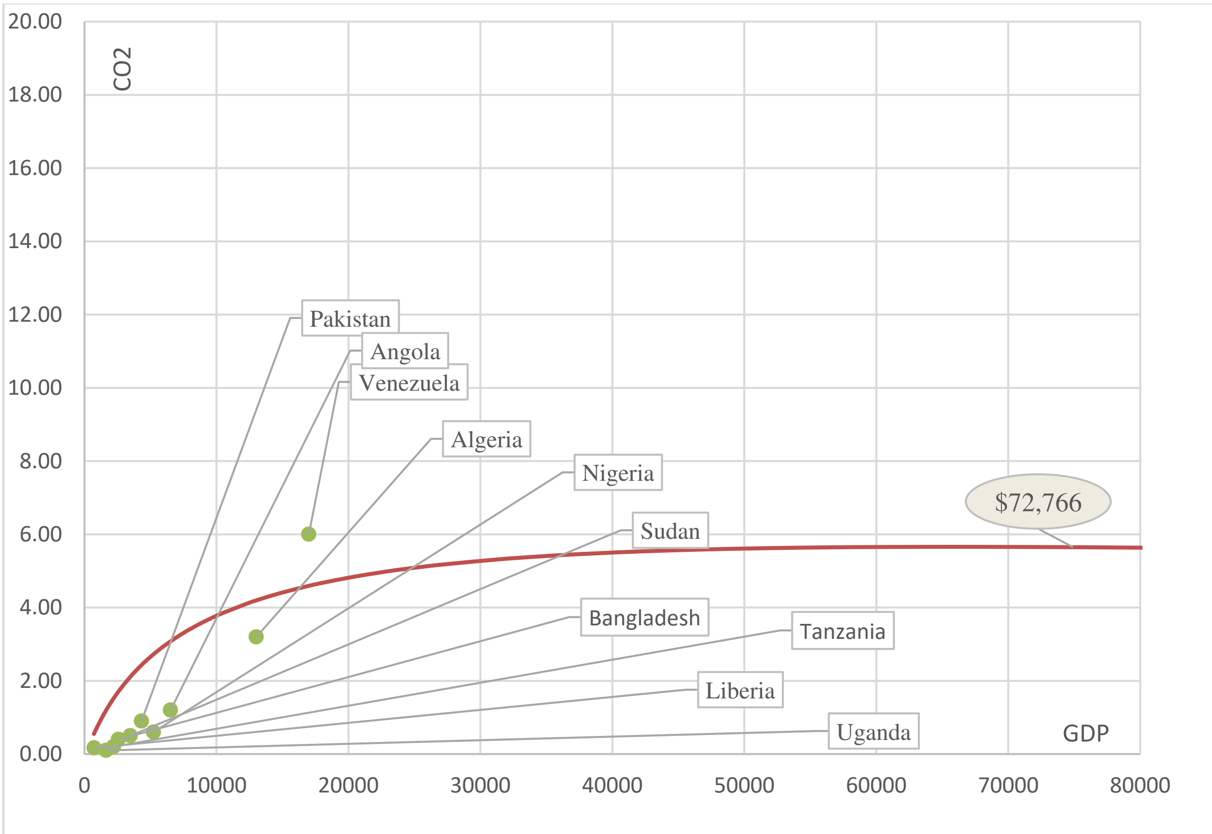

Figure 5-39: The Inverted U-shaped EKC for bottom 10 Trade Openness Countries (with Technique as function of underlying variables – log quadratic form)

Table 5-17: Comparison of subsample results

		Elasticities of GDP (slope of linear model)	*Turning point of quadratic model*	
			GDP pc	*Metric ton*
Education	Top 10	0.218179	$65,578	8.59
	Bottom 10	0.65858	$129,314	6.85
Transparency	Top 10	0.4416857	$83,034	7.53
	Bottom 10	0.291039	$62,630	5.93
Democracy	Top 10	0.470263	$108,337	7.56
	Bottom 10	0.221166	$86,855	75.415
Regulatory Effort	Top 10	0.329266	$55,771	5.92
	Bottom 10	0.431363	$192,529	0.003
Trade Openness	Top 10	0.347739	$90,129	8.85
	Bottom 10	0.391947	$72,766	6.43

Table 5-17 provides a summary comparison of key aspects of the EKCs recomposed from the estimated T function using $\ln E = \ln A + \ln T$, applying sample mean values of the underlying variables except using Top 10 and Bottom 10 subsample means to isolate the effect of each underlying variable in turn. The summary comparison suggests the following conclusions:

