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Economic Growth and Environmental Degradation: The Environmental Kuznets Curve and Sustainable Development

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Summary. — In this paper we critically examine the concept of the environmental Kuznets curve (EKC). It proposes that there is an inverted U-shape relation between environmental degradation and income per capita, so that, eventually, growth reduces the environmental impact of economic activity. The concept is dependent on a model of the economy in which there is no feedback from the quality of the environment to production possibilities, and in which trade has a neutral effect on environmental degradation. The actual violation of these assumptions gives rise to fundamental problems in estimating the parameters of an EKC. The paper identifies other econometric problems with estimates of the EKC, and reviews a number of empirical studies. The inference from some such EKC estimates that further development will reduce environmental degradation is dependent on the assumption that world per capita income is normally distributed when in fact median income is far below mean income. We carry out simulations combining EKC estimates from the literature with World Bank forecasts for economic growth for individual countries, aggregating over countries to derive the global impact. Within the horizon of the Bank's forecast (2025) global emissions of SO₂ continue to increase. Forest loss stabilizes before the end of the period but tropical deforestation continues at a constant rate throughout the period. Copyright © 1996 Elsevier Science Ltd

1. INTRODUCTION

The environmental Kuznets curve (EKC) hypothesis is that environmental damage first increases with income, then declines. This might be taken to suggest that economic growth is not a threat to global sustainability, and that there are no environmental limits to growth. In the last five years there have been several empirical investigations of the EKC hypothesis. The results have been mixed. This paper provides a critical review of this work.

At low levels of development both the quantity and intensity of environmental degradation is limited to the impacts of subsistence economic activity on the resource base and to limited quantities of biodegradable wastes. As economic development accelerates with the intensification of agriculture and other resource extraction and the take off of industrialisation, the rates of resource depletion begin to exceed the rates of resource regeneration, and waste generation increases in quantity and toxicity. At higher levels of development, structural change towards information-intensive industries and services, coupled with increased environmental awareness,

2. THE EKC HYPOTHESIS

The reasoning behind the EKC hypothesis has been put succinctly as follows:

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enforcement of environmental regulations, better technology and higher environmental expenditures, result in levelling off and gradual decline of environmental degradation (Panayotou, 1993).

This argument leads to a hypothesized relationship between environmental degradation and income per capita which takes the form of an inverted U. Such a relationship is sometimes called an "environmental Kuznets curve", EKC, after Kuznets (1955, 1963) who hypothesized an inverted U for the relationship between a measure of inequality in the distribution of income and the level of income. If the EKC hypothesis held generally, it could imply that instead of being a threat to the environment as argued in, for example, *The Limits to Growth* (Meadows *et al.*, 1972), economic growth is the means to environmental improvement. Figure 1 shows, as an illustration, the relationship between SO₂ emissions per capita and income per capita obtained by Panayotou (1993).

The World's Bank's *World Development Report 1992* (IBRD, 1992) was subtitled "Development and the Environment," and considered, without using the terminology, the EKC hypothesis. It noted that: "The view that greater economic activity inevitably hurts the environment is based on static assumptions about technology, tastes and environmental investments" (p. 38). It cited the following as "Factors that can play a particularly important role" in determining the environmental impact per unit of economic activity:

Structure: the goods and services produced in the economy

Efficiency: inputs used per unit of output in the economy

Substitution: the ability to substitute away from resources that are becoming scarce

Clean technologies and management practices: the ability to reduce environmental damage per unit of input or output.

The report noted that the extent to which these factors operated to reduce environmental impact per unit economic activity would depend upon the incentive

structures facing agents, and policy settings. It noted that: "As incomes rise, the demand for improvements in environmental quality will increase, as will the resources available for investment" (p. 39). In terms of actual experience, it was noted that in some cases the evidence was consistent with the EKC hypothesis, and that in others it was not.

