Economic Development and CO_2 Emissions: A Look at Disaggregated Kuznets Curves

by

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Abstract

Using data from 64 countries for the period of 1981 to 2008, this essay investigates and tests for an inverted U-shaped relationship or Environmental Kuznets Curve between economic development and CO_2 emissions. The results support an aggregate inverted U-shaped relationship between economic development and CO_2 emissions with high-income countries displaying an N-shaped relationship, middle-income countries an inverted U-shaped relationship and low-income countries a monotonic and increasing relationship. I find that the biggest contributors to the aggregate inverted U-shaped relationship come from the CO_2 emissions generated from the electricity and heat sector, with a turning point of US $36,000. This is followed by the CO_2 emissions generated from the manufacturing industries and construction, with a turning point of US $18,000, and CO_2 emissions generated from residential buildings commercial and public services, with a turning point of around US $9,000. The transportation generated CO_2 emissions have not yet achieved a turning point. Further, there is indirect evidence of a pollution haven at the aggregate level running from high-income to middle-income countries. I find that the pollution-haven hypothesis observed at the aggregate level can be attributed to the CO_2 emissions originating from (a) electricity and heat production and (b) manufacturing and construction industries.

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All errors and omissions are my own.

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1 Introduction

According to Watkins (2006), the world has consumed during the last three decades a larger amount of petroleum than it had previously recorded as proven reserves in the 1970's. Furthermore, consumption of conventional oil is projected to increase to 103 mb/d by 2030 from 82 mb/d in 2005 with Asian developing countries as the main consumers (EIA 2008). Global carbon dioxide (CO_2) emissions, an important component of greenhouse gases (GHGs), are also far from slowing down. Global Carbon Project, a community of researchers, estimates that emissions grew 3.2% per year between 2000 and 2005 which is four times faster than the growth rates in the previous 10 years. As can be seen from Figure 1, CO_2 emissions have been consistently rising since 1960 with only minor slowdowns due to major events like the US savings and loan crisis, the collapse of the Soviet Union and the Asian financial crisis. The 2008 financial crisis did decelerate the rising of CO_2 emissions, however, the slowdown was shortly lived and, according to Global Carbon Project (2011), CO_2 emissions from fossil fuel combustion and cement production grew at almost 6% in 2010.

Strong policies and regulations must be adopted for both environmental and sustainable reasons. CO_2 emissions threaten the natural temperature course of the planet which in turn can have economic and social consequences on society. In fact, developing nations, with far larger populations, will have a lead in energy consumption compared to the industrialized nations of the OECD. As Figure 2 shows, developing countries already lead the way in both emissions originating from production and those originating from consumption. While CO_2 emissions from developed countries have been consistent for the past 2 decades, the level of CO_2 emissions has dramatically increased for the developing world. If these nations were to consider energy conservation policies to try and sustain this increase in energy consumption and CO_2 emissions, they need to strongly consider the relationship between CO_2 emissions and economic development. Many lessons can be learned from countries which have already gone through the phases of economic development.

Much of the research on macroeconomic growth theory has focused on the consistencies in the growth process and the way that government can influence growth through optimal policies. A topic that has fascinated economists in recent decades, however, has been the issue of trying to sustain economic growth in the face of resource constraints while maintaining an acceptable level of environmental quality.

What is the relationship between income and environmental quality? Meadows *et al* (1972) and Cleveland (1984) believe that higher levels of economic activity, associated with production and consumption, require larger inputs of energy and therefore generate larger amounts of pollutants. Nonetheless, Beckerman (1992) argues that in order to achieve a satisfactory level of environmental quality, it is required that we speed through the process of economic growth. It is these higher levels of income that induce agents to increase demand for environmentally friendly goods. These arguments imply a simplistic monotonically increasing or decreasing assosication between environmental quality and a country’s development path. This is rarely the case.

Figure 1: Fossil Fuel CO_2 Emissions

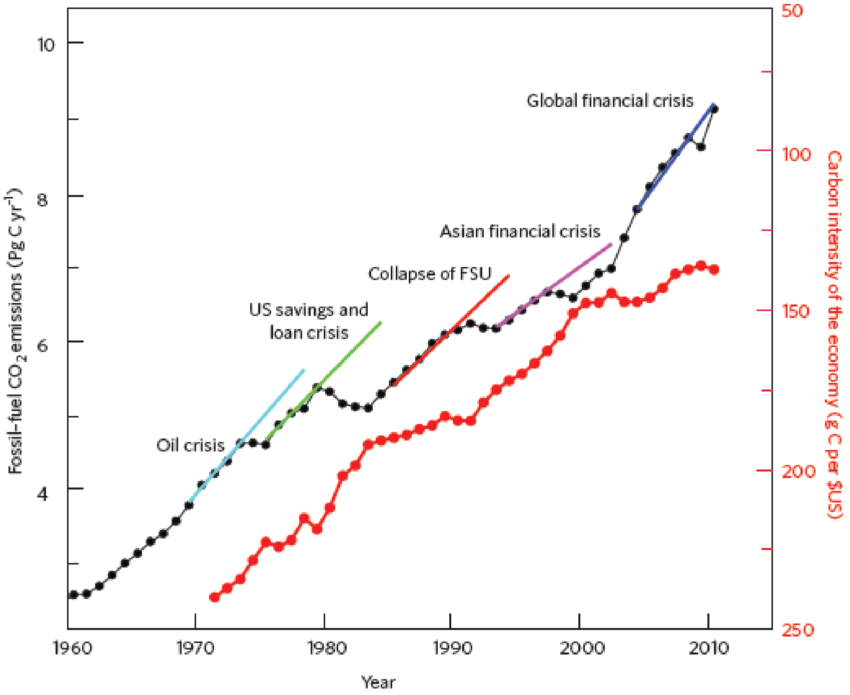
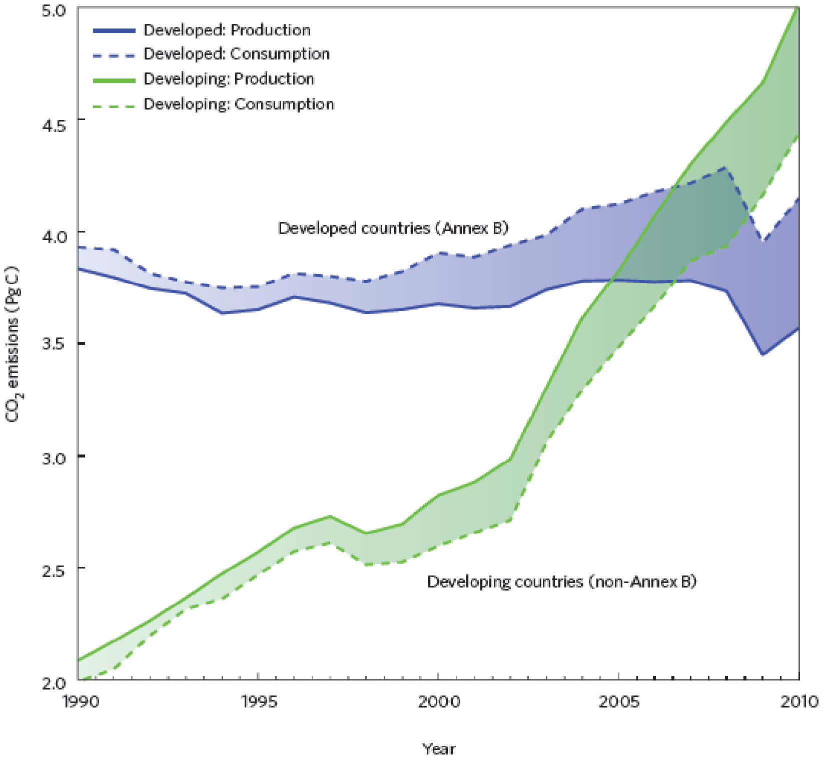


Figure 2: CO_2 Emissions Allocated by Production and Consumption



The shaded areas are trade balances between Annex B/non-Annex B production and consumption; Source: Global Carbon Project

Grossman and Krueger (1992) and Panayotou (1993) have suggested that such a relationship is much more complex and that environmental quality is not necessarily monotonic along a country's development path. An important relationship that has been proposed in the past and gained a substantial amount of attention in recent decades has been the Environmental Kuznets Curve (EKC). This was first proposed by Kuznets (1955) in relation to the income-inequality association. The idea behind the EKC is simple; at lower levels of development, environmental damage is constrained by an economy with a low intensity use of its resource base. As countries begin to industrialize and resource extraction intensifies, an economy begins to produce high levels of waste and pollution. Once a country reaches an advanced level of development, structural changes take place that move the economy towards service-based industries. This generates more efficient technologies and incentives for increased demand for environmentally friendly goods.

Empirical results in the past have tested the inverted U-shaped hypothesis using different proxy variables for environmental quality such as deforestation and suspended particle matter (SPM). These studies have used different econometric techniques and have found this pattern with regards to only certain pollutants. Due to lack of time-series data, most of the past studies have used cross-sectional models to test the EKC. However, there are major problems with obtaining estimates from cross-sectional models like endogeneity and country specific effects. To control for these problems economists have utilized panel data methods such as fixed effects, random effects and more advanced unit-root and cointegration techniques. Romero-Avila (2008) questions past studies that model emissions and income using panel data cointegration techniques and argues that the methods do not take into account multiple structural breaks and cross-sectional dependence. Thus, I do not take the unit-root and cointegration approach. I instead use traditional panel data models and focus on generating consistent and robust estimates that control for problems like cross-sectional dependence, heteroskedasticity and serial correlation.

The study that follows is an extension to the pollution-income literature. It is natural to ask which sectors have the most influence in generating the EKC shape on the global scale, if any. I contribute to this literature by estimating an EKC relationship using a more recent time frame, a new set of control variables and by disaggregating the total CO_2 emissions into its respective sources. By finding the different turning points of the disaggregated CO_2 emissions, I am able to determine the sectors that are first in reducing CO_2 emissions and the sectors that are last. I am also able to calculate the compositional effects that the different sectors have on the aggregate CO_2 emissions. Two natural questions as extensions to this essay are: (1) why some industries are able to reduce their emissions during the early process of economic development and whether it would be possible to replicate this to the industries that reduce emissions last and, (2) whether there are interaction effects between economic development and international trade.

The rest of the essay is organized as follows. Section 2 presents the related economic theory and the empirical research behind the EKC hypothesis. Section 3 describes the data source, variables and countries used. In this section, I also complete a comparison between two data sources considered and a thorough description of the relevant variables. Section 4 details the econometric theory, the different methods considered and the approach I took. Section 5 presents and discusses the empirical results for global CO_2 emissions for all countries and for high medium and low-income countries. Section 6 estimates and analyzes the disaggregated CO_2 emissions by sector. Section 7 concludes.

2 Research Context

2.1 Theoretical foundations

2.1.1 Monotonic justification for the pollution-income relationship

I explore the implications of environmental pollution, as per Siebert (1992), in a neoclassical Solow-Swan type environment where savings is determined exogenously. I assume that the neoclassical production function is, $Y = F[K(t), L(t)]$, where K and L are capital and labour respectively.[1] Time subscript will from now on be omitted to simplify notation. I further assume that the net increase in the stock of capital at a point in time equals gross investment less depreciation. Also, given that savings must equal investment, $S = I,$ it follows that the savings rate is equal to the investment rate and the growth of capital over time is equal to, $\dot{K} = I - \delta K = sF(K, L) - \delta K$. The dot over a variable represents differentiation with respect to time and $0 \leq s \leq 1$. The above equation determines the dynamics over time for a given level of capital and labour. I also make the assumption that $\dot{L}/L = n$ is the exogenous rate of population growth.

Because $\dot{K}/L = s[F(K, L)/L] - \delta(K/L) = sf(k) - \delta k$ and $\dot{k} = d\big(\dot{K}/L\big)/dt = \dot{K}/L - nk$, I am able to write the evolution of the stock of capital in per capita terms as:

$$\dot{k} = sf(k) - (\delta + n)k \tag{1}$$

The population growth rate of $L(0)$ has been normalized to 1 and δ is the depreciation rate. Further, assume that the production process generates emissions and that emissions per unit of output are constant at the level of φ. Pollution is accumulated according to the

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[1] See Barro and Sala-i-Martin (2004 p. 27*)* for the definition of constant returns to scale

expression of $\dot{P} = \varphi F(K, L) - mP$. This is equivalent, in form, to the capital accumulation equation where it is assumed that there is no disutility from pollution. I am able to write the above expression in per capita terms as:[2]

$$\dot{p} = \varphi f(k) - (m + n)p \tag{2}$$

It is clear that in this economy where pollution is viewed as creating no cost in terms of utility or production, total pollution will accumulate at the constant positive rate of n, or the exogenous population growth rate. This is the case because $\dot{P}/P = \dot{p}/p + n$ and $\dot{p} = 0$ in steady state.[3] The basic model of pollution accumulation in a Solow-Swan framework is therefore consistent with an exogenous increase in the levels of pollution.

2.1.2 Inverted U-shaped justification for the pollution-income relationship

Turning our attention to a more specific study of the EKC relationship I analyze a model developed by Andreoni and Levinson (2001) and Levinson (2002). The model is Robinson-Crusoe based where the source of pollution arises from consumption, *C*. I consider the single-agent problem from the model where a single agent receives utility from consumption of a private good *C* and from pollution *P*. I write linear additive preferences as, $U = C - P$ and define pollution as, $P = C - C^{\beta} A^{\omega}$ where A is the abatement effort and $C^{\beta} A^{\omega}$ is the pollution abatement. Normalizing the relative costs of *C* and *A* to 1 and supposing that a limited endowment of *Y* can be spent on *C* and *A* then the resource constraint is simply, $C + A = Y$. The optimization problem can be written as:

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[2] I am able to write it in per capita terms, following the same method as that in equation (1), that is, $\frac{\dot{P}}{L} = s\frac{F(K,L)}{L} - \frac{\varphi P}{L} = sf(k) - \varphi p$ where $\dot{p} = \frac{d(\dot{P}/L)}{dt} = \frac{\dot{P}}{L} - nk$.

