Are Environmental Kuznets Curves Misleading Us? The Case of CO2 Emissions

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ARE ENVIRONMENTAL KUZNETS CURVES MISLEADING US?

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Introduction

Environmental Kuznets curve (EKC) analysis is an econometric methodology that assumes that environmental quality or pollutant emissions are correlated with economic growth, specifically per capita gross domestic product (GDP). Regression analysis has in some cases found an "inverted U-shaped" relationship between the variables. This has been interpreted to mean that pollution increases with national industrial and income growth, but once a specific income "turning point" is reached, environmental quality begins to improve as incomes grow further (Shafik and Bandyopadhyay 1992; World Bank 1992; Grossman and Krueger 1993; Selden and Song 1994). Economist Simon Kuznets originally identified a similar historic relationship between income distribution and income growth in the 1940's which is known as the "Kuznets curve" (KC), and this antecedent is the source of the environmental, EKC hypothesis.

Based on economic theory, two dominant explanations have been put forth to explain the relationship. The first is that Kuznets behavior is an income effect and results because the environment is a luxury good. Early in the economic development process individuals are unwilling to trade consumption for investment in environmental protection; as a result environmental quality declines. Once individuals reach a given level of consumption, known in the EKC literature as the "income turning point", they begin to demand increasing investments in an improved environment. Thus after the turning point, environmental quality indicators begin to demonstrate decreases in pollution and environmental degradation.

The other common explanation is that the EKC is another expression of the "stages of economic growth" economies pass through as they make a transition from agriculturally based to industrial and then post-industrial service based economies. The transition from agricultural to industrial economies results in increasing environmental degradation as mass production and consumption grow in the economy. The transition from industrial to service based economy is assumed to result in decreasing degradation due to the lower impact of service industries. A slightly modified view is the idea that economies pass through technological life cycles, moving from smokestack technology to high technology.

We find neither explanation compelling and question whether the econometric analysis is identifying a true income/environment effect or is merely a result of polynomial curve fitting. The EKC analysis commonly used in the literature is to specify the following functional form:

$$Y_{it} = \beta_0 + \beta_1 X_{it} + \beta_2 X_{it}^2 + \beta_3 X_{it}^3 + \varepsilon_{it} \qquad (1)$$

where,

$i = 1, \ldots N$, countries

$t = 1, \ldots T$, years

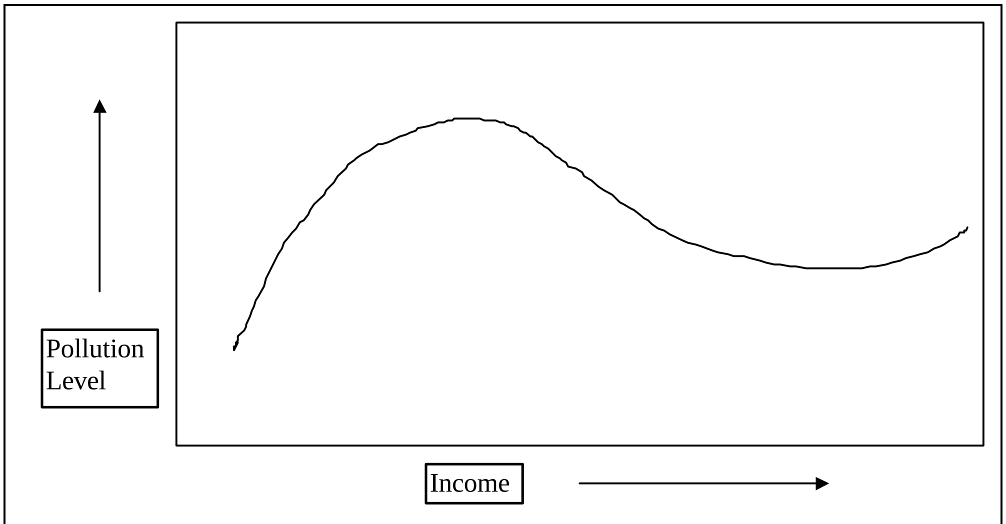
Y_{it} = CO_2 emissions per capita

β_0 = country specific intercept

X_{it} = real GDP per capita

ε_{it} = an error term

The squared term produces the inverted U behavior, and the cubic term accounts for increases that sometimes return at the highest income levels. This is the functional form Simon Kuznets originally used in his studies of income inequality, and it has since become a common tool used in econometric analyses of many economic phenomena. For example, a recent study used the approach to study the dynamics of foreign direct investment with economic growth.[1] However, because in the post-war period most of the OECD countries have maintained exponential income growth, GDP behaves much like a “counter”, counting the passage of time. Nearly any measure of activity which changes through time — such as the annual sales of black and white television sets sold each year — could be correlated to GDP This number, like many others, is also likely to rise and fall with income growth in historic records. This observation, that measurable quantities rise and fall over time, tells us nothing about the underlying causes of the dynamics. A generalized EKC (illustrating these dynamics) is shown below.



The Environmental Kuznets Curve (EKC) Hypothesis

The real observation that drives the EKC is that most wealthy OECD countries since the 1970’s have demonstrated decreasing emissions intensities for many forms of pollution. Pollution emissions intensity is the quantity of pollution emissions per unit of GDP. This observation is not, however, universally true for all wealthy countries. We will cite several contra-factual examples latter in the paper. The EKC approach, however, implicitly assumes that economic growth and the resulting pollution relations are universal processes and thus can justify the use of cross sectional analysis. We find that it is more revealing to focus on the countries that have demonstrated a transition to lower pollution intensities to determine if income is the most powerful explanatory variable.

[1] Narula, R., Multinational Investment and Economic Structure, Routledge, NY, NY, 1996.