The *World Development Report 1992* was careful in its analysis and conclusions, did not claim that economic growth alone is the solution to all environmental problems, and emphasized the importance of policies to protect the environment. Many of the other contributions to the EKC literature, reviewed in section 3 below, are similarly cautious in interpreting the policy implications of their empirical results. Other economists and policy analysts, however, appear to have missed the qualifications in this literature. In our view this is a serious oversight. It is necessary to be clear about the empirical status and implications of the EKC hypothesis before attempting to derive far-reaching policy conclusions. Others share this view. In a recent short paper in the Policy Forum section of *Science*, Arrow *et al.* (1995) note that:

The general proposition that economic growth is good for the environment has been justified by the claim that there exists an empirical relation between per capita income and some measures of environmental quality.

Here the authors refer to the EKC hypothesis as "the inverted-U relation" and note that it has been "shown to apply to a selected set of pollutants only," but that some economists "have conjectured that the curve applies to environmental quality generally." Arrow *et al.* conclude that: "Economic growth is not a panacea for environmental quality; indeed it is not even the main issue."

The need to clarify the status and implications of the EKC hypothesis is exemplified by the following quotation from an article appearing in this journal:

Furthermore 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 (Beckerman, 1992).

In the next section, 3, we review the "clear evidence," and in section 4 we discuss generic problems attending attempts to generate evidence on the EKC hypothesis. In section 5 we consider the use of such evidence to derive implications for future prospects, especially in regard to sustainable development.

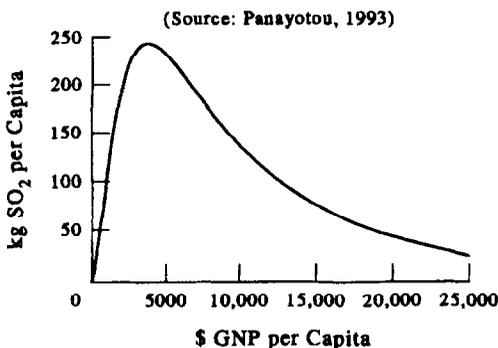


Figure 1. An estimated EKC for SO₂.

3. EMPIRICAL RESULTS ON THE EKC HYPOTHESIS

In this section we review five empirical studies of

the EKC hypothesis, and report some results of our own. Where an inverted-U relationship between impact and income is found to fit the data, the level of income corresponding to the peak level of impact is obviously of interest for inferred future global prospects. We refer to this income level as "the turning point."

(a) *Grossman and Krueger (1994)*¹

Grossman and Krueger estimated EKCs for SO₂, dark matter (fine smoke), and suspended particles (SPM), as part of a study assessing the impact of the North American Free Trade Agreement (NAFTA) on the environment in Mexico. The data were taken from the GEMS (Global Environmental Monitoring System) data published by the World Health Organization. These data refer to measurements of ambient air quality in two or three locations in each of a group of cities in a number of countries during 1977–88. The number of locations varies over time (52 cities in 32 countries in 1982, but only 27 cities in 14 countries in 1988), but the data are believed to be fairly representative of varying levels of economic development and geographical conditions (Bennett *et al.*, 1985).

Each regression involves a cubic function of real 1985 per capita GDP measured in purchasing power parity dollars (\$PPP) taken from the Summers and Heston (1991) data. Each includes 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. They 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 trade intensity variable was included under the hypothesis 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."

The turning points for SO₂ and dark matter are at around \$4,000–5,000. 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 SO₂ regression. 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 \$10,000–15,000 Grossman and Krueger's estimates show increasing levels of all three pollutants. Though economic growth at middle-

income levels would improve environmental quality, growth at high-income levels would be detrimental.

(b) *Shafik and Bandyopadhyay (1992)*²

Shafik and Bandyopadhyay estimated EKCs for 10 different indicators of environmental degradation as part of the background study for the 1992 *World Development Report* (IBRD, 1992). The indicators are: lack of clean water, lack of urban sanitation, ambient levels of suspended particulate matter, ambient sulfur oxides, change in forest area during 1961–86, the annual rate of deforestation during 1961–86 (i.e. observations for each individual year), dissolved oxygen in rivers, faecal coliforms in rivers, municipal waste per capita, and carbon emissions per capita. The sample includes observations on up to 149 countries for 1960–90, 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 and, in the most general case, a logarithmic cubic polynomial in GDP per capita and a time trend. As in Grossman and Krueger'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 Grossman and Krueger. There are interactive dummies for commercial, industrial etc., locations, and also interactive dummies for each city within a given country (whereas Grossman and Krueger used dummies for physical features, and a population density variable). Shafik and Bandyopadhyay 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. Shafik and Bandyopadhyay 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. Moreover, the proportional rate of deforestation depends on the area of forest in each country (Burgess, 1993; Barbier *et al.*, 1995). This variable is not accounted for in this study. The turning point is around \$2,000 per capita, though of course it is impossible to distinguish this from zero, given the lack of statistical significance.