- All the EKC models' slopes in the linear estimations show positive elasticities. The Bottom 10 countries for Education, Trade Openness, and Regulatory Efforts are associated with higher GDP impact on CO_2 than the Top 10 countries; on the other hand, the Top 10 economies for Transparency and Democracy are associated with higher GDP impact than the Bottom 10 economies.
- All EKC models based on the T function recompositions with the quadratic coefficient estimates show turning points at a high level of GDP, with all the countries in all samples still on the upsloping side of the Environmental Kuznets Curve, below the turning point.
- From the quadratic estimations, the Bottom 10 economies for Education, Trade Openness, and Regulatory Effort have higher turning points than the Top 10 economies, but the emission level at the turning point of the Bottom 10 economies for Regulatory Effort is much less than the Top 10 (even though the GDP point is higher); this is due to the economic structure of the two groups, as the Top 10 countries' subsample includes mainly industrial countries, while the Bottom 10 countries' subsample depends mainly on agriculture. On the other hand, the Top 10 economies for Transparency and Democracy have higher turning points than the Bottom 10 economies.
- Based on the elasticity and turning point comparisons, we conclude that some underlying variables -- Education, Formal Regulation, and Trade Openness -- may have a positive

effect on emission efficiency; on the other hand Transparency and Democracy may not have the same effect on emission efficiency.

5.3.4. Level 3 summary

In the Level 3 analysis, we investigated the impact of underlying variables which may tend to encourage or inhibit the down turning of the CO_2 EKC through the technique factor (reflecting structural and technological differences)[14]. Here are the key results:

- The overall conclusion is that a quadratic polynomial relationship plausibly exists between CO_2 and per capita GDP, giving the expected inverse U-shaped EKC. But the critical value, or turning point, is at a relatively high level of GDP, which means the world's economies are still on the upside side of the Environmental Kuznets Curve, and this is consistent with Level 1 and Level 2 of our analysis.
- From the analysis using underlying variables that affect Technique (T) as a proximate variable, we confirm the EKC hypothesis for our sample of 65 countries, that CO_2 emissions have a positive relationship with the level of income before the EKC threshold and then a negative relationship beyond the threshold. That can be explained by improved technology or emissions efficiency; we find the log models to have higher statistical significance in estimating that technology function. So, those models are more suitable to examination of the implied shape of the EKC using the original IPAT formulation.

[14] When countries become more affluent, they start to demand proportionally more services, which would decrease the polluting income, but there is a suspicion of endogeneity (two-way causality) when we estimate Industrial Share as a function of income. Therefore, we estimate technique (T) as a function of income, rather than industrial technology (t); consequently, structural changes are implicit in technological changes

- The results confirm that some underlying variables -- Education, Trade Openness, and Regulatory Effort -- affect the relationship between carbon dioxide emissions and income with a positive impact on the efficiency of emissions, but others -- Transparency and Democracy -- may not have the same effect on emissions efficiency.
- The evidence is not sufficient to confirm a negative impact of the ability be a global free rider.
- Most of the results are consistent with theory and numerous studies. There is a negative relationship between policy or formal regulation and CO_2 emissions (e.g., Panayiotou, 1997; Stern, 2004). Though trade openness is associated with elevated levels of CO_2 emissions, the overall effects of trade are seen to have some beneficial effects on environmental quality (Twerefou, 2019). Countries that are more trade open may benefit through a composition effect and transfer of technology, and countries that place restrictions on imports will be affected more by the scale effect especially in emerging countries that may become pollution havens (Ertugrul, 2016). Some studies show that transparency and democracy have a positive effect on the efficiency of emissions in general and may be more effective in developing countries. This may agree with the result that developed countries are associated with higher GDP impact than developing countries which are ranked lower in terms of democracy and transparency (e.g., Gani, 2012 and Zhike, 2017).
- For Education, empirically, we did not see an underlying variable role in our EKC models, though Romuald (2010) had found that education in developing countries has more effect on CO_2 emission than developed countries.

Chapter 6. Conclusions and Recommendations

6.1 Conclusions

This research aims to study the relationship between economic growth and CO_2 emissions (specifically those that result from burning fossil fuels in production processes), under the assumptions of the Environmental Kuznets Curve, with an emphasis on the impact of underlying variables that may tend to induce or inhibit the down-turning of the CO_2 EKC through the technique variables (structural and technological change). Based on the plan presented in Chapter 1, we have reached a set of theoretical and empirical contributions.

