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ECONOMIC GROWTH AND ENVIRONMENTAL DEGRADATION: A CRITIQUE OF THE ENVIRONMENTAL KUZNETS CURVE

by

David I. Stern, Michael S. Common, and Edward B. Barbier

Heslington, York, YO1 5DD
Telephone: 44 (0)904 432 999
Telefax: 44 (0)904 432 998

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David I. Stern *, Michael S. Common **, Edward B. Barbier ***

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* Department of Environmental Economics and Environmental Management (EEEM), University of York, Heslington, York, YO1 5DD, UNITED KINGDOM. Fax : 44-904-432998 Tel : 44-904-4324061 E-Mail : dis5@tower.york.ac.uk

** EEEM and CRES, Australian National University, Canberra, Australia.

*** EEEM.

Abstract

In this paper we critically examine the concept of the environmental Kuznets curve (EKC). This concept, most prominently promoted in the World Development Report 1992, proposes that there is an inverted U-shape relation between environmental degradation and income per capita. The concept is dependent on a model of the economy in which there is no feedback from the quality of the environment to economic growth and in which trade has a neutral effect on environmental degradation. There are also some econometric problems with previous estimates of the EKC. The inference from the EKC estimates that further development will reduce environmental degradation is dependent on the assumption that World income is normally distributed when in fact median income is far below mean income. To illustrate the latter point we carry out a simulation under the assumption that one could actually analyze the economy-environment relationship in the way suggested by the EKC. We combine published estimates of the EKC with World Bank forecasts for long-run economic growth. The analysis shows that within the horizon of the Bank's forecast (2025) global emissions of SO2 will continue to increase. Forest loss stabilizes before the end of the period but tropical deforestation continues to proceed at a constant rate throughout the period. This is despite a near doubling in mean world income per capita.

Economic Growth and Environmental Degradation: A Critique of the Environmental Kuznets Curve

1.0 Introduction

In this paper we critically examine the concept of the environmental Kuznets curve (EKC) (Selden and Song, 1992; Panayotou, 1993). This term refers to the empirical regularity that pollution and deforestation rates in the most developed countries tend to be lower than in many middle income countries. Likewise pollution and deforestation rates tend to be higher in many middle income countries than in the less developed countries. Also, in recent years, the concentration of many pollutants has declined in the industrialized economies. Extrapolating from these regularities, several authors (Bernstam, 1991; Beckerman, 1992; IBRD, 1992; Grossman and Krueger, 1991 (henceforth GK); Shafik and Bandyopadhyay, 1992 (henceforth SB); Selden and Song, 1992 (henceforth SS); Panayotou, 1993 (henceforth P); Cropper and Griffiths, 1994 (henceforth CG)) have proposed that individual countries will go through a period of high environmental degradation followed by a period of much lower environmental degradation as they develop. Research along these lines is continuing apace (IBRD, 1994, 8).

Bernstam (1991) argued that declining pollution with growth in industrialized countries could offset rising pollution emissions in the developing countries. Beckerman (1992) further asserted that growth in developing countries would reduce pollution levels in those countries. However, in Indonesia, Thailand, and the Philippines, for example, pollution levels have risen much faster than GDP in the last twenty years (The Economist, 1993). A number of authors have made econometric estimates of the EKC (GK, SB, SS, P, CG). The fitted econometric estimates show that levels of pollution emissions per capita and deforestation are much lower in both the industrialized nations and the lowest income countries than they are in middle income countries. The estimates would appear to support Bernstam's (1991) arguments though not those of Beckerman (1992).

In the next section of the paper we examine the major shortcomings of this approach. The third section goes into more detail in examining the existing empirical studies of the EKC. In the fourth section of the paper we combine existing estimates of the EKC with long-term regional projections for economic growth to obtain a projection of two representative indices of environmental degradation: SO_2 emissions and deforestation. Finally we discuss directions for future research.

2.0 Critique of the Environmental Kuznets Curve

There are several major problems with the literature on the environmental Kuznets curve: Inference from the EKC estimates has been based on mean income per capita rather than median income per capita; the EKC assumes unidirectional causality from growth to environmental quality; the EKC assumes that changes in trade relationships associated with development have no effect on environmental quality; the econometric literature presumes that ordinary least squares is an appropriate estimation technique; problems with data; and finally, many environmental problems are known to increase monotonically with income per capita.