River quality tends to worsen with increasing income. Shafik and Bandyopadhyay 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 EKC hypothesis. The turning points for both pollutants are found for income levels of between \$3,000 and \$4,000. The selected functional form implies that the levels of these pollutants could go to zero as income increases. The adjusted R-Squared is surprisingly high, 0.96 and greater, 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 faecal 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 Shafik and Bandyopadhyay clearly shows a much more ambiguous picture of the relationship between environment and development than indicated by Grossman and Krueger's more limited study. Shafik and Bandyopadhyay summarize the implications of their results 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.

(c) *Selden and Song (1994)*

Selden and Song estimated EKC's for four airborne emissions: SO₂, NO_x, SPM, and CO. The emissions are measured in terms of kilograms per capita on a national basis. The data are pooled time-series and cross-sectional data drawn from World Resources (WRI, 1991). The data are averages for 1973–75, 1979–81, and 1982–84. Of the 30 countries in the sample, 22 were categorized as high income, six as middle income, and two as low income. The maximum number of observations in any regression was 68. Selden and Song estimated a variety of specifications. We concentrate on the results they present for a fixed effects model including a population density variable. The fitted equations were of the form

$$m_{it} = b_0 + b_1 y_{it} + b_2 y_{it}^2 + b_3 d_{it} + c_i + v_t$$

where m is per capita emissions, y is real GDP per capita in \$PPP, i indexes location, and t indexes time. The c_i are country specific effects, the v_t are time period specific effects, and d is population density. The authors suggest that in countries with low population densities there will be less pressure to adopt stringent environmental standards and emissions due to transportation will be higher. The formulation implies that pollution could fall to zero at sufficiently high levels of income.

With the exception of the CO model, the coefficient estimates for the income terms were significantly different from zero. The estimated turning points are all very high in relation to other studies: SO₂, \$8,709; NO_x, \$11,217; SPM, \$10,289; and CO, \$5,963. Selden and Song suggest that this is because ambient pollution levels are likely to decline before aggregate emissions. Societies tend to go through a process of increasing and then falling urban population densities as they develop (see Stern, 1992). The concentration of pollution sources is then likely to go through a similar process, so that declining ambient concentrations do not necessarily mean that total emissions are declining. There is some support for this interpretation from Panayotou's results discussed below.

(d) *Panayotou (1993)*

Panayotou estimated EKC's for SO₂, NO_x, SPM, and deforestation. In contrast to the three studies already discussed, this study employs only cross-sectional data and GDP is in nominal, 1985, US dollars. In common with Selden and Song, the three pollutants are measured in terms of emissions per capita on a national basis. Data for developing countries were estimated from fuel use and fuel mix data. This means that these data are likely to be inaccurate. The sulfur content of a single fuel type will, for example, vary according to its source, and Panayotou appears to have made no allowance for this. In addition, fossil fuel combustion is not the only source of these pollutants. Deforestation is measured as the mean annual rate of deforestation in the mid-1980s, plus unity. There are problems with these data also. Tropical deforestation appears to relate to both open and closed forests. Open forests may have as little as 10% tree cover. Panayotou'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). Panayotou records positive deforestation for these countries, ignoring the afforestation. For many of the developed countries for which he uses FAO data, however, he uses net deforestation data and records negative deforestation (i.e. 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 fitted equations for the three pollutants are logarithmic quadratics in income per capita. For deforestation Panayotou fits 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. For the sample mean population density, the turning point for deforestation is \$823 per capita. Deforestation rates were significantly greater in tropical countries.