Chapter 2 offered a survey review of the relevant CO_2 EKC literature, organized according to the results and date of the publication. Our survey shows that it has taken two directions: first, research that deals with the analysis of this relationship at the level of a single country and second, analysis at the level of multiple countries. In most of these studies, the interaction between environmental degradation and income was modeled in terms of a quadratic or log quadratic functional form. The results were presented by category:

- Studies grouped by sample type
- Studies grouped by implied curve shape
- Studies grouped by data source and logarithmic treatment
- Studies grouped by econometric model
- Studies grouped by endogeneity treatment

In Chapter 3, we gave a theoretical framework that started with the basic IPAT Model; we elaborated on the identity, by decomposing emissions per person into the affluence or "scale" effect and a technique effect. As an identity, the nature of the relationship is irrefutable and implies that emissions will be linear in affluence given a level of technology, with affluence always bringing proportionally more environmental impact if it were assumed that the technique was fixed, and the EKC can arise from that context.

$$CO_2 \text{ emissions} = (\text{Affluence})\ (\text{Technology})$$

Subsequently we elaborated on the original identity to further decompose the technique factor, to a technology effect and a structural effect. It has been broadly observed that as societies develop to high levels of affluence, the composition of their output mixes tends to become more service-intensive, and services tend to have a lower environmental impact than industrial production. Even if manufacturing itself does not decline in total activity, it usually falls as a proportion of GDP. This output composition effect, one example of a structural effect, can be incorporated into the identity as follows:

$$CO_2 \text{ emissions} = (\text{Affluence})\ (\text{Industrial Share})\ (\text{Industrial Technology})$$

In either the abbreviated or expanded form, the right-hand-side factors are considered "proximate" explanatory variables, and in either form we hypothesized that both the scale effect and the technique effect depend on affluence or income (GDP per capita), possibly in countervailing directions. Then to expand the analysis of explanatory variables (for subsequent empirical work), we incorporated "underlying" variables that affect the proximate variables. The decomposition into proximate explanatory variables depending on affluence is a first step away from the original mechanical, deterministic identity with unitary elasticities; a second step is then to explore the stochastic dependency of the proximate variables on a vector of underlying variables. Based on the literature, we described the hypothesized direction of causality, from affluence and plausible socio-political factors, to technique, and finally emissions. So, we assume that underlying variables affect the proximate variable Technique, directly and in interaction with affluence. We thereby enrich the mechanisms by which affluence affects technique and ultimately emissions; the plausible underlying variables include trade openness (both import penetration and export specialization), as well as education, democracy, transparency, and regulatory effort indicators.

In Chapter 5, we present the results of the empirical contribution. We used the various model specifications detailed in the methodology chapter. The first section (Level 1 analysis) presented OLS estimation for the standard EKC regression model in order to establish a benchmark model using our panel data sample. We pursued a traditional EKC estimation with per capita GDP as the only independent variable, applying our data to a simple quadratic functional form. We also explored possible differences between certain subsamples segregated according to several variables of interest, including the underlying variables. The second section (Level 2 analysis) presented OLS empirical estimation of additional proximate explanatory variables (Industrial Share and Technology) as functions of Affluence. Then we plugged those equations into the IPAT identity to examine the implied EKC shape. The third section (Level 3 analysis) presented OLS empirical estimation of the equations for the proximate variables Industrial Share and Technology, as functions of the underlying variables as well as Affluence. Then again we plugged those functions into the IPAT identity to examine the implied EKC shape. The key results are as follows:

1. The overall conclusion is that a quadratic polynomial relationship plausibly exists between CO_2 and per capita GDP (giving an inverse U-shaped EKC), but the turning point is at a relatively high level of GDP, which means the world's economies are still on the upside side of the EKC.

2. There is variation in the turning point levels according to the level of income in particular samples.

- The comparison of the rich country subsamples compared to poor country subsamples shows a higher turning point for rich countries; this phenomenon can be explained by:

    - Differing standards of living from one country to another that may affect the turning point; in developed countries, the base standard of living is higher, and achieving perceived "basic needs" requires higher income levels before demand for a clean environment starts having its effect.
    - Developing countries benefitting from technology transfer from developed countries and achieving environmental improvement faster.

- Consistent with the conclusion from the literature review, as the sample size increases, the turning point rises to a higher level of GDP. This phenomenon can be explained as follows: Larger samples have larger variation, while smaller mostly homogeneous samples are isolated in those differences from the rest of the countries and their behavior; and the estimation results in turning points for these samples only.
- Despite the variation in the turning point levels between log and non-log models, the points are very high in log models, which is consistent with previous studies. But the use of logarithms does restrict the unlogged levels of the indicators from being zero or negative, which is appropriate and pushes the estimated function to higher values.