This paper examines the case of carbon dioxide (CO_2), an important atmospheric gas which contributes to global warming. Several recent econometric studies have estimated the relation between CO_2 emissions per capita and per capita GDP growth using cross-country, and often unbalanced, panel data (World Bank 1992; Shafik 1994; Sengupta 1996). The authors of these studies reach conflicting conclusions about the CO_2 /GDP relation. The World Bank (1992) and Shafik (1993) find that per capita CO_2 emissions increase monotonically with income growth. In contrast, Holtz-Eakin and Selden (1995) generate an out-of-sample turning point of $35,428 per capita (1986$), indicating that substantial economic growth would be required before CO_2 emissions begin to decline. In a separate monograph, Sengupta models the CO_2 /GDP relation for a mixed subset of 16 countries that includes both developed and developing countries. His models generate a much lower income turning point of $8,740 (in PPP 1985$), but also find the tendency for positive emissions elasticities beyond $15,300, indicating that emissions decline over a mid-range of incomes before reestablishing an upward trend with GDP growth. Other authors have found evidence for this “N-shaped” curve when modeling other environmental quality indicators such as solid waste volumes and heavy metal concentrations in river water (Grossman and Krueger 1995). Despite the discrepancies, these studies seem to indicate that CO_2 emissions will continue to rise as countries pursue economic growth policies; results that are disturbing to policy makers interested in pursuing the goal of stabilizing and reducing of CO_2 emissions.

Interestingly, Holtz-Eakin & Selden (1995) note that country-specific effects shift the locus of the CO_2 /GDP relation in important ways that could affect the interpretation of the econometric results. In their cross-sectional analysis, it is industrialized countries that demonstrate the greatest MPE, whereas fixed-effects estimates indicate low income countries have the greatest MPE. These results indicate a sensitivity to which countries are included in the modeling effort and reveal a potential for important differences in individual country behavior. This observation is substantiated by the results of Sengupta (1996) who finds a much lower emissions turning point based on his 16 country subset. These findings suggest that it is useful to ask if a subset of countries exists for which sustained GDP growth continues while contemporaneous CO_2 emissions stabilize or decline. Identifying countries that meet these criteria could then provide a source of insight for policy makers seeking to reduce CO_2 emissions while meeting the social and political demand for continued economic growth. Having a set of countries with complete time series that demonstrate EKC type behavior would also allow fuller testing of the assumptions underlying this modeling approach.

This study builds on work previously presented in GDAE Discussion Paper # 2 and the work of Moomaw and Tullis (1992;1994) who put forward the *Development Plane Concept*; a variation of a resource wealth correlation diagram which plots parameters of economic achievement against indicators of environmental impact. For this study, scatter plots of per capita CO_2 versus per capita GDP were generated for the countries for which matched data were available over the time period 1950 to 1992. For CO_2 emissions data we use per capita numbers from Oak Ridge National laboratory (ORNL 1989, 1994) and for the income measure we use the RGDPCH series on real per capita GDP (1985 U.S. dollars) from Penn World Tables (Summers and Heston, 1989,1993). From this analysis three basic types of CO_2 /GDP relations were classified. Of principle interest to this study are the countries termed *Type 1* which pass through a discontinuous transition in which the CO_2 /GDP relation changes from a strong positive covariance to a negative or weakly correlated relation. These countries turn out to be a subset of OECD member states. Type 1 countries are summarized in Table 1. Their apparent EKC behavior is illustrated in Figure 1. In contrast, *Type 2* countries demonstrate a purely positive correlation between CO_2 /GDP, with those countries that undergo an economic contraction showing a “backtracking” or reduction in CO_2 emissions as incomes decline. This subset is dominated by present and former centrally planned economies and some developing countries. Finally there are the *Type 3* countries, described as “chaotic” as they show no consistent relation between the variables. This set is dominated by developing countries that have failed to generate consistent GDP growth over the period of the data set.

In this paper we analyze the Type 1 countries using two methodologies: that of non-linear systems dynamics versus the more standard econometric analysis. Below we present the methodological approaches and results of each technique. In the subsequent sections we discuss the implications for interpreting standard EKC results as well as the policy implications of our findings.

Research Methodology and Results

Non-linear Dynamical Systems Approach

Dynamical systems are nonlinear feedback systems that can produce complex behavior from relatively simple functions. These systems are generally characterized by no single solution but rather by multiple or even an infinite number of solutions, indicating that a multitude of states are possible. Because there is no single solution, analytic methods are rarely useful. Researchers have therefore relied on phase space diagrams to identify possible limits to the range of potential solutions (Cambel, 1993). A useful approach for this analysis is a time-based space comparing emissions in the previous year (y-axis) with those in the current year (x-axis). The dynamics of a system, in this case an economy’s emissions, then traces out a trajectory phase space which can reveal whether the measure is changing in a systematic or irregular fashion. Systems will often be “attracted” to a region of the phase space indicating that emissions are fluctuating around an average value. A description of attractor can provide a classification for a given dynamical system (Peters, 1991).

Whereas EKC analysis seeks correlations between temporally paired variables, emissions and income, phase diagram/attractor analysis reveals the behavior of an individual variable, emissions, through time. For this reason complete time series are most useful. However, there are few national data sets which include time series with measures of emissions before and after the transition to stable or declining levels. Carbon dioxide is one of the more complete sets of emissions data and is therefore suited to attractor analysis.