Deforestation was also higher in countries with higher population densities. For SO₂ emissions the turning point is around \$3,000 per capita, for NO_x around \$5,500 per capita, and for SPM around \$4,500. As noted above, Panayotou uses official exchange rates rather than \$PPP rates. This tends to lower the income levels of developing countries relative to most developed countries. Despite this the turning points for the pollutants are in a similar range to those reported by Grossman and Krueger and Shafik and Bandyopadhyay. This may be because Panayotou uses emissions per capita rather than ambient concentrations.

(e) *Cropper and Griffiths (1994)*

Cropper and Griffiths estimate three regional EKC's for deforestation only. The regions are Africa, Latin America, and Asia. For each region pooled time series cross-section data are used. The dependent variable is the percentage change in forest area between two years (with the sign changed). Deforestation is observed for 1961–91 for 64 countries. The independent variables in each regression are: rural population density, percentage change in population, timber price, per capita GDP and percentage change in per capita GDP (\$PPP), square of per capita GDP, a dummy variable for each country, and a time trend.

The results for Africa and Latin America show adjusted R-squares of 0.63 and 0.47 respectively, which given the use of the dummy variables is perhaps surprisingly 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. None of the coefficients in the Asian regression were significant and the R-square is only 0.13. For Africa the turning point is \$4,760, and for Latin America \$5,420. These levels are very much higher than those from either Panayotou's or Shafik and Bandyopadhyay's results. In contrast to Shafik and Bandyopadhyay, and to a lesser degree Panayotou, Cropper and Griffiths conclude that economic growth will clearly not solve the problem of deforestation.

4. PROBLEMS ATTENDING THE ESTIMATION OF EKCS

There are several major generic problems with hypothesis testing and estimation in relation to the environmental Kuznets curve: the assumption of unidirectional causality from growth to environmental quality; the assumption that changes in trade relationships associated with development have no effect on environmental quality; and data problems and their implications.

(a) *Simultaneity*

The EKC hypothesis derives from a model of the economy in which there is no feedback from the state of the environment to economic growth. Rising levels of deforestation and pollution are seen as having harmful effects on the quality of life but not on production possibilities. In the absence of any such feedback to production, if the EKC hypothesis were confirmed, this would suggest growth maximization as the solution to the quality of life problem in a poor country. But, given such feedback, attempting to grow fast in the early stages of development when environmental degradation is rising may be counterproductive, i.e. unsustainable. There is clear evidence of this from many developing countries (Barbier, 1994).

Arrow *et al.* (1995) note that "all economic activity ultimately depends" on the "environmental resource base," imprudent use of which "may irreversibly reduce the capacity for generating material production in the future." The environmental resource base includes assimilative capacities for waste discharges. Exceeding assimilative capacity gives rise to pollution, which in addition to being directly offensive and/or injurious to humans, can reduce the availability and productivity of renewable resources, and interfere with the operation of environmental life support services (Common, 1995).

Generally, the economy and its environment are jointly determined (Perrings, 1987). In modeling empirically the relationship between economic output and major impacts on the environment arising, it is inappropriate to estimate a single equation model assuming unidirectional causality from economy to environment. All of the results considered in the previous section were obtained using ordinary least-squares (OLS) estimation methods. Estimating single-equation relationships by ordinary least squares where simultaneity exists produces biased and inconsistent estimates.

(b) *International trade*

Countries, such as Japan for example, that import most of their raw materials may be exporting environmental impacts to the countries with which they trade (Herendeen, 1994). Japan has also moved over time to importing more processed raw materials such as aluminium metal instead of bauxite (Bohi and Darmstadter, 1994), with similar implications. The Office of Technology Assessment (US 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 20 years. Moreover, 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 struc-

tural differences between economies (Kaufmann, 1992). As this structural change has, in countries such as Japan and the United States, been partly accomplished through specialization toward activities with lower energy and resource intensities, it is not clear that the world as a whole can achieve a similar transformation.

Standard trade theory suggests that, under free trade, developing countries would specialize toward the production of goods which are intensive in the factors that they are endowed with in relative abundance: labor and natural resources. The developed countries would specialize toward 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 (Hettige, Lucas and Wheeler, 1992). The empirical evidence here, however, is rather mixed. Hettige, Lucas and Wheeler (1992) found that toxic emissions grew faster in the developing countries than in developed countries, but also that more open economies have less growth in toxic emissions. The environmental intensity of domestic production depends partly on the environmental intensity of imports and vice versa. They are the outcome of simultaneous decisions that depend on relative factor costs in the consuming and producing countries. A single-equation reduced form model, such as the EKC, does not allow the identification of the structural equations and the separation of the different causal chains.

