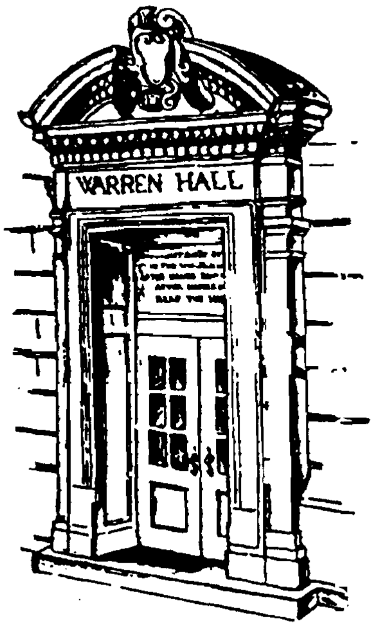
WP 97 - 07
July 1997



Working Paper

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Is There an Environmental Kuznets Curve for Energy?
An Econometric Analysis

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ABSTRACT

The Environmental Kuznets Curve (EKC) hypothesis states that pollution levels are increasing as a country develops, but will begin to decrease as rising incomes pass beyond a turning point. EKC analyses test the relationship between a measure of environmental quality and income (usually expressed in a quadratic equation). Other explanatory variables have been included in these models, but income regularly has had the most significant effect on indicators of environmental quality. One variable consistently omitted in these relationships is energy prices. This paper analyzes previous models to illustrate the importance of prices in these models and then includes prices in an econometric EKC framework testing energy/income and CO_2/income relationships. These long-run price/income models find that income is no longer the most relevant indicator of environmental quality or energy demand. Indeed, we find no significant evidence for the existence of an EKC within the range of current incomes for energy in the presence of price and trade variables.

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I. Introduction

The Environmental Kuznets Curve (EKC) hypothesis states that pollution levels are increasing as a country develops, but will begin to decrease as rising incomes pass beyond a turning point. This is reflected as an inverted-U curve, expressing the relationship between pollution levels and income. This hypothesis was first proposed by Grossman and Krueger (GK) in 1992, and restated by them in 1995.[1] In their view it arises from a complex set of relationships that have not yet been fully identified. They note that:

> "[a]n alternative to our reduced-form approach would be to model the structural equations relating environmental regulations, technology, and industrial composition to GDP, and then to link the level of pollution to the regulations, technology and industrial composition." (GK, 1995, p. 360)

One variable that has consistently been omitted in the conceptualization of the EKC relationship is energy prices. The interaction between pollution and energy prices is explainable through economic theory and is clearly illustrated in the following stylized facts. Total carbon (CO_2) emissions declined from 1979 to 1982, corresponding to the steep, brief spike in oil prices in the late 70s and early 80s (crude oil reached a peak of $50/barrel in 1980 (Brown et al., 1996; in 1994 US$)). Since 1985, as nominal oil prices have stabilized in the $15 to $20 per barrel range, there has been a steady

[1] The first mention of the Environmental Kuznets Curve can be traced to a paper by T. Panayotou (1993) written for the World Employment Programme Research Working Paper series. The first use of it in an academic journal was by Selden and Song (1994). The original Kuznets "Inverted-U" hypothesis refers to the relationship between income inequality and per capita income - that in early stages of economic growth the distribution of income worsens, while at later stages it improves (Kuznets, 1955).

increase in CO_2 emissions (Brown et al.). The pattern is consistent across developing and industrialized nations.

The EKC hypothesis has usually been investigated by analyzing the relationship between a specific pollutant (ambient concentrations of sulfur dioxide (SO_2), suspended particulate matter (SPM), etc.) and income. This practice has developed because of the widely available UNEP data on pollution concentration levels in urban areas (UNEP, 1991). However, since emission sources are strongly influenced by location of rural natural resource extraction, a country's urban concentrations of SO_2 in many cases do not reflect that country's sulfur emissions. This is particularly true with respect to copper ore smelting, oil refining and desulfurization, and natural gas processing and desulfurization. Since energy is used everywhere, and most forms of energy use release pollutants, we add to the EKC literature by evaluating the relationship between energy use and income to determine if the EKC exists here as well. Also, because CO_2 arises everywhere from fossil energy use,[2] we examine the CO_2-income relationship for an EKC curve and examine the impact of nuclear and hydro-electric power on that curve.

This paper tests three related propositions: (i) there will be an EKC for energy, (ii) trade is an important structural aspect of the EKC, and (iii) energy prices strongly influence the EKC.

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[2] Of course, anthropogenic CO_2 originates from other sources, but oil, natural gas, and coal use always release CO_2.

II. Review of EKC Findings

Grossman and Krueger (GK) initiated this research in 1992 with an analysis of the relationship between air quality and economic growth. This work hypothesized what would later come to be called the Environmental Kuznets Curve (EKC). They hypothesized that for certain pollutants, concentrations would increase at low levels of per capita income, but decrease with GDP growth at higher income levels. GK (1992) estimated the relationship between concentrations of several pollutants (SO_2, SPM, and dark matter)[3] and GDP using a cubic functional form. A time trend and fixed-effect variables were utilized to detect technological change, country, climactic and measurement differences. They also included the ratio of the sum of exports and imports to GDP to capture trade effects. In a revised version of their original paper, GK (1995) confirmed their earlier results on air quality and expanded their research to evaluate water quality issues as well.

Their model has since been duplicated using other measures of environmental quality and additional explanatory variables (Shafik and Bandyopadhyay (SB), 1992; Selden and Song (SS), 1995; Agras, 1995; Suri and Chapman (SC), forthcoming; Tucker, (1995); Holtz-Eakin and Selden (H-ES), (1995); and others[4]). The common thread that runs through all these models is estimating the quadratic relationship

[3] These data were collected by the Global Environmental Monitoring System (GEMS) and are readily available through UNEP (1991).

[4] There are forthcoming special issues on the EKC in both *Ecological Economics* and *Environment and Development Economics*.

between per capita income[5] and some measure of environmental quality to generate the inverted-U shape of the EKC.

SB (1992) used GK's original measures of environmental quality, as well as new variables for lack of safe water, lack of urban sanitation, annual deforestation, municipal solid waste per capita, CO_2 per capita, and others, as dependent variables. They added explanatory variables for investment shares, electricity tariffs, debt per capita, political rights, civil liberties, and three different types of trade variables. In the end, they concluded that income has the most significant effect of all the indicators of environmental quality that they tested.

SS (1994) examined the relationship between country level per capita emissions of SO_2, SPM, nitrogen oxides and carbon monoxide and a quadratic function of GDP and population density. They used both fixed-effects and random-effects models, with and without the population density variable, and consistently achieved good results - highly significant statistics and the anticipated signs on their variables.

A comparison point for all of these models is the turning point of the quadratic relationship between income and pollution, that is the point at which countries will begin to demand better environmental quality. For SO_2, SB's turning point was consistent with GK, at around $5,000 per capita income. Agras found an Asian turning point of $6,654, while SS consistently found turning points of over $8,500. From their results, SS projected future global emissions for SO_2 and other pollutants, and found that emissions would be increasing through the year 2100 in most cases.

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[5] Usually taken from the Penn World Tables (Summers and Heston, 1985). All income variables are in 1985 international prices, unless otherwise stated.

One concern in these analyses is the lack of, or poor representation of trade. The trade variable used by most authors is the ratio of the sum of exports and imports to income ((X+M)/GDP). This variable captures total trade, but may not reflect the impact of the differential competition between imports and exports.

Wycoff and Roop (WR, 1994) emphasized this point when they found that the total carbon embodied[6] in imports for six countries[7] was one-fifth of the amount produced annually by the US, more than is generated by Japan, and double that produced by France or Canada. The percentage of carbon embodiment in imports of manufactured goods to total carbon emissions ranges from just 8% for Japan and the US to over 40% for France. This illustrates the importance of including trade as an explanatory variable for changing pollution levels within nations.

