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The Rise and Fall of the Environmental Kuznets Curve

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Abstract

This paper chronicles the story of the environmental Kuznets curve (EKC). The EKC proposes that indicators of environmental degradation first rise, and then fall with increasing income per capita. However, recent evidence shows that developing countries are addressing environmental issues, sometimes adopting developed country standards with a short time lag and sometimes performing better than some wealthy countries, and that the EKC results have a very flimsy statistical foundation. A new generation of decomposition models can help disentangle the true relations between development and the environment.

Keywords: Environmental Kuznets curve, pollution, economic development, econometrics, review, global

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1.   Introduction

The environmental Kuznets curve is a hypothesized relationship between various indicators of environmental degradation and income per capita. In the early stages of economic growth degradation and pollution increase, but beyond some level of income per capita, which will vary for different indicators, the trend reverses, so that at high income levels economic growth leads to environmental improvement. This implies that the environmental impact indicator is an inverted U-shaped function of income per capita. Typically the logarithm of the indicator is modeled as a quadratic function of the logarithm of income. An example of an estimated EKC is shown in Figure 1. The EKC is named for Kuznets (1955) who hypothesized that income inequality first rises and then falls as economic development proceeds.

The EKC is an essentially empirical phenomenon, but most of the EKC literature is econometrically weak. In particular, little or no attention has been paid to the statistical properties of the data used - e.g. serial dependence or stochastic trends in time series (exceptions include Coondoo and Dinda, 2002; Day and Grafton, 2003; De Bruyn, 2000; Stern and Common, 2001; Perman and Stern, 2003; Friedl and Getzner, 2003; Heil and Selden, 1999, 2001) - and little consideration has been paid to issues of model adequacy such as the possibility of omitted variables bias. Most studies assume that if the regression coefficients are individually or jointly nominally significant and have the expected signs then an EKC relation exists. However, one of the main purposes of doing econometrics is to test which apparent relationships, or "stylized facts", are valid and which are spurious correlations.

When we do take diagnostic statistics and specification tests into account and use appropriate techniques we find that the EKC does not exist (Perman and Stern 2003). Instead we get a more realistic view of the effect of economic growth and technological changes on environmental quality. It seems that most indicators of environmental degradation are monotonically rising in income though the "income elasticity" is less than one and is not a simple function of income alone. Time related effects reduce environmental impacts in countries at all levels of income. The new (post-Brundtland) conventional wisdom that developing countries are "too poor to be green" (Martinez-Alier, 1995) is lacking in wisdom. However, in rapidly growing middle income countries the scale effect, which increases pollution and other degradation, overwhelms the time effect. In wealthy countries, growth is slower, and pollution reduction efforts can overcome the scale effect. This is the origin of the apparent EKC effect. The econometric results are supported by recent evidence that, in fact, pollution problems are being addressed and remedied in developing economies (e.g. Dasgupta *et al*., 2002).

This paper follows the development of the EKC concept in approximately chronological order. No attempt is made to review or cite all of the rapidly growing number of studies. The next two sections of the paper review in more detail the theory behind the EKC and the econometric methods used in EKC studies. The following sections review some EKC analyses and their critique. Sections 6 and 7 discuss the more important recent developments that have changed the picture that we have of the EKC. The final sections discuss an alternative approach - decomposition of emissions - and summarize the findings.

2.   Theoretical Background

The EKC concept emerged in the early 1990s with Grossman and Krueger's (1991) pathbreaking study of the potential impacts of NAFTA and Shafik and Bandyopadhyay's (1992) background study for the 1992 *World Development Report*. However, the idea that economic growth is necessary in order for environmental quality to be maintained or improved is an essential part of the sustainable development argument promulgated by the World Commission on Environment and Development (1987) in *Our Common Future*.

The EKC theme was popularized by the World Bank's *World Development Report 1992* (IBRD, 1992), which argued that: "The view that greater economic activity inevitably hurts the environment is based on static assumptions about technology, tastes and environmental investments" (p 38) and that "As incomes rise, the demand for improvements in environmental quality will increase, as will the resources available for investment" (p. 39). Others have expounded this position even more forcefully with Beckerman (1992) claiming that "there is clear evidence that, although economic growth usually leads to environmental degradation in the early stages of the process, in the end the best – and probably the only – way to attain a decent environment in most countries is to become rich." (p. 491). In his highly publicized and controversial book, *The Skeptical Environmentalist*, Lomborg (2001) relies heavily on the 1992 *World Development Report* (Cole, 2003) to argue the same point, while Stokey (1998) and Lieb (2001) assume that the EKC is a stylized fact that needs to be explained. All this is despite the fact that the EKC has never been shown to apply to all pollutants or environmental impacts and recent evidence (Dasgupta *et al*., 2002; Harbaugh *et al*., 2002; Perman and Stern, 2003; Koop and Tole, 1999) challenges the notion of the EKC in general. The remainder of this section discusses the economic factors that drive changes in environmental impacts and may be responsible for rising or declining environmental degradation over the course of economic development.

If there were no change in the structure or technology of the economy, pure growth in the scale of the economy would result in a proportional growth in pollution and other environmental impacts. This is called the scale effect. The traditional view that economic development and environmental quality are conflicting goals reflects the scale effect alone. Proponents of the EKC hypothesis argue that "at higher levels of development, structural change towards information-intensive industries and services, coupled with increased environmental awareness, enforcement of environmental regulations, better technology and higher environmental expenditures, result in leveling off and gradual decline of environmental degradation." (Panayotou, 1993, p1). Thus there are both proximate causes of the EKC relationship – scale, changes in economic structure or product mix, changes in technology, and changes in input mix, as well as underlying causes such as environmental regulation, awareness, and education, which can only have an effect via the proximate variables.

First, let us look in more detail at the proximate variables:

1. **Scale** of production implies expanding production at given factor-input ratios, output mix, and state of technology. The scale effect is normally assumed to increase emissions proportionally so that a 1% increase in scale results in a 1% increase in emissions. This is because if there is no change in the input-output ratio or in technique there has to be a proportional increase in aggregate inputs. There could be in theory, however, scale economies or diseconomies of pollution (Andreoni and Levinson, 2001). Some pollution control techniques may not be practical at a small scale of production and vice versa or may operate more or less effectively at different levels of output.

2. Different industries have different pollution intensities. Typically, over the course of economic development the **output mix** changes. In the earlier phases of development there is a shift away from agriculture towards heavy industry which increases emissions, while in the later stages of development there is a shift from the more resource intensive extractive and heavy industrial sectors towards services and lighter manufacturing, which supposedly have lower emissions per unit of output.

3. Changes in **input mix** involve the substitution of less environmentally damaging inputs for more damaging inputs and vice versa. Examples include substituting natural gas for coal as well as substituting low sulfur coal in place of high sulfur content coal. As scale, output mix, and technology are held constant, this is equivalent to moving along the isoquants of a neoclassical production function.

4. Improvements in the **state of technology** involve changes in both:

a. **Productivity** in terms of using less, *ceteris paribus*, of the polluting inputs per unit of output. A general increase in total factor productivity will result in less pollutant being emitted per unit of output if input mix is held constant even though this is not necessarily an intended consequence.

b. **Emissions specific changes in process** result in less pollutant being emitted per unit of input. These innovations are directed specifically to reducing emissions.