Environmental regulation in developed countries might further encourage polluting activities to gravitate toward the developing countries (Hettige, Lucas and Wheeler, 1992; Ekins, Folke and Costanza, 1994). The econometric results of Hettige, Lucas and Wheeler (1992) are to some extent consistent with the operation of such an effect. When the poorer countries apply similar levels of environmental regulation, however, they will face the more difficult task of abating these activities rather than hiving them off to other countries, there being nowhere for unregulated activities to migrate to. This is another particular example of the general point that the historical experience of some economies cannot be extrapolated to the future of the global economy.

(c) *Data problems*

Data on environmental problems are notoriously patchy in coverage and/or poor in quality. The only available data are not necessarily appropriate for testing the EKC hypothesis, estimating its parameters, and drawing inferences about future trends. Some of the considerations arising in particular studies were discussed in section 3 above. The nature of the general problem can be illustrated for the case of atmospheric pollution.

The studies of Grossman and Krueger and Shafik and Bandyopadhyay both use ambient pollution data from urban areas. This is appropriate if the effects on human health in urban areas is the environmental impact of interest. The EKC relationship thus estimated would be misleading, however, for the purpose of projecting the acid burden from nitrogen and sulfur oxide emissions on natural and agricultural ecosystems. From a sustainable development perspective, these burdens are at least as important as direct effects on human health. Panayotou used emissions rather than concentrations, but sparse data for developing countries required him to estimate their emissions using simplifying assumptions. Selden and Song used emissions per capita and emissions per hectare as dependent variables, in the light of the problems with concentrations discussed here.

The data used in EKC studies are likely to give rise to heteroskedasticity problems in estimation, arising, for example, from the use of observations which are aggregations over varying numbers of subunits. In the presence of heteroskedasticity, OLS estimation is inefficient, though unbiased. When using cross-sectional data and OLS, diagnostic tests on the residuals should be used to check for heteroskedasticity, and generalized least squares estimation methods used to get efficient estimates if the presence of heteroskedasticity is detected (see Stern, 1993). All of the studies reviewed here use OLS: results from tests for heteroskedasticity are not reported.

5. IMPLICATIONS FOR SUSTAINABLE DEVELOPMENT

In this section we first consider the implications that would follow if one were to accept that an EKC fitted to historical data were an appropriate basis on which to extrapolate the future course of the environmental impact in question over the medium term. We then consider the relevance of such extrapolations to the question of sustainable development prospects. We do this because, as noted in section 2 above, notwithstanding the care taken to put their results in context by contributors to the EKC literature, many economists, and perhaps others, draw inappropriate conclusions from the literature.

(a) *Medium-term projections using estimated EKCs*

Some of the EKC estimates considered above for a number of environmental impacts — SO₂ emissions, NO_x emissions, and deforestation — show them peaking at income levels around the current world mean per capita income. A cursory glance at one such estimate, as in Figure 1 here for example, might lead one to believe that, given likely future levels of income per capita, these environmental impacts would decline in

the medium-term future. The distribution of income for the world, however, is not normal. It is very skewed, with much larger numbers of people below world mean income per capita than above it. Hence, it is median rather than mean income that is relevant. Therefore taking such EKC estimates as given, the global environmental impacts are likely to continue to rise through the medium term.

To illustrate this, we use the projections of world economic growth and world population growth published in the *World Bank Development Report 1992* (IBRD, 1992), together with Panayotou's EKC estimates for deforestation and SO₂ emissions to produce global projections of these variables for 1990–2025.