2.1 Mean and Median Income

As discussed in the next section the EKC estimates for a number of indicators: SO_2 emissions, NO_x emissions, and deforestation, peak at income levels around the current World mean per capita income. So a cursory glance at the available econometric estimates might lead one to believe that, given likely future levels of mean income per capita, environmental degradation should decline. 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 and of course World median income per capita is much lower than world mean income per capita. This means that assuming that the EKC relationship is valid, global environmental degradation is set to rise for a long time to come. In section 4.0 below we combine P's estimates of the EKC with the World Bank's (IBRD, 1992) long-term regional projections for economic growth to obtain a projection to 2025 of two indices of environmental degradation: SO_2 emissions and deforestation. The level of the indicators is projected for each individual country and total World emissions or forest loss aggregated up from the individual countries.

CG conclude that despite finding an inverted U relationship between deforestation and income in Africa and Latin America, the majority of the countries in their sample are below the peak level and therefore economic growth would not reduce deforestation. SS conclude that the majority of the countries are below their estimated peak levels for air pollutants and therefore economic growth would be unlikley to reduce air pollution. Our analysis extends these conclusions to the World as a whole.

2.2 Simultaneity of Economy and Environment

More fundamentally, the EKC concept is dependent on a model of the economy in which there is no feedback from the quality of the environment to economic growth. Rising levels of deforestation and pollution are seen as having harmful effects only on the quality of life but not on the possible level of material output. Assuming that the EKC relationship was true and emissions tended to zero at high levels of income, the appropriate policy to reduce environmental problems would be to maximize growth. This is the principal message of the 1992 World Bank Development Report (IBRD, 1992) though other authors (eg. P) are more more cautious. But attempting to grow fast in the early stages of development when environmental degradation is rising may be counterproductive ie. unsustainable. There is clear evidence of this from many developing countries (Barbier, 1994). An alternative route through which GDP growth may be reduced due to deteriorating environmental quality is through the diversion of resources to the clean up of environmental problems. More generally, economy and environment are jointly determined (Perrings, 1987) so that it is inappropriate to estimate a single equation model where there is unidirectional causality from income to environment.

Economic activity inevitably implies the use of resources. By the laws of thermodynamics, use of resources inevitably implies the production of waste. It is quite clear that the levels of many pollutants per unit of output in specific processes have declined in the 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 even if per unit output waste has declined. de Bruyn and Opschoor (1994) present results that suggest that at high income levels material use again increases so that the EKC is N-shaped. GK's results and some of SB's results present a similar picture. If emissions do not eventually tend to zero in the very long-run then rising income, if it could be sustained, would inevitably mean rising pollution. Pezzey (1989, 20-23) presents arguments in favor of an N-shaped EKC. Pezzey proposes that the optimal path of environmental degradation may be monotonically increasing with the level of development. Initially, property rights are not established and environmental degradation increases more rapidly than the optimal rate. As environmental degradation and the level of development increase property rights are established and the level of environmental degradation declines until it "catches up" to the optimal path and the increase in environmental degradation recommences.

The environmental Kuznets curve literature implicitly assumes that there are no limits to growth. Some of the strongest proponents of the EKC were also the strongest opponents of the "Limits to Growth" thesis (Beckerman, 1974; 1993). Though the model and assumptions used by Meadows *et al.* (1972) were deeply flawed, their basic propositions were well founded (Perrings, 1987; Common, in press; Stern, 1994).

2.3 *Trade and the EKC*

Countries such as Japan that import most of their raw materials may in fact be exporting their environmental problems to the countries with which they trade (Herendeen, 1994). The Office of Technology Assessment (U.S. Congress, 1990) has shown that the energy intensity of US imports has been increasing. This is one way in which the US has managed to reduce the energy intensity of its output over the last twenty years. Also much of the reduction in the energy / GDP ratio in individual economies over time and the international variations in the energy / GDP ratio are due to structural change within economies and structural differences between economies (Kaufmann, 1992). As this structural change has been partly accomplished through specialization towards activities with a lower resource intensity it is not clear that the world as a whole can achieve a similar transformation.

The Hecksher-Ohlin trade theory suggests that, under free trade, developing countries would specialize towards the production of goods which are intensive of the factors that they are endowed with in relative abundance: labor and natural resources. The developed countries would specialize towards 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.*, 1991). The environmental intensity of domestic production depends partly on the environmental intensity of imports and vice versa. They are simultaneous decisions that depend on relative factor costs in the consuming and producing countries. A single equation model of the EKC does not allow the identification of the two different models of movement along the EKC.