Table 1	Summary Data

rtCountry	Date attractor develops	Income in 1973 (1985 US$)	Emissions in 1973 (tons per capita)	Peak Year	Income at Peak (1985 US$)	Emissions at Peak (tons per capita)
Austria	1973	8,884	2.16	1973	8,884	2.16
Belgium	1973	9,958	3.79	1973	9,958	3.79
Canada	1973	11,963	4.58	1979	14,036	4.92
Denmark	1973	11,194	3.23	1979	11,756	3.46
Finland	1973	9,517	2.85	1980	10,802	3.15
France	1973	10,763	2.61	1973	10,763	2.61
West Germany	1973	10,681	3.48	1979	12,172	3.50
Iceland	1973	8,878	2.25	1977	11,700	2.34
Italy	1973	7,929	1.68	1979	9,596	1.83
Japan	1973	9,048	2.31	1973	9,100	2.39
Luxembourg	1973	12,212	10.92	1974	12,736	10.95
Netherlands	1973	10,301	2.92	1979	11,291	3.01
Sweden	1973	11,890	2.92	1970	11,305	3.13
Switzerland	1973	13,766	1.96	1973	13,766	1.96
United Kingdom	1973	9,520	3.17	1973	9,520	3.17
United States	1973	14,533	6.03	1978	15,425	5.80
MEAN (M)	-	*10,672*	*3.55*	*1975.75*	*11,426*	*3.64*
STANDARD DEVIATION (SD)	-	*1760*	*2.17*	*3.15*	*1813*	*2.14*
% SD/M	-	*16.49*	*61.00*	*0.16*	*15.87*	*58.97*

Results of Attractor Analysis

We have produced phase diagrams for the majority of countries in the ORNL CO_2 data set and have inspected them for evidence of attractors. Selected phase diagrams which demonstrate attractors are presented Figures 2 through 4. In these figures, the ordinate represents emission levels in the present year and the abscissa indicates emissions in the previous year. Individual points are labeled with the previous year, and are connected together in time sequence. If emissions levels simply increased at a constant rate, the path would trace a straight line.

Figure 2 is a phase diagram which illustrates the dynamics of French CO_2 emissions. Emissions rise at first until an attractor develops in the early 1970's which is followed by a period decline and stabilization around a new attractor in the late 1980's. In contrast, the phase diagram for Finland is presented in Figure 3 and demonstrates two periods major periods of behavior of approximately equal duration: one, a period of steady growth in emissions from 1950 to the 1970s and the other, a period of oscillation around an apparent attractor with an unstable central value. The United States pattern in Figure 4 is more complex, with several, more ephemeral areas of cycling attraction: one in the 1950s before the sustained growth phase and another downward spiral following the 1970s transition.