3. The result from the analysis using Technique (T) as an additional proximate explanatory (Level 2), or using underlying variables that affect Technique (Level 3), confirms the EKC hypothesis for the 65 countries using the original IPAT formulation, where CO_2 emissions have a positive relationship with the level of income before the EKC threshold and then a negative relationship beyond the threshold, and this can be explained by improved technology or emission efficiency.

4. In Levels 1 and 3 we investigated the impact of underlying variables that may tend to induce or inhibit the down-turning of the CO_2 EKC through the technique variables (structural and technological change). Applying different techniques of analysis and different sample methodologies in the two levels of analysis, in both cases we compared the effects of the underlying variables both in terms of the GDP elasticity effects on emissions and in terms of the turning points.

    - The results confirm that Education and Regulatory Effort affect the relationship between CO_2 emissions and income with a positive impact on the emissions efficiency of output. In Level 3, although there is positive elasticity for both variables, low levels of Education and Regulatory Effort are associated with higher GDP impact on CO_2 (in terms of elasticity) than high levels, *ceteris paribus*. On the other hand, in Level 1 the Top 10 countries are on the downside of their inverse-U shape of the EKC after the turning point, which means that the relationship between emissions and GDP turns negative (environmentally beneficial), while the Bottom 10 countries are still on the upside of the curve before the turning point, which means that the relationship between emissions and GDP is still positive (environmentally detrimental). Still, in both cases Education and Regulatory Effort have beneficial impacts on the affluence-emissions relationship.

- Regarding Trade Openness, it might seem paradoxical if we take the analyses from Levels 1 and 3 separately. In Level 1, despite the different curve shapes for the Top 10 and Bottom 10 subsamples, in both cases the subsample countries fall on positively sloped sections of their curves, indicating a negative impact on emission efficiency. In Level 3, elasticity is positive and the GDP level is on the upside of the inverse-U EKC for both high and low Trade Openness, but low Trade Openness is associated with higher GDP impact on CO_2 than with high Trade Openness, which suggests that Trade Openness may have a beneficial effect on emission efficiency. Theoretically, Trade Openness can have an effect in both directions, so the net beneficial effect of high openness compared to low openness suggests a benefit from the composition effect relative to any scale effect; openness lessens the negative impact of affluence.
- The same applies to Democracy and Transparency, that it might seem paradoxical if we take the Level 1 and Level 3 analyses separately. In Level 1, the level of GDP is on the downside of the inverse-U shape of the EKC after the turning point for the Top 10 countries, which means that the relationship between emissions and GDP turns negative (beneficial), while the Bottom10 countries show a U-shaped EKC, and the level of GDP is on the upside of the curve after the turning point, which means that the relationship between emissions and GDP is positive (detrimental), which suggests that both Democracy and Transparency may have a positive effect on emission intensity. In Level 3, elasticity is positive and the GDP level is on the

upside of the inverse-U shape of the EKC before the turning point, but high Democracy and Transparency are associated with higher GDP impact on CO_2 compared with low Democracy and Transparency. This conclusion is in contrast with the conclusions form Level 1, and also contradicts our expectation, but the Level 3 analysis was designed to isolate the impact of each underlying variable on its own, *ceteris paribus*. So this Level 3 result is surprising. The inconsistent conclusions lead us to not draw any strong implications overall. This could be attributed to the bottom 10 countries' subsamples, likely involve significant heterogeneity that is not fully addressed by the country fixed-effects.

- The evidence is not sufficient to confirm any negative impact of the ability be a global free rider.

6.2 Recommendations

- It appears that in the short term, economic development may continue to harm the environment, but in the long run, we hope that complementary policy strategies will help mitigate global climate change, particularly where results confirm that underlying variables affect the relationship between carbon dioxide emissions and income via the proximate variables. Despite the promise of the EKC hypothesis, economies are unlikely to simply grow their way out of high emissions in time to make a difference for climate change. The effects of economic growth can be moderated by policies that may move the EKC turning point to earlier stages of development with lower peak emission levels. The key policy recommendations suggested by our analysis are the following.