Though any actual change in the level of the pollution must be a result of change in one of the proximate variables, those variables may be driven by changes in underlying variables that also vary over the course of economic development. A number of papers have developed theoretical models of how preferences and technology might interact to result in different time paths of environmental quality. The various studies make different simplifying assumptions about the economy. Most of these studies can generate an inverted U shape curve of pollution intensity but there is no inevitability about this. The result depends on the assumptions made and the value of particular parameters. Lopez (1994) and Selden and Song (1995) assume infinitely lived agents, exogenous technological change and that pollution is generated by production and not by consumption. John and Pecchenino (1994), John *et al*. (1995), and McConnell (1997) develop models based on overlapping generations where pollution is generated by

consumption rather than by production activities. Additionally Stokey (1998) allows endogenous technical change and Lieb (2001) generalizes Stokey's (1998) model, arguing that satiation in consumption is needed to generate the EKC. Finally, Ansuategi and Perrings (2000) incorporate transboundary externalities. All these models are for pollution emissions or concentrations. Lopez (1994) and Bulte and van Soest (2001) develop models for the depletion of natural resources such as forests or agricultural land fertility. It seems fairly easy to develop models that generate EKCs under appropriate assumptions. None of these theoretical models has been tested by fitting to actual data. Furthermore, if, in fact, the EKC for emissions is monotonic as more recent evidence suggests, the ability of a model to produce an inverted U-shaped curve is not a particularly desirable property.

3.   Econometric Framework

The earliest EKCs were simple quadratic functions of the levels of income. However, economic activity inevitably implies the use of resources and, by the laws of thermodynamics, use of resources inevitably implies the production of waste. Regressions that allow levels of indicators to become zero or negative are inappropriate except in the case of deforestation where afforestation can occur. This restriction can be applied by using a logarithmic dependent variable. Some studies including the original Grossman and Krueger (1991) paper used a cubic EKC in levels and found an N shape EKC. But this result could due to not placing the non-negative concentrations condition on the model. The standard EKC regression model is, therefore:

$$\ln(E/P)_{it} = \alpha_i + \gamma_t + \beta_1 \ln(GDP/P)_{it} + \beta_2 (\ln(GDP/P))^2{}_{it} + \varepsilon_{it} \qquad (1)$$

where E is emissions, P is population, and ln indicates natural logarithms. The first two terms on the RHS are intercept parameters which vary across countries or regions i and years t. The assumption is that though the level of emissions per capita may differ over countries at any particular income level the income elasticity is the same in all countries at a given income level. The time specific intercepts are intended to account for time-varying omitted variables and stochastic shocks that are common to all countries.

The "turning point" level of income, where emissions or concentrations are at a maximum, can be found using the following formula:

$$\tau = \exp(-\beta_1 / (2 \beta_2)) \qquad (2)$$

Usually the model is estimated with panel data. Most studies attempt to estimate both the fixed effects and random effects models. The fixed effects model treats the $_i$ and $_t$ as regression parameters. In practice, the means of each variable for each country are subtracted from the data for that country and the mean for all countries in the sample in each individual time period is also deducted from the observations for that period. Then OLS is used to estimate the regression with the transformed data. The random effects model treats the $_i$ and $_t$ as components of the random disturbance. The residuals from an OLS estimate of the model with a single intercept are used to construct variances utilized in a GLS estimate.

If the effects α_i and γ_t and the explanatory variables are correlated, then the random effects model cannot be estimated consistently (Mundlak, 1978; Hsiao, 1986). Only the fixed effects model can be estimated consistently. A Hausman (1978) test can be used to test for inconsistency in the random effects estimate by comparing the fixed effects and random effects slope parameters. A significant difference indicates that the random effects model is estimated inconsistently, due to correlation between the explanatory variables and the error components. Assuming that there are no other statistical problems, the fixed effects model can be estimated consistently, but the estimated parameters are conditional on the country and time effects in the selected sample of data (Hsiao, 1986). Therefore, they cannot be used to extrapolate to other samples of data. This means that an EKC estimated with fixed effects using only developed country data might say little about the future behavior of developing countries. Many studies compute the Hausman statistic and finding that the random effects model cannot be consistently estimated estimate the fixed effects model. But few have pondered the deeper implications of the failure of this orthogonality test.

GDP may be an integrated variable (Nelson and Plosser, 1982). If the EKC regressions do not cointegrate then the estimates will be spurious. Very few studies have reported any diagnostic statistics for integration of the variables or cointegration of the regressions. Therefore, it is unclear what we can infer from the majority of EKC studies. Testing for integration and cointegration in panel data is a rapidly developing field. Perman and Stern (2003) employ some of these tests and find that sulfur emissions and GDP per capita may be integrated variables. The unit root hypothesis could be rejected for sulfur (but not GDP) using the Im Pesaran and Shin (2003) (IPS) test when the alternative was trend stationarity. But alternative hypotheses and tests result in acceptance of the unit root hypothesis. Heil and Selden (1999) find the same result for carbon dioxide emissions and GDP using the IPS test. However, they prefer results that allow for a structural break in 1974, in which case the unit root hypothesis can be rejected strongly for both GDP and carbon. Coondoo and Dinda (2002) yield similar results to Perman and Stern (1993) for carbon dioxide emissions. De Bruyn (2000) and Day and Grafton (2003) carry out time series unit root tests for the Netherlands, UK, USA, W. Germany, and Canada for a variety of pollutants with very similar results.

4.   Results of EKC Studies

Many basic EKC models relating environmental impacts to income without additional explanatory variables have been estimated. However, the key features differentiating the models for different pollutants, data etc. can be displayed by reviewing a few of the early studies and examining a single impact in more detail. I review the contributions of Grossman and Krueger (1991), Shafik (1994), and Selden and Song (1994) and then look in more detail at studies for sulfur pollution and emissions. Finally I briefly discuss studies that estimate an EKC for energy use. Many EKC studies have also been published that include additional explanatory additional explanatory variables. Several of these are reviewed in Stern (1998). Given the poor econometric properties of most EKC studies discussed in this paper and the problem of omitted variables bias when just one additional variable is tested I do not review these studies systematically here.

To some (e.g. Lopez, 1994) the early EKC studies indicated that local pollutants were more likely to display an inverted U shape relation with income, while global impacts like carbon dioxide did not. This picture fits environmental economics theory – local impacts are internalized in a single economy or region and are likely to give rise to environmental policies to correct the externalities on pollutees before such policies are applied to globally externalized problems. As we will see, the picture is not quite so clear cut even in the early studies. Furthermore, the more recent evidence on sulfur and carbon dioxide emissions shows there may be no strong distinction between the effect of income per capita on local and global pollutants. Stern *et al*. (1996) determined that higher turning points were found for regressions that used purchasing power parity (PPP) adjusted income compared to those that used market exchange rates and for studies using emissions of pollutants relative to studies using ambient concentrations in urban areas. In the initial stages of economic development urban and industrial development tends to become more concentrated in a smaller number of cities which also have rising central population densities. Many developing countries are characterized by a "primate city" that dominates a country's urban hierarchy and contains much of its modern industry – Bangkok is one of the best such examples. In the later stages of economic development urban and industrial development tends to decentralize. Additionally the high population densities of less developed cities are gradually reduced by suburbanization. So it is possible for peak ambient pollution concentrations to fall as income rises even if total national emissions are rising.

The first empirical EKC study was the NBER working paper by Grossman and Krueger (1991, later published as Grossman and Krueger, 1994) that estimated EKCs as part of a study of the potential environmental impacts of NAFTA. They estimated EKCs for SO_2, dark matter (fine smoke), and suspended particles (SPM) using the GEMS dataset. This dataset is a panel of ambient measurements from a number of locations in cities around the world. Each regression involves a cubic function in levels (not logarithms) of PPP (Purchasing Power Parity adjusted) per capita GDP and various site-related variables, a time trend, and a trade intensity variable. The turning points for SO_2 and dark matter are at around $4000-5000 while the concentration of suspended particles appeared to decline even at low income levels. At income levels over $10000-15000, Grossman and Krueger's estimates show increasing levels of all three pollutants though this may be an artifact of the nonlogarithmic specification.