Environmental regulation in developed countries might further encourage polluting activities to gravitate towards the developing countries (Lucas *et al.*, 1991; Ekins *et al.*, 1994). The econometric results of Lucas *et al.* (1991) strongly suggest that this phenomenon has occurred. This effect exaggerates the apparent decline in pollution intensity with rising income along the EKC. When the poorer countries apply similar levels of environmental regulation they will face the more difficult task of abating these activities rather than hiving them off to other countries.

Many have expressed the opinion that trade, as currently practiced, is inevitably harmful to the environment (eg. Ekins *et al.*, 1994; Røpke, 1994). This is not our position. Rather, trade may give an importer the opportunity to externalize some disbenefits onto the populations of other countries. The net global effect of trade on environmental quality could be positive, negative, or neutral.

2.4 Econometric Problems

As discussed above, there are a number of simultaneity issues that make identification of alternative structures difficult if not impossible within a single equation OLS framework. None of the empirical studies presents diagnostic statistics of the regression residuals. Additionally, two forms of heteroskedasticity may be important in the context of cross-sectional regressions of grouped data. There is heteroskedasticity related to the use of observations aggregated over varying numbers of subunits in any cross-section regression that uses such observations, though this may be counteracted by the presence of other heteroskedasticity effects related to the level of income or other independent variables. The appropriate GLS weights for the first problem are $\sqrt{n_i}$, where n_i is the number of units over which observation i is aggregated (Maddala, 1977, 268-274). Intuitively, individual people or firms pollute and individual square kilometers of land are cleared of trees. The EKC would ideally be estimated using these micro level observations. Aggregation obscures the heterogeneity within countries. The GLS weights take this into account and give a higher weight to the larger units. To deal with other sources of heteroskedasticity, diagnostic tests must be applied to the equations corrected for grouping heteroskedasticity. If heteroskedasticity is present, a suitable GLS regression should be estimated (see Stern, 1993).

2.5 Data Problems

Data on environmental problems are notoriously patchy in coverage or poor in quality. Those studies that have attempted to estimate the EKC have faced these problems. The only available data is not necessarily appropriate data on which to base policy conclusions of the type presented. GK and SB both use ambient pollution data from urban areas. This is appropriate in as far as the effects on human health in urban areas is concerned. However, the estimated EKC relationship can be misleading in projecting the expected change in the acid burden from nitrogen and sulfur oxide emissions on natural and agricultural ecosystems. As is well known, societies tend to go through a process of increasing and then falling urban population densities and concentrations as they develop (see Stern, 1992, for references). The concentration of pollution sources is therefore also likely to go through a similar process. Declining ambient concentrations of pollutants does not mean necessarily that the overall pollution burden is declining. GK do include city population density as an explanatory variable but SB make no corrections. P tried to circumvent this problem by using total emissions, but sparse data for developing countries required him to make considerable simplifying assumptions in estimating total emissions. SS explicitly used emissions per capita and emissions per hectare as dependent variables as they were clearly aware of the problems discussed in this section. More details are presented in section 3.0 below.

2.6 Aggravation of Other Environmental Problems

The enhanced greenhouse effect is probably the most serious threat to global sustainability (Common, 1993), but no-one suggests that an inverted U-shaped curve applies for the greenhouse gasses. In fact the World Bank (IBRD, 1992, 11) and SB emphasize that CO_2 emissions increase with per capita income. Therefore even if economic growth could greatly lower the current rates of per capita emissions of other pollutants and deforestation in developing countries it would be likely to increase these countries contribution to global warming.

Given our critique of EKC fitting exercises, detailed examination of single equation relationships for such environmental problems would be inappropriate. However, some brief remarks are in order, so as to put the results discussed later in the paper in perspective.

The Human Development Report for 1992 (UNDP, 1992; Tables 23 and 43) gives data for a greenhouse index for 1988-89. This index is: 'Net emissions of three major greenhouse gasses (carbon dioxide, methane, and CFCs) weighting each gas according to its heat trapping quality in carbon dioxide equivalents and expressed in metric tons of carbon per capita'. The report also gives data for on per capita income in purchasing power parity dollars, for 1989. There was data on both variables for 132 countries. We fitted a quadratic to this data, with an additional explanatory variable for national average annual temperature (Showers, 1979). The coefficient on the square of income was positive, but statistically insignificant. Therefore, the greenhouse index increases linearly with income (t values in parentheses):

$$g = -.9450 + 0.0023\,y + 0.0248\,T \qquad (1)$$
$$\quad (1.04) \quad (7.76) \quad (2.05)$$

where g is the index, y is income, and T is temperature. The adjusted R squares for this regression is 0.3255.