SC (forthcoming) included the ratio of imports and exports of all manufactured goods to domestic production of manufactured goods in an EKC framework. The coefficients of these two variables were expected to be negative and positive, respectively - lower emissions with increased imports and higher emissions with increased exports. With per capita energy use as the dependent variable, they found turning points for per capita income from $54,000 to over $200,000 with the inclusion of the trade variables. For the most part, the trade variables were of the correct signs and highly significant. Their work shows that trade in manufactured goods has an important structural effect on per capita energy use.

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[6] Embodied refers to the total carbon released from energy used in production of commodities.

[7] The countries included Canada, France, Germany, Japan, United Kingdom, and the US.

Recently, several authors have estimated EKCs for CO_2 emissions. Holtz-Eakin and Selden (H-ES, 1995) do a traditional EKC analysis with CO_2 as the dependent variable. Turning points were estimated at $35,428 with a quadratic function and $8 million with a log quadratic specification. Their forecasts of future CO_2 emissions fall within the range of other well-known projections (Nordhaus and Yohe, 1993; Reilly et al., 1987; Manne and Richels, 1992).

Tucker (1995) also looks at changes in CO_2 versus income, but in yearly cross-sectional analyses. Within the time period 1971-1991 (especially from 1977 -1991), in a quadratic relationship, he finds that the coefficients shift in a continuous pattern, such that the turning point is decreasing over time. He also notes that changes in CO_2 emissions are clearly related to changes in oil prices.

The current focus on the EKC has arisen out of the trade, environment, and development debate. However, there is analogous interest in the climate change literature about a related concept, autonomous energy efficiency improvement. The leading authors in this field (Manne and Richels; Nordhaus[8]) assume that energy use and CO_2 emissions, each per dollar of world gross economic product (energy intensity and carbon intensity), will decline into the indefinite future. Perhaps implicitly there is an unstated assumption that at some prior period there was a growth in this ratio which is now declining.

In general, energy and carbon intensity in the high income countries have on the whole been declining, while rest of the world ratios of carbon intensity have been

[8] Manne and Richels, 1992; see especially pages 30-34. Nordhaus, 1994; see especially pages 66-70.

increasing in the last two decades. The net impact in the last three decades of the 20th Century appears to be stability in the overall ratio of CO_2 to GDP and perhaps a very slight insignificant increase in energy use per dollar of world GDP (Nordhaus, 1994; Khanna and Chapman, 1997).

Notwithstanding Manne and Richels' projection of improving autonomous energy efficiency into the future, they summarize the existing literature on the point in this way: "econometric investigations of the US post-1947 historical record show no evidence for autonomous time trends of energy conservation" (Manne and Richels, 1992, p. 32).

Arrow, et al. in their widely discussed *Science* essay (1995), raised several critical points with regard to the EKC concept. They note that the relationship has only been demonstrated for a few pollutants, especially those with short-term environmental costs, and that these relationships represent the effects on emissions, not on stocks. Furthermore, reductions in one pollutant, may be at the expense of others, with an unknown effect on overall, national or world, environmental quality.

In summary, the EKC literature, as well as the related work on autonomous energy efficiency, find that as incomes rise, there is a domain of incomes over which per capita measures of environmental degradation, or pollution, or energy use declines. In general, neither trade nor energy prices have been considered to be important explanatory factors. This study provides interpretive analysis of the EKC with the incorporation of trade variables and energy prices.

III. The Use of Quadratic versus Log Quadratic

All of the EKC studies use functional forms where results can be evaluated with respect to the presence or absence of a turning point and the significance of its parameters. The form may be either quadratic or log quadratic. With the latter, the analysis of the relationship between some measure of environmental degradation, ED, and real per capita GDP, Y, and other variables, Z (for example, population density, trade, investment, etc.), takes the following form:

$$ln(ED_{it}) = \alpha_i + \gamma_t + \beta_1 ln(Y_{it}) + \beta_2 \{ln(Y_{it})\}^2 + \beta_k ln(Z_{it}) + \varepsilon_{it} \qquad (1)$$

where, α_i is a fixed country or site-specific effect, γ_t is a fixed time effect, i is a country index, t is a time index, and ε_{it} is a stochastic error term.

The turning point values are

$$Y(TP) = -\beta_1/2\beta_2 \text{, for quadratic functions, and} \qquad (2a)$$

$$Y(TP) = e^{-\beta_1/2\beta_2} \text{, for log quadratic functions,} \qquad (2b)$$

where β_1 is the coefficient for the income variable and β_2 is the coefficient for the income squared term.

The choice of quadratic versus log quadratic depends on the anticipated shape of the relationship. The quadratic model assumes a symmetrical curve where increases in environmental degradation on the upward slope are exactly offset by decreases on the downward side, implying that pollution decreases as quickly as it increases. A model in log quadratic assumes a quicker increase as a country industrializes, with a more gradual decrease on the downward slope as a country becomes less energy intensive, switches to more service industries, or begins importing more pollution intensive goods. Figure 1 graphically illustrates these relationships.

Results from both types of models have been extensively reported in the literature. GK (1995) and SS (1994) used quadratic relationships, while SB (1992), SC (forthcoming), and Panayotou (1993) used log quadratic specifications. Unfortunately, these models are not directly comparable. Although they all use GDP and GDP squared, they use different pollutants as measures of environmental degradation and different sets of explanatory variables. H-ES (1995) report results for both quadratic and log quadratic specifications in their analysis of the relationship between per capita CO_2 emissions and per capita income. For the most part, the results are consistent across the two analyses, however, drastically different turning points of $35,000 and $8 million for the quadratic and log quadratic functions, respectively, are reported.

Figure 2 shows the relationship between per capita CO_2 emissions and per capita income. For most of these models it is difficult to say anything about the rate of increase versus the rate of decrease because the turning points calculated fall outside of the range of data. The choice of quadratic versus log quadratic must be made by what the researcher feels will happen in the future - will the improvement in environmental quality happen as quickly as the deterioration, or will it take much longer for countries to reduce their emissions than it did for them to increase their emissions? In our perspective, the latter seems the more likely alternative and the rest of this paper will concentrate on logarithmic models of the EKC.