Shafik and Bandyopadhyay's (1992, later published as Shafik, 1994) study was particularly influential as the results were used in the 1992 *World Development Report* (IBRD 1992). They estimated EKCs for ten different indicators: lack of clean water, lack of urban sanitation, ambient levels of suspended particulate matter, ambient sulfur oxides, change in forest area between 1961 and 1986, the annual observations of deforestation between 1961 and 1986, dissolved oxygen in rivers, fecal coliform in rivers, municipal waste per capita, and carbon emissions per capita.

They used three different functional forms: log-linear, log-quadratic and, in the most general case, a logarithmic cubic polynomial in PPP GDP per capita as well as a time trend and site related variables. In each case the dependent variable was untransformed. Lack of clean water and lack of urban sanitation were found to decline uniformly with increasing income, and over time. Both measures of deforestation were found to be insignificantly

related to the income terms. River quality tended to worsen with increasing income. The two air pollutants, however, conform to the EKC hypothesis. The turning points for both pollutants are found for income levels of between $3000 and $4000. Finally, both municipal waste and carbon emissions per capita increased unambiguously with rising income.

Selden and Song (1994) estimated EKCs for four emissions series: SO_2, NO_x, SPM, and CO using longitudinal data from World Resources (WRI, 1991). The data are primarily from developed countries. The estimated turning points are all very high compared to the two earlier studies. For the fixed effects version of their model they are (points converted to 1990 US dollars using the U.S. GDP implicit price deflator): SO_2, $10391; NO_x, $13383; SPM, $12275; and CO, $7114. This study showed that the turning point for emissions was likely to be higher than that for ambient concentrations.

Table 1 summarizes several studies of sulfur emissions and concentrations, listed in order of estimated income turning point. Panayotou (1993) uses cross-sectional data, nominal GDP, and the assumption that the emission factor for each fuel is the same in all countries and this study has the lowest estimated turning point of all. With the exception of the Kaufmann *et al*. (1998) estimate, all turning point estimates using concentration data are less than $6000. Kaufmann *et al*. used an unusual specification that includes GDP per area and GDP per area squared variables.

Among the emissions based estimates, both Selden and Song (1994) and Cole *et al*. (1997) use databases that are dominated by, or consist solely of, emissions from OECD countries. Their estimated turning points are $10391 and $8232 respectively. List and Gallet (1999) use data for 1929 to 1994 for the fifty U.S. states. Their estimated turning point is the second highest in the table. Income per capita in their sample ranges from $1162 to $22462 in 1987 US dollars. This is a greater range of income levels than is found in the OECD based panels for recent decades. This suggests that including more low-income data points in the sample might yield a higher turning point. Stern and Common (2001) estimated the turning point at over $100,000. They used an emissions database produced for the US Department of Energy by ASL (Lefohn *et al*., 1999) that covers a greater range of income levels and includes more data points than any of the other sulfur EKC studies.

We see that the recent studies that used more representative samples of the data find that there is a monotonic relation between sulfur emissions and income just as there is between carbon dioxide and income. Interestingly, Dijkgraaf and Vollebergh (1998) estimate a carbon EKC for a panel data set of OECD countries finding an inverted-U shape EKC in the sample as a whole (as well as many signs of poor econometric behavior). The turning point is at only 54% of maximal GDP in the sample. A study by Schmalensee *et al*. (1998) also finds a within sample turning point for carbon. In this case, a ten-piece spline was fitted to the data such that the coefficient estimates for high-income countries are allowed to vary from those for low-income countries. All these studies suggest that the

differences in turning points that have been found for different pollutants may be due, at least partly, to the different samples used. The econometric reasons for this sample dependent behavior will be discussed below.

In an attempt to capture all environmental impacts of whatever type, a number of researchers (e.g. Cole *et al*., 1997; Suri and Chapman, 1998) have estimated EKCs for a proxy total environmental impact indicator - total energy use. In each case they found that energy use per capita increases monotonically with income per capita. This result does not preclude the possibility that energy intensity – energy used per dollar of GDP produced – declines with rising income or even follows an inverted U-shaped path (e.g. Galli, 1998).

The only robust conclusions from the EKC literature appear to be that concentrations of pollutants may decline from middle income levels, while emissions tend to be monotonic in income. As we will see below, emissions may decline over time in countries at many different levels of development. Given the poor statistical properties of most EKC models it is hard to come to any conclusions about the roles of other additional variables such as trade. Too few quality studies have been done of other indicators apart from air pollution to come to any firm conclusions about those impacts either.

5.   Theoretical Critique of the EKC

A number of critical surveys of the EKC literature have been published (e.g. Ansuategi *et al*., 1998; Arrow *et al*., 1995; Ekins, 1997; Pearson, 1994; Stern *et al*., 1996; Stern, 1998). This section discusses the criticisms that were raised against the EKC on theoretical (rather than methodological) grounds.

The key criticism of Arrow *et al*. (1995) and others was that the EKC model, as presented in the *1992 World Development Report* and elsewhere, assumes that there is no feedback from environmental damage to economic production as income is assumed to be an exogenous variable. The assumption is that environmental damage does not reduce economic activity sufficiently to stop the growth process and that any irreversibility is not too severe to reduce the level of income in the future. In other words there is an assumption that the economy is sustainable. But, if higher levels of economic activity are not sustainable, attempting to grow fast in the early stages of development when environmental degradation is rising may prove counterproductive.

It is clear that the levels of many pollutants per unit of output in specific processes have declined in developed countries over time with increasingly stringent environmental regulations and technical innovations. However, the mix of effluent has shifted from sulfur and nitrogen oxides to carbon dioxide and solid waste so that aggregate waste is still high and per capita waste may not have declined. Economic activity is inevitably environmentally disruptive in some way. Satisfying the material needs of people requires the use and disturbance of energy flows and materials stocks. Therefore, an effort to reduce some environmental impacts may just aggravate other problems. Estimation of EKCs for total energy use are an attempt to capture environmental impact whatever its nature (e.g. Suri and Chapman, 1998).

Both Arrow *et al*. (1995) and Stern *et al* (1996) argued that if there was an EKC type relationship it might be partly or largely a result of the effects of trade on the distribution of polluting industries. The Hecksher-Ohlin trade theory suggests that, under free trade, developing countries would specialize in the production of goods that are intensive in the factors that they are endowed with in relative abundance: labor and natural resources. The developed countries would specialize in human capital and manufactured capital intensive activities. Part of the reduction in environmental degradation levels in the developed countries and increases in environmental degradation in middle income countries may reflect this specialization (Lucas *et al*., 1992; Hettige *et al*., 1992; Suri and Chapman, 1998). Environmental regulation in developed countries might further encourage polluting activities to gravitate towards the developing countries (Lucas *et al*., 1992).

These effects would exaggerate any apparent decline in pollution intensity with rising income along the EKC. In our finite world the poor countries of today would be unable to find further countries from which to import resource intensive products as they themselves become wealthy. When the poorer countries apply similar levels of environmental regulation they would face the more difficult task of abating these activities rather than outsourcing them to other countries (Arrow *et al*., 1995; Stern *et al*., 1996). On the other hand, Antweiler *et al*. (2001) argue that the capital-intensive activities that are concentrated in the developed countries are more polluting. There are no clear answers on the impact of trade on pollution from the empirical EKC literature.

Stern *et al*. (1996) argued that early EKC studies showed that a number of indicators: SO_2 emissions, NO_x, and deforestation, peak at income levels around the current world mean per capita income. A cursory glance at the available econometric estimates might have lead one to believe that, given likely future levels of mean income per capita, environmental degradation should decline from now on. This interpretation is evident in the 1992 World Bank Development Report (IBRD, 1992). However, income is not normally distributed but very skewed, with much larger numbers of people below mean income per capita than above it. Therefore, it is median rather than mean income that is the relevant variable. Selden and Song (1994) and Stern *et al*. (1996) performed simulations that, assuming that the EKC relationship is valid, showed that global environmental degradation was set to rise for a long time to come. Figure 2 presents projected sulfur emissions using the EKC in Figure 1 and UN and World Bank forecasts of economic and population growth. More recent estimates show that the turning point is higher or does not occur but the impression produced by the early studies in the policy, academic, and business communities seems slow to fade (e.g. Lomborg, 2001).