- **<u>Strengthen environmental regulation and enforcement</u>**. Formal regulation plays an intermediary role between root causal factors (Proximate and Underlying variables), and pollution grows unless environmental regulation is enforced by controlling both emission flows and stocks. The study recommends the adoption of strong policies and enforcement efforts that advance environmental sustainability in the public interest.
- **<u>Raise education levels</u>**. Education enhances awareness and understanding of environmental issues, which motivates people to increase their demand for a clean environment, evaluate policy options, and pressure government to improve environmental policy and enforcement. Education also encourages more non-government to help improve the environment. The study recommends support raise education levels policy as an important factor in spreading environmental awareness towards raising the demand for a clean environment
- **<u>Manage trade openness carefully</u>**. Although other studies suggest trade could have a positive effect on emission efficiency through the composition effect and/or technique effect, it also is true that increased trade, particularly export volume, can increase the size of the economy and consumption levels leading to an increase in pollution. The results of this study support those mixed results. Therefore, the recommendations are focused on using Trade indicators, by sector, if the data are available, can be used under benefits and costs analyses to estimate the degree to which can be imported or exported, affecting country capacity and incentives to reign in emissions.
- **<u>Pair trade openness with multilateral international collaboration, other domestic strategies.</u>** If trade is inclined to increase emissions via the scale effect but nevertheless is a policy imperative for reasons of economic growth, then authorities can seek to offset

environmental impacts by simultaneous pursuit of countervailing efforts. Given that CO_2 emissions are a global issue, this study recommends international collective action linked with commercial openness, with environmental improvements agreed by group members enjoying trade benefits, and implied costs imposed on outsiders. This creates an incentive to join and get the benefits and avoid the costs or penalties. Trade openness also can be complemented by appropriate domestic policies. Specifically, this study suggests that trade and affluence should be accompanied by social advance in education and formal regulation as discussed above, as well as by strategic domestic sectoral strategies for trade. Policy directions need not be taken in isolation, and optimal policy combinations can offer strong benefits.

References

Agras, Chapman. (1999). A dynamic approach to the environmental Kuznets curve hypothesis. Ecological Economics 28: 267–277.

Akbostancı E., S. Türüt-Aşık and G. Đpek-Tunç (2009). The relationship between income and environment in Turkey: Is there an environmental Kuznets curve?. Energy Policy 37: 861-867.

Alwan, K. H., & Al-Tarawneh, S. (2014. الآثار المتبادلة بين النمو الاقتصادي وانبعاثات ثاني أكسيد الكربون (The Interrelationship between Economic Growth and CO_2 Emissions under Environmental Kuznets Curve Hypothesis: A Case Study for Jordan) 2)1 ,المجلة الاردنية للعلوم الاقتصادية)

Al-Mulali, U., Tang, C. F., & Ozturk, I. (2015). Does financial development reduce environmental degradation? Evidence from a panel study of 129 countries. Environmental Science and Pollution Research, 22(19): 14891-14900.

Al-Mulali, U., Saboori, B., & Ozturk, I. (2015). Investigating the environmental Kuznets curve hypothesis in Vietnam. Energy Policy, 76: 123-131.

Al-Mulali, U., Tang, C. F., & Ozturk, I. (2015). Estimating the environment Kuznets curve hypothesis: Evidence from Latin America and the Caribbean countries. Renewable and Sustainable Energy Reviews, 50: 918-924.

Amigues, J. P., Chakravorty, U., & Moreaux, M. (2009). Think Globally, Act Locally? Stock vs Flow Regulation of a Fossil Fuel. Toulouse School of Economics.Working Paper 09-155.

Ang, J. (2007). CO_2 emissions, energy consumption, and output in France, Energy Policy, 35 (10): 4772-4778.

Apergis, N., & Ozturk, I. (2015). Testing environmental Kuznets curve hypothesis in Asian countries. Ecological Indicators, 52:16-22.

Atici, C. (2009). Carbon emissions in Central and Eastern Europe: environmental Kuznets curve and implications for sustainable development. Sustainable Development, 17(3): 155-160.

Azomahou, T., Laisney, F., Phu, N.V., 2006. Economic development and CO_2 emissions: a nonparametric panel approach. Journal of Public Economics 90: 1347–1363.

Begum, R. A., Sohag, K., Abdullah, S. M. S., & Jaafar, M. (2015). CO_2 emissions, energy consumption, economic and population growth in Malaysia. Renewable and Sustainable Energy Reviews, 41: 594-601.

Carlsson, F., & Lundström, S. (2003). The effects of economic and political freedom on CO2 emissions. Economic Studies, Department of Economics, School of Economics and Commercial Law, Göteborg University: Gothenburg, Sweden, 79.

Changyong, F. E. N. G., Hongyue, W. A. N. G., Naiji, L. U., Tian, C. H. E. N., Hua, H. E., & Ying, L. U. (2014). Log-transformation and its implications for data analysis. Shanghai archives of psychiatry, 26(2): 105.