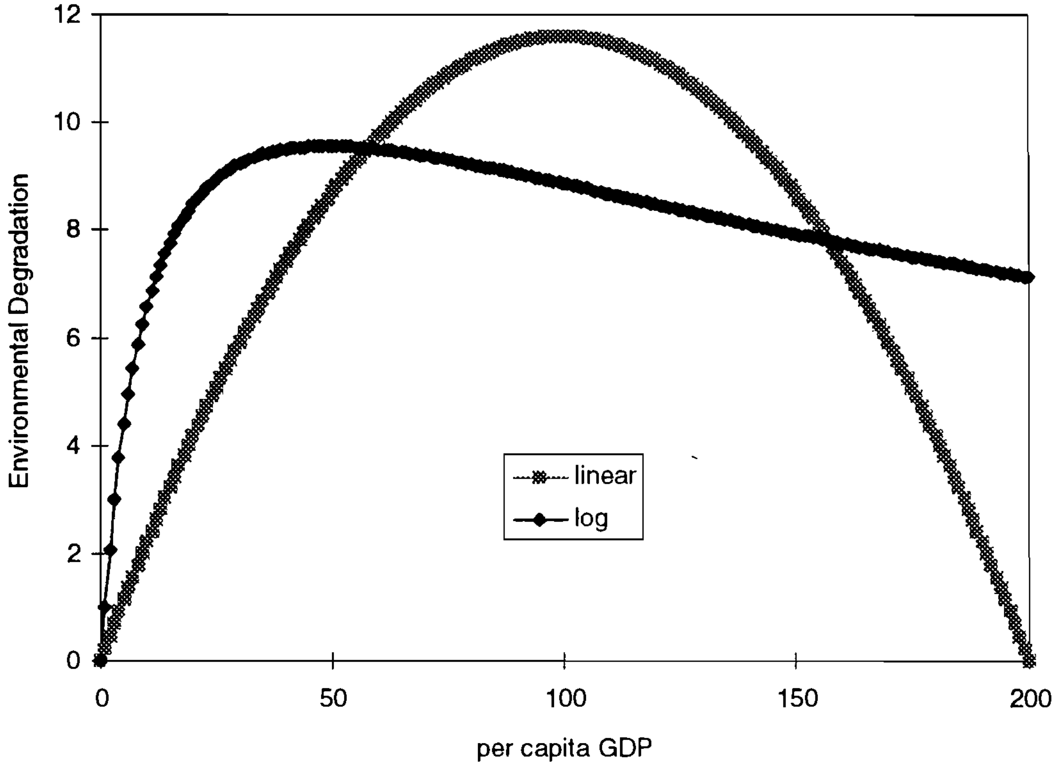

Figure 1: Quadratic versus Log Quadratic Relationship

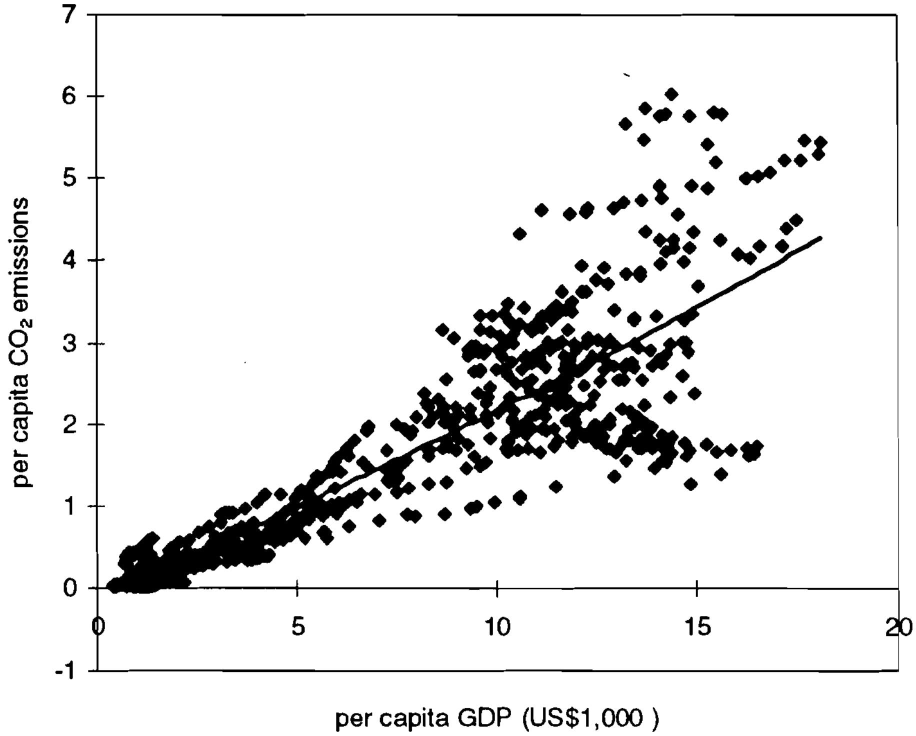

Figure 2: World Per Capita CO_2 Emissions versus GDP with Quadratic Trend Line

Source: CO_2 data are from ORNL (1992).
Income data are from Summers and Heston (1991).

IV. Inclusion of Year and Country Effects

Many of the models mentioned above used fixed country and/or time specific intercepts. GK and SB included site specific variables to isolate the effect of the location of the testing site, the land use of the area near the site, coastal sites, and sites located in communist countries. They included a time trend, but neither fixed year nor country specific variables. SS, H-ES and SC used fixed country and year effects. These intercepts capture other variables that are often not measurable. Country or site specific variables capture factors such as resource endowments, climate, geography and culture. Year specific intercepts capture factors that evolve over time, such as energy prices and technological change. However, none of these papers analyzed the country or time specific intercepts. We examine the time, γ_t, and country, α_i, coefficients for the following model:

$$ln(E_{it}) = \alpha_i + \gamma_t + \beta_1 ln(Y_{it}) + \beta_2\{ln(Y_{it})\}^2 + \beta_3 ln\left(M/_{GDP}\right) + \beta_4 ln\left(X/_{GDP}\right) + \varepsilon_{it} \tag{3}$$

which tests the relationship between per capita energy use, E; real per capita GDP, Y; and trade variables, represented by the ratio of imports of all manufactured goods to domestic production of all manufactures (M/GDP) and the ratio of exports of manufactured goods to domestic manufacturing production (X/GDP).[9]

[9] The data for the energy, income, and trade variables comes from IEA (various years); Summers and Heston (1991); and the UN (1991/1992), respectively.

IV.a. Time Specific Intercepts

The inclusion of variables for individual years can capture the change in energy (oil) prices over the time period. Figure 3 shows the movement of gasoline prices (Chapman, 1995; in real $) and the time specific intercept for the estimated energy model. There is an obvious lagged response in the coefficient to changes in oil prices. A rise in oil prices from 1978 to 1980 corresponds to a significant decrease in the value of the time coefficient. This indicates that, holding all else constant, countries are using less energy per capita as energy prices increase. Similarly, a price decrease from 1981 is shortly followed by an increase in the time coefficient as countries re-adjust to lower prices and become less concerned about conserving energy. Since the time coefficients track a change in energy prices, this could be an important variable that has previously been omitted.

IV.b. Country Specific Effects

As previously discussed, fixed country effects capture factors such as resource endowments, climate, geography and culture. For example, consider the US and Japan which both have comparably high income levels. The US has a large coal and energy endowment, and consumes more energy per capita than Japan which imports almost all of its energy. Or consider Latvia, a Baltic country with a cold climate, and Thailand, an Asian country with a warm climate, with comparable incomes. Latvia uses more energy per capita, in part because of greater heating requirements.

Ranking the countries by their country coefficients illustrates some visible trends (see Figure 4[10]). Climate and resource endowment emerge as potentially significant

[10] The US is the index country. The coefficients reflect the difference between each country and the US.