6.   Recent Developments

A number of studies built on the basic EKC model by introducing additional explanatory variables intended to model underlying or proximate factors such as "political freedom" (e.g. Torras and Boyce, 1998) or output structure (e.g. Panayotou, 1997), or trade (e.g. Suri and Chapman, 1998). Stern (1998) reviews many of these papers in detail. On the whole the included variables turn out to be significant at traditional significance levels. However, testing different variables individually is subject to the problem of potential omitted variables bias. Further, these studies do not report cointegration statistics that might tell us if omitted variables bias is likely to be a problem or not. Therefore, it is not really clear what we can infer from this body of work.

Since 1998 significant developments fall into three classes: a. Empirical case study evidence on environmental performance and policy in developing countries that is discussed in this section; b. Improved econometric testing and estimates discussed in the following section; and c. Decomposition analysis representing a new wave in the investigation of environment-development relations, discussed in section 8.

Dasgupta *et al*. (2002) wrote a critical review of the EKC literature and other evidence on the relation between environmental quality and economic development in the *Journal of Economic Perspectives*. Figure 3. presents four alternative viewpoints regarding the nature of the emissions and income relation discussed in the article. The conventional EKC needs no further discussion. Two viewpoints argue that the EKC is monotonic. The new toxics scenario claims that while some traditional pollutants might have an inverted U shape curve the new pollutants that are replacing them do not. These include carcinogenic chemicals, carbon dioxide etc. As the older pollutants are cleaned up, new ones emerge, so that overall environmental impact is not reduced. The race to the bottom scenario posits that emissions were reduced in developed countries by outsourcing dirty production to developing countries. These countries will find it harder to reduce emissions. But also the pressure of globalization may preclude further tightening of environmental regulation in developed countries and may even result in its loosening in the name of competitiveness.

The revised EKC scenario does not reject the inverted U shape curve but suggests that it is shifting downwards and to the left over time due to technological change. However, this argument is already present in the *1992 World Development Report* (IBRD, 1992). They also review the theoretical literature and some of the econometric specification issues. But their main contribution is presenting evidence that environmental improvements are possible in developing countries and that peak levels of environmental degradation will be lower than in countries that developed earlier.

Regulation of pollution seems to increase with income as does enforcement but the greatest increases happen from low to middle income levels. There would also be expected to be diminishing returns to increased regulation. There is also informal or decentralized regulation in developing countries – Coasian bargaining. Further, liberalization of developing economies over the last two decades has encouraged more efficient use of inputs and less subsidization

of environmentally damaging activities – globalization is in fact good for the environment. The evidence seems to contradict the "race to the bottom" scenario. Multinational companies respond to investor and consumer pressure in their home countries and raise standards in the countries they invest in. Further, better methods of regulating pollution such as market instruments are having an impact even in developing countries. Better information on pollution is available, encouraging government to regulate and empowering local communities. Those that argue that there is no regulatory capacity in developing countries seem to be wrong.

Much of Dasgupta *et al.*'s evidence is from China. Other researchers of environmental and economic developments in China come to similar conclusions. Gallagher (2003) finds that China is adopting European Union standards for pollution emissions from cars with an approximately eight to ten year lag. Clearly China's income per capita is far more than ten years behind that of Western Europe. Diesendorf (2003), Zhang (2002), Jiang and McKibbin (2002), and Wang and Wheeler (2003) all report on substantial reductions of pollution intensities and levels in recent years.

7.   Econometric Critique of the EKC

Econometric criticisms of the EKC fall into four main categories: heteroskedasticity, simultaneity, omitted variables bias, and cointegration issues.

Stern *et al.* (1996) raised the issue of heteroskedasticity that may be important in the context of cross-sectional regressions of grouped data (see Maddala, 1977). Schmalensee *et al.* (1998) found that regression residuals from OLS were heteroskedastic with smaller residuals associated with countries with higher total GDP and population as predicted by Stern *et al.* (1996). Stern (2002) estimated a decomposition model using feasible GLS. Adjusting for heteroskedasticity in the estimation significantly improved the goodness of fit of globally aggregated fitted emissions to actual emissions.

Cole *et al.* (1997) and Holtz-Eakin and Selden (1995) used Hausman tests for regressor exogeneity to directly address the simultaneity issue. They found no evidence of simultaneity. In any case simultaneity bias is less serious in models involving integrated variables than in the traditional stationary econometric model (Perman and Stern, 2003). Coondoo and Dinda (2002) test for Granger Causality between CO_2 emissions and income in various individual countries and regions. As the data are differenced to ensure stationarity this test can only address short-run effects. The overall pattern that emerges is that causality runs from income to emissions or there is no significant relationship in developing countries, while in developed countries causality runs from emissions to income. However, in each case the relationship is positive so that there is no EKC type effect.

Stern and Common (2001) use three lines of evidence to suggest that the EKC is an incomplete model and that estimates of the EKC in levels can suffer from significant omitted variables bias: a. Differences between the parameters of the random effects and fixed effects models, tested using the Hausman test; b. Differences between the estimated coefficients in different subsamples, and c. Tests for serial correlation. Table 2 presents the key results

from an EKC model estimated with data from 74 countries (in the World sample) over the period 1960-90. For the non-OECD and World samples the Hausman test shows a significant difference in the parameter estimates for the random effects and fixed effects model. This indicates that the regressors – the level and square of the logarithm of income per capita are correlated with the country effects and time effects. As these effects model the mean effects of omitted variables that vary across countries or across time, this indicates that the regressors are likely correlated with omitted variables and the regression coefficients are biased. The OECD results pass this Hausman test but this result turned out to be very sensitive to the exact sample of countries included in the subsample. As explained in section 3. the fixed effects model can provide a consistent but sample dependent estimate of the parameters. Most EKC studies report significant Hausman test statistics and consequently estimate the fixed effect model. But, they do not discuss the implications of the statistic for the validity and applicability of the estimated parameters.

As expected, given the Hausman test results, the parameter estimates are dependent on the sample used, with the non-OECD estimates showing a turning point at extremely high income levels and the OECD estimates a within sample turning point (Table 2.). As mentioned above, these results exactly parallel those for developed and developing country samples of carbon emissions. The Chow F-Test tests whether the two subsamples can be pooled, and therefore that there is a common regression parameter vector, a hypothesis that is rejected.

The parameter ρ is the first order autoregressive coefficient of the regression residuals. This level of serial correlation indicates misspecification either in terms of omitted variables or missing dynamics.

Harbaugh *et al.* (2002) carry out a sensitivity analysis of the original Grossman and Krueger (1995) results. They use an updated and larger version of the ambient pollution data set and also test a number of alternative specifications. They report that the shape of the estimated curves differs widely across these specifications. The general equation they estimate is:

$$C_{it} = \beta_1 G_{it} + \beta_2 G_{it}^2 + \beta_3 G_{it}^3 + \beta_4 G_{il} + \beta_5 G_{il}^2 + \beta_6 G_{il}^3 + \mathbf{X}_{it}\beta_7 + \mu_i + \upsilon_{it} \quad (3)$$

which is a cubic polynomial in income and lagged income as well as conditioning variables X and site effects. In the original specification lagged income is the mean of the last three years. The long-run income effect is, therefore, given by: $(\beta_1 + \beta_4, \beta_2 + \beta_5, \beta_3 + \beta_6)$. Using the new extended dataset with Grossman and Krueger's original specification results in these three coefficients changing sign and peak and trough levels altering wildly. Altering the specification in various ways – adding explanatory variables, using time dummies instead of a time trend, using logs, removing outliers, and averaging the observations across monitors in each country - also changes the shape of the curve. The final experiment they carry out is to include only countries with GDP per capita above $8000. In contrast to Stern and Common (2001), this results in a monotonic curve. The author's comment: "This may seem counterintuitive. SO2 concentrations in Canada and the United States have declined over time at ever decreasing rates…the regressions…include … a linear time trend… after detrending the data with the time function, pollution

appears to increase as a function of GDP." (548). There are several differences between the Harbaugh *et al.* (2002) model and the Stern and Common (2001) model that may explain the different results obtained for high income countries. Harbaugh *et al.* (2002) use concentrations data, a linear time trend and a dynamic specification, while Stern and Common (2001) use emissions data, individual time dummies, and a static specification. Stern and Common's (2001) first differences results (Table 2) are very similar to Harbaugh et al.'s (2002) results, which suggests that the dynamic specification could be important.