Given that this greenhouse gas index includes the CFCs, it is inappropriate to use it to project future global emissions. In its 1992 report, the Intergovernmental Panel on Climate Change considers six scenarios for global greenhouse gas emissions until 2100, which take account of international agreements on CFCs. The scenarios span a range of assumptions about population and economic growth. According to all the scenarios, CH_4 and N_2O emissions are lower in 2100, but only one scenario results in lower CO_2 emissions (Houghton et al., 1992, 69-96).

As energy is required to move and transform matter, energy use is as an approximate first order indicator of overall environmental impact. A regression of per capita energy consumption for 1989 (UNDP, 1992) on income and temperature gives an inverted U-shaped relationship between energy and income. When a quadratic in income is fitted, the coefficient on the squared income term is negative and statistically significant, but small in magnitude, approximately .7E-05 (adjusted R square 0.8081). Per capita energy consumption peaks at $14600.

The World Development Report (IBRD, 1992) also gives data on per capita energy consumption (Table 5) and per capita national income (Tables 1 and 30) for 1990. For this data set there are 101 observations. Using this data to fit a quadratic in income produces results which depend upon the income measure used. Whichever income measure is used, the coefficient on temperature, is not statistically significant. If the purchasing power parity income measure is used, the coefficient on squared income is positive but small and statistically insignificant - energy use per capita increases linearly with per capita income (adjusted R square 0.7165). If income per capita is measured using official exchange rates, the fitted energy income relationship is of the inverted U-shape - squared income has a negative and statistically significant coefficient (adjusted R square 0.6564). However, the coefficient is very small, .9E-05, and energy use per capita peaks at a per capita income of $23900, which is more than $2000 above the reported OECD average.

The most interesting thing about these regressions is that they demonstrate the sensitivity of the results to the data sources. For income reported in purchasing power parity dollars, UN data can be represented as an EKC type relationship, whereas World Bank data cannot.

3.0 Review of Principal Econometric Studies of the EKC

This section enters into more specific detail regarding the individual empirical studies of the EKC. There have been five principal studies : GK; SB; SS; P; and CG.

3.1 Grossman and Krueger

GK estimated EKC's for SO_2, dark matter (fine smoke), and suspended particles (SPM), as part of a study assessing the impact of NAFTA on the environment in Mexico. The data were taken from the GEMS (Global Environmental Monitoring System) data published by WHO. This data refers to measurements of ambient air quality in two or three locations in each of a group of cities in a number of countries between 1977 and 1988. The number of locations varies over time eg. 52 cities in 32 countries in 1982 but only 27 cities in 14 countries in 1988, but is believed to be fairly representative of varying levels of economic development and geographical conditions (Bennett *et al.*, 1985).

Each regression consisted of a cubic function of real 1985 international per capita GDP taken from the Summers and Heston (1991) data, with the addition of site related variables, a time trend, and a trade intensity variable. The site related variables were included to differentiate between variation in ambient levels of pollution due to the influence of city and site characteristics and that due to the EKC relationship. These included the population density of the city in question, whether the observations were from commercial, industrial, or residential areas, and whether the city was located on the coast, in a desert etc. The time trend was intended to take into account any global trend in pollution. The trade intensity variable was included under the hypothesis that that "a country's level of pollution might be directly related to its openness to international trade, perhaps because environmental regulations tend to a least common denominator" (13).

The estimated peak level of SO_2 and dark matter was at around $4000-5000. The joint significance levels for the three income variables in each of these regressions are less than 0.0001. The concentration of suspended particles appeared to decline even at low income levels. Both the time trend and the trade intensity variables had a significant negative coefficient in the SO_2 regression. On the former GK comment "The downward trend may reflect an increasing global awareness of the health problems associated with SO_2, and the expanding efforts that are being made worldwide to limit sulfur emissions" (p16). On the latter they state that they "have no good economic explanation for this finding" (p17). As discussed in section 2.3, there may be a number of explanations for this observation which cannot be explored in a single equation context. Neither the time trend nor the trade variable were significant in the equation explaining the concentration of dark matter. The time trend was significant in the suspended particles regression but again the trade variable was insignificant.