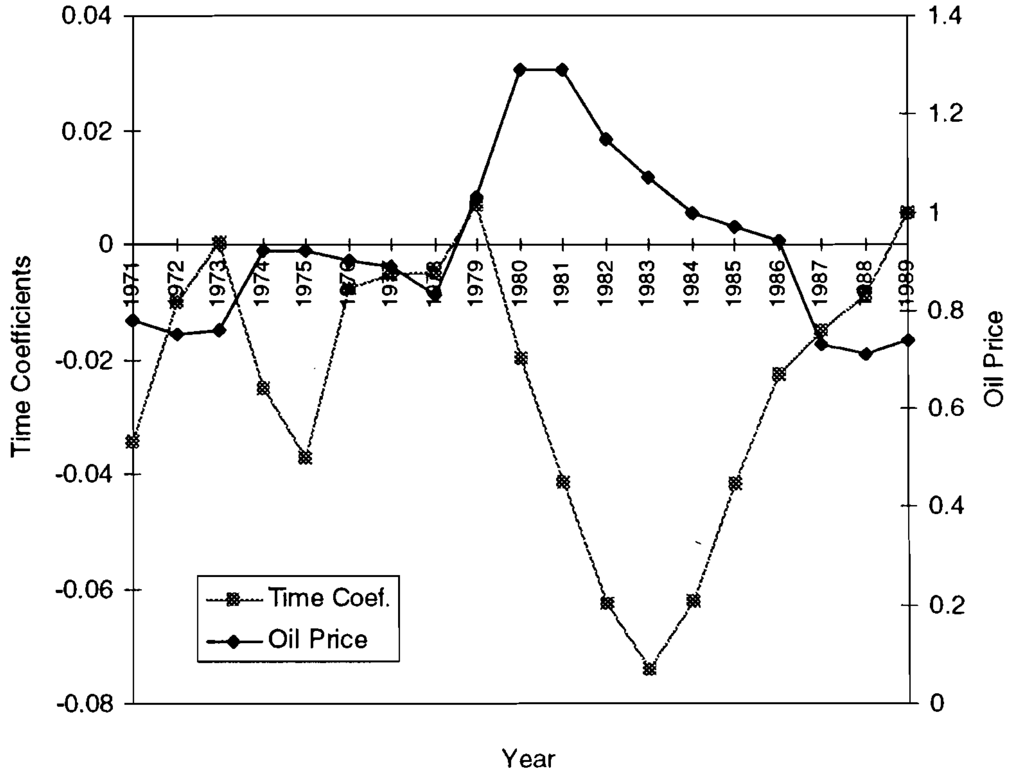

Figure 3: Trend of Oil Prices and Time Coefficients for Ln Energy Model

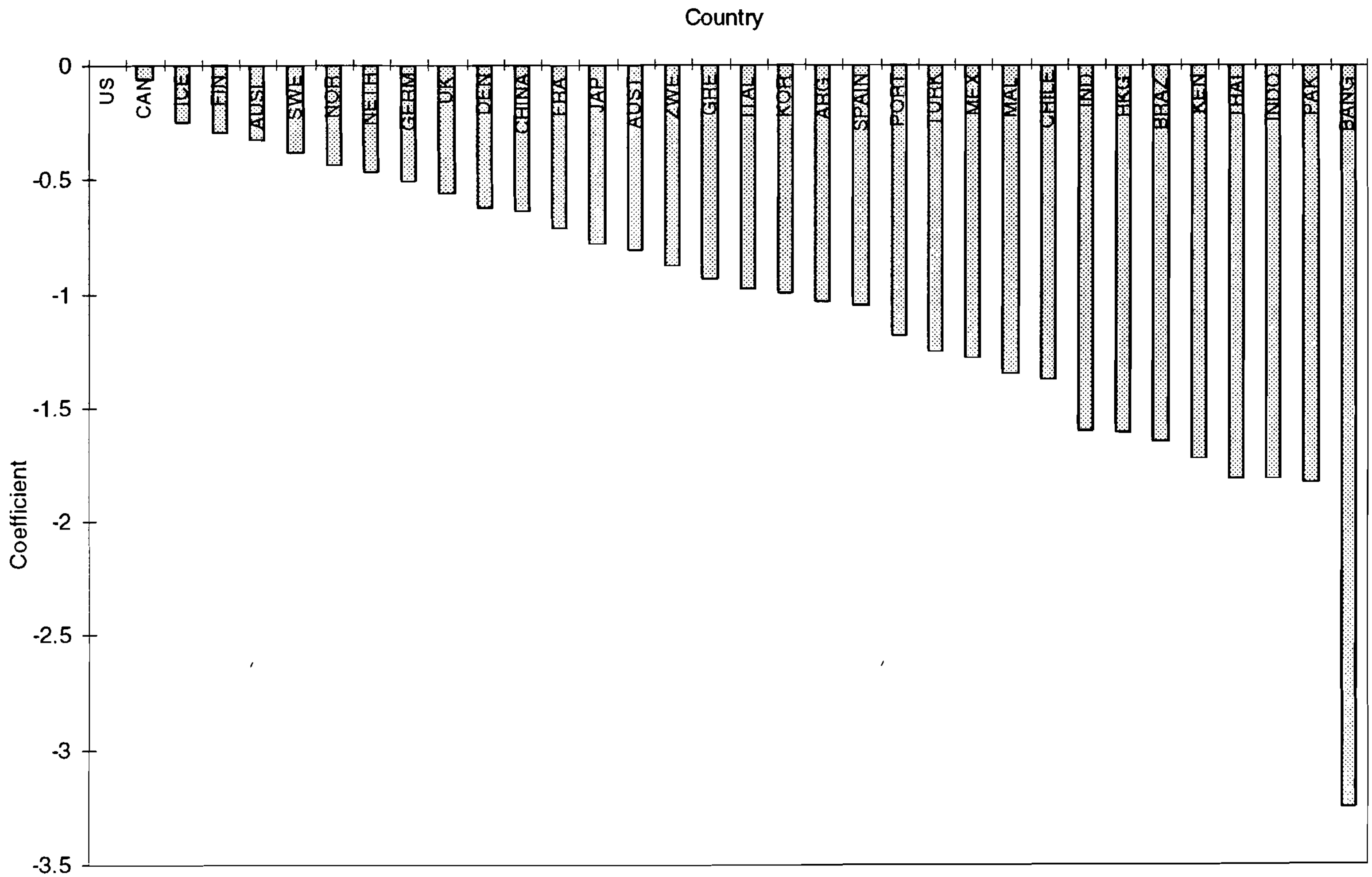

Figure 4: Country Coefficients for Ln Energy Model

NOTE: See Appendix A for explanation of country abbreviations variables. The country coefficients for Canada, Iceland, Finland, Australia, Sweden, Norway, and the Netherlands rank the highest of all the countries. These countries consume more energy for heating than warmer climate countries, such as Greece, India or Korea. Of the countries with warmer climates, China and Zimbabwe rank fairly high. Both countries have large coal endowments, indicating that resource availability may contribute to per capita energy demand. Japan ranks quite low, possibly because of their lack of resource endowment. Importing almost all of their energy gives rise to greater energy efficiency.

V. Energy versus CO_2 as the Dependent Variable

EKCs have been estimated for many measures of environmental quality. However, the relationship between per capita energy and income is only analyzed by SC (forthcoming). A direct comparison can be made between energy and CO_2, since CO_2 data is calculated from energy use data. Since most forms of energy create pollutants, the relationship between energy use and income should also exhibit EKC tendencies.

One problem when using energy as a measure for environmental quality is that it lumps all energy sources together, without accounting for type of energy used. Countries using nuclear or hydroelectric power could have energy intensities equivalent to those countries that are more dependent on coal, but nuclear and hydro will be less carbon intensive. Secondly, energy use statistics don't account for abatement technologies, which makes an EKC analysis of the energy/income relationship less comparable to SO_2 or SPM than it is to CO_2.

Substituting per capita CO_2 (ORNL, 1992) into equation (3) as the dependent variable should yield similar results overall, but with a few specific differences. Firstly, the country coefficients will show a reordering. Countries that use more natural gas, nuclear, and hydroelectricity will have smaller country coefficients relative to the US. Countries with a high dependence on coal reserves will have higher coefficients. Secondly, the turning point may be lower, since countries can reduce CO_2 by switching to less carbon intensive fuels, while not affecting the amount of energy used.

Table 1 shows the results of a model similar to that used by SC. It compares the estimation results of an energy and a CO_2 model. As expected, the results are quite similar. The turning point is considerably lower in the CO_2 model, but still falls outside of the range of data points. As discussed above, the lower turning point comes about by switching from carbon intensive energy sources to less carbon intensive sources such as natural gas, nuclear or hydroelectric power. During the energy crisis in the 1970s there was a large increase in these types of energy sources, causing the turning point to be lower for the CO_2 model than for the energy model.

Changes in the time and country effects support hypotheses stated above. Figure 5 shows the trends of the time coefficients for the CO_2 model and oil prices over the time period. The pattern is similar to Figure 3 up to 1983. In the CO_2 model, the time coefficients are stable until 1979 and then there is a marked decrease until 1983, corresponding to the increase in the price of oil from 1978 to 1980. This pattern is consistent with the time coefficients in the energy model. However, after 1983 the trend of the CO_2 time coefficients differs from the energy model. In the energy model,

Table 1: Estimation Results for Ln Energy and Ln CO_2 Models[a]
(standard errors in parentheses)

	per capita Energy Model	per capita CO_2 Model
ln GDP	1.159*** (0.055)	1.312*** (0.077)
(ln GDP)^2	-0.121*** (0.017)	-0.153*** (0.024)
ln M-MFG	-0.032** (0.016)	-0.030 (0.022)
ln X-MFG	0.087*** (0.014)	0.090*** (0.019)
R^2	.9865	.9676
Turning Point	$121,487	$72,793

[a] Energy is per capita and measured in oil equivalents. CO_2 is per capita and measured in metric tons. Income is per capita and measured in thousands of 1985 international prices. M-MFG and X-MFG represent imports and exports, respectively, of manufactured goods as a proportion of manufactured goods produced domestically.
* Coefficient estimate is significantly different from zero at 0.10 level.
** Coefficient estimate is significantly different from zero at 0.05 level.
*** Coefficient estimate is significantly different from zero at 0.01 level.