[3] I define a steady state (SS) level such that the various quantities grow at a constant rate. In the Solow-Swan model this corresponds to $\dot{k}(t) = \dot{p}(t) = 0$ therefore $f(k^*) = (\delta + n)k^*$ and $p^* = \frac{\varphi f[k^*]}{(m+n)}$.

$$\max_{C,A} C - \left(C - C^{\beta} A^{\omega}\right) \; s.t. \; C + A = Y \tag{3}$$

The Lagrangian is equal to $\mathcal{L} = C^{\beta} A^{\omega} - \lambda(C + A - Y)$ which yields the first order conditions (FOCs):

$$\frac{\partial \mathcal{L}}{\partial C} = 0 \rightarrow \beta C^{\beta-1} A^{\omega} = \lambda; \quad \frac{\partial \mathcal{L}}{\partial A} = 0 \rightarrow \omega A^{\omega-1} C^{\beta} = \lambda; \quad C + A = Y \tag{4}$$

From (4), the optimal quantities of consumption and abatement can be obtained:

$$C^* = \left(\frac{\beta}{\beta+\omega}\right) Y \text{ and } A^* = \left(\frac{\omega}{\omega+\beta}\right) Y \tag{5}$$

Substituting (5) into the pollution equation yields the optimal quantity of pollution as a function of total income:

$$P(Y)^* = \left(\frac{\beta}{\beta+\omega}\right) Y - \left(\frac{\beta}{\beta+\omega}\right)^{\beta} \left(\frac{\omega}{\omega+\beta}\right)^{\omega} Y^{\beta+\omega} \tag{6}$$

It can be shown that, when $\beta + \omega = 1$, the pollution-income relationship is linear and upward sloping whereas when $\beta + \omega > 1$, the pollution-income relationship is an inverted U-shape. To see this, I take the first and second derivative of (6) which gives the slope and curvature of the pollution-income relationship:

$$\frac{\partial P^*}{\partial Y} = \left(\frac{\beta}{\beta+\omega}\right) - (\beta + \omega) \left(\frac{\beta}{\beta+\omega}\right)^{\beta} \left(\frac{\omega}{\omega+\beta}\right)^{\omega} Y^{\beta+\omega-1} \tag{7}$$

$$\frac{\partial^2 P^*}{\partial Y^2} = -(\beta + \omega - 1)(\beta + \omega) \left(\frac{\beta}{\beta+\omega}\right)^{\beta} \left(\frac{\omega}{\omega+\beta}\right)^{\omega} \tag{8}$$

The slope and curvature depend on the parameters of β and ω. Only when $\beta + \omega > 1$ does one get the EKC relationship. This implies that when the abatement exhibits increasing returns to scale, one obtains the inverted U-shaped relationship associated with a concave *P(Y)**. Conversely, if it is assumed that $\beta + \omega < 1$ so that the abatement exhibits diminishing returns to scale then one gets a U-shaped relationship associated with a convex *P(Y)**.

2.1.3 General shaped justification for the pollution-income relationship

The theoretical foundations of an EKC relationship are primarily based on static or dynamic optimization problems with pollution considerations as per Van Der Ploeg and Withagan (1991), Gradus and Smulders (1993) and Beltratti (1996). For example, assume a Ramsey-Cass-Koopmans type model with pollution where the flow of emissions is described by the function, $E = g(k, a)$. In this model, k denotes capital and a denotes abatement at time t. As per Barro and Sala-i-Martin (2004), consumption-investment decisions are derived from decentralized inter-temporal utility maximizing households and perfectly competitive profit maximizing firms. Assuming no population growth, $\dot{L}/L = 0$, no technological growth, $\dot{A}/A = 0$, a separable utility function and a neoclassical production function, one can write the social planner (*i.e.* centralized) problem as:

$$max_{\{c(t)\}} \int_0^\infty e^{-pt}[U(c) - P(E)]dt, P'(E) > 0, P''(E) \geq 0 \; s.t. \; \dot{k} = f(k) - c - a - \delta k \quad (9)$$

where $U(c)$ is the utility function that depends on consumption, $P(E)$ is the pollution function which has a positive slope, is increasing and depends on the emissions function. I am able to write the current value Hamiltonian and calculate the FOCs as:

$$\mathcal{H} = U(c) - D[g(k,a,)] + \gamma[f(k) - c - a - \delta k] \tag{10}$$

$$U_c(c) = \gamma \tag{11}$$

$$P'_{g_k}(k,a) = \gamma \tag{12}$$

Conditions (11) and (12) can be solved to yield the short-run optimal level of abatement as a function of c and k, that is, $a = \tilde{a}(c,k)$. By log differentiating (11) and making the right substitutions, one can obtain the dynamic system of the economy as:

$$\frac{\dot{c}}{c} = (1/\theta)\left\{f'(k) - \left[{P'_{g_k}\left(k,\tilde{a}(c,k)\right)}\Big/{U_c(c)}\right] - \rho - \delta\right\} \; ; \; \dot{k} = f(k) - c - \tilde{a}(c,k) - \delta k \tag{13}$$

Assume that a steady-state value (c^*,k^*), with saddle point properties exists where one saddle arm converges to equilibrium, that is, $c = \check{c}(k)$. Given the steady state value, I can define the pollution-income relationship as:

$$\{(P,y): P = g\{k,\tilde{a}[\check{c}(k),k]\}, y = f(k)\} \tag{14}$$

Equation (13) describes the pollution-income relationship in a socially optimal path, which might not be the case with most countries. However, it can be shown that the shape of the pollution-income hypothesis can take on many different shapes and depends on a multitude of factors including an agent's preference function, regulation on whether or not an economy is in an optimal path and the abatement technology. All these factors affect the pollution-income relationship found in equation (14). This is to show that a variety of shapes can be obtained from the pollution-income relationship which may be a possible reason why one observes mixed results when testing for an EKC.

2.2 Empirical Research

2.2.1 Motivation for empirical research

The Environmental Kuznets relationship is one of the main hypotheses on the subject of environmental quality and income. Stern (2004) says that, initially, expansion of scale starts to increase emissions that are eventually dominated by changes in the output mix given that the economy shifts to industries which pollute less. Copeland and Taylor (2004) further suggest that as per capita income increases there is political pressure for environmental protection which further decreases emissions. The relationship, according to Grubb and Feldman (2006), depends on the policies adopted in each of the different countries and their specific economies. Panayotou (1993) has a more elaborate explanation behind the EKC hypothesis:

> At low levels of development both the quantity and intensity of environmental degradation is limited to the impacts of substance economic activity on the resource base and to limited quantities of biodegradable wastes. As economic development accelerates with the intensification of agriculture and other resource extraction and the take-off of industrialization, the rates of resource depletion begin to exceed the rates of resource regeneration, and waste generation increases in quantity and toxicity. At higher levels of development, structural change towards informative-intensive industries and services, coupled with increased environmental awareness, enforcement of environmental regulations, better technology and higher environmental expenditures, result in levelling off and gradual decline in environmental degradation.

Figure 3: The EKC Hypothesis

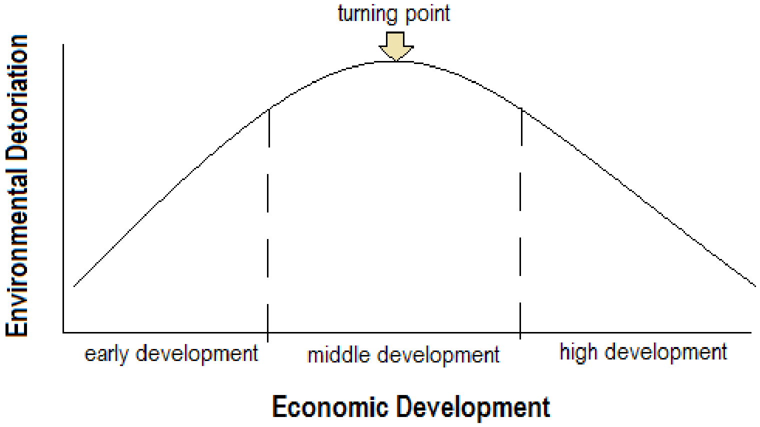


Figure 3 illustrates the EKC hypothesis as described by Panayotou (1993). The EKC hypothesis suggests that, to reduce emissions and environmental problems, there must be an increase in the economic well-being of countries. The World Bank concluded the same in its *World Development Report* (1992) but was careful in its deduction and did not claim that the solution to all environmental problems is economic growth alone. The report stressed that other policies focused on environmental protection need to also be considered alongside economic development policies.

2.2.2 Past research relating to the EKC

Turning our attention to specific papers and their study of pollution and income, a paper that has been influential in this regard is Grossman and Krueger (1992). The authors estimated EKCs for different pollutants, including SO_2 and SPM, in order to assess the impact of the recently established free trade agreement (NAFTA) on the environment in Mexico. They ran regressions on the cubic function of real 1985 per capita GDP while controlling for site-related variables, a time trend and trade intensity. Site-related variables include population density of the city and location (*ie.* desert, coastal, land). Trade intensity was included to test for the hypothesis that a country's pollution level depends on its openness to international trade. The results found statistical significance for SO_2 but not for SPM. The authors also concluded the income level turning point to be around US $4,000 to US $5,000.

Seldon and Song (1994) estimated EKCs for the airborne emissions of SO_2, NO_x, SPM and CO using panel data method. They estimated a quadratic function of real GDP per capita while also controlling for population density. The reason they control for population density is that countries with low population densities may have less stringent environmental standards due to longer transportation. The authors find statistical significant relationships for all models, with the exception of the CO model. The turning points in the income levels were higher than in previous studies. They were US $8,709 for SO_2, US $11,217 for NO_x, US $10,289 for SPM and US $5,963 for CO. The authors conclude that the reason their income turning points are higher than in previous studies is that ambient pollution levels generally decline before aggregate emissions. This implies that ambient concentrations of pollution can decline but this does not mean that total emissions are declining.

Moomaw and Uhruh (1997) analyze the relationship between CO_2 emissions and the level of income. They select 16 OECD countries and estimate both a quadratic and cubic specification for the income level. The authors find statistically significant coefficients supporting an N-shaped relationship between economic growth and CO_2 emissions for all 16 countries. The N-shaped relationship indicates that pollution increases during early development, decreases once it hits the first turning point during middle development and again increases after a second trough point during high development. Egli and Steger (2007) offer an explanation for this through a dynamic model. They attribute the first turning point to regulations aimed at reducing pollution and the second turning point to the fact that further growth gives rise to further pollution. Friedl and Getzner (2003) support the Mommaw and Uhruh (1997) study and find that, when analyzing the case for Austria through time-series methods, an N-shape functional form is the best representative model. In this study the authors control for short term fluctuations in GDP which can be hypothesized to have a positive coefficient, given that a GDP above the long-term trend would lead to short term fluctuations in CO_2 emissions. In order to test for structural changes to the Austrian economy the authors also include two more variables, namely, value added by the tertiary industry and the level of openness of the Austrian economy.

Huang *et al* (2008) studied the relationship between GHGs and economic development. They focused on GHGs because of the Kyoto Protocol which is an environmental treaty that was set up in 1997 to combat global warming. One of the main discussions regarding the Kyoto Protocol has been centered on whether restricting the amount of emissions, especially CO_2 emissions, hinders the economic growth of countries. The Huang *et al* (2008) study focuses on single-country time series analyses of the Annex II countries and finds no evidence of an EKC hypothesis.

Many of the studies examined above assume that there is no feedback effect from the state of the environment and the economy. However, Perrings (1987) concludes that the economy and the environment are jointly determined. Assuming uni-directional causality from economy to environment creates simultaneity problems. Estimating such relationships through the use of ordinary least squares (OLS) when simultaneity is present creates biased and inconsistent estimates. But, when looking at a global pollutant such as CO_2 emissions, it is unlikely to expect such simultaneity problems. It would be very improbable to find that a single country's CO_2 emissions would affect economic growth due to the rather small amount of emissions that many countries have relative to total emissions. Given the uncertain empirical status of the EKC hypothesis, economists and policymakers should be careful in attempting to derive far reaching policy conclusions. This view has also been shared by Arrow *et al* (1995) which note that the EKC hypothesis has only been shown to apply to a few pollutants and not necessarily to general environmental quality, as suggested by some economists.

More recent studies include that of Aslanidis and Iranzo (2009) which studies the relationship between CO_2 and income for non-OECD countries between 1971 to 1997 using non-linear least squares. The authors find no evidence of an EKC relationship; however they do find evidence of a deceleration of emissions as developing countries grow. Jaunky (2011) and Arouri *et al* (2012) use panel unit-root and cointegration methods for roughly the same time period of 1980 to 2005 but with different subsets of countries. Jaunky (2011) studies the relationship in 36 high-income countries, whereas Arouri *et al* (2012) studies the relationship for Middle East and North African countries. Both studies find evidence of an EKC for the whole data sets.

Lee *et al* (2009) examine the pollution-income relationship for 89 countries between 1960 and 2000 but using dynamic panel methods as per Arellano and Bond (1991). The study finds evidence of an EKC for the global data set, middle-income countries and European countries while controlling for population density, trade openness and energy use. Another closely related study is that of Poumanyvong *et al* (2012) which examines the effect of urbanization on residential emissions in 88 countries between 1975 and 2005. The authors have the log of residential emissions as the dependent variable and the logs of GDP, urbanization and population as the control variables. The results give evidence of an inverted U-shaped relationship between residential emissions and GDP per capita for high-income countries only. Table 1 highlights selected panel data studies involving GDP and CO_2 emissions and the mixed empirical results of these studies.

When compared to previous literature, my essay is most closely related to that of Lee *et al* (2009) and Poumanyvong *et al* (2012). In contrast to past literature, I include 64 countries and update the time span to include from 1981 to 2008. I also control for variables such as trade share, urban population and disaggregate energy use into its components of alternative and nuclear energy and fossil fuel energy. Past literature has almost exclusively used aggregated CO_2 emissions in order to test the EKC relationship. I deviate from this path by disaggregating CO_2 emissions by sector in order to check for an EKC among the different sectors and analyze which of the specific sectors generates the EKC on an aggregate scale. Through the disaggregation of CO_2 emissions, I am able to determine the compositional effects that different sectors have. This is interesting because it would suggest that different countries with the same GDP do not necessarily lie on the same EKC due to the different composition of an economy's sectors.

Table 1: Selected Panel Data Studies of the CO_2-GDP nexus

Authors	Countries /Provinces	Time Span	Method	Control variables	Disaggregation	Result
Shafik (1994)	149	1960-1990	FE	No	No	No
Holtz and Selden (1995)	108	1951-1986	FE	No	No	EKC
Galeotti and Lanza (2000)	108	1971-1995	FE	No	No	EKC
Bengochea *et al* (2001)	10 EU only	1981-1995	FE RE, FD, TSLS	No	No	Mixed
Azamahou *et al* (2006)	100	1960-1996	Non-parametric	No	No	No
Richmond and Kaufmann (2006)	36 OECD & Non-OECD	1973-1997	OLS, FE, RE	Fuel shares	No	Mixed
Aslanidis and Iranzo (2009)	Non-OECD	1971-1997	NLS	No	No	No
Lee, Chiu and Sun (2009)	89	1960-2000	FE, RE, DPM	Trade, PD, EC	No	EKC
Jaunky (2011)	36 High-Income only	1980-2005	VECM	No	No	EKC
Wang *et al* (2011)	28 Chinese provinces	1995-2007	VECM	EC	No	EKC
Poumanyvong *et al* (2012)	88	1975-2005	OLS, FE, RE	Urban	Residential	Mixed
Arouri *et al* (2012)	12 Middle East & North Africa	1981-2005	Cointegration	No	No	Mixed

FE stands for fixed effects; RE for random effects; FD for first difference; TSLS for two stage least squares; NLS for non-linear least squares; DPM for dynamic panel methods; VECM for a vector error correction model; PD for population density; EC for energy consumption.

