Environment and Development Economics 3 (1998): 173–196
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Progress on the environmental Kuznets curve?

David I. Stern
Centre for Resource and Environmental Studies, The Australian National University, Canberra ACT 0200 Australia

ABSTRACT. The environmental Kuznets curve (EKC) hypothesis proposes that there is an inverted U-shape relation between environmental degradation and income per capita. This has been taken to imply that economic growth will eventually redress the environmental impacts of the early stages of economic development. The literature on this issue has developed rapidly over the last few years. This paper examines whether progress has been made on both understanding the EKC phenomenon and on addressing the various criticisms raised against some of the empirical studies and their interpretation in the policy literature. Though basic EKC studies continue to be carried out, recent work has focused on the effect of a variety of conditioning variables on the environmental impact–GDP relationship. Some attempts have also been made to examine the history of the relationship in individual countries. The econometric techniques used have improved. However, empirical decompositions of the EKC into proximate or underlying causes are either limited in scope or non-systematic, and explicit testing of the various theoretical models has not yet been attempted.

1. Introduction

The environmental Kuznets curve (EKC) hypothesis proposes that there is an inverted U-shape relation between various indicators of environmental degradation and income per capita. This has been taken to imply that economic growth will eventually redress the environmental impacts of the early stages of economic development and that growth will lead to further environmental improvements in the developed countries. Far from being a threat to the environment in the long-term, as argued by Meadows *et al.* (1972) and Meadows *et al.* (1992) among others, economic growth is necessary in order for environmental quality to be maintained or improved. This is an essential part of the sustainable development argument as put forward by the World Commission on Environment and Development (1987) in *Our Common Future.* The EKC is named after Kuznets (1955) who hypothesized that the relationship between a measure of inequality in the distribution of income and the level of income is an inverted U-shape curve. An example of an estimated EKC is shown in figure 1.

I thank the authors of the Boston ISEE Conference papers and Dale Rothman for making copies of those papers available to me. Charles Perrings provided me with preprints of the papers in the special issue of Environment and Development Economics on the EKC. Charles Perrings, Mick Common, Dale Rothman, and three anonymous referees made very useful comments on draft versions of this paper.

https://doi.org/10.1017/S1355770X98000102 Published online by Cambridge University Press

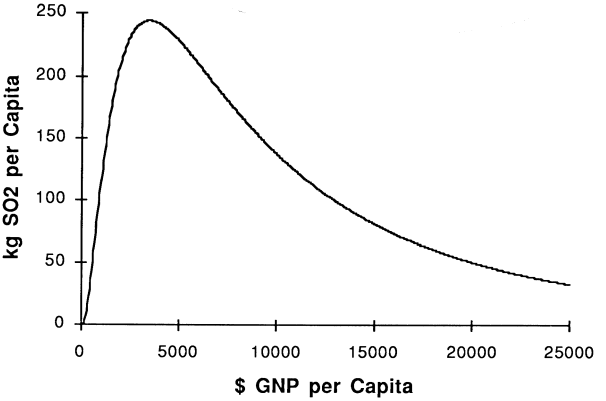


Figure 1. *Environmental Kuznets curve for sulphur Source: Panayotou 1993.*

Proponents of the EKC hypothesis argue that at very low levels of economic activity environmental impacts are generally low but as development proceeds the rates of land clearance, resource use, and waste generation per capita increase rapidly. However, '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 levelling off and gradual decline of environmental degradation' (Panayotou, 1993). Thus there are both proximate causes of the EKC relationship—changes in economic structure or product mix, changes in technology, and changes in input mix, as well as underlying causes such as environmental regulation, awareness, and education. These effects act to counteract or exaggerate the gross impact of economic growth or the scale effect.

The EKC theme was promoted by the World Bank's *World Development Report 1992* (IBRD, 1992). The authors 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), 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: '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).

These views have been countered by critics of the EKC concept (e.g., Arrow *et al*., 1995; Stern *et al*., 1996). The main arguments against the EKC are: much of the empirical evidence is weak and statistical techniques inappropriate, the static relationship between rich and poor countries does not necessarily tell us about dynamics as countries experience economic growth, and EKC relationships have been found for only a subset of indicators—growth might improve some but would lead to worsening levels of others. In addition, even where EKC relationships might hold

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true, projections (Stern *et al*., 1996; Seldon and Song, 1994) show that global levels of environmental impacts are likely to rise over the next few decades.