At income levels over $10000-15000 GK's estimates show increasing levels of all three pollutants. Their results are therefore not in violation of the first law of thermodynamics. Though economic growth at middle income levels would improve environmental quality, growth at high income levels would be detrimental. This is similar to de Bruyn and Opschoor's (1994) results discussed in 2.2.

3.2 Shafik and Bandyopadhyay

SB estimated EKC's for ten different indicators of environmental degradation as part of the background study for the 1992 World Development Report. The indicators are : 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 rate of deforestation between 1961 and 1986 (ie. observations for each individual year), dissolved oxygen in rivers, fecal coliforms in rivers, municipal waste per capita, and carbon emissions per capita. The sample includes observations on up to 149 countries for the period 1960-1990, though the coverage is very patchy. Some of the dependent variables are observed for cities within countries, others for countries as a whole.

The study uses three different functional forms. Log-linear, log-quadratic in income, and in the most general case a logarithmic cubic polynomial in GDP per capita and a time trend. As in

GK's study, GDP per capita was measured in PPP terms and site related variables were added where relevant. These site variables are cruder than those used by GK. There are interactive dummies for commercial, industrial etc, locations, but also interactive dummies for each city within a given country whereas GK used dummies for physical features and a population density variable. SB also carried out a number of additional regressions adding various policy variables such as trade orientation, electricity prices etc. The results for these are rather ambiguous and difficult to interpret.

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 (Adjusted R-Square close to zero). SB point out that neither of the measures that they use fully captures the extent of deforestation as this may have commenced hundreds or thousands of years ago. Annual deforestation data are notoriously inaccurate as in most cases they are simply interpolations between benchmark years in which surveys have been conducted. Also the proportional rate of deforestation depends on the area of forest in each country (Burgess, 1992; Barbier and Burgess, 1993). This variable is not accounted for in either this study or in P's study. The fitted peak is around $2000 per capita, though of course it is impossible to distinguish this from zero.

River quality tends to worsen with increasing income. The authors suppose that this is because the external costs imposed by this form of pollution may decline as water supply systems improve. The two air pollutants, however, conform to the inverted U curve. The peak levels of both pollutants are found for income levels of between $3000 and $4000. The selected functional form implies that the levels of these pollutants could approach zero as income increases in apparent violation of the first law of thermodynamics. The adjusted R-Square is between 0.96 and 1.00 for all the water and air quality regressions. This is probably the result of the site dummies in these equations. The time trend is significantly positive for fecal coliform and significantly negative for air quality. Finally, both municipal waste and carbon emissions per capita unambiguously increase with rising income.

The broader range of indicators examined by SB clearly show a much more ambiguous picture of the relationship between environment and development than indicated by GK's more limited study. They summarize the situation by stating :

> "It is possible to "grow out of" some environmental problems, but there is nothing automatic about doing so. Action tends to be taken where there are generalized local costs and substantial private and social benefits." (from the abstract)

Given the results presented by SB this seems to overstate the case.

3.3 Selden and Song

SS estimated EKC's for four air pollutants: SO_2, NO_x, SPM, and CO. The pollutants are measured in terms of both kilograms per capita and kilograms per hectare, calculated on a national basis. This is a departure from the previous two studies. The data are pooled time-series and cross sectional data drawn from *World Resources* (WRI, 1991). The data are averages for the periods 1973-75, 1979-81, and 1982-84. It is unclear how many or which countries are in the sample- the maximum number of observations in any regression was 68.

The econometric equations were as follows:

$$m_{it} = \delta_0 + c_i + v_t + \delta_1 y_{it} + \delta_2 y_{it}^2 + (\alpha - 1)\,\delta_1 y_{it-1} + (\alpha - 1)\,\delta_2 y_{it-1}^2 + \varepsilon_{it} \qquad (2)$$

where y is real GDP per capita (Summers and Heston's (1991) data); the c_i country specific effects; the v_t time period specific effects; and ε is a random error term. The lagged values of income represent a partial adjustment process where pollution moves towards the equilibrium level at a given income per capita with partial adjustment coefficient α. The levels formulation implies that pollution could fall to zero or become negative at sufficiently high levels of income. The authors were aware of this shortcoming and adapted their forecasts to avoid negative projections. The authors were also very thorough in checking the specification of their models.

With the exception of the equation for per capita emissions of NO_x, the coefficient estimates were in general significant. The estimated turning points are all very high. For per hectare emissions: SO_2, \$9900; NO_x, \$6475; SPM, \$10354; and CO, \$9909. For per capita emissions: SO_2, \$9486; NO_x, \$8768; SPM, \$23734; and CO, \$12435. SS suggest that this is because ambient pollution levels are likely to decline before aggregate emissions. There is some support for this interpretation from P's results discussed in the next section. The time specific effects show a declining trend in pollution, *ceteris paribus*.