Perman and Stern (2003) test Stern and Common's (2001) data and models for unit roots and cointegration respectively. Panel unit root tests indicate that all three series – log sulfur emissions per capita, log GDP capita, and its square – have stochastic trends. Results for cointegration are less clear cut. Around half the individual country EKC regressions cointegrate, but many of these have parameters with "incorrect signs". Some panel cointegration tests indicate cointegration in all countries and some accept the non-cointegration hypothesis. But even when cointegration is found, the form of the EKC relationship varies radically across countries with many countries having U-shaped EKCs. A common cointegrating vector in all countries is strongly rejected. Koop and Tole (1999) similarly found that random and fixed effects specifications of a deforestation EKC were strongly rejected in favor of a random coefficients model with widely varying coefficients and insignificant mean coefficients.

In the presence of possible non-cointegration we can estimate a model in first differences. The estimated turning points are much more similar across subsamples (Table 2), though they are still significantly different, and indicate a largely monotonic EKC relationship. The estimated income elasticity is less than one – there are factors that change with income which offset the scale effect, but they are insufficiently powerful to fully overcome the scale effect.

Figure 4. presents the time effects from the first difference estimates. The OECD saw declining emissions holding income constant over the entire time period, though the introduction of the LRTAP agreement in the mid-1980s in Europe resulted in a larger decline. Developing countries saw rising emissions in the 1960s and declining emissions since 1973, *ceteris paribus*.

Day and Grafton (2003) test for cointegration of the EKC relation using Canadian time series data on a number of pollutants using the Engle-Granger and Johansen methods. They fail to reject the non-cointegration hypothesis in almost every case. De Bruyn's (2000) time series Engle-Granger tests for the Netherlands, UK, USA, and W. Germany for SOx, NOx and CO2 finds cointegration for the CO2 EKC in the Netherlands and W. Germany, but not in any other case.

8. Decomposing Emissions

As an alternative to the EKC, an increasing number of studies carry out decompositions of emissions into the proximate sources of emissions changes described in section 2. The usual approach is to utilize index numbers and detailed sectoral information on fuel use, production, emissions etc. Stern (2002) develops an alternative

econometric method, which still requires national data on fuel mix but does not require fuel use data at an industry level. Usually, fuel use is collected on a different sectoral basis than output is measured making index number studies impossible to implement for most countries. Hamilton and Turton's (2002) and Zhang's (2000) index number decomposition of CO2 emissions does not explicitly include fuel mix or output structure and so also does not require industry level data. Antweiler *et al*. (2001) develop an econometric model of the effects of trade on environmental quality which includes capital/labor abundance but no energy data. Hilton and Levinson (1998) and Hettige *et al*. (2000) decompose emissions into different components, which are then regressed on other variables including income in the same style as the EKC. The various predicted components can then be reassembled to predicted total emissions.

Grossman (1995) and de Bruyn (1997) proposed the following decomposition:

$$E_{it} \quad = \quad \sum_{j=1}^{n} Y_{it} I_{ijt} S_{ijt} \tag{4}$$

where E_{it} is emissions in country i in year t, Y is GDP, I_j is the emissions intensity of sector j, and S_j is the share of that sector in GDP. This decomposition, therefore attributes emissions to what Grossman calls the scale, composition (output mix), and technique effects. The latter includes the effects of both fuel mix and "technological change" with the latter breaking down into general productivity improvements where more output is derived from a unit of input and emissions reducing technological change where less emissions are produced per unit of input. De Bruyn (1997) implements the decomposition for sulfur emissions in the Netherlands and Western Germany. Between 1980 and 1990 GDP grew by 26-28% in the two countries, structural change on the output side contributed –4.5% to emissions in Western Germany and +5.7% in the Netherlands. Other effects contributed around -74% in the two countries with energy efficiency contributing 15-20% and therefore energy mix and emissions specific technological change contributed a 55-60% reduction in sulfur emissions.

Viguier (1999) computes his own data set for the USSR/Russia, Poland, Hungary, USA, UK, and France for 1970-94. He carries out a Divisia index decomposition of changes in emissions of SOx, NOx, and CO2 into fuel quality, fuel mix, industrial structure, and energy intensity at the aggregate level. For sulfur emissions specific reductions followed by changes in energy intensity seem most important. In Eastern Europe energy intensity increased over parts of the period. Input and output structure played a minor role though fuel mix acted to increase emissions in the US. For nitrogen and carbon, energy intensity was the most important factor.

Selden *et al*. (1999) carry out a decomposition of US emissions of the EPA's six criteria pollutants that allows identification of all five effects identified in section 2. They found that input and output mix did not contribute much to offsetting the scale effect. In fact shifts in fuel use increased some pollutants. Reductions in energy intensity were important in reducing emissions. Even so all these effects could not overcome even growth in emissions per capita, let alone total emissions growth. The most important factor was, therefore, specific emissions reducing technological change. Bruvoll and Medin (2003) add CO_2, CH_4, N_2O, and NH_3 to Selden *et al*.'s (1999) six pollutants in their

decomposition analysis for Norway. Their analysis identifies up to seven components for both energy related and process emissions. The results are essentially identical to those of Selden *et al*. (1999) for the US with technique effects dominating the factors offsetting the increase in scale and energy intensity reductions second in importance across the ten pollutants. However, energy mix is important in reducing sulfur and carbon dioxide emissions and composiitonal effects are important for some other pollutants.

Hamilton and Turton (2002) and Zhang (2000) carry out decompositions of carbon emissions for the OECD countries and China respectively using the following decomposition:

$$E_t = \frac{E_t}{FEC_t} \frac{FEC_t}{TEC_t} \frac{TEC_t}{GDP_t} \frac{GDP_t}{P_t} P_t \qquad (5)$$

where FEC and TEC are fossil fuel and total energy consumption respectively and P is population. Hamilton and Turton (2002) include an additional factor reflecting the conversion efficiency from primary to final energy use. As carbon emission reduction technologies do not yet effectively exist, the first term on the RHS reflects the impact of shifts in the mix of fossil fuel types. The second term reflects shifts between fossil and non-fossil fuels, while the remaining terms are energy intensity and two components of the scale effect. Hamilton and Turton (2002) find that the main factor increasing carbon emissions in the OECD from 1982 to 1997 is income per capita (37%) and the second population growth (12%). The main factor reducing emissions was energy intensity. Zhang (2002) finds that the decline in energy intensity in China almost halved the increase in emissions that would otherwise have occurred. Other factors had very minor effects.