Chinn, M. D., & Prasad, E. S. (2003). Medium-term determinants of current accounts in industrial and developing countries: an empirical exploration. Journal of International Economics, 59(1): 47-76.

Choi, E., Heshmati, A., & Cho, Y. (2010). An empirical study of the relationships between CO_2 emissions, economic growth, and openness.

Clarke, L., Kyle, P., Wise, M., Calvin, K., Edmonds, J., Kim, S., & Smith, S. (2008). CO_2 emissions mitigation and technological advance: an updated analysis of advanced technology scenarios. PNNL Report Pacific Northwest National Laboratory, Richmond.

Cole, M. A., Rayner, A. J., & Bates, J. M. (1997). The environmental Kuznets curve: an empirical analysis. Environment and development economics, 2: 401-416.

Cole, M. A. (2004). US environmental load displacement: examining consumption, regulations and the role of NAFTA. Ecological economics, 48(4): 439-450.

Dinh, H. L., & Shih-Mo, L. (2014). CO2 emissions, energy consumption, economic growth and FDI in Vietnam. Managing Global Transitions, 12(3): 219.

Dinda, S. (2004). Environmental Kuznets curve hypothesis: a survey. Ecological economics, 49(4): 431-455.

Dinda, S. (2004). Environmental Kuznets curve hypothesis: a survey. Ecological economics, 49(4): 431-455.

Dong, B., Wang, F., & Wang, Y. (2011). Trade, leakage and Consumption-based EKC. University of International Business and Economics, Beijing China.

Du, L., Wei, C., & Cai, S. (2012). Economic development and carbon dioxide emissions in China: Provincial panel data analysis. China Economic Review, 23(2): 371-384.

Ehrlich, P., & Holdren, J. (1971). Impact of Population Growth. Science, 171(3977), 1212-1217. Retrieved from http://www.jstor.org/stable/1731166

Elhemri, Maged A. (2019).Environmental Kuznets Curve for CO_2 in Egypt & South Korea, unpublished technical paper, Agricultural & Resource Economics, Colorado State University.

Friedl, B., & Getzner, M. (2003). Determinants of CO_2 emissions in a small open economy. Ecological economics, 45(1):133–148.

Galeotti, M., Lanza, A. (1999). Richer and cleaner? A study on carbon dioxide emissions in developing countries. Energy Policy 27(10): 565–573.

Galeotti, M., & Lanza, A. (2005). Desperately seeking environmental Kuznets. Environmental Modelling & Software, 20(11):1379-1388.

Galeotti, M., Lanza, A., & Pauli, F. (2001). Desperately seeking (environmental) Kuznets: A new look at the evidence. Centro Euro-Mediterraneo per i Cambiamenti Climatici (CMCC)

Galeotti, M., & Lanza, A. (2005). Desperately seeking environmental Kuznets. Environmental Modelling & Software, 20(11): 1379-1388.

Galeotti, M., Lanza, A. Pauli, F. (2006). Reassessing the environmental Kuznets curve for CO_2 emission: a robustness exercise. Ecological Economics 57: 152–163.

Galeotti, M. (2007). Economic growth and the quality of the environment: taking stock. Environment, Development and Sustainability, 9(4): 427-454.

Gani, A. (2012). The relationship between good governance and carbon dioxide emissions: Evidence from developing economies. Journal of Economic Development, 37(1): 77.

Grossman, G. M., & Krueger, A. B. (1991). Environmental impacts of a North American free trade agreement (No. w3914). National Bureau of economic research.

Grunewald, N., & Martínez-Zarzoso, I. (2009). Carbon dioxide emissions, economic growth and the impact of the Kyoto protocol. Online] http://www. Web meets. com/files/papers/EAERE/2011/1163/Grunewald% 20and% 20Martinez-Zarzoso_Carbon% 20Dioxide% 20Emissions,% 20Economic% 20Growth% 20and% 20the. Pdf (accessed 10 February 2016).

Grossman, G and Krueger, A. (1995). Economic growth and the environment. The Quarterly Journal of Economics 110:353–377.

He, J., & Richard, P. (2010). Environmental Kuznets curve for CO_2 in Canada. Ecological Economics, 69(5): 1083-1093.

Heil, M. T., & Selden, T. M. (2001). Carbon emissions and economic development: future trajectories based on historical experience. Environment and Development Economics, 63-83.

Heidari, H., Katircioğlu, S. T., & Saeidpour, L. (2015). Economic growth, CO_2 emissions, and energy consumption in the five ASEAN countries. International Journal of Electrical Power & Energy Systems, 64: 785-791.