3.4 Panayotou

P estimated EKC's for SO_2, NO_x, SPM, and deforestation. At variance to the previous three studies he only employs cross sectional data and GDP is in nominal US dollars (1985). In common with SS the three pollutants are measured in terms of emissions per capita on a national basis. Data for developing countries were estimated on the basis of the fuel mix and level of fuel consumption in those countries. This means that these data are very inaccurate as the sulfur content of a single fuel type will vary depending on its source and metal smelting and other activities are large contributors to atmospheric pollution. Deforestation is measured as the mean annual rate of deforestation in the mid 1980's plus unity. There are various problems with this data. Tropical deforestation appears to include both open and closed forests. Open forests may have as few as 10% tree cover. P's data appear to be for gross deforestation in some developing countries such as Chile and Algeria where afforestation exceeded deforestation in the period in question (WRI, 1991). P records positive deforestation for these countries. However, for many of the developed countries for which he uses FAO data he records negative deforestation (ie afforestation). This bias will increase the significance of the estimated EKC. There are 68 countries in the deforestation sample and 54 in the pollution sample.

The equations for the three pollutants are logarithmic quadratics in income per capita, and for deforestation a translog function in population density and income per capita with the addition of a dummy variable for tropical countries. All the estimated curves are inverted U's which conforms to the results for these variables in the other studies. This form implies that emissions of pollutants could tend to zero as income increases in apparent violation of the laws of thermodynamics. At the sample mean population density peak deforestation is reached at $823 per capita. Deforestation rates were significantly greater in tropical countries. Deforestation was also higher in countries with higher population densities. Peak per capita SO_2 emissions occur around $3000 per capita, peak NO_x per capita at about $5500 per capita, and peak SPM at $4500. P uses current exchange rates rather than PPP rates. This tends to lower the income levels of developing countries relative to most developed countries, though also lower the incomes of a number of developed countries. Despite this the turning points for the pollutants are in a similar range to those reported by GK and SB. This may be because P uses a per capita formulation in place of ambient concentrations which, as discussed in 2.5 and 3.4, will tend to increase measured pollution at higher income levels.

3.5 Cropper and Griffiths

CG estimate three regional EKC's for deforestation only. The dependent variable is minus the percentage change in forest area between two years. Deforestation is observed for 1961 to 1991 for 64 countries. The separate regressions are for Africa, Latin America, and Asia. The data are pooled time series cross section data on a regional basis. The independent variables in each regression are: rural population density, percentage change in population, timber price, percentage change in per capita GDP (PPP terms), per capita GDP, square of per capita GDP, a dummy variable for each country, and a time trend.

The results for Africa and Latin America show an R-square of 0.63 and 0.47 respectively, which given the dummy variables is fairly low. Neither the population growth rate nor the time trend were significant in either region, and the price of tropical logs was insignificant in Africa.

Otherwise the coefficients were significantly different from zero (t statistic ≥ 1). None of the coefficients in the Asian regression were significant and the R-square is only 0.13. For Africa the income level at which deforestation peaks is \$4760, and for Latin America, \$5420. These levels are very much higher than either P's or SB's results and in fact most of the observations fall between the peak and the origin. This suggests that deforestation increases at a slowing rate rather than actually peaking as income rises. In contrast to SB and to a lesser degree P, CG conclude that economic growth will clearly not solve the problem of deforestation.

4.0 Forecast of World Environmental Degradation using Panayotou's EKC Estimate and IBRD Growth Forecasts

In this section we use the projections of world economic growth and world population growth published in the World Bank Development Report 1992 (IBRD, 1992), together with P's econometric estimates of the environmental Kuznets curve for deforestation and SO_2 emissions to produce global projections of these variables for the period 1990-2025. We chose these two indices because they can be aggregated on a global basis and represent two major aspects of environmental degradation. We did not use GK's or SB's results because their SO_2 models are for ambient air quality which we cannot use to find World emissions. Also they use differing intercepts for individual sites which cannot be generalized on a world scale. SB's deforestation regressions have adjusted R squares of zero or close to zero. CG's deforestation regressions do not cover the developed countries and therefore cannot be used for a global projection and again have unreported intercept terms for each country. SS's SO_2 model is not logarithmic and also uses differing intercepts for individual countries which cannot be generalized on a world scale.