2.2.3 Functional forms for the CO_2–GDP nexus

There have been three main functional forms for CO_2 and income that have been previously studied; linear, quadratic and cubic. Looking at the cubic general functional form for the level of CO_2 emissions, with only income as the explanatory variable, there are in total 6 possible relationships as illustrated in figure 4:

$$CO_{2it} = \beta_{i0} + \beta_1 GDP_{it} + \beta_2 GDP_{it}^2 + \beta_3 GDP_{it}^3 + \varepsilon_{it} \qquad (15)$$

where; 1. $\beta_1 > 0$ and $\beta_2 = \beta_3 = 0$, in the linear upward sloping case (*Figure 4a and 4b*)

2. $\beta_1 < 0$ and $\beta_2 = \beta_3 = 0$, in the linear downward sloping case (*Figure 4a and 4b*)

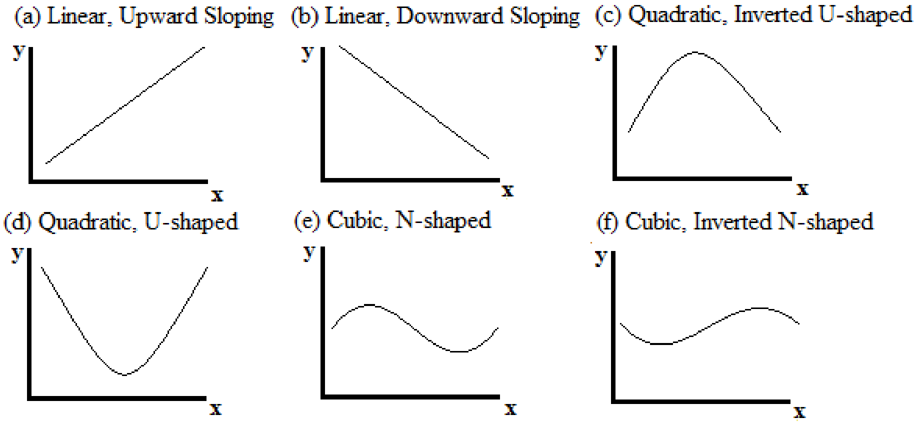
3. $\beta_1 > 0, \beta_2 < 0$ and $\beta_3 = 0,$ in the quadratic inverted U-shaped case, (*Figure 4c*)

4. $\beta_1 < 0, \beta_2 > 0$ and $\beta_3 = 0,$ in the quadratic U-shaped case, (*Figure 4d*)

5. $\beta_1 > 0, \beta_2 < 0$ and $\beta_3 > 0,$ in the N-shaped case, (*Figure 4e*)

6. $\beta_1 < 0, \beta_2 > 0$ and $\beta_3 < 0,$ in the inverted N-shaped case, (*Figure 4f*)

Figure 4: Possible Shapes for the CO_2-GDP Relationship



The x-axis corresponds to CO_2 emissions whereas the y-axis corresponds to GDP

It can be seen that the EKC would correspond to figure 4c. But, it should be noted that, for the EKC hypothesis to hold, it is required that $|\beta_2| < |\beta_1|$. Also, as Ekins (1997) points out, the N-shaped relationship only holds if $|\beta_3| < |\beta_2| < |\beta_1|$. The general functional form above is on the levels of the variables but past studies, including that of Holtz-Eakin and Selden (1995), have also analyzed the natural logarithmic form of (1):

$$\log(CO_{2it}) = \alpha_{i0} + \varphi_1 \log(GDP_{it}) + \varphi_2 log(GDP_{it})^2 + \varphi_3 log(GDP_{it})^3 + \varepsilon_{it} \quad (16)$$

As for past studies that have confirmed the above functional forms; Shafik (1994) confirmed the linear case through a panel data analysis whereas De Bruyn *et al* (1998) confirmed it for four single countries, namely Netherlands, UK, USA and Western Germany; the inverted U-shaped case has been confirmed through panel data analysis of worldwide data by Heil and Selden (2001) and Galeotti and Lanza (1999).

Most of the previous studies are conducted on large panel data sets for many different countries and do not reveal the pollution-income relationship for an individual country. The evidence for the pollution-income relationship using panel and cross country data sets is diverse whereas studies on single countries are quite rare. This is largely due to a lack of long time series data for CO_2 emissions. A few past studies have considered alternative specifications to the usual polynomial relationship discussed above. A reason for this is that economists want to try and explain the relationship more thoroughly econometrically so that it outperforms the polynomial specification on statistical grounds. Another reason is that the polynomial functional form restrains the range of possible shapes that the pollution-income relationship can take.

Three non-linear functional forms that have been considered in the past have included the three parameter Gamma, Weibull and Lognormal functions. These have been used because their asymptotic behaviour depends substantially on the values of the parameters and has fewer constraints on the a priori range of possible shapes which can characterize the pollution-income relationship. Galeotti and Lanza (1999) find evidence that the relationship between CO_2 emissions and income is described by a non-linear Gamma and Weibull function than the usual linear and log-linear cases. However, as Bai *et al* (1992) confirm, selecting an appropriate distribution for a specific pollutant such as CO_2 depends on the specific time period and on the specific sites. This can be inaccurate when studying the pollution-income relationship on a global scale.

Due to the difficulties and inaccuracies associated with selecting the appropriate distribution for CO_2 emissions and the fact that I have a global data set, I have decided to opt for the traditional way of modeling the relationship between CO_2 emissions and income. That is, I consider the quadratic and cubic functional forms as opposed to the alternative specifications which are more appropriate for individual countries.

3 Data – Source and Countries

3.1 The set of data

My study involves a panel data analysis between per capita GDP and per capita CO_2 emissions while controlling for relevant explanatory variables. The data obtained for the dependent and independent variables are in panel form and, given the fact that there is a scarcity of data, I have limited the study to include time periods and countries so that the data is fully balanced. I narrowed the period to include the years from 1981 to 2008 or 28 yearly time periods. The essay looks at 64 countries which include 21 high-income countries, 21 middle-income countries and 22 lower-income countries. The data has been acquired from the *World Development Indicator* (WDI) database (WDI - CD 2011).

From the WDI database, I retrieved specific indicators relating to climate change, the environment and economy. The data of interest in our study that were obtained from the World Bank and OECD National Accounts Data files inside the WDI includes; Gross Domestic Product (GDP) measured in constant 2000 US dollars; trade as a percentage of GDP; industry value added and service value added, both measured in constant 2000 US dollars. The data which I obtained from the United Nations Population Division inside the WDI database includes; population and population in urban areas. The data obtained from the International Energy Agency (IEA) database includes; alternative and nuclear energy and fossil fuel energy, both calculated as percentages of total energy use.

I retrieved CO_2 emissions data from two sources. First, total CO_2 emissions measured in kilotons were obtained from the Carbon Dioxide Information Analysis Center at the Oak Ridge National Laboratory. Second, I obtained total CO_2 emissions measured in million metric tons from the IEA statistics database divided into the following categories; (a) residential buildings commercial and public services, (b) electricity and heat production, (c) manufacturing industries and construction and (d) transportation.

I divided total GDP by population in order to obtain the per capita GDP and converted it into thousands of dollars. I transformed industry value added and service value added into shares of total GDP in order to obtain industry share and service share. I also divided urban population by total population to obtain the urban share. Lastly, I converted total CO_2 emissions data from both sources into metric tons (MT) for easier interpretation and also divided CO_2 emissions by population to obtain the per capita emission values. Table 2 lists the countries and table 3 explains the variables included in the essay.

Table 2: Countries Classified by Income Level

High-Income Countries	Middle-Income Countries	Lower-Income Countries
Australia	Algeria	Bolivia
Austria	Argentina	Congo
Canada	Botswana	Cote d`Ivoire
Denmark	Brazil	Egypt
Finland	Chile	El Salvador
France	China	Guatemala
Hungary	Colombia	Honduras
Iceland	Costa Rica	India
Italy	Cuba	Indonesia
Japan	Dominican Republic	Morocco
South Korea	Ecuador	Pakistan
Luxembourg	Iran	Paraguay
Netherlands	Malaysia	Philippines
New Zealand	Mexico	Sri Lanka
Norway	Panama	Sudan
Portugal	Peru	Zambia
Spain	South Africa	Cameroon
Sweden	Thailand	Bangladesh
Switzerland	Tunisia	Ethiopia
United Kingdom	Turkey	Kenya
United States	Venezuela	Nepal
		Zimbabwe

The countries have been sorted by income level as per the World Bank (2011) income classification

Table 3: Description of Dependent and Control Variables

Variables	Description
Dependent (metric tons)	
Total CO_2 per capita	Total CO_2 emissions are calculated as the addition of CO_2 emissions from buildings, commercial, public, electricity, heat, manufacturing, construction, transportation and other emissions
CO_2 per capita (Buildings, Commercial, Public)	CO_2 emissions from residential buildings and commercial and public services contain all emissions from fuel combustion in households
CO_2 per capita (Electricity, Heat)	CO_2 emissions from electricity and heat production is the sum of CO_2 emissions from main activity producer electricity generation, combined heat, power generation, heat plants, generation of electricity and heat by auto-producers, petroleum refineries, the manufacturing of solid fuels, coal mining, oil and gas extraction and other energy-producing industries
CO_2 per capita (Manufacturing, Construction)	CO_2 emissions from manufacturing industries and construction contain the emissions from combustion of fuels in industry
CO_2 per capita (Transportation)	CO_2 emissions from transport contains emissions from the combustion of fuel for all transport activity which includes domestic aviation, domestic navigation, road, rail and pipeline transport
Control	
GDP per capita	GDP is measured per 1000 constant 2000 US$
Trade share	Trade is the sum of exports and imports of goods and services measured as a share of GDP
Alternative and nuclear energy (AE) share	Alternative energy is measured as a share of total energy use and includes hydropower and nuclear, geothermal, and solar power and other clean energy sources
Fossil energy (FE) share	Fossil energy is measured as a share of total energy use and includes coal, oil, petroleum, and natural gas products
Urban share	Urban share is measured as the urban population as a percentage of total population
Industry share	Industry share is the industry value added measured in constant 2000 US$ and includes mining, manufacturing, construction, electricity, water, and gas
Service share	Service share is the service value added measured in constant 2000 US$ and includes wholesale and retail trade, transport, government, financial, professional, and personal services such as education, health care, and real estate services

3.2 Comparison between Oak Ridge Laboratory and International Energy Agency

Previous studies on this relationship have almost exclusively used the CO_2 emissions data from the Carbon Dioxide Information Analysis Center at the Oak Ridge National Laboratory. On the other hand, I have obtained total and disaggregated CO_2 data from the IEA statistics database. For thoroughness, I have compared the data from both sources to check for any substantial inconsistencies that would suggest inaccuracy of the IEA data. Table 4 reports the correlation coefficients and the basic summary statistics. Figure 5 showcases the scatter plots of the two different data sets.

The correlation coefficient is nearly one in both per capita and total terms. The means for the per capita values are very close, at around 4 MT of CO_2 emissions. The corresponding standard deviation and variance are identical at around 5 MT and 25 MT, respectively. Likewise, the shape of the distribution of CO_2 emissions is similar given that both the skewness and kurtosis are almost the same.

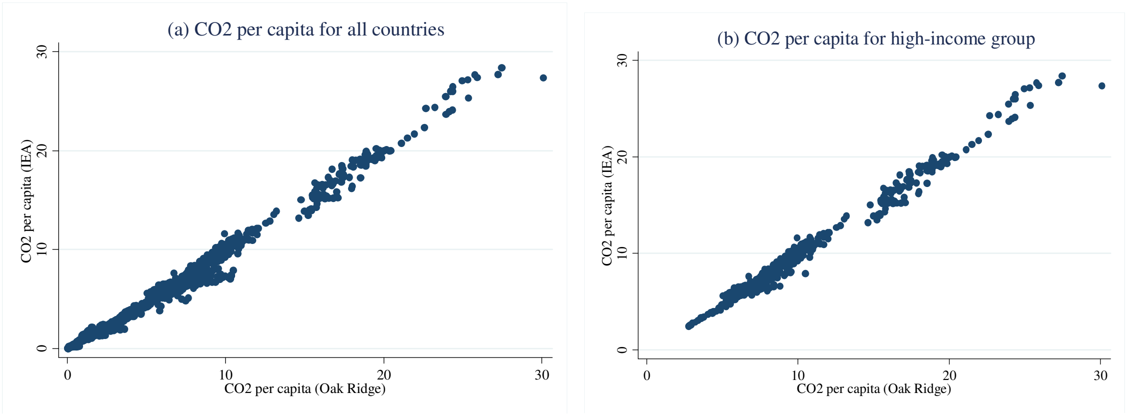
Table 4: Comparison of Oak Ridge and IEA Data

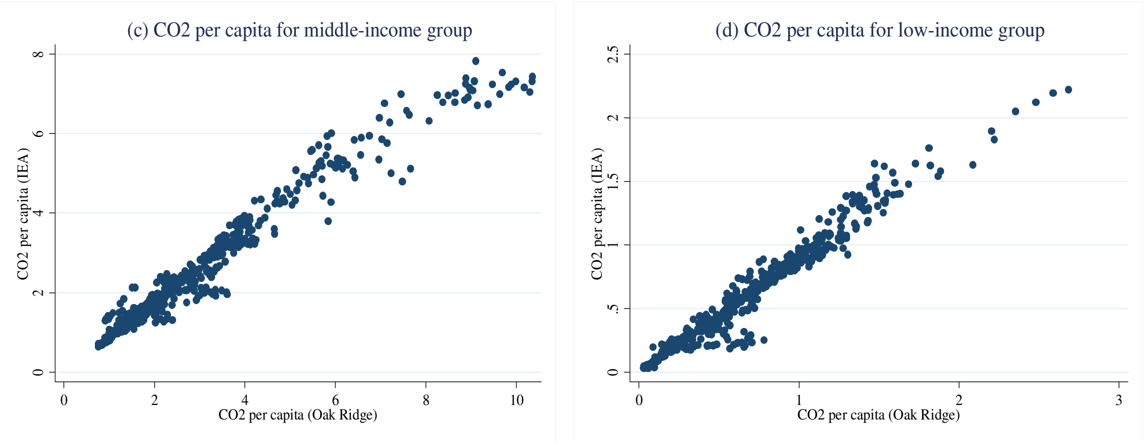
Summary Statistics	Mean	Variance	Skewness	Kurtosis	Min	Max	Correlation
CO_2 per capita (Oak Ridge)	4.46	24.68	1.75	6.33	0.03	30.10	0.99
CO_2 per capita (IEA)	4.23	24.68	1.91	7.08	0.03	28.37	

This view is further strengthened when looking at the scatter plots from figure 5 for the CO_2 emissions from the IEA database versus those from the Oak Ridge Laboratory database. The scatter plots are nearly linear and along the identity line for all cases. This implies that the two data sets have very similar CO_2 emissions values.