TYPE 1 CARBON TRANSISTION COUNTRIES

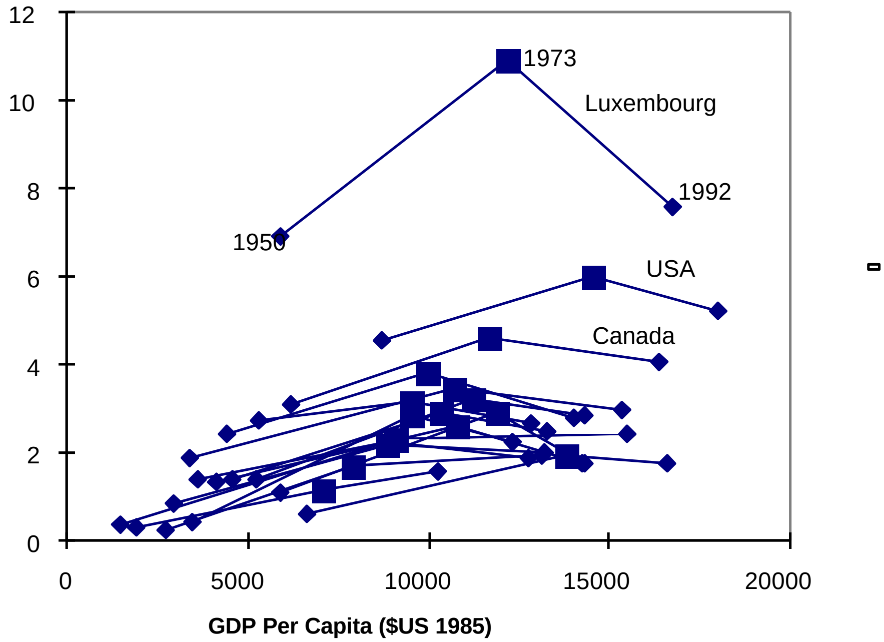


Figure 2. Phase Diagram: CO2 Emissions
France 1950-1992

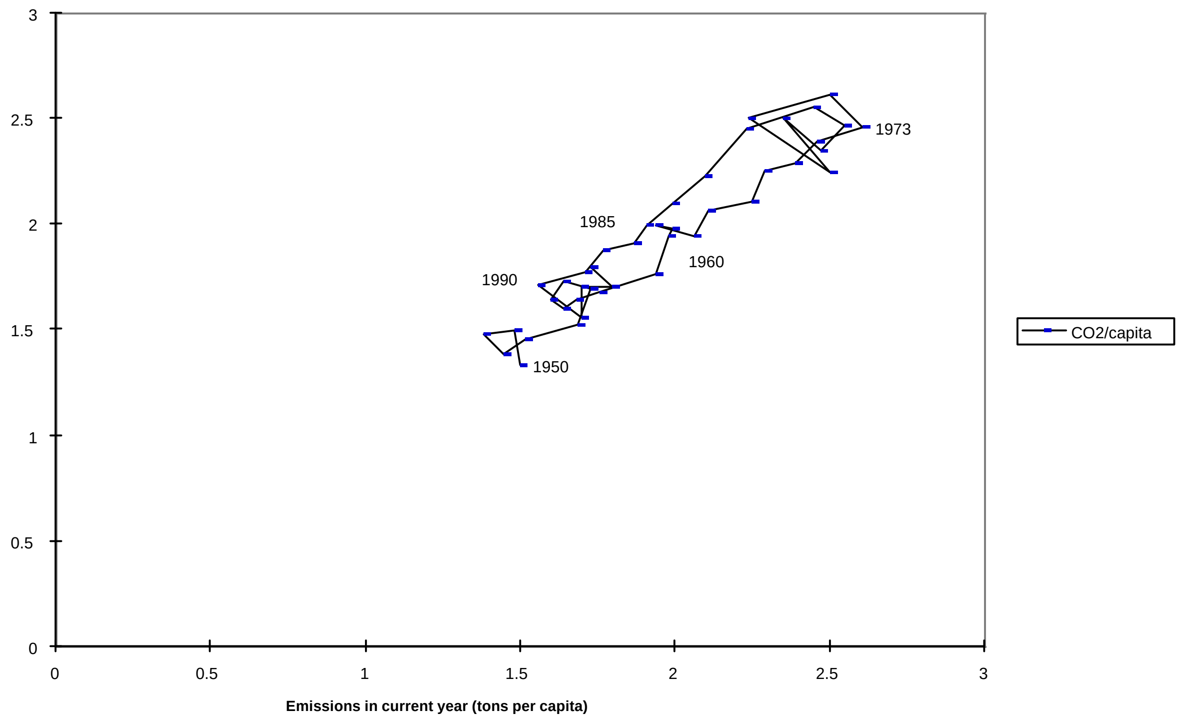


Figure 3. Phase Diagram: CO2 Emissions.
Finland 1950-1992

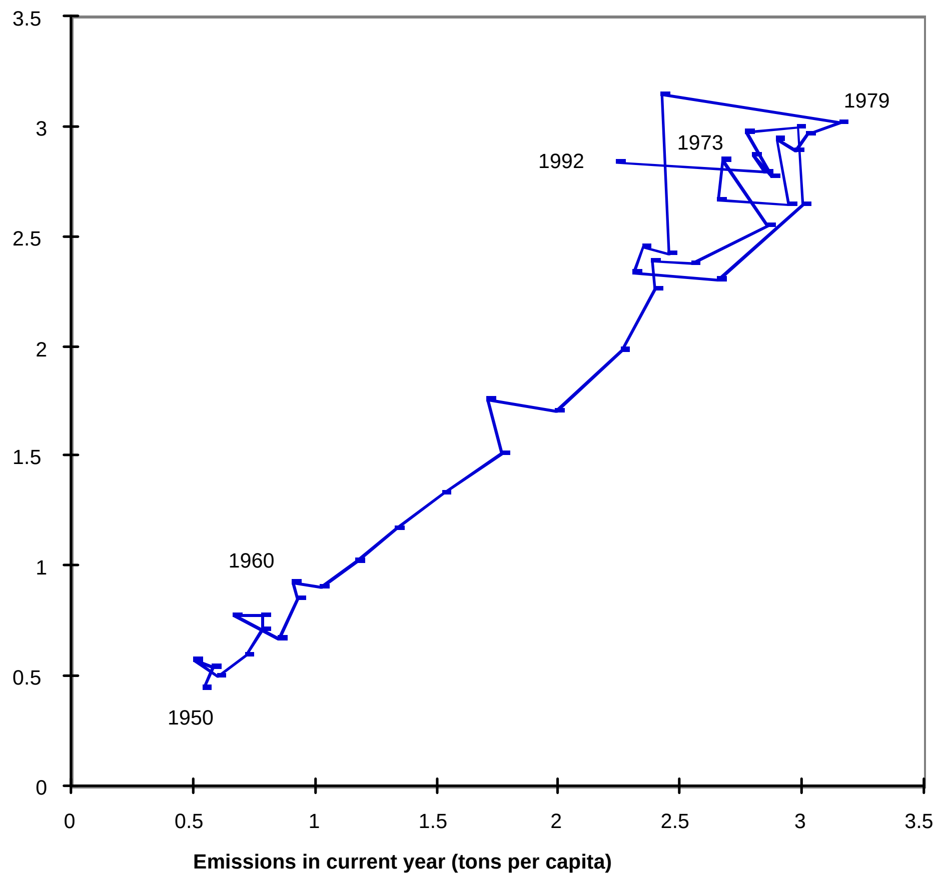
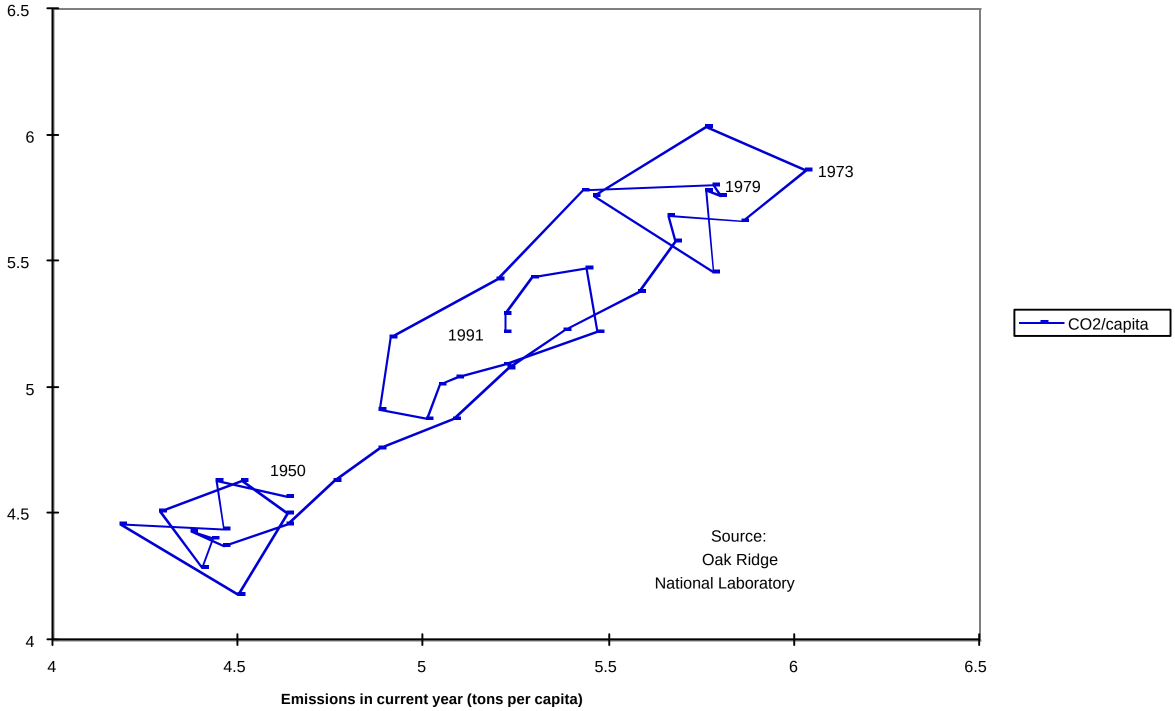