A population and an economic growth projection was calculated for every country in the World with a population greater than 1 million in 1990 : all those countries appearing in the tables at the rear of the World Bank Development Report plus Cuba, North Korea, the former USSR, and Taiwan. Then forecasts of deforestation and emissions were estimated for each country individually using P's equations. The results of these were aggregated into global projections of forest cover and emissions.

The population projection is based on the projections for 1990, 2000, and 2025 in Table 26 of IBRD (1992, 268). Populations in internodal years were estimated by least squares curve-fitting according to the following equation :

$$P_t = \exp[\alpha + \beta t + \gamma t^2] \qquad (3)$$

where P_t is population in year t. As there are only three observations per country the fitted regression hyperplane is a perfect fit to the data. Economic growth projections use the forecast growth rates for different world regions of Table 1.2 in IBRD (1992, 32). The growth rates were held constant over 1990-2025, which seems roughly consistent with Figure 1.3 in the same source (IBRD, 1992, 33). Data for 1990 are from Table 1 in IBRD (1992, 218). World population grows from 5265 million in 1990 to 8322 million in 2025. Mean world per capita income rises from \$3957 in 1990 to \$7127 in 2025. P's SO_2 equation is :

$$\ln(SO_2/P) = -35.26 + 8.13 \ln Y/P + 8.13 (\ln Y/P)^2 \qquad (4)$$

where Y is GNP in US dollars at current exchange rates, SO_2 is tonnes of sulphur dioxide, and P is population. If all countries were actually at the mean income level then emissions of SO_2 per capita would decline from 55kg to 38kg from 1990 to 2025. Total emissions would be fairly constant, rising from 287 million tonnes to 315 million tonnes. However, as world income distribution is strongly skewed downwards the results using the disaggregated data are sharply different. Emissions of SO_2 per capita rise from 73kg to 142kg from 1990 to 2025. Global emissions rise from 383 million tonnes in 1990 to 1181 million tonnes in 2025 (Figure 1). In particular, increasing pollution in China and India swamps the effect of reductions in the NICs and HDCs.

P's deforestation equation is :

$$\ln(DEF+1) = 0.0133 \ln Y/P - 0.0181 \ln P/A - 0.0013 (\ln Y/P)^2 + 0.011 (\ln P/A)^2 + 0.00096 \ln Y/P \ln P/A + 0.0189\, TROPICAL \qquad (5)$$

where A is the area of the country in thousands of hectares and TROPICAL is a dummy variable for all tropical countries. We estimated the area of forest cover in each country in 1990 from Table A.6 in IBRD (1992, 200). Then using the estimated deforestation rates from equation (5) we projected the remaining forest cover in each country in each year :

$$F_T = F_{1990} \prod_{t=1}^{T} (1 - \widehat{DEF}_t) \qquad (6)$$

where F_{1990} is the area of forest cover in 1990 and $\widehat{DEF}_t$ is the estimated rate of deforestation in year t. Despite the maximum rate of deforestation at P's sample mean population density occurring at \$823, global forest cover declines until 2016 when mean World income is \$5962 (Figure 2). From then on forest cover recovers somewhat. This is partly because rising population density balances rising income. Global forest cover declines from 40.4 million km^2 in 1990 to a minimum of 37.2 million km^2. The final level of forest cover is 37.6 million km^2. However, tropical forest cover continues to decline throughout the period from 18.4 million km^2 in 1990 to 9.7 million km^2 in 2025. The rate of tropical deforestation stays constant at

1.8% per annum. This implies net temperate reforestation of 6 million km^2. This unlikely number implies net reforestation of around 70% of the land area of the UK or the entire area of the state of Missouri each year for 35 years.

SS carried out a somewhat similar projection exercise for their four air pollutants. They used the 1985 data for 127 countries in the Penn World Table as the benchmark and made projections for 1995, 2005, 2015, and 2025. Forecasts of GDP and population growth are simple extrapolations of the 1975-85 growth rates. The levels formulation of their model required SS to transform their pollution projections using a tobit functional form that results in assymptotically zero pollution at highest and lowest GDP per capita. The country and time specific effects are ignored in the projection. Nitrogen oxides showed continuous growth through the projection horizon for a total of 350% increase over 40 years. The other three pollutants increased until 2015, and declined thereafter. In 2025 sulfur dioxide emissions were 65% higher than in 1985.