When previously comparing the two data sets, I noticed some deviation that came from 10 data points. I isolated these data points that came from one country, namely, Gabon and, in order to keep the data consistent with both sources, I removed Gabon from the study. Thus, I only kept data that is relatively consistent with both sources. For thoroughness, I ran the regressions for total CO_2 emissions per capita from both sources and found the economic and statistical significance to be practically identical. This gives me confidence in using the data for total and disaggregated CO_2 emissions from the IEA source.

Figure 5: Scatterplots of CO_2 Emissions from Oak Ridge versus IEA Source





3.3 The relevant measure for CO_2 emissions

The dependent variable in considering the pollution-income relationship is total per capita CO_2 emissions and per capita CO_2 emissions disaggregated into sectors. In terms of cross-sectional data, the most commonly used indicator has been CO_2 emissions per capita (Liski and Toppinen 2001). When it comes to panel and time-series data, different indinenafili1cators have been used, including, emissions per capita, emissions per gross domestic product or pollution intensity, and ambient levels of pollution.

I will use the total CO_2 emissions per capita and the disaggregated CO_2 emissions per capita indicators. I use CO_2 emissions per capita as opposed to CO_2 emissions per unit of GDP because, as Tisdell (2001) has shown, total CO_2 emissions can increase even if CO_2 emissions per unit of GDP decrease. This is attributed to the fact that economic growth can outweigh CO_2 emissions growth. I also do not use ambient levels of pollution because, while concentrated levels are appropriate for localized pollutants such as sulphur dioxide, they are not appropriate for global pollutant like carbon dioxide.

3.4 Other explanatory variables included

Other than the main explanatory variable of GDP, I will also include control variables that could potentially explain the variation in CO_2 emissions. I include a trade openness variable to test the pollution-haven hypothesis. The pollution-haven hypothesis is the idea that polluting industries, or countries, will relocate their operations to jurisdictions with non-stringent environmental regulations. The concept behind this is simple; stringent environmental regulations raise the cost of pollution-intensive production and to avoid these costs, industries and countries move their production to pollution havens. I want to test whether greater openness to trade will lead to lower environmental standards so as to preserve international competitiveness. I suspect a negative coefficient for high-income countries and a positive coefficient for middle and low-income countries. This would give indirect evidence that, with increasing trade openness, high-income countries export their pollution to middle and low-income countries.

In order to account for structural changes in the different countries considered, I include the variables of industry value added and service value added as a share of GDP. Value added by both the industry and service sector have increased substantially in many of the 64 countries and I want to be able to account for this structural change in economies over the sample years. I hypothesize a negative coefficient on the service share variable and a positive coefficient on the industry share variable given. The reason for this is because a larger share of services should reduce pollution-intensive industries and CO_2 emissions.

Many studies in the pollution-income sphere assume that the relationship is homogenous of degree one and that population do not matter once the per capita component has been captured. This does not have to be the case and population density, or urbanization, might affect the pollution-income relationship. One would hypothesize that the higher the levels of urbanization and population densities, the higher the CO_2 emissions. However, Selden and Song (1994) hypothesize that countries with low population densities have less pressure in adopting stringent environmental standards which increases emissions. Another hypothesis is that higher growth of population densities and urbanization could be potentially harmful for natural resources. Nguyen (1999) found that countries with low incomes are likely to have negative environmental effects due to higher population densities as opposed to countries with higher incomes. Given this uncertainty, I would like to test for the effect that urbanization has on per capita CO_2 emissions.

3.5 Descriptive statistics and graphs

Looking at the summary statistics from Table 5, one sees that CO_2 emissions are at 4.23 MT per person with some countries having emissions as low as 0.0282 MT per person as in the case of Ethiopia and some having them as high as 28.4 MT per person as in the case of Luxembourg. This is no surprise given Luxembourg's low population and its heavy usage of road vehicles. As of 2008, Luxembourg's emissions had been reduced to 21.3 MT per person where 13.2 MT came solely from transportation sources. Almost exclusively, Luxembourg has the highest CO_2 emissions in each of the disaggregated emissions, with the exception of electricity and heat whereby Australia has the highest per capita CO_2 emissions. This is largely due to the vast reliance that Australia has on coal for electricity and heat.

Turning attention to some of the other variables, I notice that the per capita GDP is at around US $8,421 with a maximum of US $56,389 from Luxembourg in 2007 and a minimum of US $82.7 per capita from the Congo Democratic Republic in 2001. The mean trade share throughout the years is at around 62% which can be attributed to the vast expansion of globalization in the past decades. As expected, fossil energy is the most prevalent form of energy use with an average of 63% as compared to 11% from alternative and nuclear energy. Looking at urbanization one notices that, on average, 57% of the population in the sample through the years live in urban areas. Some countries have as low as 6.4% like Nepal during 1982 and some have as high as 93.3% like Venezuela during 2008. Also notice that the service sector generates more value than industry, having a mean of 52.6% of GDP across the sample years. As countries continue on their development path, they generate less value through agriculture and industry and start to increase the value added through the service sector.

Table 5: Summary Statistics for CO_2 and Control Variables

Variables	Mean	Standard Deviation	Min	Max
CO_2 per capita (metric tons)				
Total CO_2 per capita	4.229	4.966	0.028	28.372
CO_2 (Buildings, Commercial, Public)	0.547	0.772	0.001	3.979
CO_2 (Electricity, Heat)	1.446	1.990	0.000	12.077
CO_2 (Manufacturing, Construction)	0.937	1.428	0.002	16.247
CO_2 (Transportation)	1.153	1.543	0.006	14.855
Control variables				
GDP per capita	8.421	10.965	0.083	56.389
Trade share (% of GDP)	62.958	37.641	10.831	319.554
Alternative and nuclear energy share (% of total energy use)	11.040	16.436	0.006	100.000
Fossil energy share (% of total energy use)	63.166	26.948	2.707	100.000
Urban share (% of total population)	57.242	21.500	6.360	93.320
Industry share (% of GDP)	28.025	8.407	9.173	60.302
Service share (% of GDP)	52.642	9.559	21.575	76.268

In figure 6, I have disaggregated total CO_2 emissions by time and income level. Looking at all countries in figure 6a, notice that CO_2 emissions in 2008 from transportation, manufacturing and construction contribute marginally less to total CO_2 emissions when compared to 1985. CO_2 emissions from buildings commercial and public sources have also decreased by 5% from 1985 to 2008. The big difference over the years lies in the increase in CO_2 emissions from electricity and heat sources which, as of 2008, take up almost 50% of total CO_2 emissions.

Looking at only high-income countries in figure 6b, one does not notice much variation in the share of the disaggregated emission sources. There is an increase of 8% and a decrease of 6% in CO_2 emissions from (a) electricity and heat sources and from (b) manufacturing and construction, respectively. This can be attributed to the fact that developed economies have shifted their focus to less pollution-intensive service industries and rely less on manufacturing industries. In figures 6c and 6d one notices an increase of 19% for middle-income countries and 17% for low-income countries from 1985 to 2008 in CO_2 emissions from electricity and heat sources. This implies that CO_2 emissions from electricity and heat sources are going to be an important element in explaining the compositional effects.

Figure 6: Structure of CO_2 Emissions by Income Group

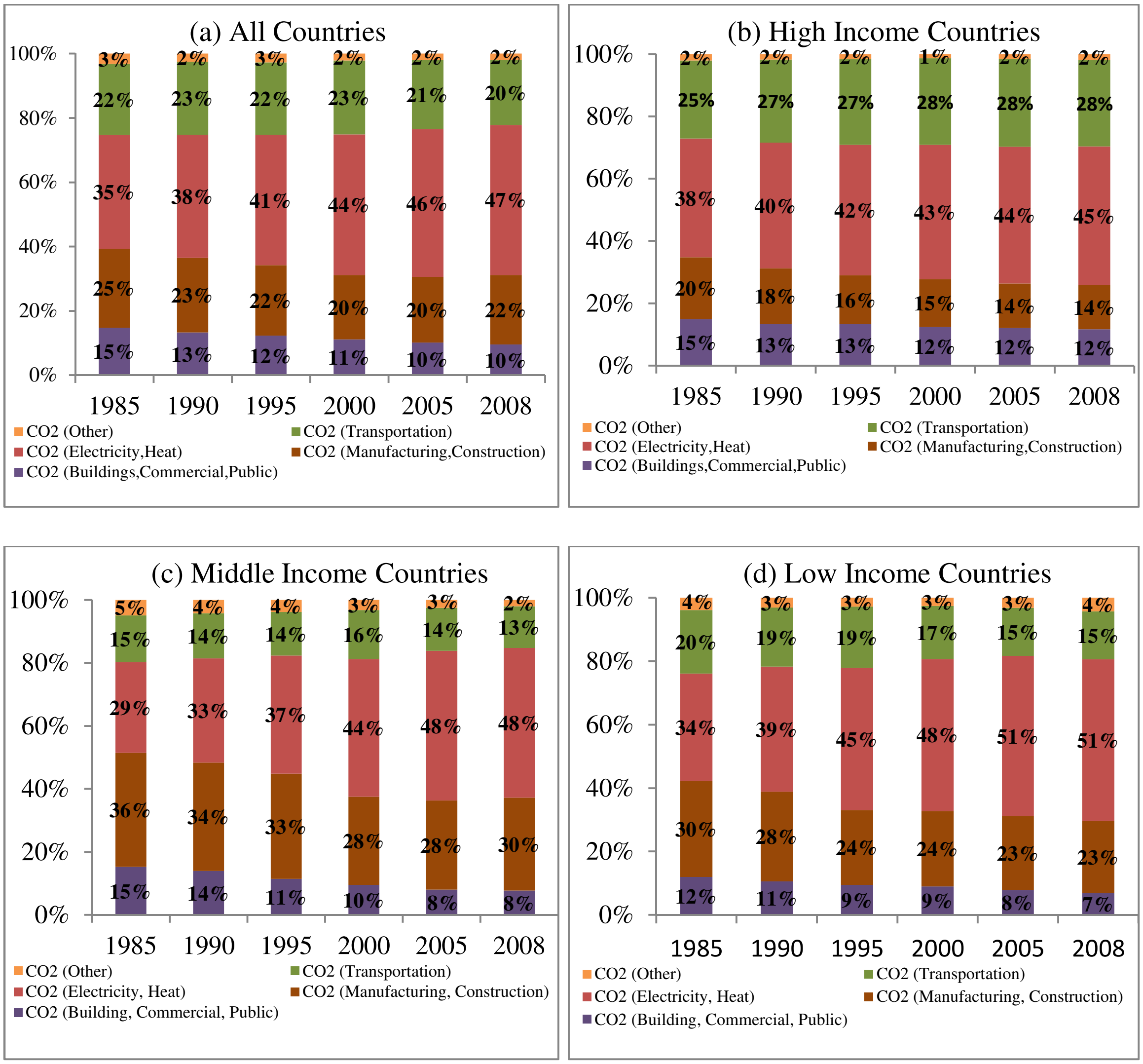
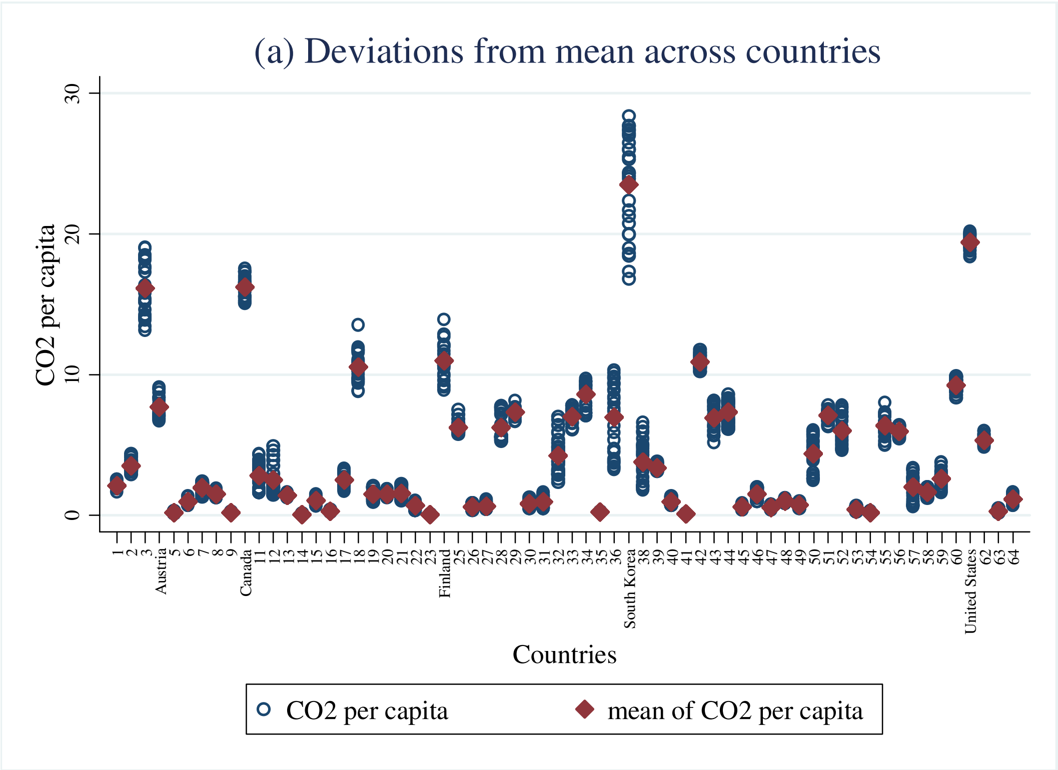


