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The Environmental Kuznets Curve

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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 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. It is very easy to do bad econometrics and the history of the EKC exemplifies what can go wrong. The EKC idea rose to prominence because few paid sufficient attention to econometric diagnostic statistics. Little or no attention has been paid to the statistical properties of the data used such as serial dependence or stochastic trends in time series and few tests of model adequacy have been carried out or presented. 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 such statistics 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. 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 article follows the development of the EKC concept in approximately chronological order. Sections 2 and 3 of the article review in more detail the theory behind the EKC and the econometric methods used in EKC studies. Sections 4 through 6 review some EKC analyses and their critique. Sections 7 discusses the recent evidence from Dasgupta *et al*. and others that has changed the picture that we have of the EKC. The final two 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, p 482) 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." However, the EKC has never been shown to apply to all pollutants or environmental impacts and recent evidence (Dasgupta *et al*., 2002; Perman and Stern, 2003) 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, p 1).

Therefore, at one level the EKC is explained by the following ‘proximate factors’:

1. **Scale** of production implies expanding production at given factor-input ratios, output mix, and state of technology.

2. Different industries have different pollution intensities and typically, over the course of economic development the **output mix** changes.

3. Changes in **input mix** involve the substitution of less environmentally damaging inputs for more damaging inputs and vice versa.

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

a. **Production efficiency** in terms of using less, *ceteris paribus*, of the polluting inputs per unit of output.

b. **Emissions specific changes in process** result in less pollutant being emitted per unit of input.

These proximate variables may in turn be driven by changes in underlying variables such as environmental regulation, awareness, and education in the course of economic development. A number of papers have developed theoretical models about how preferences and technology might interact to result in different time paths of environmental quality. The different 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. Stokey (1998) allows endogenous technical change. It seems fairly easy to develop models that generate EKCs under appropriate assumptions but none of these theoretical models has been empirically tested. 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 necessarily a 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. The standard EKC regression model is:

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

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.

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 α_i and γ_t as regression parameters while the random effects model treats them as components of the random disturbance. 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.

Perman and Stern (2003) employ some newly developed panel unit root and cointegration tests and find that sulfur emissions and GDP per capita may be integrated variables. Coondoo and Dinda (2002) yield similar results for carbon dioxide emissions. If 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 and so it is unclear what we can infer from the majority of EKC studies.

4. Results of EKC Studies

The key features differentiating EKC studies for different pollutants, data etc. can be displayed by reviewing a few of the early studies and examining a single indicator (sulfur) in more detail.

The early EKC studies appeared to indicate 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.

Grossman and Krueger (1991) produced the first EKC study 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 involved 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.

Shafik and Bandyopadhyay's (1992) study was particularly influential as the results were used in the 1992 World Development Report (IBRD 1992). They estimated EKCs for ten different indicators using three different functional forms. Lack of clean water and lack of urban sanitation were found to decline uniformly with increasing income, and over time. Both deforestation regressions showed no relation between income and deforestation. River quality tended to worsen with increasing income. Local air pollutant concentrations, however, conformed to the EKC hypothesis with turning points 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. 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 with the reverse happening in the later stages of development. So it is possible for peak ambient pollution concentrations to fall as income rises even if total national emissions are rising (Stern *et al*., 1996)

Table 1 summarizes several studies of sulfur emissions and concentrations, listed in order of estimated income turning point. On the whole the emissions based studies have higher turning points than the concentrations based studies. The studies of Kaufmann *et al*. (1998) and Panayotou (1993) have unusual features which make them exceptions to the rule (Stern, 1998).

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 bigger 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.

The recent studies that use 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. The turning point is at only 54% of maximal GDP in the sample. A study by Schmalensee *et al*. (1998) also implies a within sample turning point for carbon for high-income countries (Stern and Common, 2001). 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.

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.

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. 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). There are no clear answers on the impact of trade on pollution from the empirical EKC literature.

Some 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 (Stern *et al*., 1996). 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. More recent estimates show that the turning point is higher and therefore there should not be room for confusion on this issue.

6. Econometric Critique of the EKC

Econometric criticisms of the EKC concern four main issues: 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. The overall pattern that emerges is that causality runs from income to emissions or that 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) estimate a sulfur emissions EKC for 74 countries over the period 1960-90. They 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.

The Hausman test statistic showed 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, which indicates that the regressors are likely correlated with omitted variables and the regression coefficients are biased. As expected, given the Hausman test results, the parameter estimates turned out to be 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. As mentioned above, these results exactly parallel those for developed and developing country samples of carbon emissions. There was also a very high level of serial correlation indicating misspecification either in terms of omitted variables or missing dynamics.

Perman and Stern (2003) test the 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.