Hilton and Levinson (1998) estimate EKCs for automotive lead emissions. Data is available on both the total consumption of gasoline and the lead content of gasoline. Hence, decomposition into scale and technical change effects is easy in this special case. The regression estimates use total lead emissions as the dependent variable for unclear reasons and so are difficult to interpret. There is some evidence of an EKC effect in 1992 when lead content per gallon of gasoline was a declining function of income. Per capita gasoline use rises strongly with income. However, there is a wide scatter in developing countries with many low and middle income countries having low lead contents. Before 1983 there is no evidence of an EKC type relation in the data. The inference is that there was a technological innovation that was preferentially adopted in high income countries. As Gallagher (2003) suggests, these innovations may be adopted with a relatively short lag in developing countries. Hettige *et al*. (2000) use a similar approach to model industrial BOD emissions in a range of developing and developed countries. The share of manufacturing industry in national income and the share of polluting industries within total manufacturing represent composition effects and actual plant level end of pipe BOD emissions per unit output represent technique effects. Each component is modeled as a function of income and other variables and then the components are reassembled to predict emissions at different levels of development. Emissions rise up to around $7000 per capita and then are fairly constant at higher income levels. Composition effects work together with scale at lower income levels to increase

this form of pollution. At higher income levels they reduce pollution, but together with the technique effect, which acts against the scale effect at every level of income, only just exactly offset the effects of rising scale.

Stern (2002) uses the following econometric model to decompose sulfur emissions in 64 countries in the period 1973-90:

$$\frac{S_{it}}{P_{it}} = \gamma_i \frac{Y_{it}}{P_{it}} A_t \frac{E_{it}}{Y_{it}} \prod_{j=1}^{J} \left(\frac{y_{jit}}{Y_{it}} \right)^{\alpha_j} \sum_{k=1}^{K} \frac{e_{kit}}{E_{it}} \varepsilon_{it} \qquad (6)$$

where S is sulfur emissions and P population and the RHS decomposes per capita emissions into the following five effects:

$\dfrac{Y_{it}}{P_{it}}$	Scale – GDP per capita
A_t	A common global time effect representing the effects of emissions specific technical progress
$\dfrac{E_{it}}{Y_{it}}$	Energy intensity – the effect of general productivity on emissions.
$\dfrac{y1_{it}}{Y_{it}}, \dots, \dfrac{yJ_{it}}{Y_{it}}$	Output Mix – shares of the output of different industries y in total GDP Y.
$\dfrac{e_{1it}}{E_{it}}, \dots, \dfrac{e_{Kit}}{E_{it}}$	Input Mix – shares of different energy sources e in total energy use E.

The contributions of the five effects at the global level are given in Table 3. Input and output effects contributed little globally, though in individual countries they can have important effects. At the global level the two forms of technological change reduced the increase in emissions to half of what it would have been in their absence with emissions specific technological change lowered aggregate emissions by around 20%. The residuals from the model show it to be a statistically adequate representation of the data. A nested test of this model and the EKC showed that the income squared term in the EKC added no explanatory power to that provided by the decomposition model.

Antweiler *et al.* (2001) come full circle from Grossman and Krueger's (1991) study of the potential impacts of NAFTA by applying what they describe as a decomposition model to the question of whether free trade is good for the environment. This model does not however, attribute changes in emissions to a comprehensive set of sources. They develop a reduced form econometric model from a theoretical structural model of the demand and supply of pollution and estimate it using the GEMS sulfur dioxide concentration data. The theoretical model allows an increase in openness to trade to have scale, compositional, and technique effects. However, the technique effect is assumed to be induced by the increase in income due to trade. This model, therefore, takes the EKC hypothesis as a given. Compositional effects are expected to differ in capital intensive and labor intensive economies. Trade is likely to increase pollution in the former and reduce it in the latter. Therefore, the capital/labor ratio is controlled for. The

"scale elasticity" is estimated to average 0.266. But this is the elasticity of concentrations to a city-based measure of GDP per square kilometer. In no way can this be a legitimate measure of scale, as urban expansion (holding GDP per square kilometer constant) is an increase in scale and, as discussed above, suburbanization and decentralization also accompany economic development. The sample mean of the technique elasticity (elasticity of concentrations w.r.t. GNP per capita) is –1.15. The composition elasticity (elasticity of concentrations w.r.t. capital/labor ratio) is 1.01 and trade intensity has an elasticity of –0.864. Combining the effects, trade has a negative impact on emissions, but this effect is a function of income with small or positive impacts in high-income countries and reductions in emissions in developing countries. This is because high-income countries are capital intensive and low income countries labor intensive.

Judson *et al*. (1999) estimate separate EKC relations for energy consumption in each of a number of energy-consuming sectors for a large panel data set using spline regression. This allows them to estimate different time effects in each sector and these vary substantially. Time effects show rising energy consumption over time in the household and other sector but flat to declining time effects in industry and construction. Technical innovations tend to introduce more energy using appliances to households and energy saving techniques to industry. The income effects add explanatory power. Income elasticities decline with rising income but this effect is most pronounced for the households and other sector. The share of transportation tends to rise with rising income. Industry and construction has a U-shaped EKC for energy consumption.

The conclusion from all these studies is that the main means by which emissions of pollutants can be reduced is by time related technique effects and in particular those directed specifically at emissions reduction, though productivity growth or declining energy intensity has a role to play. Though structural change and shifts in fuel composition may be important in some countries at some times their average contribution seems less important quantitatively. Those studies that include developing countries – Judson et al. (1999), Antweiler *et al*. (2001), and Stern (2002) – find that these technological changes are occurring in both developing and developed countries. Innovations may first be adopted preferentially in higher income countries (Hilton and Levinson, 1998) but seem to be adopted in developing countries with relatively short lags (Gallagher, 2003). This result is in line with the evidence of Dasgupta *et al*. (2002) and the EKC based estimates of time effects in Stern and Common (2001) and Stern (2002).

9.   Conclusions

The evidence presented in this paper shows that the statistical analysis on which the environmental Kuznets curve is based is not robust. There is little evidence for a common inverted U-shaped pathway which countries follow as their income rises. There may be an inverted U-shaped relation between urban ambient concentrations of some pollutants and income though this should be tested with more rigorous time series or panel data methods. It seems unlikely that the EKC is a complete model of emissions or concentrations.

The true form of the emissions-income relationship is likely a mix of two of the scenarios proposed by Dasgupta *et al*. (2002) illustrated in Figure 3. The overall shape is that of their "new toxics" EKC - a monotonic increase of emissions in income. But over time this curve shifts down. This is analogous to their "revised EKC" scenario, which is intended to indicate that over time the conventional EKC curve shifts down. Some evidence shows that a particular innovation is likely to be adopted preferentially in high-income countries first with a short lag before it is adopted in the majority of poorer countries. However, emissions may be declining simultaneously in low and high income countries over time, *ceteris paribus*, though the particular innovations typically adopted at any one time could be different in different countries.

It seems that structural factors on both the input and output side do play a role in modifying the gross scale effect though they are less influential on the whole than time related effects. The income elasticity of emissions is likely to be less than one - but not negative in wealthy countries as proposed by the EKC hypothesis.

In slower growing economies, emissions-reducing technological change can overcome the scale effect of rising income per capita on emissions. As a result, substantial reductions in sulfur emissions per capita have been observed in many OECD countries in the last few decades. In faster growing middle income economies the effects of rising income overwhelmed the contribution of technological change in reducing emissions.

The research challenge now is to revisit some of the issues addressed earlier in the EKC literature using the new decomposition models and rigorous panel data and time series statistics. For example, how can the effects of trade on emissions be modeled in the context of the decomposition model? Rigorous answers to such questions are central to the debate on globalization and the environment.