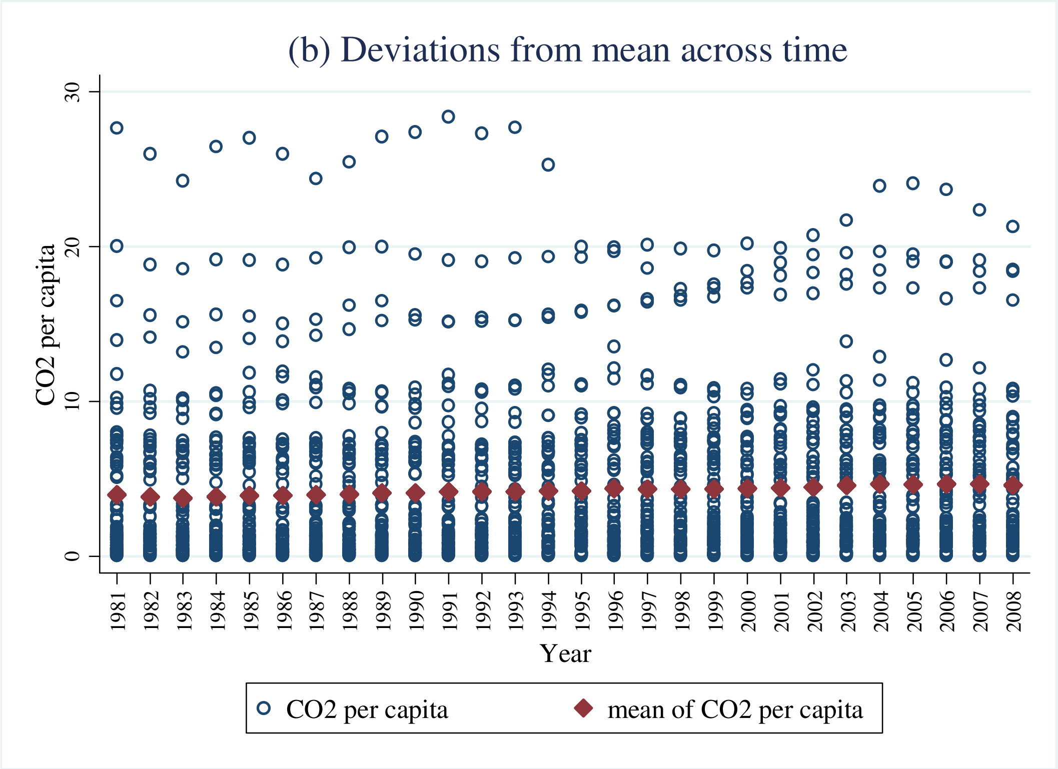
Figure 7 lays out the heterogeneity across countries and time. Figure 7a shows that there is a vast amount of diversity among countries in their levels of per capita CO_2 emissions. For example, when looking at South Korea or country 37 in the data set, one notices a large amount of variation in per capita CO_2 emissions across time with a low of 3 MT per person in 1982 to a high of 10 MT per person in 2008. This is due to the fast economic development that South Korea and other East Asian countries experienced during the 1980's and 1990's. Compare this to Austria or the United States, which does not have as large a variation in CO_2 emission levels mainly because they have been developed countries for longer. Looking at the heterogeneity across time in figure 7b**,** one again notices variation, as in the country heterogeneity, although less so. While there is heterogeneity across time, one sees much more consistency across time than countries. This finding suggests that the cross-sectional dimension will be particularly important in identifying the EKC.

Figure 8 graphs scatterplots of CO_2 emissions and GDP as a way of looking for a possible EKC. Looking at the total CO_2 emissions for all countries in figure 8a, notice the inverted U-shaped relationship of the EKC and a possible N-shaped relationship although not as significant. For the disaggregated CO_2 emissions, one can see a significant inverted U-shaped relationship for (a) manufacturing and construction and (b) electricity and heat. There is also a possible N-shaped or a monotonically increasing relationship for emissions originating from the transportation sector. As for CO_2 emissions from buildings commercial and public sources, one can observe a somewhat weak inverted U-shaped or possibly N-shaped relationship.

Figure 7: Heterogeneity of CO_2 Emissions across Countries and Time

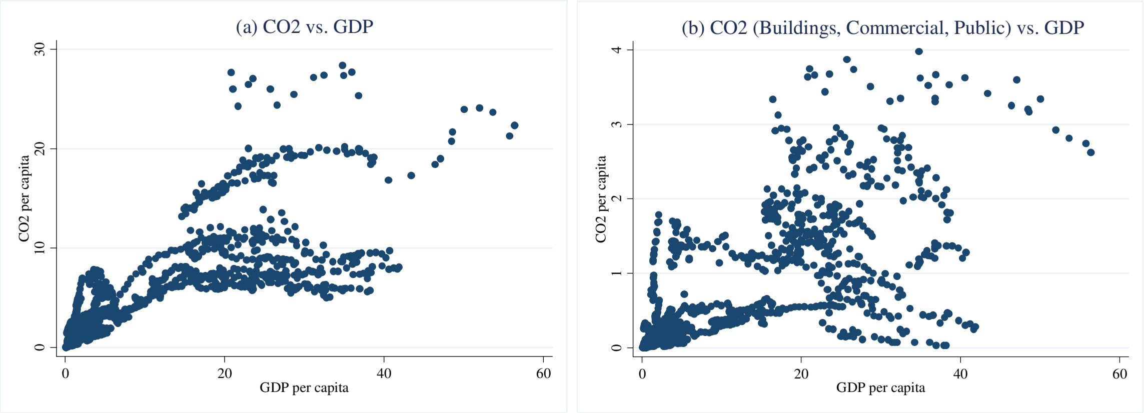


(a) Deviations from mean across countries

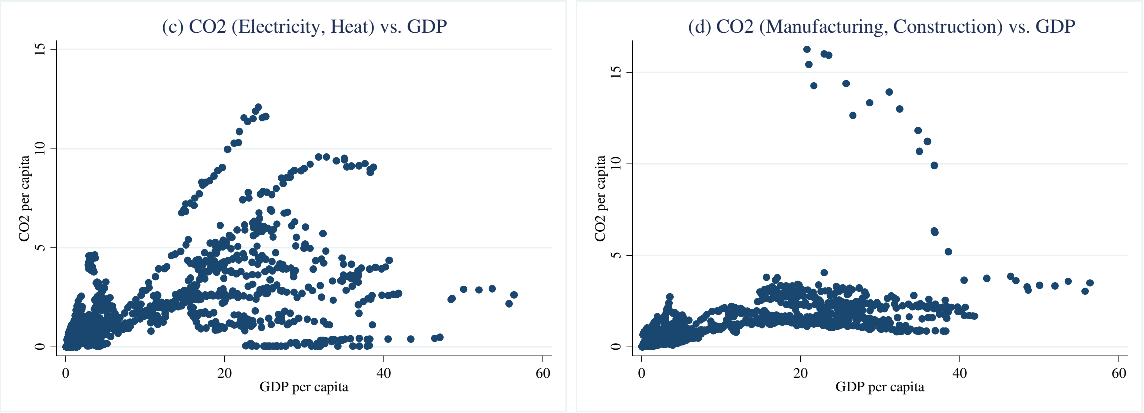


(b) Deviations from mean across time

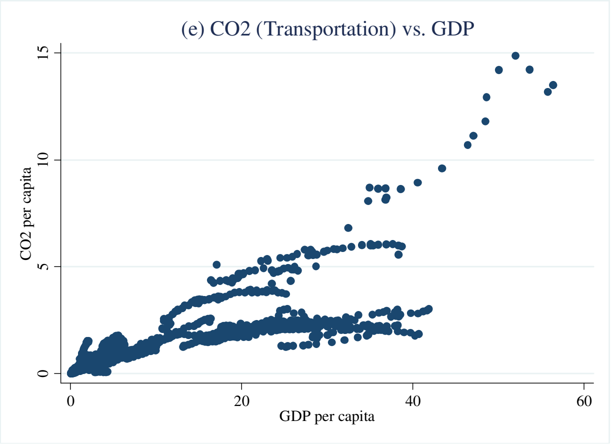
Figure 8: Scatterplots for GDP, Total and Disaggregated CO_2 Emissions


(a) CO2 vs. GDP

(b) CO2 (Buildings, Commercial, Public) vs. GDP


(c) CO2 (Electricity, Heat) vs. GDP

(d) CO2 (Manufacturing, Construction) vs. GDP


(e) CO2 (Transportation) vs. GDP

4 Econometric Model and Method

4.1 Econometric Model and Theory

I observe the variables of CO_2 per capita and GDP per capita over the 1981 to 2008 time period. That is, our data looks like:

$$\begin{pmatrix} (y_{11}, x_{11}, z_{11}) & \dots & (y_{1T}, x_{1T}, z_{1T}) \\ \vdots & \ddots & \vdots \\ (y_{N1}, x_{N1}, z_{N1}) & \dots & (y_{NT}, x_{NT}, z_{NT}) \end{pmatrix}$$

where y is per capita CO_2, x is the per capita GDP variables and z contains other control variables. I use panel data as opposed to cross-sectional because, with panel data, I can control for unobserved effects that can be correlated with the regressors that are time-invariant and individual-specific. With respect to time-series, I am able to control for unobserved effects that are correlated with regressors that are common for all individuals.

The model in matrix form is:

$$y_{it} = g_{it}{}'\gamma + e_{it} = x_{it}{}'\beta + z_{it}'\varphi + \delta_i + u_{it} \quad i = 1,2,\dots,N,\ t = 1,2,\dots,T \quad (17)$$

where g_{it} includes x_{it}, the vector of GDP regressors which may also include time dummies in order to capture the effect of aggregate shocks and z_{it}, the vector of other explanatory variables. The error structure of e_{it} includes $\delta_i$and u_{it} which are independent and unobservable with zero mean where $\delta_i \sim iid(0, \sigma_\delta^2)$. The vector x_{it} is the set of economic development explanatory variables which in this case will include GDP per capita, GDP per capita squared, GDP per capita cubed and possibly time dummies. The vector z_{it} includes other explanatory regressors such as trade share, alternative and nuclear energy share, fossil fuel energy share, urban share, industry share and service share.

Under the strict exogeneity assumption, it must be the that $E[u_{it}|\boldsymbol{x}_{i1}, \ldots, \boldsymbol{x}_{iT}] = 0$ and $E[u_{it}|\boldsymbol{z}_{i1}, \ldots, \boldsymbol{z}_{iT}] = 0$. However, an important issue in panel data models is the endogeneity issue that arises from the correlation between the regressors and the unobserved heterogeneity, that is, $E[x_{it}\delta_i] \neq 0$ and $E[z_{it}\delta_i] \neq 0$. There are generally two traditional approaches in dealing with the endogeneity problem; the fixed effects and the random effects approach. The fixed effects approach does not make assumptions about the joint distribution of x_{it}, z_{it} and δ_i whereas the random effects approach does.

I first considered the estimating methods of pooled ordinary least squares (POLS), fixed effects and random effects. Between POLS, fixed effects and random effects it was decided, through a Breusch-Pagan LM and Hausman test, that the fixed effects approach was preferred. I explain more of the fixed effects approach below.

4.1.1 Least squares dummy variable approach

In a least squares dummy variables approach I treat the individual effects $\{\delta_1, \delta_2, \ldots \delta_N\}$ as parameters to be estimated. The model in matrix form is:

$$y = G\gamma + D\delta + u = [G \quad D]\begin{bmatrix}\gamma \\ \delta\end{bmatrix} + u \tag{18}$$

where D is a matrix of dummy variables. Through the Frisch-Waugh-Lovell theorem, the OLS estimator of γ can be written as $(G'MG)^{-1}G'My$ where $MG = G^*$or $g^*_{it} = g_{it} - \overline{g_\iota}$ and $My = y^*$or $y^*_{it} = y_{it} - \overline{y_\iota}$. The matrix M is idempotent, that is, $M * M = [I_{NT} - D(D'D)^{-1}D'] * [I_{NT} - D(D'D)^{-1}D'] = I_{NT} - D(D'D)^{-1}D' - D(D'D)^{-1}D' +$

$D(D'D)^{-1}D'D(D'D)^{-1}D' = I_{NT} - D(D'D)^{-1}D'$, and $M' = [I_{NT} - D(D'D)^{-1}D']' = [I_{NT} - D(D'D)^{-1}D']$. Given the above, I can write the estimator of $\hat{\gamma}$ and prove its consistency as:

$$\hat{\gamma} = (G^{*\prime}G^{*})^{-1}G^{*\prime}y^{*} \tag{19}$$

$$E[(g_{it} - \bar{g}_{i})(u_{it} - \bar{u}_{i})] = \underbrace{E[(g_{it}u_{it})]}_{0} - \underbrace{E[(\bar{g}_{i}u_{it})]}_{0} - \underbrace{E[(g_{it}\bar{u}_{i})]}_{0} + \underbrace{E[(\bar{g}_{i}\bar{u}_{i})]}_{0} = 0 \tag{20}$$

The estimator in equation (19) is equivalent to the OLS estimator of the transformed model of $y_{it} - \bar{y}_{i} = (g_{it} - \bar{g}_{i})'\gamma + \varepsilon^{*}$. Thus, the fixed effects model does not make an assumption about the joint distribution of g_{it} and δ_i and hence it is a non-parametric approach to estimating the model. By transforming the model I eliminate the individual country and time fixed effects.

4.2 Econometric Method

I first decide between whether I should use the fixed effects or the random effects approach. To do this I make use of the Hausman test whereby the null hypothesis is that of random effects and the alternative hypothesis is that there are fixed effects. As per Greene (2000), this basically tests whether the transitory shock of u_{it} is correlated with the regressors with the null being that they are not. Before doing this, I first check for evidence of heteroskedasticity. In the fixed effects model, I use the Wald statistic for groupwise heteroskedasticity as per Greene (2000, p. 598). In the random effects model, I use Levene's (1960) robust test statistic for the equality of variances between the countries. If I find strong evidence of groupwise heteroskedasticity, I proceed to use the robust Hausman test to choose between fixed effects or random effects which uses the approach from Arellano (1993) and more specifically Wooldridge (2002, p. 290). The robust Hausman test estimates the random effects model and re-estimates the same model but further including the transformed deviations from mean form of the original regressors. I then test these extra regressors through a Wald test. The null and alternative hypotheses are the same as in the original Hausman test and under conditional homoscedasticity the two tests give identical results.

Given that a common assumption in panel data models is that the error terms are independent across the cross-sections, I test for cross-sectional dependence by implementing the semi-parametric tests proposed by Friedman (1937) and Frees (2004) and the parametric test proposed by Pesaran (2004). I further test for serial correlation in the idiosyncratic errors using the testing method as per Wooldridge (2002) which Drukker (2003) concludes has good size and power properties.

If heteroskedasticity, cross-sectional dependence and serial correlation are present, I estimate the model using the Driscoll and Kraay (1998) standard errors. If heteroskedasticity and serial correlation are present, I use a cluster–robust VCE with the panel variable as the clustering variable (Froot 1989; Frees 1995; Williams 2000*)*. If only heteroskedasticity is present, I use White's (1980) robust standard errors. In all cases, I have tried to keep the standard errors robust given the above disturbances.

Lastly, I test whether time fixed effects should be included using an *F*-test on the joint significance of the time parameters. If time fixed effects are significant, I estimate the regression with the time dummies included. For the sake of brevity, I do not include the estimated dummies in the regression output.

Table 6 shows the decision matrix for the choice of robust standard errors.