In the several years since Grossman and Krueger's (1991) pathbreaking study a large literature has developed that reports EKC estimates and discusses their implications. This paper reviews that literature. The question I ask in order to evaluate the contributions is: 'Do developments in the literature represent advances in terms of our knowledge about the existence of such relations, in our understanding of their determinants and implications, and in the methods used to investigate them?'

There have been four main types of contributions to the literature: estimation of 'basic' EKCs, studies of the theoretical determinants of the EKC, studies of the empirical determinants of the EKC, and critique of EKCs. The paper is organized so that theoretical studies that build on the basic background discussed above are reviewed in the next section, followed by a survey of estimates of basic EKCs. These sections are followed by a review of the critiques of these basic EKCs and their interpretation. The fifth section surveys studies that have examined empirical determinants of the EKC, while the final two sections of the paper examine whether progress is being made in our understanding of the EKC and suggest directions for further research.

2. Theoretical determinants of the EKC

A number of papers have built on the heuristic theory of the EKC described in the previous section to mathematically relate plausible assumptions about technology and preferences to the shape of the time path of environmental impacts.

Lopez (1994) provides a theoretical analysis of environment–growth relationships at a fairly high level of generality. His model has two production sectors, weak separability between pollution and the conventional factors of production, constant returns to scale, quasi-fixed inputs of capital and labour, exogenous technical change, and exogenous output prices. Preferences are a function of revenue, pollution, and the output price vector. If producers pay a zero or fixed pollution price, then increases in output unambiguously result in increases in pollution in this system, irrespective of the features of the technology or preferences. However, when producers pay the social marginal cost of pollution then the relation between emissions and income depends on the properties of the technology and preferences. If preferences are homothetic, increasing output again results in increasing pollution. However, when preferences are non-homothetic, as is likely in reality (Pollak and Wales, 1992), the response of pollution to growth depends on the elasticity of substitution in production between pollution and the conventional inputs, and the degree of relative risk aversion, i.e., the rate at which marginal utility declines with rising consumption of produced goods.[1] The faster marginal utility declines and the more substitution is possible in production the less pollution will tend to increase with production. For empirically reasonable values of these two

[1] This specific result depends on a CES revenue function. For other aggregators the path could depend on further parameters.

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parameters pollution may increase at low levels of income and fall at high levels—the inverted U. The role of pollution prices seems to be critical. Pollutants such as SO_2 which are subject to control in many countries might have effective prices that are close to being optimal. Inverted U-shape EKCs have been found for these pollutants. On the other hand, the effective price of CO_2 is probably far from optimal and this pollutant appears to have a monotonic EKC. Also, in the latter case the elasticity of substitution is probably lower and the apparent damage less evident to consumers, both implying a higher turning point. Lopez also constructs a model for deforestation, where, as might be expected, if the stock effects of the forest on agricultural production are internalized then growth results in less deforestation and vice-versa.

Selden and Song (1995) derive an inverted U curve for the optimal path of pollution using Forster's (1973) growth and pollution model. The latter model is similar to Lopez's model but assumes *a priori* that utility is additively separable in consumption and pollution. It therefore corresponds to Lopez's non-homothetic preferences case. Optimal abatement is zero until a given capital stock is achieved whereafter it rises sharply at an increasing rate. As a result, the optimal pollution path is an inverted U in the capital stock.

While Lopez (1994) and Selden and Song (1995) both develop models based on infinitely lived agents, John and Pecchenino (1994) and John *et al.* (1995) develop models based on overlapping generations (McConnell, 1997). In these models, the externality of pollution is, therefore, only partially internalized. Also pollution is generated in these latter models by consumption rather than production activities. All these models can generate inverted U-shape curves under appropriate conditions. McConnell (1997) develops a model of consumption pollution.[2] He uses this model to argue that there is no defining role for the income elasticity for environmental quality in the EKC model. While a higher elasticity will lead, *ceteris paribus*, to a faster reduction in pollution, pollution can decline even if the elasticity is non-positive.

In summary, it seems fairly easy to develop models that generate EKCs under appropriate assumptions. The challenge would appear to be to find empirical evidence as to which of these stories, if any, is more plausible.

3. Basic EKCs

In this section I survey studies whose primary purpose is to estimate the relationship between environmental impact indicators and GDP. Several of these studies also examined the effects of possible conditioning variables such as trade intensity, but that was a secondary focus of these papers.

The first empirical EKC study appears to have been the NBER working paper by Grossman and Krueger (1991)[3] that estimated EKCs as part of a

[2] A similar model is developed by Ansuategi *et al.* (1996).