7. Other Evidence

Dasgupta *et al*. (2002) present 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. They present data that shows declines in various pollutants in developing countries over time. They show that though regulation of pollution increases with income the greatest increases happen from low to middle income levels and there would be expected to be diminishing returns to increased regulation, though also better enforcement at higher income levels. 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. Multinational companies respond to investor and consumer pressure in their home countries and raise standards in the countries they invest in. Furthermore, 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) reports that China has reduced sulfur emissions and even carbon emissions in recent years. Ambient air pollution has been reduced in several major cities and, with the exception of some encouragement of road transport, the government is making a sustained effort in the direction of environmentally friendly policies and sustainable development.

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. that, unfortunately is unavailable for most countries. Stern (2002) and Antweiler *et al*. (2001) develop econometric models that do not require sectoral emissions or input data.

Grossman (1995) and de Bruyn (1997) proposed the following decomposition into 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) carries out a Divisia index decomposition of changes in emissions of SOx, NOx, and CO2 for the USSR/Russia, Poland, Hungary, USA, UK, and France for 1970-94 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. 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.

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. 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.

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.

Stern (2002) uses an econometric model to decompose sulfur emissions in 64 countries in the period 1973-90 into the five components identified previously. 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 – 28% from 54% - in their absence with emissions specific technological change lowering aggregate emissions by around 20% and reduced energy intensity contributing a 10% reduction. 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) apply an econometric decomposition model to the question of whether free trade is good for the environment using the GEMS sulfur dioxide concentration data. Combining the various effects that they estimate, 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.

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 - 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 to be monotonic but the curve shifts down over time. 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 sides 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. Rigorous answers to these questions are central to the debate on globalization and the environment.

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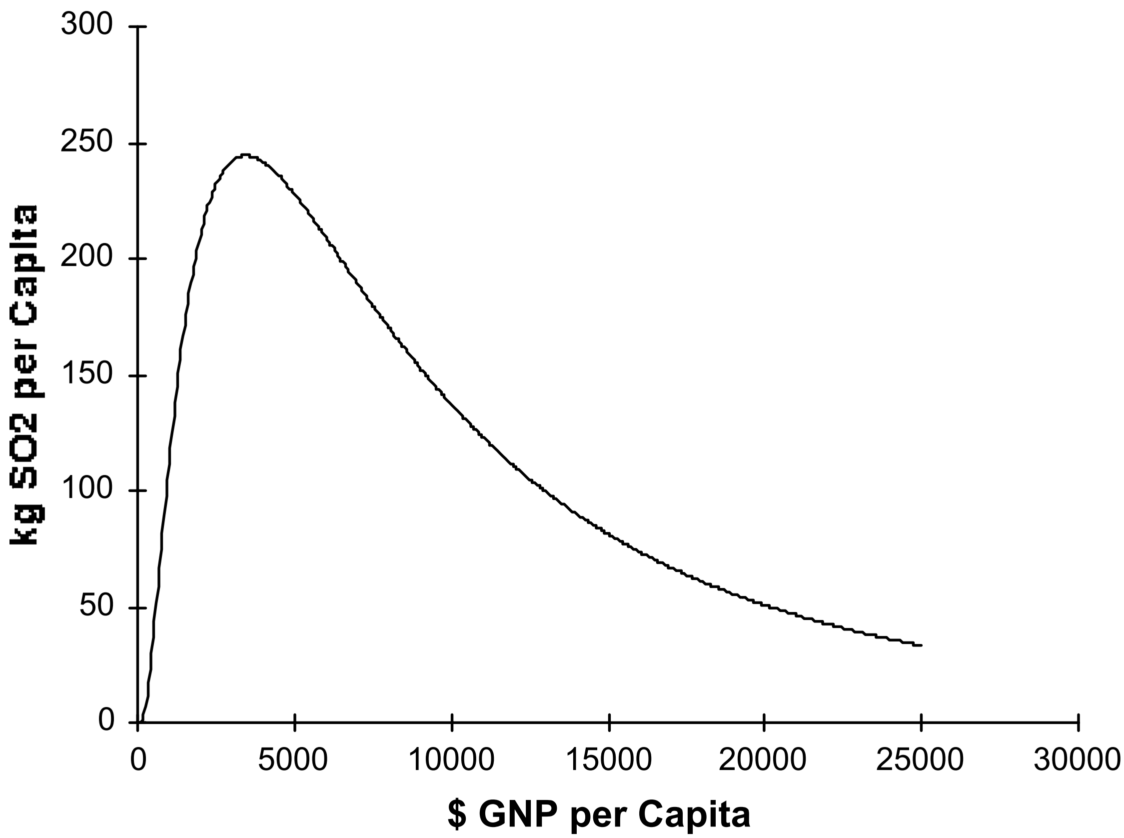
Online Sources

A more complete version of this article is available at: http://www.rpi.edu/~sternd/Riseandfall.pdf

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

Figure 1: Environmental Kuznets Curve for Sulfur Emissions



Source: Panayotou (1993), Stern *et al*. (1996).