Holtz-Eakin, D., & Selden, T. M. (1995). Stoking the fires? CO_2 emissions and economic growth. Journal of public economics, 57(1): 85-101.

Huang, H. C. R. (2004). A flexible nonlinear inference to the Kuznets hypothesis. Economics Letters, 84(2): 289-296.

Huang, W. M., Lee, G. W., & Wu, C. C. (2008). GHG emissions, GDP growth and the Kyoto Protocol: A revisit of Environmental Kuznets Curve hypothesis. Energy Policy, 36(1): 239-247.

IEA (2017), World Energy Outlook 2017, IEA, Paris https://www.iea.org/reports/world-energy-outlook-2017.

Jalil, A., & Mahmud, S. F. (2009). Environment Kuznets curve for CO_2 emissions: a cointegration analysis for China. Energy policy, 37(12): 5167-5172.

Jaunky, V. C. (2011). The CO_2 emissions-income nexus: evidence from rich countries. Energy Policy, 39(3): 1228-1240.

Jula, D., Dumitrescu, C. I., Lie, I. R., & Dobrescu, R. M. (2015). Environmental Kuznets curve. Evidence from Romania. Theoretical & Applied Economics, 22(1).

Kasman, A., & Duman, Y. S. (2015). CO2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: a panel data analysis. Economic Modelling, 44: 97-103.

Katircioğlu, S. T. (2010). International tourism, higher education and economic growth: The case of North Cyprus. The World Economy, 33(12): 1955-1972.

Katircioğlu, S. T. (2014). Testing the tourism-induced EKC hypothesis: The case of Singapore. Economic Modelling, 41: 383-391.

Komen, M. H., Gerking, S., & Folmer, H. (1997). Income and environmental R&D: empirical evidence from OECD countries. Environment and Development Economics, 2(4): 505-515.

Kuznets, S. (1955). Economic growth and income inequality. The American economic review, 45(1), 1-28.

Lean, H. H., & Smyth, R. (2010). CO_2 emissions, electricity consumption and output in ASEAN. Applied Energy, 87(6): 1858-1864.

Lin, C. Y. C., & Liscow, Z. D. (2013). Endogeneity in the environmental Kuznets curve: an instrumental variables approach. American Journal of Agricultural Economics, 95(2): 268-274.

List, J. A., & Gallet, C. A. (1999). The environmental Kuznets curve: does one size fit all?. Ecological economics, 31(3): 409-423.

Lise W. & Montfort K. V. (2007). Energy consumption and GDP in Turkey: Is there a co-integration relationship? Energy Econ, 27: 1166–78.

Magazzino, C. (2016). The relationship between CO_2 emissions, energy consumption and economic growth in Italy. International Journal of Sustainable Energy, 35(9): 844-857.

Martínez-Zarzoso, I., & Bengochea-Morancho, A. (2004). Pooled mean group estimation of an environmental Kuznets curve for CO_2. Economics letters, 82(1): 121-126.

Martino, R., & Nguyen-Van, P. (2016). Environmental Kuznets curve and environmental convergence: A unified empirical framework for CO_2 emissions. Working Paper (2016-18).

Meadows, D. H., Meadows, D. L., Randers, J., & Behrens, W. (1972). The Limits to Growth. New York: Universe Books.

Magazzino, C. (2016). The relationship between CO_2 emissions, energy consumption and economic growth in Italy. International Journal of Sustainable Energy, 35(9): 844-857.

Montero, J. T., & Perrings, C. (2011). The provision of international environmental public goods. United Nations Environment Program. Nairobi: United Nations Environment Program.

Mutascu, M., Pereau, J. C., & Ursu, E. (2016). A wavelet analysis of the environmental Kuznets curve in France. In GRETHA UMR CNRS 5113. Université de Bordeaux, France.

Moomaw, W.R. and G.C. Unruh (1997), Are environmental Kuznets curves misleading us? The case of CO2 emissions, Environment and Development Economics 2: 451– 463.

Nasir, M., & Rehman, F. U. (2011). Environmental Kuznets curve for carbon emissions in Pakistan: an empirical investigation. Energy Policy, 39(3): 1857-1864.

Neumayer, E. (2004). National carbon dioxide emissions: geography matters. Area, 36(1), 33-40.

Olson, M. (2009). The Logic of Collective Action: Public Goods and the Theory of Groups, Second Printing with a New Preface and Appendix (Vol. 124). Harvard University Press.

Omri, A., Daly, S., Rault, C., & Chaibi, A. (2015). Financial development, environmental quality, trade and economic growth: What causes what in MENA countries. Energy Economics, 48: 242-252.