Figure 4: Phase Diagram: CO2 Emissions
USA 1950-1992



While many countries follow this basic pattern, other countries in the data set later break out of the attractor and resume an upward trend. However when a subset of 16 Type 1 countries, is analyzed in phase space, these countries all demonstrate persistent emissions attractors while maintaining per capita GDP growth. Table 1 summarizes the date the attractor develops and the income and emissions levels at this date for Type 1 countries. In addition, any post-transition peak level measures for income and emissions are presented, along with the date of the highest emissions level. The mean and standard deviation are summarized at the bottom of each column where appropriate.

A review of the table provides several insights. First, the reader should note that the attractor develops in countries over a nearly two-fold range of national incomes - \$7,900 to \$14,500. In contrast we have identified at least seven other countries, including Norway and Spain, that fall within this income range but have not undergone an EKC-like transition. Given such a broad income range and inconsistent behaviors, choosing a single income turning point seems inappropriate. As most EKC studies seek to identify an income level at which emissions peak, we present a second set of statistics for each country at the emissions maximum. Using the simple comparison of dividing the standard deviation of each measure by the mean and converting to percentages, we find that the dispersion is greatest for the emissions level measure and narrowest for the peak year measure. In fact, the dispersion around the mean of both the emissions and the income measures are two orders of magnitude greater than the peak year measure. Clearly the transition is not best correlated to a specific income level but to historic events common to the 16 country set. This is not to say that the level of industrialization or income is unimportant , as all 16 countries are members of the OECD group of most developed economies. However, we hypothesize that income levels are an imperfect proxy for some other underlying similarities which conditioned the countries' response to the events of the 1970's.

Given the results of the attractor analysis we proceed to model the Type 1 countries using more standard econometric techniques. We test two different functional model forms: (1) the standard EKC model commonly found in the literature and (2) a structural transition model which captures the dynamics found in the attractor analysis.

Econometric Modeling Approach

EKC Models

To test the standard EKC model we pool our Type 1 country data and utilize the functional form given in equation (1). We run the models with and without the third order polynomial term. The results of the two EKC models are presented in Table 2. The EKC emission reversal at higher incomes is clearly present in the data, with appropriate signs on the model coefficients. All t-statistics indicate the results to be significant. The fixed effect estimate indicates an income turn over the point of \$12,813 which is significantly lower than the results of Holtz-Eakin & Selden (1995) who identify a turning point of \$35,428. In the second model, the cubic term is also statistically significant, indicating an N-shaped curve. This would indicate that emissions would begin to rise again once a second income turning point is passed. This second income turning point is \$18,333 which would imply only a very narrow income range for CO_2

declines.

x3090Table 2: *EKC as a Panel* **Standard EKC Models**				
1 **Variable**	Fixed Effects	Cross Section (OLS)	Fixed Effects	Cross Section (OLS)
Intercept	—	-0.35 (-0.84)	—	-3.25 (-4.01)
GDP/Capita (x10^-3)	0.40 (14.16)	0.52 (5.65)	0.60 (6.47)	1.66 (5.75)
GDP Squared (x10^-7)	-0.16 (-10.98)	-0.17 (-3.68)	-0.38 (-3.80)	-1.45 (-4.67)
GDP Cubed (x10^-11)	—	—	0.07 (2.20)	0.43 (4.16)
R squared	0.92	0.14	0.92	0.16
Parenthesis: t-statistic				

Structural Transition Models

The second task is to model the transition observed in Type 1 countries as a discontinuous structural change in the coefficients. To do so, a piece-wise linear spline function was used for the periods 1950 to 1973 and 1974 to 1992, with the structure break occurring in 1973. The two part linear model simply involves a change in the value and variance of the model coefficients between the two periods. The following relations were tested for each country in each of the two time periods:

(2)

$$Y_t = \beta_0 + \beta_1 X_t + \varepsilon_t$$

where,

$t = 1, . . ., T$ years

Yt = CO_2 emissions per capita

β_0 = country specific intercept

X_t = GDP per capita.

ε_t = an error term.

We first tested the relation for individual countries and then applied the same two time period model to the full panel of 16 countries. Following the procedure specified in Quant (1960) we test and fail the null hypothesis that no structural shift has occurred, statistically demonstrating that a structural transition did indeed occur in 1973. We have further allowed the error variance to vary between the two periods after failing the null hypothesis that the error variance is constant between periods by using the procedure in Quant (1958).

The regression results for individual Type 1 countries are presented in Table 3. Each of the 16 individual countries demonstrate a strong positive correlation to GDP in the first period with all variable coefficients positive and significant. Eleven of the countries have adjusted R-squares values in excess of 0.90. The second period is much less homogeneous. Only eight of the variable coefficients are significant at the 95% level, and of these six are negative and two are positive. The remaining eight countries have coefficients which are not statistically different from zero. Adjusted R-squared values for all countries are substantially reduced and only France and Sweden demonstrate a convincing correlation which is negative.

The results of running the panel data as a two period model are presented in Table 4 and, in general, mirror the individual country regressions. In the first period the positive relation is demonstrated with highly significant coefficients. The second period fixed effect model indicates a negative relation. A significant increase in the variance occurs in the second period as demonstrated by the decreases in the t-statistics.