Table 6: Decision Matrix for the Choice of Robust Standard Errors

Run random effects model

Test for groupwise heteroskedasticity using Levene's (1960) robust test statistic for the equality of variance.	If evidence of heteroskedasticity, use White's robust standard errors as per White (1980).	Test for time fixed effects using an F-test to check for significance of time fixed effects. Include if significant.	Test for a fixed effects versus a random effects model using the robust Hausman test from Arellano (1993) and Wooldridge (2002, p.290).	If results were in favor of a fixed effects model, then check again for heteroskedasticity using the modified Wald statistic for groupwise heteroskedasticity following Greene (2000, p.598).	If the fixed effects model shows evidence of groupwise heteroskedasticity, serial correlation and cross-sectional dependence, then run fixed effects model and control for these disturbances using the Driscoll and Kray (1998) standard errors which are robust to such disturbances.
Test for serial correlation using Wooldridge (2002).	If evidence of serial correlation and heteroskedasticity, use cluster-robust VCE with the panel identification variable (*country*) as the clustering variable as per Froot (1989), Frees (1995) and Williams (2000).	If time fixed effects are not significant, do not include them.	Test for a random effects versus a pooled OLS model using the Breusch-Pagan LM test for random effects.	If results were in favor of a fixed effects model then also check for cross-sectional dependence using Friedman (1937), Frees (1995,2004) and Pesaran (2004).	

5 Empirical Results for Total CO_2 Emissions

The test results support a fixed effects model. The data also show strong evidence of an error structure that is groupwise heteroskedastic, autocorrelated and cross-sectionally dependent. I use of the Driscoll and Kraay (1998) robust standard errors to control for such disturbances. Also, as discussed above, I test for time fixed effects and include them in the regression given a statistically significant *F*-test.[4]

5.1 CO_2 per capita for all countries

Table 7 shows the results for total CO_2 emissions per capita. In all cases, the estimated coefficients of real per capita GDP are economically and statistically significant at the 1% level. As expected, the signs on the coefficients of income (*i.e.* GDP, GDP-SQ*)* are positive and then negative. This suggests that per capita CO_2 emissions increase in the early stages of economic development and decrease as economic development continues. The within R^2 is around 40%. I also tested for a cubic specification but I found the second trough point to be outside the in-sample values for GDP. This implies stronger evidence that the data supports an inverted U-shaped EKC relationship as opposed to the N-shaped or a monotonically increasing relationship.

The turning points of real income per capita can be found, through simple quadratic maximization, to be at around US \$31,000. This turning point falls within our sample of GDP per capita which is between US \$82.67 and US \$56,389. When looking at the quadratic coefficients in table 7, a US \$1,000 increase in GDP per capita evaluated at the

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[4] For the sake of brevity, I have not shown the tests for heteroskedasticity, autocorrelation, cross-sectional dependence and time fixed effects.

mean of GDP of US $8,400, is equal to about a 0.4 MT increase in the per capita CO_2 emissions across the regressions. This is economically significant.

The trade share variable is not statistically significant. The alternative and nuclear energy share and fossil energy share are economically and statistically significant at the 1% level. One can see that increasing the share of alternative energy reduces per capita CO_2 emissions. This makes sense given that alternative energy sources do not emit as much CO_2 emissions. Also, as expected, increasing the share of fossil-provided energy increases CO_2 emissions. It is interesting to note that increasing the share of alternative energy by 10% decreases per capita CO_2 emissions by around 0.1 MT whereas an equivalent increase in fossil energy increases emissions by around 0.3 MT.

One also notices a significant but economically comparable relationship between the service and industry shares and CO_2 emissions. As predicted earlier, increasing the service sector as a share of GDP reduces pollution-intensive industries and ultimately CO_2 emissions. Similarly, growing the share of industrial value added as a share of GDP increases pollution-intensive industries and CO_2 emissions. Lastly, there is a positive and significant relationship between urbanization and CO_2 emissions. It can be argued that as urbanization increases, energy demand does as well which in turn generates further CO_2 emissions.

Table 7: CO$_2$ per capita: Results for All Countries

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
GDP	0.536***	0.540***	0.598***	0.596***	0.599***	0.588***
	(0.0907)	(0.0879)	(0.0846)	(0.0831)	(0.0851)	(0.0861)
GDP - SQ	-0.00887***	-0.00895***	-0.00941***	-0.00927***	-0.00924***	-0.00905***
	(0.00171)	(0.00163)	(0.00159)	(0.00158)	(0.00161)	(0.00163)
Trade share		0.00158	-4.77e-05	0.000300	-0.000443	-0.00146
		(0.00251)	(0.00284)	(0.00290)	(0.00271)	(0.00248)
AE share			-0.00822***	-0.0105***	-0.0104***	-0.00962***
			(0.00192)	(0.00250)	(0.00269)	(0.00259)
FE share			0.0374***	0.0329***	0.0348***	0.0321***
			(0.00294)	(0.00374)	(0.00345)	(0.00418)
Urban share				0.0288***	0.0294***	0.0289***
				(0.00543)	(0.00526)	(0.00536)
Service share					-0.0257***	-0.0228***
					(0.00428)	(0.00396)
Industry share						0.0173**
						(0.00657)
Constant	1.449***	1.343***	-1.154***	-2.349***	-1.156***	-1.498***
	(0.412)	(0.385)	(0.284)	(0.246)	(0.329)	(0.330)
Peak	30.21	30.17	31.77	32.15	32.41	32.49
F-test	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
R-squared	0.3417	0.3423	0.3905	0.3992	0.4073	0.4097
Observations	1,792	1,792	1,792	1,792	1,792	1,792
Groups	64	64	64	64	64	64

Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

5.2 CO$_2$ per capita for high, middle and low income countries

When looking at the specific subset of high-income countries in table 8, one notices statistically and economically significant income coefficients for the cubic specification. The R^2 is around 60% which tells us that income and the other control variables explain around 60% of the variation in per capita CO$_2$ emissions. This implies that there is a strong inverted N-shaped relationship present for developed countries. The peak turning point is around US \$25,000 and the trough turning point is around US \$42,000 for the different specifications. I also find possible evidence of a pollution-haven hypothesis. The negative coefficient on the trade share indicates that there is a reduction of emissions as high-income countries open up to international trade, ceteris paribus.

Table 8: CO_2 per capita: Results for High-Income Countries

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
GDP	1.103***	1.222***	1.132***	1.081***	0.941***	0.860***
	(0.221)	(0.119)	(0.160)	(0.197)	(0.0546)	(0.0910)
GDP - SQ	-0.0295***	-0.0388***	-0.0348***	-0.0332***	-0.0299***	-0.0289***
	(0.00700)	(0.00611)	(0.00563)	(0.00688)	(0.00386)	(0.00375)
GDP - CB	0.000235***	0.000388***	0.000327***	0.000311***	0.000291***	0.000290***
	(7.70e-05)	(8.26e-05)	(6.70e-05)	(7.85e-05)	(6.17e-05)	(6.08e-05)
Trade share		-0.0489***	-0.0393***	-0.0377***	-0.0446***	-0.0474***
		(0.0135)	(0.0101)	(0.0114)	(0.00726)	(0.00811)
AE share			0.0499	0.0530	0.0875***	0.0893***
			(0.0748)	(0.0739)	(0.0251)	(0.0244)
FE share			0.188**	0.192**	0.229***	0.237***
			(0.0845)	(0.0822)	(0.0344)	(0.0336)
Urban share				0.0250	-0.00774	0.00376
				(0.0559)	(0.0213)	(0.0211)
Service share					-0.179***	-0.0897
					(0.0261)	(0.0575)
Industry share						0.110
						(0.0677)
Constant	-0.830	2.299	-13.63*	-15.48**	-4.325	-12.87**
	(2.586)	(1.828)	(7.487)	(7.187)	(3.153)	(4.962)
Peak/Trough	28.19/55.4	25.5/41.16	25.3/45.7	25.2/45.9	24.5/44.0	22.5/43.9
F-test	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
R-squared	0.375	0.497	0.592	0.593	0.631	0.635
Observations	588	588	588	588	588	588
Groups	21	21	21	21	21	21

Standard errors in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

The results for the middle-income countries in table 9 show that the quadratic specification is preferred to that of the cubic specification. The coefficients on the income variables for the quadratic specification are positive and then negative. This implies an inverted U-shaped relationship with a turning point of around US $10,000 at the 1% significance level. This is interesting and good news because, when compared to the high-income countries, middle-income countries may have not yet reached the second trough point where emissions start to increase again.

The trade openness variable is significant and positive which now confirms the pollution-haven hypothesis inferred earlier. As middle-income economies become more and more open with regards to trade, CO_2 emissions start to increase. This is most likely due to developed countries relocating their operations, in order to avoid the cost of pollution, to middle-income countries where environmental regulations are not as strict. This reduces emissions from high-income countries and increases those from middle-income countries. Again there is a significant and negative coefficient on alternative energy and a significant and positive coefficient on industry share at the 5% significance level.

Table 9: CO_2 per capita: Results for Middle-Income Countries

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
GDP	1.277***	1.058***	0.994***	0.779***	0.834***	0.792***
	(0.296)	(0.0447)	(0.160)	(0.172)	(0.0635)	(0.192)
GDP - SQ	-0.0723**	-0.0599***	-0.0553***	-0.0387**	-0.0435***	-0.0358**
	(0.0259)	(0.00528)	(0.0180)	(0.0152)	(0.00540)	(0.0140)
Trade share		0.0120***	0.0125***	0.0138***	0.0118***	0.00890***
		(0.00256)	(0.00232)	(0.00266)	(0.00238)	(0.00251)
AE share			-0.0504***	-0.0525***	-0.0588***	-0.0576***
			(0.0177)	(0.0171)	(0.00847)	(0.0173)
FE share			0.00225	0.00499	0.00393	-0.000458
			(0.0118)	(0.0104)	(0.00521)	(0.0105)
Urban share				0.0312	0.0449***	0.0391**
				(0.0184)	(0.00891)	(0.0184)
Service share					-0.0395***	-0.0240
					(0.00729)	(0.0167)
Industry share						0.0367**
						(0.0132)
Constant	-0.517	-0.764***	-0.647	-2.171**	-0.795	-1.917
	(0.624)	(0.156)	(0.780)	(1.018)	(0.574)	(1.151)
Peak	8.83	8.83	8.99	10.06	9.59	11.06
F-test	0.000	0.000	0.000	0.000	0.000	0.000
R-squared	0.626	0.703	0.740	0.754	0.779	0.793
Observations	588	588	588	588	588	588
Groups	21	21	21	21	21	21

Standard errors in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Lastly, notice that in the quadratic specification for low-income countries in table 10, the only significant coefficient which explains most of the variation in per capita CO_2 emissions is GDP. That is, only the level of per capita GDP is statistically and economically significant. The low-income countries are still in the early path of economic development and have not yet reached turning points on a CO_2 EKC. Also, while the trade share coefficient is positive, it is not statistically significant. This suggests that the pollution-haven hypothesis runs from high-income countries to middle-income countries and not low-income countries.

Table 10: CO_2 per capita: Results for Low-Income Countries

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
GDP	1.401***	1.412***	0.955**	1.033***	1.056***	1.158***
	(0.337)	(0.351)	(0.370)	(0.352)	(0.351)	(0.355)
GDP - SQ	-0.183*	-0.188*	-0.0888	-0.107	-0.114	-0.143
	(0.0889)	(0.0903)	(0.103)	(0.102)	(0.103)	(0.0977)
Trade share		0.00214**	0.000400	0.000304	0.000399	0.000527
		(0.000965)	(0.00105)	(0.00103)	(0.000983)	(0.000948)
AE share			0.00131*	0.000958	0.000916	0.000682
			(0.000635)	(0.000707)	(0.000720)	(0.000610)
FE share			0.0102**	0.00907*	0.00897*	0.00933*
			(0.00434)	(0.00474)	(0.00462)	(0.00456)
Urban share				0.00610	0.00569	0.00524
				(0.00693)	(0.00726)	(0.00755)
Service share					-0.00149	-0.00309
					(0.00461)	(0.00417)
Industry share						-0.00454
						(0.00446)
Constant	-0.451**	-0.560**	-0.581***	-0.758***	-0.692*	-0.566
	(0.190)	(0.200)	(0.182)	(0.263)	(0.334)	(0.377)
Peak	--	--	--	--	--	--
F-test	0.000	0.000	0.000	0.000	0.000	0.000
R-squared	0.714	0.730	0.779	0.787	0.788	0.790
Observations	616	616	616	616	616	616
Groups	22	22	22	22	22	22

Standard errors in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

5.3 Remarks

The aggregate CO_2 emissions do not tell the complete story and while on an aggregate scale I find that the inverted U-shaped relationship fits the global data set best, it is a different story when countries are classified based on income. I find that high-income countries display an N-shaped relationship; middle income countries display an inverted U-shaped relationship and low-income countries display an upward and monotonic relationship. High-income and middle-income countries are the ones which are contributing to the curvature in CO_2–GDP relationship with both set of countries having turning points. Low-income countries contribute to the monotonic increase in emissions. These three different relationships generate the inverted U-shape seen in the worldwide data.

I also find that, for high-income countries, it is not a strictly good story as the results show that there is a rise in CO_2 emissions after GDP per capita hits US $42,000. It is also not good news for low-income countries given that they have not yet reached a turning point and thus CO_2 emissions are still rising. There is, however, positive news from middle-income countries as there is evidence of a peak turning point and no evidence of a second trough point.

By categorizing our data into different income groups, I also find strong evidence of a pollution-haven hypothesis. There is a negative and statistically significant relationship for the trade share variable for high-income countries whereas this coefficient is positive and significant for middle-income countries and insignificant for low-income countries. This suggests that as countries become more open to international trade, there is an export of pollution from high-income countries to middle and possibly low-income countries.

6 Empirical Results for Disaggregated CO_2 Emissions

As previously discussed, a key contribution of this essay involves disaggregating the level of CO_2 emissions into sectors. I try and analyze which sectors of an economy contribute to the aggregate EKC. I am also able to determine the sectors that have already had turning points and the ones that still need developing before they reduce their emissions. Through disaggregation, I am able to determine this compositional effect that the sectors have. This implies that countries with similar economic development might not necessarily have the same CO_2 emissions due to the different composition of an economy's sectors.

Statistical tests again suggest that a fixed effects model is preferred. Similarly, I conduct tests for heteroskedasticity, autocorrelation, cross-sectional dependence and time fixed effects and try to control for such disturbances through the use of robust standard errors.

6.1 Residential buildings commercial and public services

Looking at CO_2 emissions from residential buildings, commercial and public services in table 11, the cubic specification is preferred. The signs on the GDP coefficients are positive, negative and then positive. This suggests that an N-shaped relationship is present. The R^2 is around 30% for the different specifications and impies that our explanatory variables explain 30% of the variation in CO_2 emissions from residential buildings commercial and public sources. The first peak turning point is at US $9,000 and the second trough point is at US $50,000. Both turning points fall within our in-sample data. The peak point is quite low suggesting that reducing CO_2 emissions from buildings commercial and public services comes quite early in the process of economic development. Although the coefficients are statistically significant, a US $1,000 increase in per capita GDP evaluated at the mean of GDP is only associated with roughly a 0.0025 MT increase in emissions per capita. This is only slightly economically significant and is consistent with the fact that CO_2 emissions from residential buildings commercial and public services have been declining as a share of total CO_2 emissions over the sample period.