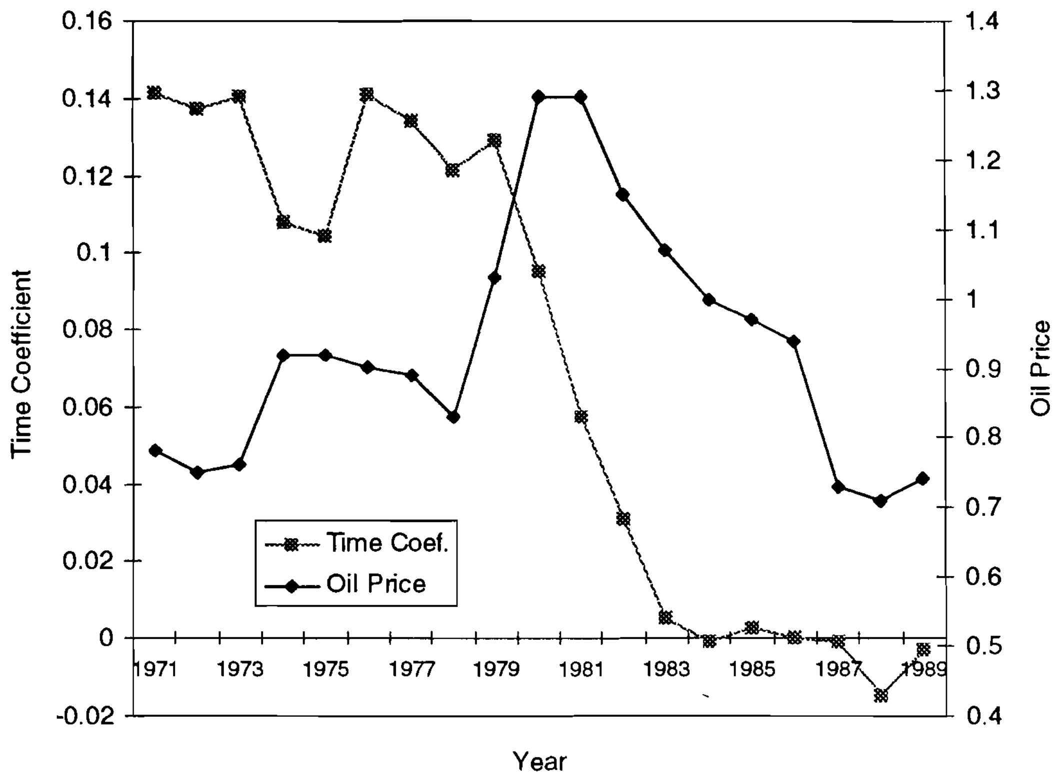

Figure 5: Trend of Oil Prices and Time Coefficients for Ln CO_2 Model

there is a dramatic increase in the coefficients as the real price of oil declines. In the CO_2 model this does not occur. After 1983, the level of the coefficients remains constant. This may be caused by countries having switched from oil to natural gas and other less carbon intensive fuels when oil prices were increasing. After the price of oil decreases, these changes in energy use remained, and there was a leveling out of per capita carbon consumed.

Similarly, the country coefficients in the CO_2 model differ from the energy model (see Figure 6). China records the second highest country coefficient in the CO_2 model, just after the US. All the other countries consume less per capita CO_2 than the US and China, but there is a marked difference in the lead countries. Zimbabwe has moved up and the top countries are larger users of domestic coal sources. France moved from 13th to 18th, reflecting their dependence on nuclear energy. However, even with these changes, there is still a general ordering by cold climate-developed country to warm climate-developing country.

VI. The Inclusion of Energy Prices in EKC Analyses

As described in the previous two sections, the price of energy is a potentially important variable that has been omitted from other models. Many of the models capture changes in energy prices through fixed time effects, but none have explicitly included it as an independent variable. In this paper we add the price of energy to two EKC relationships - one estimating the relationship between per capita energy and income and the other with per capita CO_2 emissions. We have also included a lagged dependent variable to capture short-run and long-run changes. The relationship

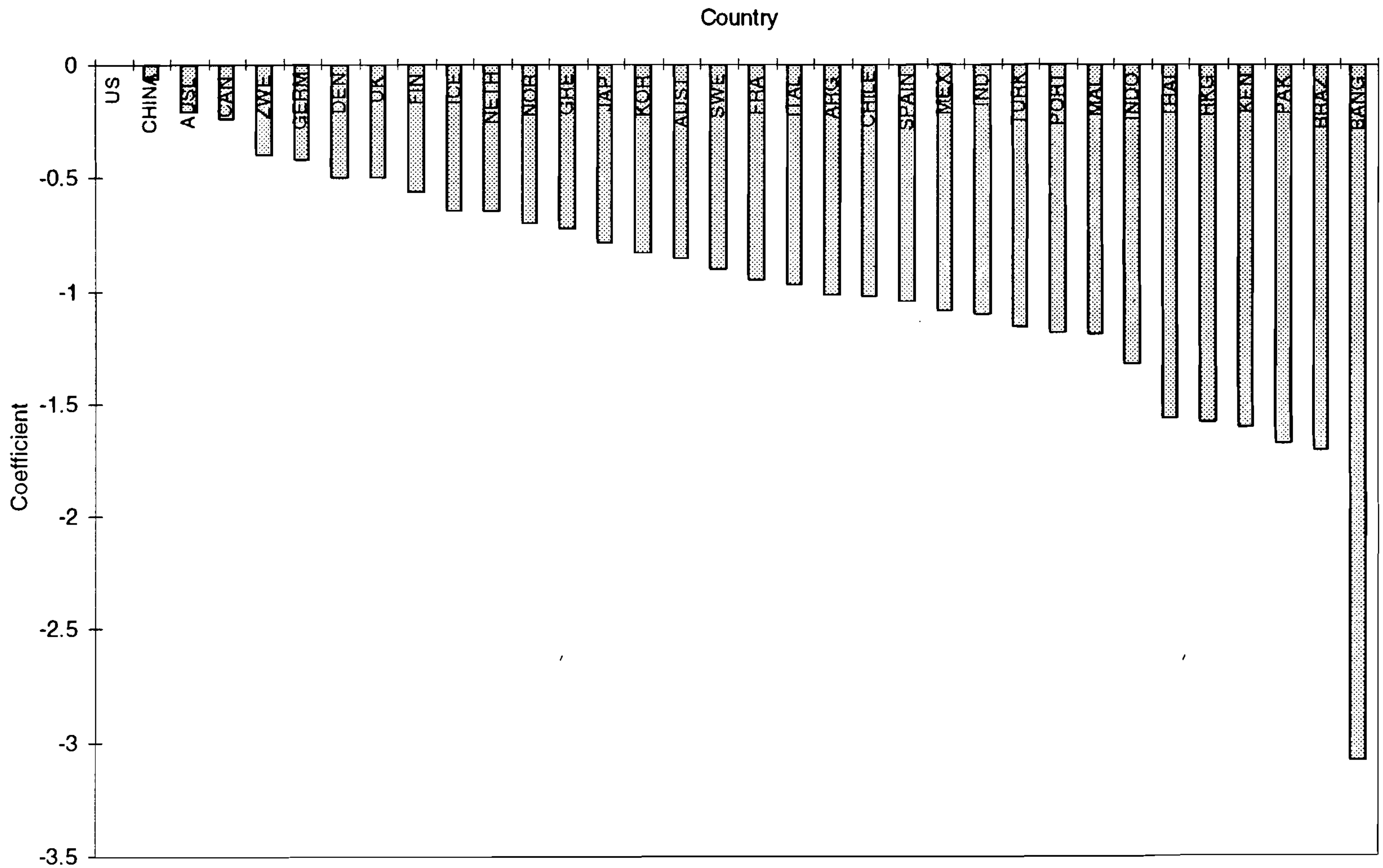

Figure 6: Country Coefficients for Ln CO_2 Model

NOTE: See Appendix A for explanation of country abbreviations.