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Table 1.			**Sulfur EKC Studies**				
Authors	Turning Point 1990 USD	Emis. or Concs.	PPP	Additional Variables	Data Source for Sulfur	Time Period	Countries/cities
Panayotou, 1993	$3137	Emis.	No	-	Own estimates	1987-88	55 developed and developing countries
Shafik, 1994	$4379	Concs.	Yes	Time trend, locational dummies	GEMS	1972-88	47 Cities in 31 Countries
Torras and Boyce, 1998	$4641	Concs.	Yes	Income inequality, literacy, political and civil rights, urbanisation, locational dummies	GEMS	1977-91	Unknown number of cities in 42 countries
Grossman and Krueger, 1991	$4772-5965	Concs.	No	Locational dummies, population density, trend	GEMS	1977, '82, '88	Up to 52 cities in up to 32 countries
Panayotou, 1997	$5965	Concs.	No	Population density, policy variables	GEMS	1982-84	Cities in 30 developed and developing countries
Cole *et al*., 1997	$8232	Emis.	Yes	Country dummy, technology level	OECD	1970-92	11 OECD countries
Selden and Song, 1994	$10391-10620	Emis.	Yes	Population density	WRI - primarily OECD source	1979--87	22 OECD and 8 developing countries
Kaufmann *et al*., 1998	$14730	Concs.	Yes	GDP/Area, steel exports/GDP	UN	1974-89	13 developed and 10 developing countries
List and Gallet, 1999	$22675	Emis.	N/A	-	US EPA	1929-1994	US States
Stern and Common, 2001	$101166	Emis.	Yes	Time and country effects	ASL	1960-90	73 developed and developing countries

		Levels				First Differences	
Region	Model	Turning Points	Hausman Test	Chow F Test	$-$	Turning Points	Mean Income Elasticity
OECD	FE	$9,239			0.9109	$55,481	0.67
	RE	$9,181	0.3146 (0.8545)		0.9070		
Non-OECD	FE	$908,178			0.8507	$18,039	0.50
	RE	$344,689	14.1904 (0.0008)		0.8574		
World	FE	$101,166		10.6587 (0.0156)	0.8569	$33,290	
	RE	$54,199	10.7873 (0.0045)	4.0256 (0.0399)	0.8624		

Table 2:   Stern and Common (2001) Key Results

All turning points in real 1990 purchasing power parity US dollars.

Table 3.   Contributions to Total Change in Global Sulfur Emissions

Total Change:	Weighted Logarithmic Percent Change
Actual Emissions	28.77%
Predicted Emissions	27.37%
Unexplained Fraction	1.40%
Decomposition:	
Scale Effect	53.78%
Emissions Related Technical Change	-19.86%
Energy Intensity	-10.20%
Output Mix	3.77%
Input Mix	-0.13%

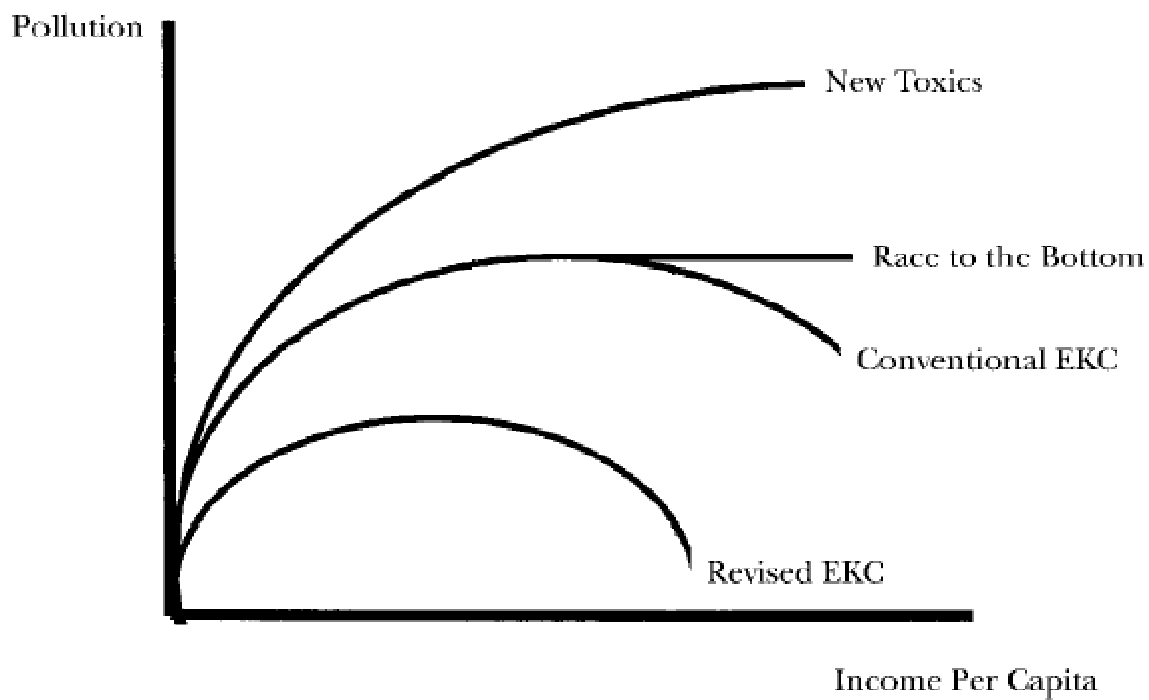**Figure 1:   Environmental Kuznets Curve for Sulfur Emissions**
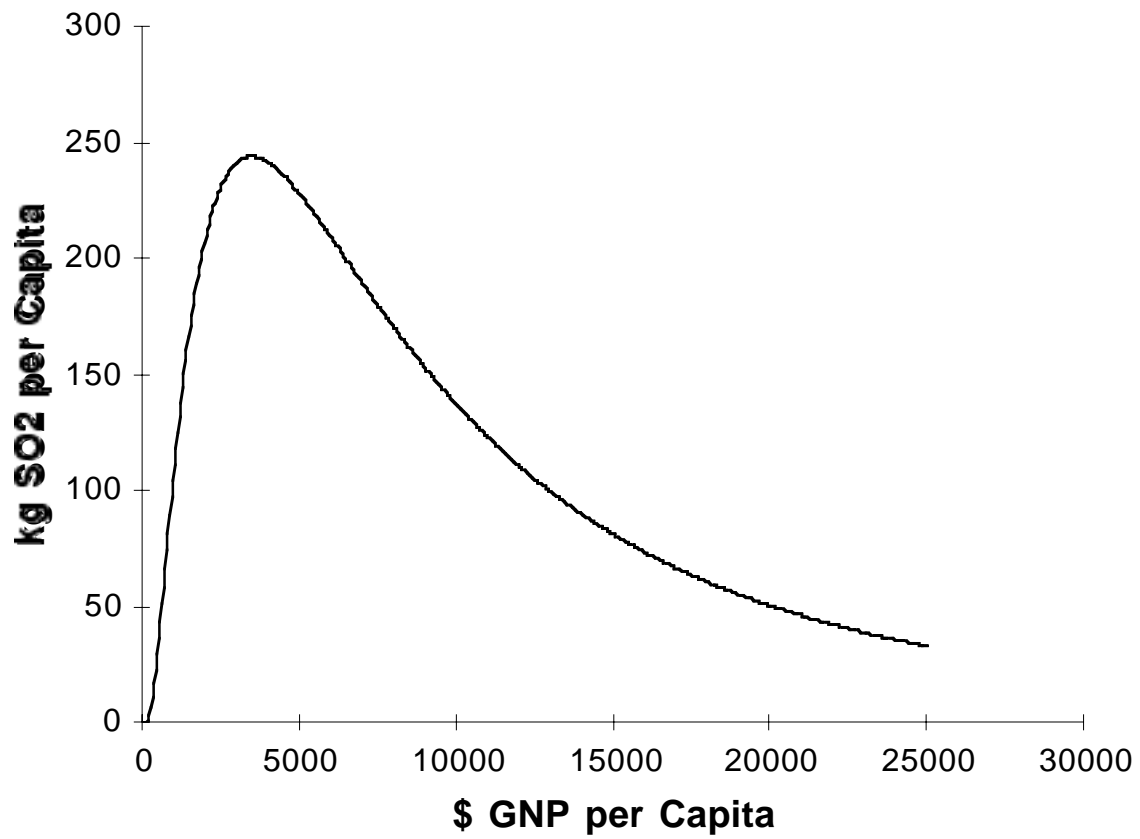
Source: Panayotou (1993), Stern *et al*. (1996).