Alternative energy and fossil energy have coefficients which are negative and positive, with both being statistically significant. It is also interesting to note that urban share is positive and significant throughout the various specifications. That is, as the urban population increases, the demand for energy in residential buildings commercial and public services also increases. Eventually it is expected that CO_2 emissions increase as well.

Table 11: Results for CO_2 (Residential Buildings, Commercial, Public Services)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
GDP	0.0387***	0.0430***	0.0418***	0.0303***	0.0302***	0.0327***
	(0.00975)	(0.00896)	(0.00904)	(0.00726)	(0.00733)	(0.00762)
GDP - SQ	-0.00250***	-0.00271***	-0.00248***	-0.00198***	-0.00198***	-0.00202***
	(0.000467)	(0.000447)	(0.000440)	(0.000360)	(0.000360)	(0.000373)
GDP - CB	2.75e-05***	3.05e-05***	2.71e-05***	2.16e-05***	2.16e-05***	2.15e-05***
	(7.20e-06)	(6.91e-06)	(6.67e-06)	(5.50e-06)	(5.52e-06)	(5.68e-06)
Trade share		-0.000866**	-0.000994***	-0.000803***	-0.000781***	-0.000540**
		(0.000313)	(0.000275)	(0.000276)	(0.000257)	(0.000249)
AE share			-0.000294	-0.000912***	-0.000914***	-0.00110***
			(0.000226)	(0.000232)	(0.000235)	(0.000298)
FE share			0.00361***	0.00262***	0.00257***	0.00320***
			(0.000378)	(0.000351)	(0.000348)	(0.000404)
Urban share				0.00755***	0.00753***	0.00765***
				(0.00128)	(0.00128)	(0.00127)
Service share					0.000761	6.68e-05
					(0.00104)	(0.000867)
Industry share						-0.00408***
						(0.00133)
Constant	0.568***	0.606***	0.381***	0.0837	0.0484	0.129*
	(0.0345)	(0.0478)	(0.0511)	(0.0797)	(0.0566)	(0.0730)
Peak/Trough	9.1/51.4	9.4/49.7	10.1/50.9	9.0/52.1	8.9/52.1	9.6/53.1
F-test	0.000	0.000	0.000	0.000	0.000	0.000
R-squared	0.278	0.284	0.297	0.315	0.315	0.319
Observations	1,792	1,792	1,792	1,792	1,792	1,792
Groups	64	64	64	64	64	64

Standard errors in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

I also estimate the quadratic and cubic relationships on a by income basis in table 12 to check for evidence of a pollution-haven hypothesis. I estimate Table 12 by including all of the control variables but only show the trade share variable as that is the coefficient of interest. The coefficients on trade share for the high-income and low-income group are not statistically significant whereas for the middle-income group they are positive and significant. This suggests that there is no evidence of a pollution-haven hypothesis for CO_2 emissions originating from residential buildings commercial and public services.

Table 12: Results by Income for CO_2 (Residential Buildings, Commercial, Public Services)

VARIABLES	High-Income		Middle-Income		Low-Income	
GDP	0.0180	0.0506**	0.0296	0.0912*	0.0127	0.0484*
	(0.0209)	(0.0222)	(0.0258)	(0.0520)	(0.0124)	(0.0247)
GDP - SQ	-0.000588***	-0.00186***	-0.00433**	-0.0179**	0.00996***	-0.0194
	(0.000202)	(0.000459)	(0.00198)	(0.00846)	(0.00314)	(0.0141)
GDP - CB		1.52e-05**		0.000875*		0.00701**
		(5.78e-06)		(0.000444)		(0.00275)
Trade share	0.000791	-0.000277	0.000484**	0.000487**	-1.19e-05	5.55e-06
	(0.000806)	(0.000826)	(0.000199)	(0.000210)	(7.55e-05)	(7.96e-05)
Constant	-4.531**	-4.088**	0.346***	0.371***	-0.0320	-0.0336
	(1.965)	(1.837)	(0.0808)	(0.0862)	(0.0245)	(0.0246)
F-test	0.000	0.000	0.000	0.000	0.000	0.000
R-squared	0.504	0.509	0.267	0.270	0.499	0.503
Observations	588	588	588	588	616	616
Groups	21	21	21	21	22	22

Standard errors in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

6.2 Electricity and heat production

Table 13 studies CO_2 emissions from electricity and heat production sources and shows that income is statistically and economically significant for all specifications. As with the previous cases, I estimate a cubic specification but I find that it is not statistically significant. Thus, an inverted U-shaped relationship is preferred. The turning point is quite high, at around US \$36,000. This says that reducing CO_2 emissions from electricity and heat production comes at a much later stage of economic development than reducing CO_2 emissions from residential buildings commercial and public sources. The economic significance is also large given that an increase of US \$1,000 in per capita GDP, evaluated at the mean of GDP, increases per capita CO_2 emissions by 0.28 MT, ceteris paribus.

Also significant are alternative energy and fossil energy shares with their expected negative and positive signs. It is interesting to note that fossil energy has a much larger impact on CO_2 emissions in electricity and heat generation than in residential buildings commercial and public services. This is the case because, as the share of fossil energy increases, the electricity and heat generation sectors use significantly more fossil energy in the form of coal, natural gas and oil when compared to residential buildings commercial and public services. Urban share is positive and statistically significant at the 1% level. This again suggests that, with increasing urbanization, there is a rise in CO_2 emissions. Lastly, I find statistical significance at the 1% level for both the service and industry share. As can be seen, the absolute decline in CO_2 emissions as service share increases is less than the absolute rise in CO_2 emissions as industry share increases.

Table 13: Results for CO_2 (Electricity, Heat Production)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
GDP	0.338***	0.337***	0.362***	0.362***	0.363***	0.354***
	(0.0305)	(0.0300)	(0.0274)	(0.0273)	(0.0278)	(0.0280)
GDP - SQ	-0.00476***	-0.00476***	-0.00496***	-0.00494***	-0.00493***	-0.00478***
	(0.000554)	(0.000525)	(0.000498)	(0.000505)	(0.000513)	(0.000527)
Trade share		-5.00e-05	-0.000396	-0.000338	-0.000586	-0.00137
		(0.00105)	(0.00116)	(0.00120)	(0.00113)	(0.000966)
AE share			-0.00841***	-0.00879***	-0.00876***	-0.00816***
			(0.000935)	(0.00115)	(0.00120)	(0.00112)
FE share			0.0163***	0.0155***	0.0161***	0.0141***
			(0.00126)	(0.00134)	(0.00132)	(0.00176)
Urban share				0.00480	0.00498	0.00461
				(0.00360)	(0.00350)	(0.00362)
Service share					-0.00858***	-0.00632***
					(0.00198)	(0.00170)
Industry share						0.0133***
						(0.00430)
Constant	-0.527***	-0.524***	-1.586***	-1.785***	-1.386***	-1.649***
	(0.143)	(0.148)	(0.116)	(0.224)	(0.218)	(0.292)
Peak	35.5	35.4	36.5	36.6	36.8	37.0
F-test	0.000	0.000	0.000	0.000	0.000	0.000
R-squared	0.384	0.384	0.418	0.419	0.421	0.425
Observations	1,792	1,792	1,792	1,792	1,792	1,792
Groups	64	64	64	64	64	64

Standard errors in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 14 runs the quadratic and cubic regressions by income group while including all control variables in order to check for a pollution haven. One notices that the coefficients on trade share for the high-income group are negative and statistically significant under both the quadratic and cubic specifications. These coefficients are positive and significant for the middle-income group and positive and insignificant for the low-income group. Thus, as trade openness increases, emissions from high-income countries decrease and those from middle-income countries increase. This provides indirect evidence that there is a pollution-haven effect from high-income countries to middle-income countries for CO_2 emissions originating from electricity and heat production.

Table 14: Results for CO_2 by Income (Electricity, Heat Production)

VARIABLES	High-Income		Middle-Income		Low-Income	
GDP	0.193***	0.360***	0.194***	0.145**	0.622***	0.248*
	(0.0646)	(0.0936)	(0.0585)	(0.0555)	(0.102)	(0.121)
GDP - SQ	-0.00280***	-0.00932***	-0.00872**	0.00225	-0.115***	0.193**
	(0.000795)	(0.00256)	(0.00424)	(0.0167)	(0.0218)	(0.0758)
GDP - CB		7.78e-05**		-0.000707		-0.0733***
		(3.00e-05)		(0.00118)		(0.0186)
Trade share	-0.0133***	-0.0188***	0.00353***	0.00353***	0.000547	0.000365
	(0.00269)	(0.00270)	(0.000853)	(0.000865)	(0.000472)	(0.000396)
Constant	-18.55***	-16.30***	-2.033***	-2.053***	-0.288***	-0.271***
	(4.488)	(3.814)	(0.554)	(0.542)	(0.0439)	(0.0470)
F-test	0.000	0.000	0.000	0.000	0.000	0.000
R-squared	0.598	0.610	0.677	0.677	0.641	0.649
Observations	588	588	588	588	616	616
Groups	21	21	21	21	22	22

Standard errors in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

6.3 Manufacturing industries and construction

Table 15 looks at the CO_2 emissions associated with the manufacturing industries and construction. There is a strong inverted U-shaped relationship at the 1% significance level. The within R^2 is around 53% which is significantly higher than in the previous two sectors. An increase in per capita GDP by US $1,000, evaluated at the mean of GDP, is associated with about a 0.14 MT increase in per capita CO_2 emissions. This is economically significant. The turning point is at US $18,000 which is an intermediate value when compared to the previous two sectors.

The trade share coefficient is negative and statistically significant at the 1% level. There is also a statistically significant relationship for the service share and industry share variables. As economies generate more value through the service sector, as in the case for high-income countries, they become less dependent on the manufacturing and construction industries. Similarly, as economies increase their share of industry, as in the case for middle and low-income economies, manufacturing and construction industries become more prevalent and, naturally, CO_2 emissions increase.

Table 15: Results for CO_2 (Manufacturing, Construction)

VARIABLES	(1)	(3)	(4)	(5)	(6)	(7)
GDP	0.242***	0.230***	0.253***	0.253***	0.241***	0.253***
	(0.0461)	(0.0466)	(0.0424)	(0.0450)	(0.0470)	(0.0455)
GDP - SQ	-0.00671***	-0.00643***	-0.00666***	-0.00666***	-0.00649***	-0.00658***
	(0.00107)	(0.00109)	(0.00104)	(0.00108)	(0.00112)	(0.00109)
Trade share		-0.00535***	-0.00456***	-0.00457***	-0.00635***	-0.00533***
		(0.00136)	(0.00125)	(0.00124)	(0.00136)	(0.00118)
AE share			0.00195**	0.00192**	0.00304***	0.00241**
			(0.000911)	(0.000787)	(0.000992)	(0.000881)
FE share			0.00545**	0.00538**	0.00671**	0.00464*
			(0.00213)	(0.00241)	(0.00242)	(0.00254)
Urban share				0.000216	-0.00297	0.00225
				(0.00194)	(0.00226)	(0.00236)
Service share					-0.0160***	-0.0104***
					(0.00231)	(0.00225)
Industry share						0.0118***
						(0.00265)
Constant	0.291	0.647***	-0.000113	-0.00438	1.171***	0.168
	(0.198)	(0.193)	(0.158)	(0.129)	(0.249)	(0.168)
Peak	18.0	17.9	19.0	19.0	18.6	19.2
F-test	0.000	0.000	0.000	0.000	0.000	0.000
R-squared	0.531	0.541	0.531	0.531	0.547	0.536
Observations	1,792	1,792	1,792	1,792	1,792	1,792
Groups	64	64	64	64	64	64

Standard errors in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 16 lays out the regressions on an income basis for CO_2 emissions originating from manufacturing industries and construction. The pollution-haven hypothesis is found to hold between high-income and middle-income countries. This can be seen by the negative and statistically significant coefficients on the trade share variable for high-income countries and the positive and significant coefficients for the middle-income countries. Again, the pollution-haven hypothesis holds between the high-income and middle-income countries and not low-income countries.

Table 16: Results by Income for CO_2 (Manufacturing, Construction)

VARIABLES	High-Income		Middle-Income		Low-Income	
GDP	-0.201*	-0.197***	0.237***	0.450***	0.216**	0.256***
	(0.0982)	(0.0642)	(0.0241)	(0.0662)	(0.0788)	(0.0908)
GDP - SQ	-0.000609	-0.000751	-0.00800***	-0.0551***	-0.0263	-0.0590
	(0.00129)	(0.00354)	(0.00223)	(0.0109)	(0.0186)	(0.0483)
GDP - CB		1.70e-06		0.00303***		0.00779
		(5.34e-05)		(0.000601)		(0.0108)
Trade share	-0.0449***	-0.0450***	0.00186***	0.00187**	-0.000943***	-0.000924***
	(0.00673)	(0.00745)	(0.000666)	(0.000680)	(0.000148)	(0.000135)
Constant	8.913***	8.963***	-0.385	-0.297	-0.202***	-0.203***
	(2.945)	(2.931)	(0.301)	(0.282)	(0.0369)	(0.0366)
F-test	0.000	0.000	0.000	0.000	0.000	0.000
R-squared	0.706	0.706	0.523	0.533	0.491	0.491
Observations	588	588	588	588	616	616
Groups	21	21	21	21	22	22

Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

6.4 Transportation

Table 17 studies CO_2 emissions from transportation sources. The per capita GDP variables are positive, negative and then positive and they are statistically significant at the 1% level. The cubic specification is preferred to that of the quadratic which would initially suggest that the N-shaped relationship is present in the transportation sector. This is not the case because it is not possible to calculate the turning points. In reality, CO_2 emissions from the transportation sector display a monotonically increasing relationship which has not yet tapered off to form a U-shaped or N-shaped relationship. This is interesting to note because it implies that CO_2 emissions from the transportation sector contribute to the high turning point that is seen in total CO_2 emissions and are still on the rise. A US $1,000 increase in the per capita GDP, evaluated at the mean, is associated with a 0.2 MT increase in the per capita CO_2 emissions.