between per capita energy consumption, E, per capita income, Y, and the price of oil in the US, P, takes the form

$$E_{it} = A_{it}(E_{it-1})^{\beta_1}(P_{it})^{\beta_2}(Y_{it})^{\beta_3}\left(e^{\beta_4(\ln Y_{it})^2}\right)(Z_{it})^{\beta_5} \qquad (4)$$

where i is the country, t is the year, and *Z* represents the same trade variables used in equation (3). By taking a logarithmic transformation of this model and including the country effects, α_i, the model resembles that used by SB and SC with the addition of the price of energy and the lagged dependent variable.

$$\begin{aligned} \ln(E_{it}) = {} & \ln(A_{it}) + \beta_1 \ln(E_{it-1}) + \beta_2 \ln(P_{it}) + \beta_3 \ln(Y_{it}) + \\ & \beta_4 \{\ln(Y_{it})\}^2 + \beta_5 \ln(Z_{it}) + \alpha_i \end{aligned} \qquad (5)$$

With this formulation the time response parameter, β_1; the short-run elasticity for the price of oil, β_2; the long-run price elasticity, $\beta_2/(1-\beta_1)$; and the turning point for income $e^{-\beta_3/\beta_4}$ are easily calculated. β_2 represents a rate of use effect, highlighting immediate changes made by individuals/companies in response to changes in energy prices. The difference between the short-run and long-run price elasticities is the capital investment effect, illustrating changes in investments of capital and stock over a longer time period.

Tables 2 and 3 present the estimation results. First, a few econometric issues concerning i) autocorrelation and ii) multicollinearity need to be discussed. SC (forthcoming) noted first order serial correlation in the residuals in their analysis of the relationship between per capita energy and per capita income. This was corrected for

Table 2: Estimation Results of Lagged Dependent Model for Ln Energy[a] (standard errors in parentheses)

	Without GDP or trade variables	With GDP, but without trade	With GDP and trade variables
$\ln(E)_{-1}$	0.999*** (0.003)	0.893*** (0.014)	0.763*** (0.023)
ln(P)	-0.068*** (0.011)	-0.082*** (0.011)	-0.089*** (0.011)
ln(GDP)	--	0.129*** (0.028)	0.311*** (0.036)
$\{\ln(GDP)\}^2$	--	-0.013* (0.008)	-0.038*** (0.008)
ln(M-MFG)	--	--	0.006 (0.009)
ln(X-MFG)	--	--	0.0006 (0.007)
number of obs.	759	676	631
R^2	.9987	.9988	.9989
Durbin m statistic[b]	5.695**	5.245**	10.258***
SR Price Elasticity	-0.068	-0.082	-0.089
LR Price Elasticity	-50.18	-0.766	-0.375
SR Income Elasticity	--	0.079	0.165
LR Income Elasticity	--	0.738	0.697
GDP Turning Point	--	$142,813	$59,218

[a] Energy is per capita and measured in oil equivalents. Price of energy is US oil prices normalized so that 1984=1. Income is per capita and measured in thousands of 1985 international prices. M-MFG and X-MFG represent imports and exports, respectively, of manufactured goods as a proportion of manufactured goods produced domestically.

[b] The Durbin m test is a special case of the Breusch-Godfrey test of higher-order autocorrelation used when the autoregressive scheme is of the first order. The statistic is based on a χ^2 distribution with one degree of freedom.

* Coefficient estimate is significantly different from zero at 0.10 level.

** Coefficient estimate is significantly different from zero at 0.05 level.

*** Coefficient estimate is significantly different from zero at 0.01 level.

Table 3: Estimation Results of Lagged Dependent Model for Ln CO_2[a]
(standard errors in parentheses)

	Without GDP or trade variables	With GDP, but without trade	With GDP and trade variables
$\ln(CO_2)_{-1}$	0.997*** (0.004)	0.929*** (0.014)	0.836*** (0.022)
ln(P)	-0.071*** (0.014)	-0.083*** (0.014)	-0.080*** (0.015)
ln(GDP)	--	0.087*** (0.034)	0.256*** (0.042)
$\{\ln(GDP)\}^2$	--	-0.013 (0.009)	-0.049*** (0.011)
ln(M-MFG)	--	--	0.031** (0.012)
ln(X-MFG)	--	--	-0.014* (0.009)
number of obs.	806	695	634
R^2	.9974	.9973	.9976
Durbin m statistic[b]	8.678***	4.303**	3.143*
SR Price Elasticity	-0.071	-0.083	-0.080
LR Price Elasticity	-27.18	-1.159	-0.490
SR Income Elasticity	--	0.036	0.067
LR Income Elasticity	--	0.502	0.411
GDP Turning Point	--	$26,019	$13,483

[a] CO_2 is per capita and measured in metric tons. Price of energy is US oil prices normalized so that 1984=1. Income is per capita and measured in thousands of 1985 international prices. M-MFG and X-MFG represent imports and exports, respectively, of manufactured goods as a proportion of manufactured goods produced domestically.
[b] The Durbin m test is a special case of the Breusch-Godfrey test of higher-order autocorrelation used when the autoregressive scheme is of the first order. The statistic is based on a χ^2 distribution with one degree of freedom.
* Coefficient estimate is significantly different from zero at 0.10 level.
** Coefficient estimate is significantly different from zero at 0.05 level.
*** Coefficient estimate is significantly different from zero at 0.01 level.

using an autocorrelation procedure. Presumably, a similar model estimated here would encounter the same problem. However, the inclusion of a lagged dependent variable usually alleviates this problem. Serial correlation was tested for in the energy and CO_2 models using the Durbin *m* test and the results are reported on Tables 2 and 3. In most of the models there was no evidence of autocorrelation.

The problem of multicollinearity is less easily detected and alleviated. Table 4 shows the correlation matrix for all the variables used in the energy model. There is high correlation between many of the variables. However, the general "rules of thumb" used to identify multicollinearity indicate that it is not evident in either the energy or CO_2 models estimated.

Table 4: Correlation Matrix for Energy Model Variables

	Energy	$Energy_{-1}$	Price	Income	M-MFG	X-MFG
Energy	1.00	0.999	0.006	0.945	0.015	0.346
$Energy_{-1}$	0.999	1.00	0.017	0.944	0.013	0.345
Price	0.006	0.017	1.00	0.012	0.002	-0.043
Income	0.945	0.944	0.012	1.00	0.057	0.365
M-MFG	0.015	0.013	0.002	0.057	1.00	0.466
X-MFG	0.346	0.345	-0.043	0.365	0.466	1.00

[a] All variables are in natural logs.

Overall the results are very strong. Estimates of the main parameters all have the expected signs. The values on β_1 become smaller as more parameters are added, indicating the lag becoming less important, but still remaining the most significant independent variable in all the models. The values on β_2 are very consistent across alternative formulations, ranging from -0.07 to -0.09. The long-run price elasticities have a greater variability. In the first models they are uncharacteristically large at -50 and -27. However, in the second and third models they range from -1.2 to -0.4. These and the short run numbers calculated fall in the range of other estimates of price elasticities for oil.[11] Income elasticities are also consistent with the literature,[12] ranging from 0.04 to 0.165 in the short-run and from 0.4 to 0.7 in the long-run.

β_3 and β_4 have the expected signs, but are not always statistically significant at the 0.05 level. β_3 is always positive and highly significant. However, β_4 is insignificant in both the models that include the lag of energy/CO_2, the price of oil and the income terms.[13] Therefore, while turning points are calculated for these models, the true relationship may be one of steadily increasing per capita energy/CO_2 with respect to income. The β_4 coefficients do become significant again with the inclusion of the trade variables. The coefficients on the trade variables were insignificant in the energy model, and while they were significant in the CO_2 model, the coefficients were not of the expected signs. SC (forthcoming) found high significance in most cases and the expected positive coefficient on export variables and negative on import variables.