5.0 Conclusions

We believe that the nature of the problems associated with both the concept and empirical implementation of the EKC make it inappropriate to conduct further studies of this type. Though we could estimate a model that improved on certain aspects of the existing literature, any cross-sectional study would still be fatally flawed by the overall problem of simultaneity between economy, environment, economic structure, and trade. The very large literature on exports and economic growth (see survey by Edwards, 1993) suffers from similar problems. Levine and Renelt (1992) concluded that few of the cross-sectional regressions, put forward in the literature as evidence for a strong relationship between exports and growth, were robust to the choice of conditioning variables. At this stage of our knowledge, more could be learnt from examining the experiences of individual countries at varying levels of development as they developed over time.

The adjustments required to move from an unsustainable World economy to a sustainable economy will be enormous (Ekins, 1993). Though some pollution emissions, and the rate of deforestation may decline with increasing GNP per capita in the richer countries of the World it seems that increasing levels of pollution and land-conversion in both middle income and low income countries will far outweigh these improvements. Going beyond the results presented in this paper increasing damage to the biosphere is likely to undermine the growth which EKC proponents postulate will be available for environmental "cleanup". As Pezzey (1989) makes clear through theoretical analysis: "It is important to state this to counteract the simplistic view still often expressed that 'we must grow in order to clean up the effects of growth'; clearly this is not always true even physically, let alone economically " (25). Neither is there any evidence to show that carbon emissions per capita are likely to decline autonomously in any country.

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Figure 1. World SO2 Emissions: Panayotou EKC Estimate

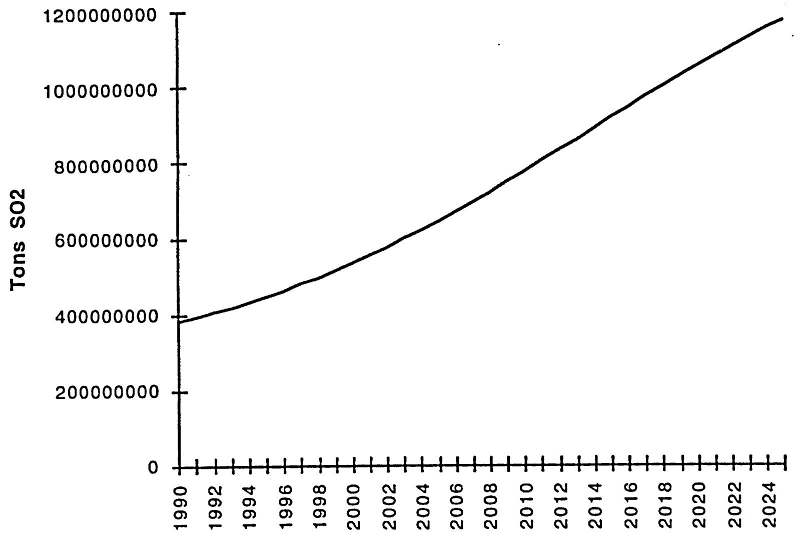
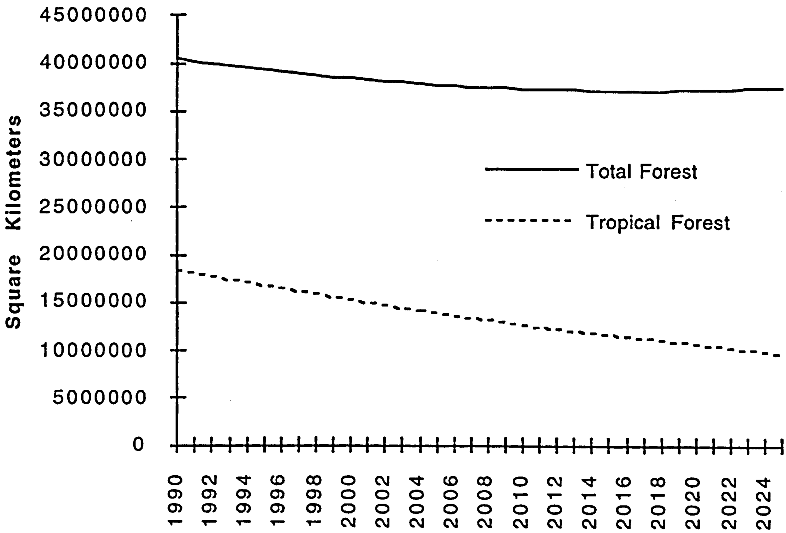


Figure 2. World Forest Cover: Panayotou EKC Estimate



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