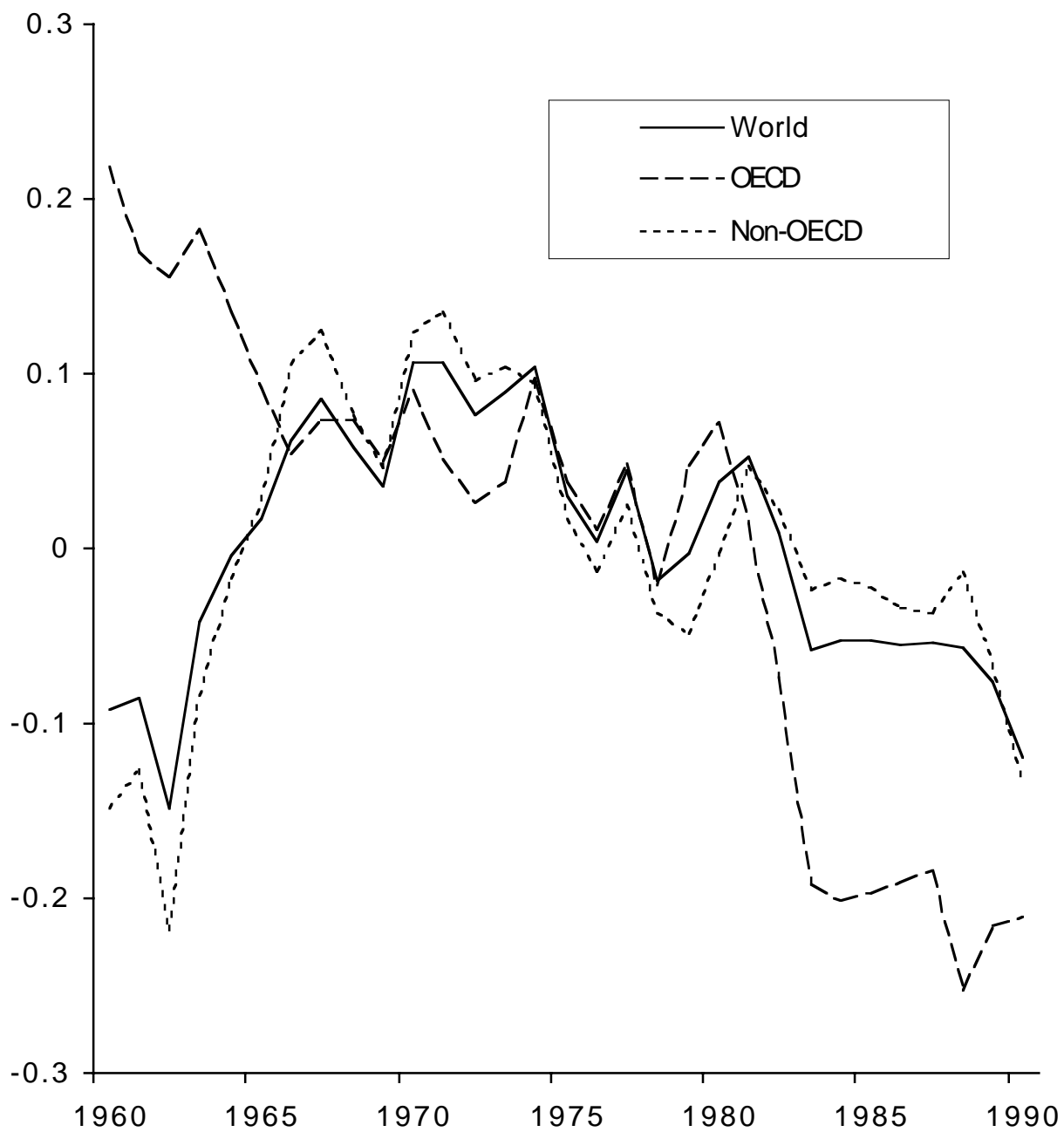**Figure 2:   Projected Sulfur Emissions (Stern et al., 1996)**
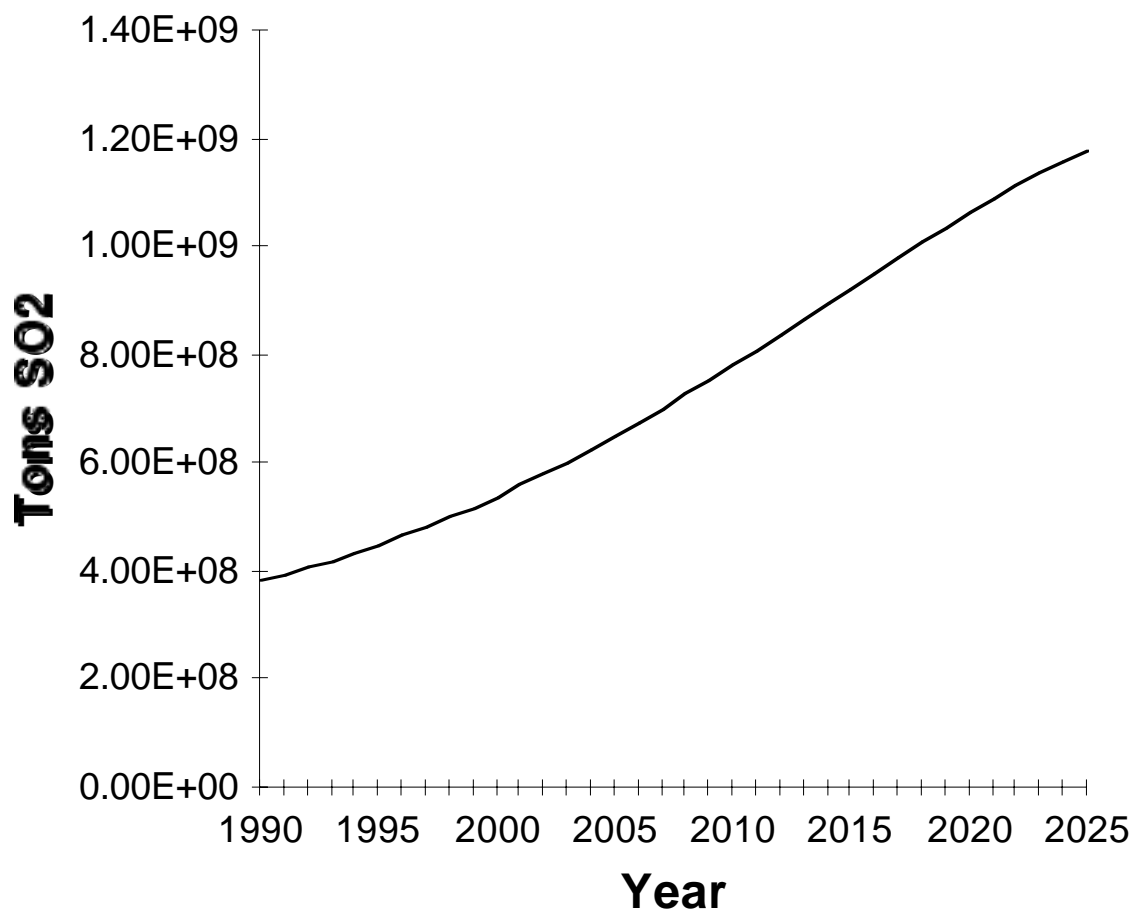
Source: Stern *et al*. (1996).

Figure 3:   Environmental Kuznets Curve: Alternative Views

Source: Dasgupta *et al*. (2002), Perman and Stern (2003).

Figure 4:   Time Effects: First Differences Sulfur EKC

Source: Stern and Common (2001).