There are several reasons for looking at these two impacts using Panayotou's estimates. We chose these two impacts because they can be aggregated on a global basis and represent two major aspects of environmental degradation. SO₂ emissions are a factor in the acid rain problem: deforestation, especially in the tropics, is considered a major source of biodiversity loss. We did not use Grossman and Krueger's or Shafik and Bandyopadhyay's SO₂ results because their models are for ambient air quality which cannot be aggregated across sites. Moreover, they use differing intercepts for individual sites which cannot be generalized on a world scale. Shafik and Bandyopadhyay's deforestation regressions have adjusted R-squares of zero or close to zero. Cropper and Griffith's deforestation regressions do not cover the developed countries so that they cannot be used for a global projection, and again have unreported intercept terms for each country. Selden and Song's SO₂ model is not logarithmic, implying that this environmental indicator can take negative values, and also uses differing intercepts for individual countries which cannot be generalized on a world scale.

We projected population and economic growth for every country in the world with a population greater than one million in 1990, i.e. all those countries appearing in the tables at the rear of the *World Bank Development Report* (IBRD, 1992), plus Cuba, North Korea, the former USSR, and Taiwan. We then forecast deforestation and SO₂ emissions for each country individually using Panayotou's regression results. These forecasts were aggregated to give global projections for forest cover and SO₂ emissions.

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

$$P_t = \exp [\alpha + \beta t + \delta t^2] \tag{1}$$

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. Our economic growth

projections use the forecast growth rates for different world regions of Table 1.2 in IBRD (1992, p. 32). The growth rates were held constant over 1990–2025, which seems roughly consistent with Figure 1.3 in the same source (IBRD, 1992, p. 33). Data for 1990 are from Table 1 in IBRD (1992, p. 218). Our aggregated projections give world population growing from 5,265 million in 1990 to 8,322 million in 2025, and mean world per capita income rising from \$3,957 in 1990 to \$7,127 in 2025.

Panayotou's SO₂ regression equation is:

$$\ln(\text{SO}_2/P) = -35.26 + 8.31 \ln(Y/P) - 0.51 \{(\ln Y/P)\}^2 \tag{2}$$

where Y is GNP in US dollars at official exchange rates, SO₂ is tons of sulphur dioxide, and P is population. If this equation is used to project world emissions using projected world mean income then world emissions of SO₂ per capita would decline from 55 kg to 38 kg from 1990 to 2025. With projected world population growth, total emissions would then rise from 287 million tons to 315 million tons. The results when individual country projections are aggregated to give world emissions are quite different, however, due to the skewed distribution of world incomes. On this basis, emissions of SO₂ per capita rise from 73 kg to 142 kg from 1990 to 2025. Total global emissions rise from 383 million tons in 1990 to 1,181 million tons in 2025, as shown in Figure 2. In particular, increasing emissions in China and India outweigh reductions in the NICs and HDCs.

Panayotou's regression equation for deforestation is

$$\ln(\text{DEF}+1) = 0.0133 \ln(Y/P) - 0.181 \ln(P/A) - 0.0013 \{(\ln Y/P)\}^2 + 0.011 \{(\ln P/A)\}^2 + 0.00096 \ln(Y/P) \ln(P/A) + 0.0189 \text{TROPICAL} \tag{3}$$

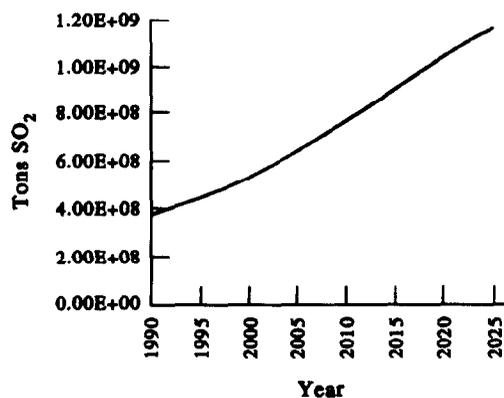


Figure 2. Global SO₂ projection.

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, p. 200). Then using (3) we projected the remaining forest cover in each country in each year according to

$$F_T = F_{1990} \prod_{t=1}^T (1 - EDEF_t)$$

where F_{1990} is the area of forest cover in 1990 and $EDEF_t$ is the estimated rate of deforestation in year t . When we aggregate the country projections, we find, as shown in Figure 3, that global forest cover declines until 2016. It then recovers somewhat, partly because rising population density balances rising income. Global forest cover declines from 40.4 million km² in 1990 to a minimum of 37.2 million km² in 2016, and then increases to 37.6 million km² in 2025.