Interpretation

The alternate modeling of the data set has produced two significantly different relations between income levels and CO_2 emission. The EKC models imply a continuous transition from positive to negative emission elasticities as national incomes rise. These EKC models, generated with data which include the only countries that have undergone such a transition, indicate that a much lower income level turning point is required than the previous published studies. However, inclusion of the cubic term suggests that the lowering of CO_2 with rising GDP is only temporary, and CO_2 emissions continue to rise at higher incomes. The absurd policy implication of this finding is that incomes should be constrained to lie between $12,813 and $18,333.

While the EKC models identify a unique turning point income, the structural transition model, like the attractor analysis, shows that the “turn over” occurs over a large range of both GDP and CO_2 emissions. The observed range in the income turning point is nearly a factor of 2, and the CO_2 peak levels vary by a factor of 6. This can be easily seen by simple inspection of Figure 1, and further weakens the argument for income as the key explanatory variable.

Table 3.		**COUNTRY REGRESSIONS 1950-1973**		**COUNTRY REGRESSIONS 1974-1992**		
3*Country*		*GDP/Capita (x 1000)*	*Adjusted R Squared*	*Intercept*	*GDP/Capita (x 1000)*	*Adjusted R Squared*

Austria	**0.21** (4.27)	**0.20** (23.94)	**0.96**	**2.19** (12.70)	**-0.02** (-1.23)	**0.03**
Belgium	**1.64** (16.07)	**0.21** (13.83)	**0.89**	**5.45** (7.66)	**-0.2** (-3.43)	**0.37**
Canada	**1.92** (17.11)	**0.56** (14.07)	**0.90**	**5.86** (14.01)	**-0.1** (-3.43)	**0.37**
Denmark	**-0.41** (-3.29)	**0.35** (21.56)	**0.95**	**3.52** (5.76)	**-0.04** (-0.73)	**-0.03**
Finland	**-1.26** (-11.76)	**0.43** (24.84)	**0.96**	**2.78** (5.81)	**-0.004** (-0.09)	**-0.06**
France	**0.65** (13.89)	**0.19** (26.84)	**0.97**	**4.92** (10.35)	**-0.23** (-6.06)	**0.67**
West Germany	**1.45** (19.21)	**0.20** (18.31)	**0.94**	**4.00** (13.90)	**-0.07** (-3.05)	**0.32**
Iceland	**1.05** (8.70)	**0.14** (6.31)	**0.63**	**2.49** (8.60)	**-0.03** (-1.43)	**0.06**
Italy	**-0.64** (-16.28)	**0.29** (39.25)	**0.99**	**1.47** (13.37)	**0.026** (2.40)	**0.23**
Japan	**-0.11** (-5.32)	**0.27** (63.60)	**0.99**	**1.83** (12.56)	**0.03** (2.18)	**0.17**
Luxembourg	**4.55** (7.70)	**0.59** (8.58)	**0.76**	**10.35** (5.08)	**-0.22** (-1.43)	**0.05**
Netherlands	**0.20** (3.55)	**0.27** (33.05)	**0.98**	**3.30** (3.92)	**-0.07** (-0.90)	**-0.01**
Sweden	**-0.78** (-6.71)	**0.36** (24.43)	**0.96**	**6.36** (8.19)	**-0.32** (-5.43)	**0.61**
Switzerland	**-0.69** (-11.93)	**0.19** (33.11)	**0.98**	**1.77** (12.78)	**-0.005** (-0.55)	**-0.04**
United Kingdom	**2.57** (25.53)	**0.07** (4.49)	**0.45**	**3.32** (15.18)	**-0.05** (-2.46)	**0.22**
United States	**1.49** (5.75)	**0.30** (13.16)	**0.88**	**6.51** (8.12)	**-0.07** (-1.45)	**0.06**
pard Parenthesis: t-statistic						

The structural transition models indicate that a change to negative emission elasticities developed, not upon reaching a unique income turning point, but as a result of historic exogenous
events around 1973. One does not need to look very hard for exogenous events at that time which could explain a structural transition in the CO_2 /GDP relation. CO_2 emissions are directly related to fossil fuel usage in an economy and thus can in some ways act as a surrogate for fossil fuel use with several caveats. The most important caveat is that CO_2 intensity of fossil fuels varies significantly from coal to natural gas. The timing of the transition corresponds with the oil price shock brought on by the 1973 oil embargo and it is common knowledge that the fossil fuel energy intensity of economic activity in many OECD countries stabilized or decreased following this event. Prior to the oil shocks, GDP growth and energy use, especially fossil fuel use, appeared to be inextricably linked. This relationship is clearly demonstrated in the pre-1973 period of our structural transition models. However in the period following the oil price shocks it has become clear that this is no longer a valid assumption. This fact is reflected in the post-1973

period of the structural transition models in which economic growth became delinked from energy use and CO_2 emissions, a trend that was further reinforced by the second price shock that occurred in 1979.

x3251Table 4: *Structural Transition Model as Panel*				
	Model 1950 - 1973		**Model** 1974 - 1992	
8 **Variable**	*Fixed Effects*	*Cross Section (OLS)*	*Fixed Effects*	*Cross Section (OLS)*
Intercept	—	-0.28 (-0.96)	—	0.26 (0.52)
GDP/Capita (x10^-3)	0.26 (36.80)	0.41 (10.74)	-0.07 (-4.63)	0.22 (5.58)
R squared	0.79	0.23	0.02	0.09
Parenthesis: t-statistic				

It could be argued that selection bias has resulted in the identification of a lower income turning point than other studies. We would point out, however, that these are the only countries that have passed through such a transition and it is therefore unlikely that historic data could accurately predict future transitions unless the EKC-like CO_2 /GDP relationship holds consistently. The structural transition models demonstrate that the CO_2 /GDP relationship is weak and that historic events and decisions, not income changes, have driven the transition.