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[11] Short run price elasticities for oil were estimated by Dahl (1991) to be -.06 for developing countries and -.35 for developed countries. Long run price elasticities for oil were estimated at -.17 for developing countries and -1.01 for developed countries (Dahl, 1991).

[12] Short-run income elasticities for oil range from 0.46 for developing countries to 0.74 for developed countries. Long-run elasticities range from 1.03 for developing countries to 1.35 for developed countries (Dahl, 1991).

[13] β_4 is significant at the .10 level in the energy model.

All of the hypotheses were supported, except for the significance of the trade variables. The first regression shows that last period's energy use is a pretty good predictor of this period's energy use. This happens as changes in energy use are fairly small from year to year. Short-run and long-run price elasticities are of the correct sign and in acceptable magnitudes. In the second models, it is interesting to note that GDP squared is not a significant variable. This implies that the EKC curve may not apply to this type of model. Instead, we see increasing energy use over all per capita income levels. In the third models, the GDP squared term does become significant, but the trade variables are insignificant and not of the proper sign. This is an interesting result and may signify that there are other relationships in these models that are not being explained. Exports could be an endogenous variable determined by the price of energy, but also determining the amount of energy that is consumed. These simple models are capturing partial equilibria, but say nothing about general equilibria.

VII. Conclusions

In general, most studies confirmed the EKC hypothesis for many pollutants and other measures of environmental quality. As GDP rises above these turning points, it is assumed that the transition to improving environmental quality takes place. However, in this paper, we find no significant evidence of the existence of the EKC for energy or CO_2 with the inclusion of energy prices in the model.

Figure 7 illustrates many of the forces that are driving the EKC relationship. The original EKC analyses capture the upward movement as low-income countries move from agriculturally based economies to industrial economies, and then the downward

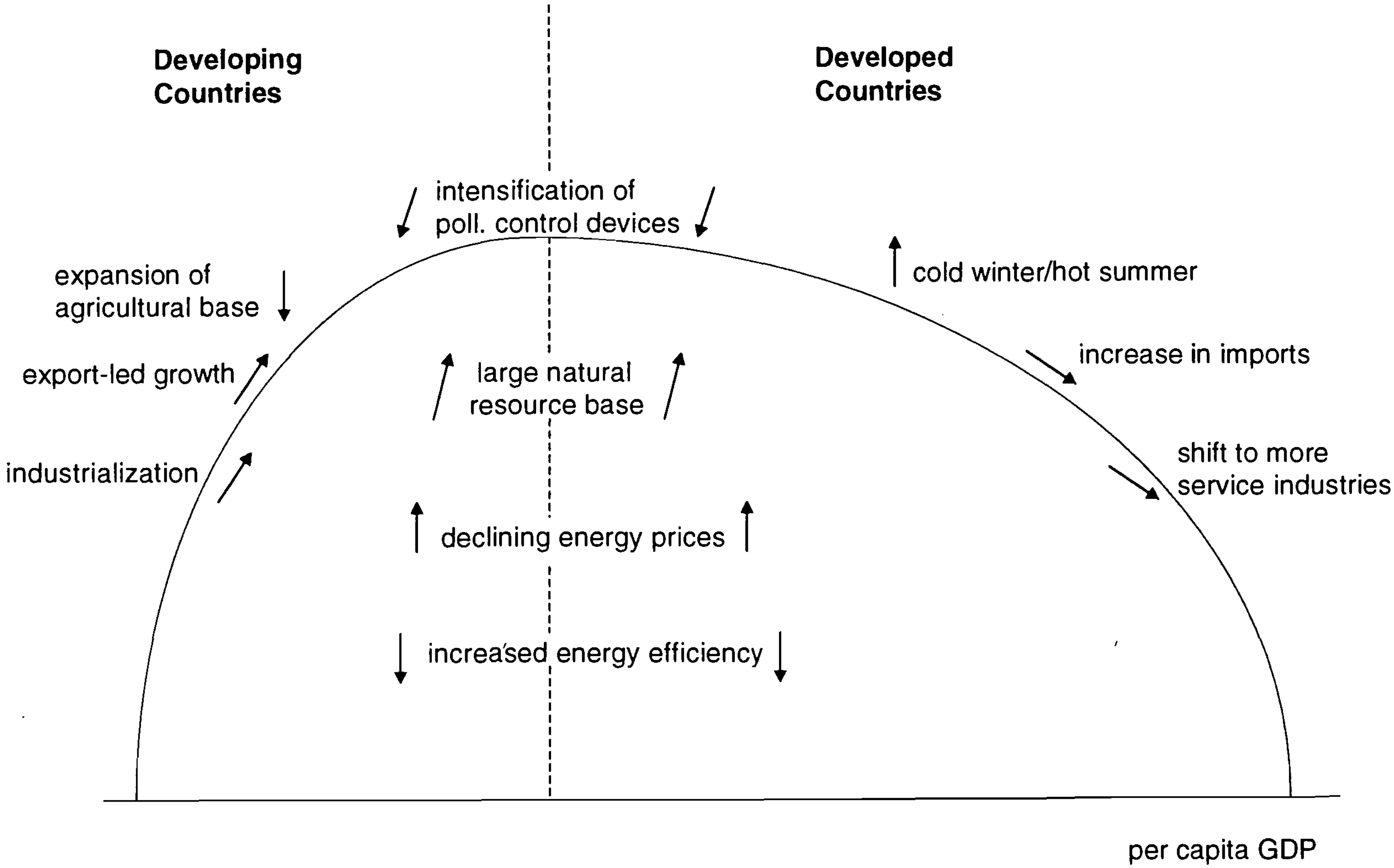

Figure 7: Conflicting Dynamics of the EKC Curve

NOTE: This diagram was developed by the authors to be purely illustrative, and is not intended to represent specific magnitudes of movement.

movement as industrial countries move into the post-industrial phase with service a larger part of the economy. SC included independent variables for trade which captured the export-led growth, leading to an increase in per capita GDP and pollution in industrial developing countries, and the increase in imports of developed countries with the opposite effect.

Prior work has not explicitly included the price of energy as an independent variable. Figure 7 illustrates the effect of declining energy prices: increased energy use and energy-based pollution in both developed and developing countries. The inclusion of this variable has strong implications for the EKC analysis. With a conventional lagged dependent variable model, the GDP squared term becomes insignificant, implying that the existence of the down-turn is uncertain. This could be because energy use at all income levels is price elastic, especially in the long-run, causing increased energy use even at high levels of GDP.

However, the long-run price model causes other factors to become insignificant that were previously important. The trade variables are now insignificant, while in other work they have been shown to have considerable explanatory value. The problem may be an over-identified model. The dependent variables are very slow moving,[14] and many of the independent variables are highly correlated. Trade and energy prices are both important variables, but trade variables become insignificant in a regression with

[14] It is interesting to note that the energy and CO_2 data that are used are very smooth throughout the years in the analysis. A comparison of different sources of data (United Nations, International Energy Agency, OECD) did show some variation between sources.

both trade and energy prices. A new approach is needed as trade could also be influenced by energy prices.

The lag model shows that energy prices and last period's production of energy or CO_2 emissions are very important variables. When one thinks of growth, automatically increased energy use comes to mind. For individual countries, options for growth without environmental degradation include: 1) rapid growth in service industries, 2) importing more pollution intensive goods, 3) installing domestic pollution control devices, and 4) increasing energy efficiency. The first two involve reducing demand for energy domestically, but there will be a compensating increase in demand for energy internationally. The third option can increase demand for energy, while reducing specific pollutants, as many pollution control devices use more energy. The final option (energy efficiency), reduces demand for energy and reduces energy-based pollution at the same time. Figure 7 illustrates how these different policies might affect individual countries and the EKC curve.