[3] The paper was later published as Grossman and Krueger (1994). See also Grossman and Krueger (1995).

https://doi.org/10.1017/S1355770X98000102 Published online by Cambridge University Press

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 data set. This data set is a panel of ambient measurements from a number of locations in cities around the world. Each regression involves a cubic function of PPP (Purchasing Power Parity) 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 \$4,000–\$5,000 while 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 while neither the time trend nor the trade variable was 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. This result may either reflect the type of phenomenon raised by Pezzey (1989) (see below) or simply be the result of an inappropriate functional form, i.e., a dependent variable in levels rather than logs.

Shafik and Bandyopadhyay's (1992)[4] study was particularly influential as the results were used in the 1992 World Development Report (IBRD, 1992). They estimated EKCs for ten different indicators: lack of clean water, lack of urban sanitation, ambient levels of suspended particulate matter, ambient sulphur oxides, change in forest area between 1961 and 1986, the annual observations of deforestation between 1961 and 1986, dissolved oxygen in rivers, faecal coliforms in rivers, municipal waste per capita, and carbon emissions per capita.

They used three different functional forms: log-linear, log-quadratic, and in the most general case, a logarithmic cubic polynomial in PPP GDP per capita, a time trend and site related variables.[5] In each case the dependent variable was untransformed. Lack of clean water and lack of urban sanitation were found to decline uniformly with increasing income, and over time. Both measures of deforestation were found to be insignificantly related to the income terms. River quality 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 time trend is significantly positive for faecal coliform and significantly negative for air quality. Finally, both municipal waste and carbon emissions per capita increase unambiguously with rising income. The broader range of indicators

[4] See also Shafik (1994).

[5] Shafik and Bandyopadhyay (1992) also carried out a number of additional regressions adding various policy variables such as trade orientation, electricity prices, etc. The results of these are rather ambiguous and are not reported in Shafik (1994).

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examined by Shafik and Bandyopadhyay shows a much more ambiguous picture of the relationship between environment and development than indicated by Grossman and Krueger's more limited study.

Subsequent studies have tended to: use pollution emissions data rather than ambient concentrations, include population density as an explanatory variable for a number of indicators, calculate future projections based on the estimated EKCs, and investigate further indicators such as energy use.

Panayotou (1993, 1995) estimated EKCs for SO_2, NO_x, SPM, and deforestation. 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. Deforestation is measured as the mean annual rate of deforestation in the mid 1980s, plus unity. In contrast to most other studies Panayotou employs only cross-sectional data and GDP is in 1985 US dollars converted at market exchange rates. 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 Us which conforms to the result 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 SO_2 emissions the turning point is around $3,000 per capita (see figure 1), for NO_x around $5,500 per capita, and for SPM around $4,500. The market exchange rates used by Panayotou tend to lower the income levels of developing countries and raise those of the developed countries (apart from the US) relative to the PPP values. Despite this, the turning points for the pollutants are in a similar range to those reported by Grossman and Krueger and Shafik and Bandyopadhyay probably because Panayotou uses emissions per capita rather than ambient concentrations.

Selden and Song (1994) estimated EKCs for four airborne emissions series: SO_2, NO_x, SPM, and CO on longitudinal data from World Resources (WRI, 1991). These primarily represent developed countries. I concentrate on the results they present for a fixed effects model including a population density variable. The authors suggest that in countries with low population densities there will be less pressure to adopt stringent environmental standards and emissions from transportation will be higher. The estimated turning points are all very high compared to the three studies discussed above: SO_2, $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. The paper also contains projections for these pollutants for the next few decades, which show a monotonic increase in global emissions.

Holtz-Eakin and Selden (1995) estimate quadratic EKCs for carbon dioxide emissions on panel data confirming the very high ($35,000 in a levels regression—$8 million in a logarithmic regression) turning points for this pollutant found by Shafik (1994). They utilize a wide range of

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diagnostic tests and statistics. They also produce projections for emissions over the next century under a number of different assumptions and a convergence-based economic growth model. Schmalensee *et al.* (1995) also look at carbon dioxide and make projections using a more extensive version of the Holtz-Eakin and Selden database. The innovation is the use of a spline regression in place of the conventional polynomials. The spline estimate has ten piecewise segments. Carbon elasticities with respect to income are negative for both the segment associated with the lowest level of income and that associated with the highest level of income (below PPP$(1985) 629 and above PPP$(1985) 9,799) but positive for middle income levels. This shows declining per capita carbon emissions with rising income well within the sample range. The time effects from the fixed effects estimator show rising emissions from 1950 to 1980 with no increase thereafter. Despite the inverted U-shape curve, emission projections using IPCC population and economic growth assumptions show a more rapid rise in emissions than assumed by the IPCC.