The Third Order Polynomial

The structural transition model can also help explain how the significant cubic term is identified by EKC analysis, and why interpreting its presence as an indication of *future* increases in emissions by the countries of this data set is probably unwarranted. An explanation of why countries should suddenly experience increasing CO_2 emissions beyond a given income level was recognized as a problem by Sengupta (1996) who attributed it to the presence of Canada and the USA in the data set. These were the only countries that exceeded his income turning point level of $15,300 income level and Sengupta attributed their positive elasticities to their endowments of natural resources and the sectoral product-composition of their economies. In contrast, our structural transition modeling of Canada and the USA show no positive emissions elasticities beyond $15,300 per capita. On the contrary the USA and Canada pass through the same transition as the other countries in our data set, they just do so at higher income and CO_2 emissions levels.

We hypothesize that modeling the relation purely as a function of income forces results such as the third order polynomial to account for countries such the USA and Canada in the data set. There are three relative outlier countries in our data set which demonstrate turning points well above the mean: Luxembourg the USA and Canada, all of which are labeled in Figure 1. The results from the structural transition models show the GDP/CO_2 relation prior to 1973 to be approximately the same for all countries, so emissions growth rates for the countries were similar throughout the period. Thus the initial conditions at which the countries resume economic growth following World War II determines their level at the transition date in 1973, *ceteris paribus*. Due to historic circumstances, the U.S., Canada and Luxembourg began at higher levels of GDP and CO_2 emissions and thus make the transition at higher levels of the variables. Following the 1973 transition, the relation begins to fluctuate along an inelastic or declining trend leaving the outlier countries at higher levels than Japan and the European countries. The cubic term is therefore generated as these countries draw the correlative function upward at the higher income end.

To test this proposition we generated a third set of EKC models using the data set with the Luxembourg, USA and Canada excluded. The results of this model are presented in Table 5. As in previous estimations the fixed effects model appears to be the most successful in predicting the values of the dependent variable. The exclusion of the these countries result in an insignificant third-order polynomial in the fixed effects model which would confirm these countries importance in generating the cubic term effect. Since each of these countries undergoes the same transition there is little reason to expect future emission increases based on the present data. It appears then that the N-shaped curve is more the result of polynomial curve fitting that a reflection of any underlying structural relation.

Discussion

The presence of nonlinear systems dynamics in the emissions data, as demonstrated by the attractor analysis and the structural transition models, requires a different interpretation than that of the “income determinism” approach implicit in the EKC-type analysis. From the perspective of nonlinear systems dynamics, a more appropriate interpretation may be one of punctuated equilibrium, where emissions trajectories follow a regular, incremental path until subjected to a shock that leads to the establishment of a new trajectory or attractor. It is difficult to verify this type of dynamics for many pollutants due to the limited nature of most emissions data. Long time series are required for accurate assessment of dynamically changing systems and there are very few countries that have published such data.

Table 5: *EKC without Canada, USA, and Luxembourg*		
Variable	Fixed Effects	Cross Section (OLS)
Intercept	—	-0.77 (-2.39)
GDP/Capita (x10^-3)	0.52 (7.45)	0.62 (5.04)
GDP Squared (x10^-7)	-0.23 (-0.28)	-0.30 (-2.15)
GDP Cubed (x10^-11)	0.04 (l.35)	0.14 (0.28)
R Squared	0.82	0.38
Parenthesis: t-statistic		

One can envision many sources of shocks in complex socio-economic systems. In the CO_2 examples, the oil price shocks of the 1970's provided the impetus to change emissions trajectories. In the case of CFC emissions, the discovery of the ozone hole could be considered the shock which created an international regime and lead to a rapid, nearly co-temporal transition. Shocks appear to provide a sufficient incentive for new policy, both at the private and public level, to overcome what could be called the "socio-economic inertia" that maintained the previous trajectory. Policy changes as well can be considered systems shocks, such as the decision in the 1980's by the German government to require scrubber installation on all power plants.

The other important observation is the speed at which these systems can alter their trajectories. In the CO_2 examples, the change in trajectory occurred within a single year. The emissions levels then continued to be attracted to a stable emissions point even when economic growth resumed and oil prices declined. This demonstrates a capacity for rapid and persistent change under appropriate circumstances, something very important to consider when discussing the transition period for eco-restructuring in industrial countries.

In the inspection of the scatter plots we identified many countries that demonstrate a decrease in CO_2 emissions following the price shocks of the 1970's, however only the Type 1 countries were able to maintain sustained economic growth. This meant that in time series analysis, countries that did not maintain continual GDP growth could not generate the EKC effect. This is to be expected, of course, because the purpose of EKC analysis is to estimate the role of economic growth in environmental degradation. The results of the structural transition models, however, indicate that the ahistorical nature of the EKC analysis can be misleading. The EKC approach, even though trying to control for exogenous events, appears in the case of CO_2 to be misinterpreting an historical discontinuous change in the model parameters for a hypothetical income effect. Under these conditions pegging the transition to a given income level is not justified.

While the structural models do not indicate a critical GDP turning point, the level of economic development and wealth have apparently played a role. All of the 16 transition countries are OECD members and are among the wealthiest states globally. There is also a high level of economic interdependence and integration among these countries as well. Furthermore they are technologically advanced countries with substantial resources for innovative conservation and substitution measures in the face of fuel price shocks. Thus it could be inferred that while income levels are not a sufficient condition to cause a change in the CO_2 /GDP relation, a certain level of technological development and income were necessary to provide the resources needed to adapt to external shocks.

This observation is important for other EKC analysis as well, because historical transitions can only clearly be identified when one has a complete time series which includes the transition event. In most cases, the data sets used in EKC models have been incomplete time series and unbalanced and have required pooled cross-sectional techniques. The results of this study indicate that it is misleading to interpret EKC results in terms of a stages of income growth process that all countries must pass through. The existence of structural transitions also make the use of forecasts based on continuous EKC transitions questionable. It is unlikely any econometric model could have predicted the dramatic economic changes that occurred in the 1970's or the events that precipitated them. It is also unlikely that we can predict future structural discontinuities.