We have mentioned previously how shifting to service industries and increasing imports creates the downward portion of the EKC. The last two options have the effect of decreasing pollution levels, but possibly also decreasing national income levels as countries spend more money on pollution control technology and research and development. This leads to an important distinction within the EKC debate. Authors are usually seeking to estimate the turning point, i.e. that level of per capita GDP where countries will begin demanding a cleaner environment. However, the corresponding global and local levels of pollution at this turning point are seldom mentioned. Policy prescriptions in the EKC literature discuss ways to shift the turning point to the left (lower levels of GDP), but have not mentioned reducing overall levels of pollution, which may be a more important issue. An increase in energy prices is one of the few items on Figure 7 that will reduce overall global levels of energy-based pollution.

What is happening to the EKC over time? While all of the previous work discussed here includes time effects, the final result is usually interpreted as representative over the whole observed period, and into the future as well. Unfortunately, the data are not extensive enough to examine our model for each year individually. Regressing the model in Section VI in four 5-year intervals did not achieve consistent results,[15] but did show an increase in the turning point from the third to the fourth time period. If there is a shifting to the northeast of the turning point, then for individual countries, growth in per capita GDP is moving against a dynamically increasing EKC.

Taking our conclusion that energy prices are an important indicator of energy demand and consequently carbon emissions, what does this mean for the future? Conventional low-cost crude oil resources will eventually become depleted. Coal, in contrast, is available in very extensive amounts for a millennium. Natural gas reserves are estimated to be viable for about another 200 years (Masters, et al., 1994; Chapman, forthcoming). Plentiful cost-effective non-renewable resources into the near future could alleviate worries about unexpected price increases in the coming years. But this won't be an incentive for countries to reduce energy use.

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[15] For both the energy and CO_2 models, in the first period (1971-1975) only the coefficient on GDP was significant. In the second period (1976-1980) all the coefficients were significant, but the coefficient on GDP squared was positive, denoting a minimum rather than a maximum.

The occurrence of the EKC depends on individual countries, either unilaterally or as part of global agreements, taking action to promote behavior that will move the peak in a southwest direction. Many of the items on Figure 7 are partially independent of government action. Shifting the turning point is independent of government action to some degree. This movement is determined by when individuals can afford to be concerned with environmental quality; after concerns over jobs, houses, health, and well-being are eliminated. However, energy taxes, environmental control policies, and incentives to increase energy efficiency are policies that governments can undertake to reduce levels of pollution, and efforts need to be taken now to begin alleviating these problems.

As noted, we have found no significant evidence for the existence of an EKC within the range of current incomes for energy in the presence of price and trade variables. Future policies for climate change and energy should explicitly recognize the need for specific policies focused on economic incentives and technological innovation.

APPENDIX A: COUNTRY ABBREVIATIONS

ARG: Argentina
AUSL: Australia
AUST: Austria
BANG: Bangladesh
BRAZ: Brazil
CAN: Canada
CHILE: Chile
CHINA: China
DEN: Denmark
FIN: Finland
FRA: France
GERM: Germany
GRE: Greece
HKG: Hong Kong
ICE: Iceland
IND: India
INDO: Indonesia
ITAL: Italy
JAP: Japan
KEN: Kenya
KOR: Korea
MAL: Malaysia
MEX: Mexico
NETH: Netherlands
NOR: Norway
PAK: Pakistan
PORT: Portugal
SPAIN: Spain
SWE: Sweden
THAI: Thailand
TURK: Turkey
UK: United Kingdom
US: United States
ZWE: Zimbabwe

REFERENCES

Agras, J. 1995. "Environment and Development: An Economic Analysis of Pollution, Growth, and Trade." Unpublished Master's Thesis. Department of Agricultural, Resource, and Managerial Economics, Cornell University.

Arrow, K., B. Bolin, R. Costanza, P. Dasgupta, C. Folke, C.S. Holling, B.-O. Jansson, S. Levin, K.-G. Mäler, C. Perrings, and D. Pimentel. 1995. "Economic growth, carrying capacity, and the environment" *Science* 268: 520-521.

Brown, L.R., C. Flavin, and H. Kane. 1996. *Vital Signs, 1996*. New York: W.W. Norton and Company.

Chapman, D. forthcoming. "World Oil: A Strategic Limited Resource?" Chapter 9 in *Environmental Economics: Theory, Application, and Policy*. Boston: HarperCollins, Addison, Wesley, Longman.

Chapman, D. 1995. "Retail Gasoline Prices, 1918-1994," copy available from author.

Dahl, C. 1991. "Survey of Energy Demand Elasticities in Developing Countries" Energy Modeling Forum WP 11.11.

Grossman, G. and A. Krueger. 1995. "Economic Growth and the Environment," *The Quarterly Journal of Economics* 110(2): 352-377.

_____________. 1992. Environmental Impacts of a North American Free Trade Agreement. Discussion Papers in Economics #158, Woodrow Wilson School of Public and International Affairs, Princeton, New Jersey.

Holtz-Eakin, D. and T.M. Selden. 1995. "Stoking the fires? CO_2 emissions and economic growth" *Journal of Public Economics* 57: 85-101.

International Energy Agency (IEA). various years. *Energy Balances of OECD Countries*. Paris: International Energy Agency.

IPCC. 1996. Climate Change 1995 Volume I: The Science of Climate Change. Cambridge: Cambridge University Press.

Khanna, N. and D. Chapman. 1997. Climate Policy and Petroleum Depletion. Working Paper 97-01, Department of Agricultural, Resource, and Managerial Economics, Cornell University, Ithaca, NY.

Kuznets, S. 1955. "Economic growth and income inequality," *American Economic Review* 45(1): 1-28.

Manne, A.S. and R.G. Richels. 1992. *Buying Greenhouse Insurance: The Economic Costs of CO_2 Emissions Limits.* Cambridge, MA: MIT Press.

Masters, C.D., E.D. Attanasi, and D.H. Root. 1994. "World Petroleum Assessment and Analysis," in *Proceedings of the 14th World Petroleum Congress.* New York: John Wiley and Son.

Nordhaus, W.D. 1994. *Managing the Global Commons: The Economics of Climate Change.* Cambridge, MA: MIT Press.

Nordhaus, W.D. and G.W. Yohe. 1983. "Future paths of energy and carbon dioxide emissions" *Changing climate: Report of the carbon dioxide assessment committee.* Washington, D.C.: National Academy Press.

Oak Ridge National Laboratory (ORNL). 1992. *Trends: '91: A Compendium of Data on Global Change.* Oak Ridge, TN.

Panayotou, T. 1993. "Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Economic Development," Working Paper WP238, Technology and Employment Programme. Geneva: ILO.

Reilly, J.M., J.A. Edmonds, R.H. Gardner, and A.L. Brenkert. 1987. "Uncertainty analysis of the IEA/ORAU CO_2 emissions model" *Energy Journal* 8(3): 1-29.

Selden, T. M. and D. Song. 1994. "Environmental Quality and Development: Is There a Kuznets Curve for Air Pollution?" *Journal of Environmental Economics and Management* 27(2): 147-162.

Shafik, N. and S. Bandyopadhyay. 1992. Economic Growth and Environmental Quality: Time-Series and Cross-Country Evidence. Background Paper for World Development Report 1992. Washington, D.C.: The World Bank.

Summers, R. and A. Heston. 1991. "The Penn World Table (Mark 5): An Expanded Set of International Comparisons, 1950-1988" *Quarterly Journal of Economics* 106(2): 327-368.

Suri, V. and D. Chapman. forthcoming. "Economic Growth, Trade and Energy: Implications for the Environmental Kuznets Curve" *Ecological Economics.*

Tucker, M. 1995. "Carbon dioxide emissions and global GDP" *Ecological Economics* 15(3): 215-223.

United Nations (UN). 1991/1992. *International Trade Statistics Yearbook.* New York: UN.

United Nations Environment Program (UNEP). 1991. *Environmental Data Report*, Oxford: The Alden Press.

Wycoff, A. W. and J. M. Roop. 1994. "The embodiment of carbon in imports of manufactured products: Implications for international agreements on greenhouse gas emissions" *Energy Policy* 22(3): 187-194.

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