Onafowora, O. A., & Owoye, O. (2014). Bounds testing approach to analysis of the environment Kuznets curve hypothesis. Energy Economics, 44: 47-62.

Ozturk, I., & Acaravci, A. (2013). The long-run and causal analysis of energy, growth, openness and financial development on carbon emissions in Turkey. Energy Economics, 36: 262-267.

Ozturk, I., & Al-Mulali, U. (2015). Investigating the validity of the environmental Kuznets curve hypothesis in Cambodia. Ecological Indicators, 57, 324-330.

Prakash, S. (2012, January First). Clean Planet. Better Life. Live Longer. Retrieved Nov 15 2015 from http://en.envirocitiesmag.com/articles/pdf/envirocities-article11.pdf .

Panayotou, T. (1997). Demystifying the environmental Kuznets curve: turning a black box into a policy tool. Environment and development economics, 465-484.

PBL Netherlands Environmental Assessment Agency. (2013). Trends in global CO_2 emissions: 2013 Report, http://www.pbl.nl/sites/default/files/cms/publicaties/pbl-2013-trends-in-global-co2-emissions-2013-report-1148.pdf

Peters, G. P., & Hertwich, E. G. (2008). CO_2 embodied in international trade with implications for global climate policy. Industrial Ecology Programme, Norwegian University of Science and Technology. Trondheim .NO-7491,

Roca, J., Padilla, E., Farré, M., & Galletto, V. (2001). Economic growth and atmospheric pollution in Spain: discussing the environmental Kuznets curve hypothesis. Ecological Economics, 39(1):85-99.

Robalino-López, A., Mena-Nieto, Á., García-Ramos, J. E., & Golpe, A. A. (2015). Studying the relationship between economic growth, CO2 emissions, and the environmental Kuznets curve in Venezuela (1980–2025). Renewable and Sustainable Energy Reviews, 41: 602-614.

Roberts, J. T., & Grimes, P. E. (1997). Carbon intensity and economic development 1962–1991: a brief exploration of the environmental Kuznets curve. World development, 25(2):191-198.

Romuald, K. S. (2010). Does Education Really Matter for Environmental Quality?. PhD student at CERDI, Université d'Auvergne, 65, bd F. Mitterrand, 63000 Clermont Ferrand - France.

Selden, T. M., & Song, D. (1994). Environmental quality and development: is there a Kuznets curve for air pollution emissions?. Journal of Environmental Economics and management, 27(2):147-162.

Sengupta, R. (1996). CO2 emission-income relationship: policy approach for climate control. Pacific and Asian Journal of Energy, 7(2): 207-229.

Shafik, N. (1994). Economic development and environmental quality: an econometric analysis. Oxford economic papers, 46:757-773.

Shafik, N., & Bandyopadhyay, S. (1992). Economic growth and environmental quality: time-series and cross-country evidence (Vol. 904). World Bank Publications.

Shahbaz, M., Ozturk, I., Afza, T, & Ali, A. (2013). Revisiting the environmental Kuznets curve in a global economy. Renewable and Sustainable Energy Reviews, 25: 494-502.

Schmalensee, R., Stoker, T. M., & Judson, R. A. (1998). World carbon dioxide emissions: 1950–2050. Review of Economics and Statistics, 80(1): 15-27.

Stern, D. I. (2004). The rise and fall of the environmental Kuznets curve. World development, 32(8): 1419-1439.

Stern, D. I. (2014). The environmental Kuznets curve.Australian National University.Crawford School of Public Policy.Centre for Climate Economics & Policy.Working Paper 1404: A primer (No. 450-2016-34062).

Suri, V., & Chapman, D. (1998). Economic growth, trade and energy: implications for the environmental Kuznets curve. Ecological economics, 25(2): 195-208.

Torras, M., & Boyce, J. K. (1998). Income, inequality, and pollution: a reassessment of the environmental Kuznets curve. Ecological economics, 25(2): 147-160.

Twerefou, D. K., Akpalu, W., & Mensah, A. C. E. (2019). Trade-induced environmental quality: the role of factor endowment and environmental regulation in Africa. Climate and Development, 11(9): 786-798.

Yandle, B., Vijayaraghavan, M., & Bhattarai, M. (2002). The environmental Kuznets curve. A Primer, PERC Research Study, 02-01.

York, R., Rosa, E. A., & Dietz, T. (2003). STIRPAT, IPAT and ImPACT: analytic tools for unpacking the driving forces of environmental impacts. Ecological economics, 46(3): 351-365.