Unlike the EKC models, the structural transition models indicate the ability of economies to change rapidly given shocks or the appropriate conditions. Hence, in the face of shocks, structural transition models replace the "inverted-U" of the EKC with an "inverted-V." The models indicate an apparently permanent change from the previous relation, even after the removal of many of the factors that were in place at the time of the transition such as high energy prices. This observation should be encouraging to policy makers interested in reducing pollution emissions because it indicates that significant improvements in environmental quality can be obtained without halting the political imperative of economic growth. The difficulty will of course be in identifying the policies required to make similar transitions in the least disruptive manner, at lowest cost and at the lower incomes.

These results suggest an alternative to the implications of the EKC relationship: that "doing nothing" is the best policy because the problem will resolve itself as incomes rise. On the contrary, the structural transition identified here shows that lower emissions levels can be induced at different levels of income. The oil shocks produced a combination of effects, including high fossil fuel prices and a series of governmental policy initiatives, which certainly influenced the use of CO_2 emissions producing fuels. It is widely recognized, however, that in many countries some policy responses to the oil shocks were at crossed purposes, partially inducing conservation and partially encouraging continued energy use by preventing price rises to be felt at the consumer level.. Even so there was a perceptible change in energy intensities and therefore, derivatively, CO_2 emissions. Even with this uncoordinated response, the economies of the 16 countries in this study continued to grow in GDP terms. The global economic recession that followed the oil shocks is also controversial, with some analysts claiming that the oil price increases induced the contraction and other analysts claiming that misguided government interventions were responsible. In one study Bohi (1989) found, contrary to popular opinion, little evidence that the energy price shocks had important or lasting effects on macroeconomic performance. This should encourage policy makers to consider that well coordinated policies could result in reduction of CO_2 emissions without sacrificing long term economic performance. However the structural change models indicate that this should not be expected to occur "by itself" over time. In fact, the stabilizations in CO_2 emissions observed in the 16 countries is not sufficient to lower atmospheric concentrations. Due to its long residence time, the stock of CO_2 in the atmosphere will continue to rise unless major reductions in emissions occur.

Conclusions

This study has compared two models of the relation between environmental quality and economic growth. The main conclusions of this study are presented below:

- Sixteen industrial countries have passed through a discontinuous transition in their CO_2 /GDP emissions trajectory. Following the transition, countries demonstrate continued income growth without contemporaneous per capita CO_2 emissions growth. Thus earlier conclusions that CO_2 emissions will not decrease at higher incomes or that "turning points" occur at only very high incomes ($35,428), are incorrect.

- This transition to decreasing CO_2 emissions does not appear to correlate with specific income levels, as previous studies have indicated, but to a specific point in time, apparently in response to an historical exogenous shock to these economies.

- Countries are found to pass through the carbon transition simultaneously and rapidly indicating previously unrecognized short term adaptability.

- Much of the "inverted U-shaped relation" effect and the presence of the third order polynomial may be attributable to polynomial curve fitting rather than to underlying structural relationships. The findings of structural transition modeling do not support income as the decisive factor in a transition away from positive emissions elasticities.

- The use of EKC models to forecast future emissions behavior may not be appropriate as they do not account very well for the discontinuous changes identified in this study. The structural transition model provides a better description by accounting for historical shocks and the resulting market and regulatory responses, but is equally incapable of predicting future changes.

In addition, we suggest three reasons why the EKC methodology produces conclusions that differ from those of nonlinear dynamic systems approach.

- First, income is an inexact proxy for a number of factors including capacity for technological innovation, investment capital, basic science and technology knowledge, and the potential for existing technology to reduce emissions in pollution intensive industries. In addition, we expect learning curve effects for polluters and regulatory regimes which can become available internationally to other public and private institutions over a broad GDP range.

- Second, the EKC methodology determines a statistical correlation of pollutant emissions and GDP among many countries either at a single point in time or among many countries at different times. It then infers from this static correlation a time evolution for individual national pollution trajectories that is dependent upon GDP. It does not seem appropriate in the case of pollutant emissions to infer a GDP dependent dynamic equation of motion for a national pollution trajectory from a such a static analysis.

- Third, due to the history of environmental data collection, most available time series begin at the end of the 1970's or even later. Many developed countries had already initiated downward trends for many pollutants by this time and it is therefore not possible to identify the date of the transition with available data. Thus EKC methodology may be missing the possibility that transitions began relatively simultaneously as a result of exogenous factors, as appears to be the case for countries that have stabilized per capita CO_2 emissions while maintaining income growth.

An examination of the actual dynamic trajectory of individual nations, either in a pollution/GDP development plane (Moomaw and Tullis, 1994) or by utilizing phase diagrams, demonstrates that the actual behavior of individual pollution trajectories depends on many internal policy decisions and exogenous factors. We recognize, as most EKC researchers do, the desire, and potential to achieve improved environmental quality in all countries. We agree most strongly with the findings of the early EKC studies, especially World Bank (1992), that policy choices and resource prices are the principle cause of these transitions. Wealth may be a conditioning factor that allows certain countries to be "first movers" but low income need not be a hindrance to other countries in achievinglower pollution levels in the future

The reconciling ofeconomic growth and environmental quality is at the heart of the searchfor "sustainable development."EKC models implythat economies can reach a stage of relative environmental improvement if income levels are high enough. In other words, environmentaldegradation does not necessarily increase as income grows. EKC models have not,however, provided any understanding of the processes underlying thereduced form function they generate. In contrast, the structuraltransition models presented here indicate the existence of rapid changes in response to historical events that have resulted in an improved emissions/GDP relation. While they have not identified the underlying processes either, they have at least tied them to historical events and a given time period. Further research is underway to identify the effective actions taken during the structural transition identified in this study.

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