Table 17: Results for CO_2 (Transportation)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
GDP	0.405***	0.388***	0.387***	0.386***	0.387***	0.391***
	(0.0339)	(0.0323)	(0.0323)	(0.0354)	(0.0355)	(0.0368)
GDP - SQ	-0.0145***	-0.0137***	-0.0136***	-0.0136***	-0.0136***	-0.0136***
	(0.00190)	(0.00178)	(0.00181)	(0.00194)	(0.00194)	(0.00196)
GDP - CB	0.000207***	0.000195***	0.000194***	0.000193***	0.000193***	0.000193***
	(3.10e-05)	(2.93e-05)	(2.96e-05)	(3.12e-05)	(3.11e-05)	(3.13e-05)
Trade share		0.00340***	0.00336***	0.00337***	0.00333***	0.00372***
		(0.000969)	(0.00107)	(0.00106)	(0.00105)	(0.00107)
AE share			-0.000385	-0.000418	-0.000414	-0.000711
			(0.000685)	(0.000727)	(0.000728)	(0.000750)
FE share			0.00163	0.00158	0.00167	0.00268*
			(0.00141)	(0.00140)	(0.00138)	(0.00141)
Urban share				0.000403	0.000429	0.000620
				(0.00244)	(0.00242)	(0.00239)
Service share					-0.00120	-0.00230*
					(0.00101)	(0.00133)
Industry share						-0.00651***
						(0.00157)
Constant	-0.622***	-0.768***	-0.868***	-0.884***	-0.828***	-0.700***
	(0.0878)	(0.103)	(0.0951)	(0.0644)	(0.0786)	(0.101)
Peak/Trough	--	--	--	--	--	--
F-test	0.000	0.000	0.000	0.000	0.000	0.000
R-squared	0.764	0.770	0.771	0.771	0.771	0.772
Observations	1,792	1,792	1,792	1,792	1,792	1,792
Groups	64	64	64	64	64	64

Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

Looking at the trade share coefficients for the regressions sorted by income in table 18, one notices that the coefficients for all three income groups are positive and mostly significant at the 1% level. This holds for both the quadratic and cubic specifications. As a country's trade share increases, it can be seen that this is associated with an increase in CO_2 emissions among all income groups. This makes sense given that trade and transportation are inextricably linked to one another and as a country opens up, transportation demand increases. Thus, there is no evidence to suggest that there exists a pollution haven for CO_2 emissions originating from the transportation sector.

Table 18: Results by Income for CO_2 (Transportation)

VARIABLES	High-Income		Middle-Income		Low-Income	
GDP	0.235***	0.617***	0.320***	0.216***	0.249***	-0.332***
	(0.0329)	(0.0589)	(0.0293)	(0.0372)	(0.0508)	(0.0740)
GDP - SQ	-0.000700*	-0.0156***	-0.0157***	0.00731	0.00448	0.482***
	(0.000367)	(0.00241)	(0.00258)	(0.00532)	(0.0145)	(0.0538)
GDP - CB		0.000178***		-0.00148***		-0.114***
		(3.46e-05)		(0.000242)		(0.0135)
Trade share	0.0315***	0.0190***	0.00275***	0.00275***	0.000537**	0.000254
	(0.00541)	(0.00359)	(0.000522)	(0.000506)	(0.000200)	(0.000183)
Constant	-7.170***	-1.993	0.156	0.114	-0.0541	-0.0286
	(1.908)	(1.758)	(0.240)	(0.232)	(0.0549)	(0.0412)
F-test	0.000	0.000	0.000	0.000	0.000	0.000
R-squared	0.781	0.833	0.758	0.760	0.772	0.819
Observations	588	588	588	588	616	616
Groups	21	21	21	21	22	22

Standard errors in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

6.5 Final remarks

Figure 9 graphs the disaggregated fitted CO_2 emission values in red, from the basic model of column (1) in the regressions above, with their actual emission values in blue. The figure shows that the models fit the actual values quite well given the 95% confidence interval is very close to the fitted values. This is especially true for the CO_2 emissions generated from the manufacturing and construction industries and transportation.

Table 19 recaps some of the important results found. The biggest contributors to the observed, aggregate, inverted U-shaped relationship come from the CO_2 emissions from electricity and heat production, with a turning point of US $36,000. This is followed by the CO_2 emissions from manufacturing industries and construction, with a turning point of US \$18,000, and CO_2 emissions from residential buildings commercial and public services, with a turning point of US \$9,000. Transportation emissions do not display an inverted U-shaped relationship but they do contribute to the high turning point that is seen for total CO_2 emissions. They are eventually dominated by the declining per capita CO_2 emissions from the other sectors.

I also find that the sectors which contribute to the pollution-haven result for total CO_2 emissions are (a) electricity and heat production and (b) manufacturing and construction. The CO_2 emissions from residential buildings commercial and public sources and transportation show no evidence of a pollution haven.

Figure 9: Fitted and Actual CO_2 Values for Disaggregated CO_2

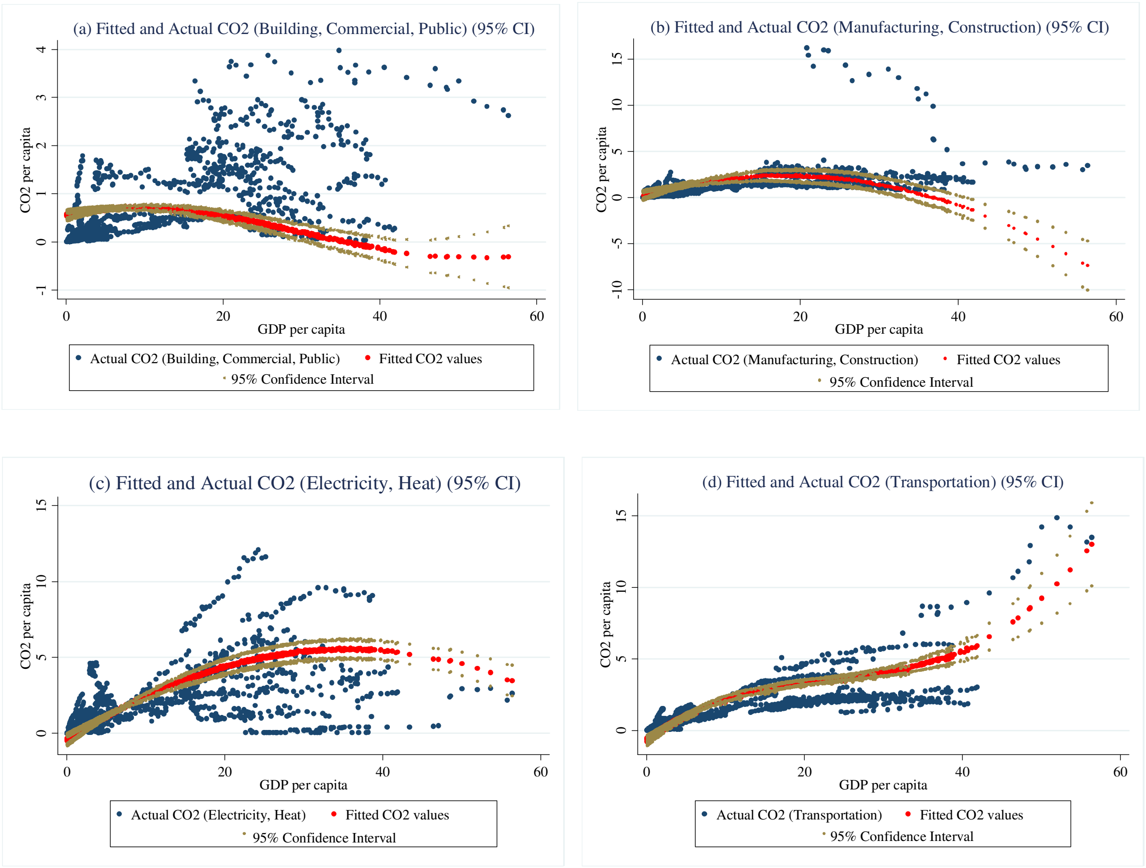


Table 19: Recap of Results

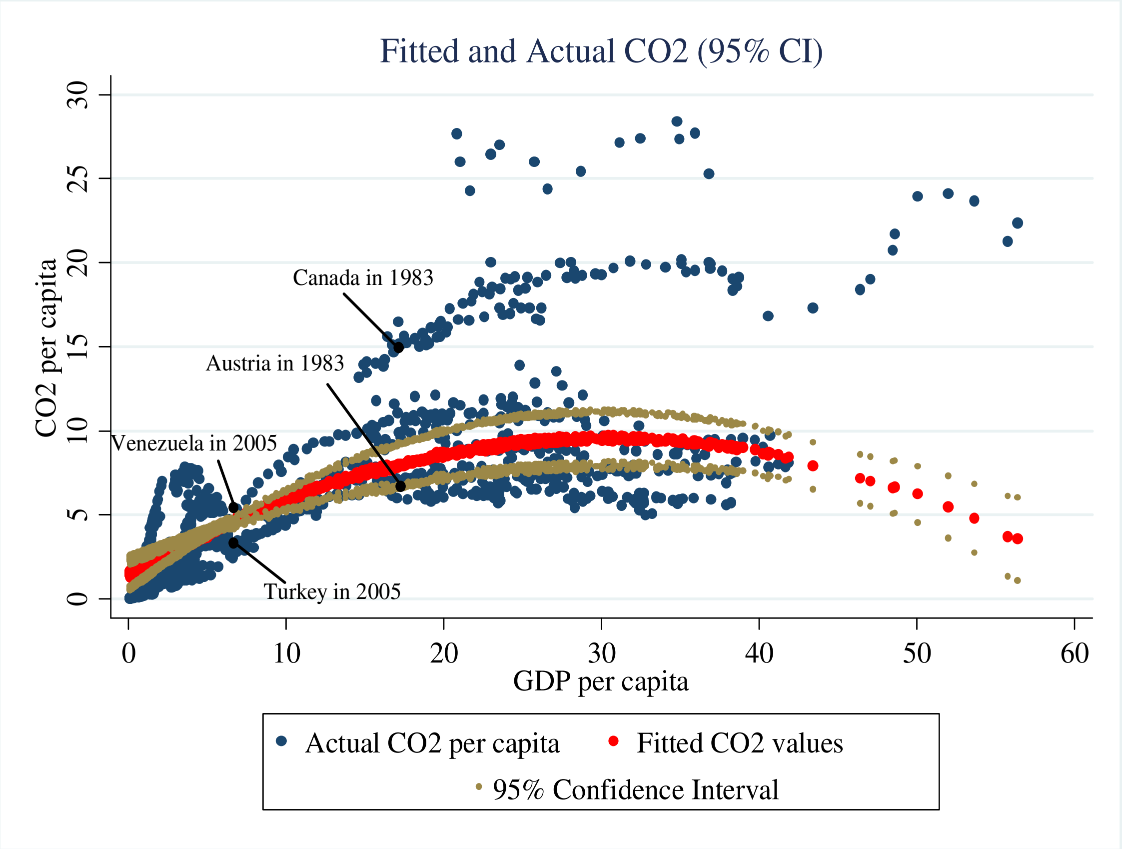
Sources of Emissions	Turning Point-Trough Point	Economic Significance (evaluated at the mean of GDP)	Pollution-Haven Hypothesis
Electricity and heat production	US$36,000	0.28MT	High-Income → Middle-Income
Transportation	No EKC	0.19MT	No Haven
Manufacturing industries and construction	US$18,000	0.14MT	High-Income → Middle-Income
Residential buildings commercial and public	US$9,000-US$50,000	0.0025MT	No Haven
Total CO_2 emissions	US$31,000	0.50MT	High-Income → Middle-Income

Lastly, it should be noted that past studies have not endeavoured to explain where the CO_2 EKC comes from as they have sought to estimate the aggregate EKC and the various turning points. By disaggregating total CO_2 emissions into the four sectors, I am able to find out the contribution of each sector to the CO_2 EKC observed. What this essentially says is that, two countries may have the same level of GDP per capita, yet, by having a different composition of the four sectors, they might have different CO_2 emissions and hence lie on different aggregate EKCs.

Figure 10 graphs the total fitted CO_2 emission values in red, from the basic model of column (1) in the regressions, with their actual emission values in blue. Notice that while Canada and Austria had an almost identical per capita GDP in 1983, at around US $17,000, their per capita CO_2 levels were drastically different, at 15.1 MT and 6.8 MT respectively. Why? The big difference in the emission values lies in the composition of the four sectors. In 1983, almost 60% of CO_2 emissions in Canada were generated from electricity and heat and transportation which, as table 19 shows, are the most economically significant sectors. These sectors only made up 45% of CO_2 emissions for Austria.

The per capita GDP of Turkey and Venezuela in 2005 was around US $5,000 and their CO_2 emissions were at 5 MT and 3 MT respectively. The emission values are much closer than in the case of Canada and Austria. Again, investigating further, one sees that the combined sectors of electricity, heat, manufacturing and construction make up around 68% of total emissions for both countries. Thus, the reason one observes a minor difference in CO_2 emissions is that, in Venezuela, the transportation sector makes up a larger share of CO_2 emissions than in Turkey.

Figure 10: Fitted and Actual CO_2 Values for Total CO_2



7 Conclusion

This essay studies two important issues. First, it focuses on the possibility that the composition of an economy into the sectors of (a) residential buildings commercial and public services, (b) manufacturing and construction, (c) electricity and heat and (d) transportation is what determines the global Environmental Kuznets Curve. This would suggest that countries with the same GDP may have different CO_2 emission levels due to the different mix of the four sectors. Second, it tries to determine whether there are pollution havens from developed into less developed countries at the aggregate level and the likely culprits that generate pollution havens at the disaggregate level. To examine these possibilities, I develop a fixed effects model and estimate it for total and disaggregated CO_2 emissions and for countries sorted by income.

I find that the EKC holds for total CO_2 emissions but there are dark sides to the findings. First, for rich countries, there is evidence of an N-shaped relationship with a resumption of rapid emissions growth beyond US $42,000. Second, any evidence of an EKC is in the flow and not yet in the atmospheric stock of GHGs. This is to say that the stock of GHGs, measured in parts per million, is not necessarily decreasing because the flow of human-source CO_2 emissions is still positive. Given the inverted U-shaped relationship found in the flow of CO_2 emissions and depending on other additions or subtractions to GHGs, the stock could continue to increase albeit at a slower rate. Third, as economies open up to international trade, there is indirect evidence of a pollution-haven effect from high-income countries to middle-income countries.

At the disaggregated level there is strong evidence of an EKC in the (a) manufacturing and construction industries and the (b) electricity and heat sector. Both contribute to the EKC observed at the aggregate level. There is also somber news at the disaggregated level. First, I find that the CO_2 emissions from residential buildings commercial and public services display an N-shaped relationship whereas emissions from the transportation sectors have not yet had any turning point. While there was a minor slowdown in emissions originating from transportation, they are again on the rise. Second, the sectors of (a) manufacturing and construction and (b) electricity and heat show indirect evidence of pollution havens from high-income to middle-income countries. This suggests that these sectors are the ones generating the pollution haven seen at the aggregate level.

A logical extension on this topic could focus on the interaction that GDP may have with the trade openness variable. That is, the location of the turning point—and not just the overall level of CO_2 emissions—may depend on the openness to international trade. A non-linear model with an interaction term between GDP and trade could be used to estimate the variation across countries and, to hedge against the interaction between trade and GDP spuriously capturing country-varying slopes, the country-specific means could be subtracted from each of the interaction variables.

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