As shown in Figure 3, tropical forest cover declines throughout the period, from 18.4 million km² in 1990 to 9.7 million km² in 2025. The rate of tropical deforestation stays constant at 1.8% per annum. Given the results for total forest cover, this implies net temperate reforestation of six million km². This would be equivalent to net reforestation of around 70% of the land area of the United Kingdom, or the entire area of the state of Missouri, each year for 35 years.

Deforestation, especially in the tropics, is generally considered to be the principal locus for biodiversity loss. This is an irreversible environmental impact, except on evolutionary timescales. Clearly, where an environmental impact has secondary effects which are irreversible, the fact that it is characterized by an EKC relationship is of little comfort unless it is known that the turning point occurs before those secondary effects arise.

(b) *The relevance for sustainable development*

Selden and Song (1994) did, for their four air pollutants, similar disaggregated projections to those above. Their results show world emissions growing for all four through to 2025: for SPM and NO_x growth continues through to 2050. Even leaving aside the problems considered in sections 3 and 4 here, and irreversibility considerations, projections of this sort show that the existence of an EKC relationship does not necessarily imply that the associated environmental problem will, at the global level, improve with economic growth. The implications for sustainable development are twofold.

First, if it is a global policy objective, as advocated by the Brundtland Commission (WCED, 1987) and endorsed by the 1992 UN Conference on Environment and Development, then there is no warrant for interpreting (apparent) confirmation of the EKC hypothe-

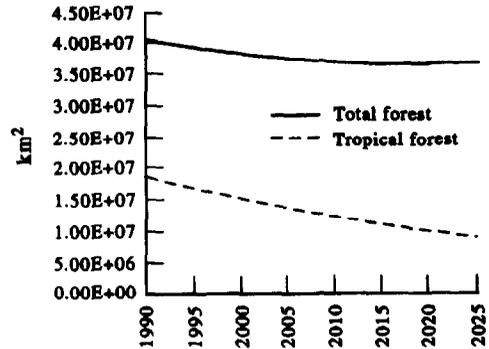


Figure 3. *Global deforestation projection.*

sis as justification for policy inaction. The existence of an EKC relationship across nations today would not guarantee that global environmental degradation would decline automatically with time and economic growth. Policies to achieve sustainable development must incorporate explicit incentives to reduce environmental degradation, rather than assume that the problem will take care of itself as the global economy continues along its current development path.

Second, and perhaps more important, EKC relationships offer very little in the way of guidance on the real policy choices concerning sustainable development. Meeting the needs of the present without compromising the ability to meet those of the future requires that decision makers have available to them a range of scientific and socioeconomic information on the implications of the alternative policy choices open to them. Such information is not, and cannot be, contained in simple single-equation regressions. While the contributors to the EKC literature have generally attempted to put their results in proper perspective, it appears that the very limited relevance of the EKC hypothesis for sustainable development policy analysis is not always properly appreciated.

6. CONCLUSIONS

We believe that the problems associated with both the concept and empirical implementation of the EKC are such that its usefulness is limited to the role of a descriptive statistic. Cross-sectional regressions of environmental impacts per capita on income per capita can identify differing patterns across impact types. Some of the estimation problems that we have identified could be addressed: heteroskedasticity could, for example, be tested for and more appropriate estimation techniques used. While the simultaneity problem could in principle be addressed by instrumental variables estimation, it is difficult to see how one would select variables in practice. The very large

literature on exports and economic growth (see the 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.

If econometric studies are to provide a basis for projections of future trends, they will need to take the form of structural models, rather than reduced form equations of the EKC type. Such models would also

have the potential to inform policy choices, which EKC results do not. We believe that a more fruitful approach to the analysis of the relationship between economic growth and environmental impact would be the examination of the historical experience of individual countries, using econometric and also qualitative historical analysis. Major policy adjustments will be required to move the global economy toward a sustainable development path. It does not appear to us that the EKC approach has much to offer in the way of informing the choices arising for policy makers.

NOTES

1. This paper first appeared in 1991 as National Bureau of Economic Research Working Paper 3914. See also Grossman and Krueger (1995).
2. See also Shafik (1994).

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