Horvath (1997) estimates an EKC for energy use per capita for a sample of 114 countries using cross-sectional and longitudinal data. Per capita energy use is increasing with rising per capita income. As suggested by Stern *et al.* (1996) and Suri and Chapman (1997) energy use might serve as an indicator of overall environmental impact.

Cole *et al.* (1997) add a number of novel indicators to those examined in previous studies including specific transport emissions for SO_2, SPM, NO_2, and total energy use, nitrates in water, CFC emissions, traffic volumes, and methane. Again local pollutants had inverted U-shape curves as did CFCs. Traffic volumes, nitrates, and methane did not have within-sample turning points.

Cropper and Griffiths (1994) estimate three regional (Africa, Latin America, and Asia) EKCs for deforestation using panel data for 64 countries over a 30 year period. The dependent variable is the negative of the percentage change in forest area between two years. The independent variables in each regression are: rural population density, percentage change in population, timber price, per capita GDP, percentage change in per capita PPP GDP, square of per capita PPP GDP, a dummy variable for each country, and a time trend. Neither the population growth rate nor the time trend was significant in either Africa or Latin America, and the price of tropical logs was insignificant in Africa. Otherwise the coefficients in these regressions were significantly different from zero. None of the coefficients in the Asian regression were significant. 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 (1993) or Shafik and Bandyopadhyay's (1992) results. Antle and Heidebrink (1995) estimate EKCs for afforestation and national parks on cross-sectional data. They find a U-shape curve for both indicators (i.e., an inverted U for environmental impact) with turning points of 2,000 and 1,200 1985 US dollars respectively—a result closer to that of Shafik and Panayotou. The use of panel data by Cropper and Griffiths might be the cause of their higher estimated turning points.

Komen *et al.* (1997) and de Bruyn (1997) estimate EKC's for dependent

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variables that do not directly reflect environmental quality or pollution emissions but instead factors which might drive those outcomes. Komen *et al.* (1997) estimate an EKC for public research and development (R&D) expenditures on environmental protection in a group of OECD countries. The main result of the paper is that the elasticity of these expenditures with respect to income is approximately unity. The authors recognize that public expenditures are only a small part of total environmental R&D expenditures. Also R&D is only a small part of total expenditure on environmental protection and may or may not actually result in improved environmental quality. Nonetheless, this is one of the links in an investigation of the empirical determinants of the EKC. De Bruyn (1997) estimates a regression of sulphur emission reduction targets for 2,000 from 1990 levels for the LRTAP countries and the USA. It is found that greater cuts are related to higher levels of income but a dummy variable for former communist countries (which are all low income) is also related to larger cuts and income explains only 13 per cent of the total variance.

4. Critique of the EKC

4.1 Identification of problems

Stern *et al.* (1996), Arrow *et al.* (1995), Ekins (1997), Pearson (1994), and Ansuategi *et al.* (1996) provide a series of reviews and critiques of the EKC studies. Rothman (1996, 1997) reviews the critiques, and numerous articles in special editions of *Ecological Economics* (1995), *Environment and Development Economics* (1996), and *Ecological Applications* (1996) discuss the Arrow *et al.* (1995) paper.

Stern *et al.* (1996) identified seven major problems with some of the basic EKC estimates and their interpretation: (a) the assumption of unidirectional causality from growth to environmental quality and the reversibility of environmental change; (b) the assumption that changes in trade relationships associated with development have no effect on environmental quality; (c) econometric problems; (d) ambient concentrations versus emissions; (e) asymptotic behaviour; (f) the mean–median income problem; and (g) the interpretation of particular EKCs in isolation from EKCs for other environmental problems. Most of the other criticisms can be fitted into this framework. The remainder of this section reviews these problems, integrating the insights from other critiques and indicating where progress has been made in empirical studies since the writing of Stern *et al.* (1996).

(a) Simultaneity and irreversibility

The EKC hypothesis derives from a model of the economy in which environmental damage is reversible and there are special assumptions regarding the impact of environmental damage on growth. For example, in the McConnell (1997) and Ansuategi *et al.* (1996) models, consumption pollution affects output negatively, but neither abatement activities nor production itself generate any pollution. In the Lopez (1994) pollution model, pollution does not affect production. In the absence of feedback to production or irreversibilities, uncontrolled economic growth would max-

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imize economic output and environmental quality in the long-run. But, given such feedback, and/or irreversibility, attempting to grow fast in the early stages of development, when environmental degradation is rising, may prove unsustainable. There is clear evidence of this from many developing countries (Barbier, 1994).

Generally, the economy and its environment are jointly determined (Perrings, 1987). Estimating single equation relationships by ordinary least squares where simultaneity exists produces biased and inconsistent estimates. In practice, this criticism is most likely to be of relevance for samples including very poor countries where land degradation and the like are having a current impact on GDP (Barbier, 1994) and for regressions where the dependent variable is a general indicator such as energy use whose increase enables broad economic growth. The simultaneity issue was directly addressed by Cole *et al.* (1997) and Holtz-Eakin and Selden (1995) who used Hausman tests for regressor exogeneity. They found no evidence of simultaneity.

(b) Trade and the EKC

Several of the early EKC studies included trade variables. These variables were indicators of openness to trade rather than measures of actual physical trade. Whereas *ceteris paribus* openness might be expected to reduce environmental damage in both developing and developed countries (Grossman and Krueger, 1991), trade itself is likely to increase impacts in developing countries and reduce them in the developed countries. This may be one of the determinants of the EKC relationship (see discussion of Suri and Chapman, 1997). The Hecksher–Ohlin trade theory suggests that, under free trade, developing countries would specialize towards the production of goods that are intensive in the factors that they are endowed with in relative abundance: labour 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.*, 1992; Hettige *et al.*, 1992; Suri and Chapman, 1997). Environmental regulation in developed countries might further encourage polluting activities to gravitate toward the developing countries (Lucas *et al.*, 1992; Ekins *et al.*, 1994).

These effects would exaggerate the 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 will face the more difficult task of abating these activities rather than hiving them off to other countries (Arrow *et al.*, 1995; Stern *et al.*, 1996). Several papers have now attempted to capture the effects of actual trade flows (see below).

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(c) 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/GLS framework and especially using cross-section data.[6] Also none of the early EKC studies presented diagnostic statistics of the regression residuals. Stern *et al.* (1996) raised the issue of heteroscedasticity that may be important in the context of cross-sectional regressions of grouped data. Schmalensee *et al.* (1995) found that regression residuals from OLS were heteroscedastic with smaller residuals associated with countries with higher total GDP and population, as predicted by Stern *et al.* (1996). Ekins (1997) points out that even for the same pollutant, different researchers have found different results by investigating different data sets, using different functional forms (e.g., logarithmic versus levels) and different estimation techniques. This seems to indicate that the relationship if any is fragile.[7]

(d) Ambient concentrations versus emissions

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 available data are not necessarily appropriate data on which to base policy conclusions. Grossman and Krueger and Shafik and Bandyopadhyay both used 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 sulphur 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 of population 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 do not mean necessarily that the overall pollution burden is declining. Many more studies have now been carried out using emissions data. As predicted, EKC estimates based on emissions show much higher turning points than do ambient concentration EKCs.

(e) Asymptotic behaviour

Economic activity inevitably implies the use of resources. 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.[8] This restriction can be applied by using a logarithmic dependent variable. De Bruyn and Opschoor (1994) present

[6] The majority of studies use panel data (table 2).

[7] See Levine and Renelt (1992) for a possible approach to investigating this problem.

[8] For some pollutants one could imagine future technologies where emissions are essentially zero, e.g., for sulphur dioxide. A 100 per cent efficient pollutant recovery process is either physically infeasible or just uneconomic given the energy and material expenditures involved. So eliminating sulphur dioxide

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evidence that the 'delinking' of GDP from material use in the 1970s and early 1980s was partially reversed in the late 1980s. Pezzey (1989) proposes that the optimal level 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. As total impacts cannot eventually tend to zero in the very long run (Common, 1995), then rising income, if it could be sustained, would inevitably mean rising degradation. Various results that use cubic regressions find that pollution rises again at high income levels (e.g., Grossman and Krueger, 1991). However, none of these studies used logarithmic dependent variables (see table 1) and so the cubic term might be modelling a slow decline in pollution and an asymmetric EKC that would be better captured using a logarithmic dependent variable.

(f) Mean versus median income

Some studies show that EKC estimates for a number of indicators: SO_2 emissions, NO_x, 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. 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. This means that assuming that the EKC relationship is valid, global environmental degradation is set to rise for a long time to come (Stern *et al*., 1996; Ekins, 1997; Seldon and Song, 1994). On the other hand, some other studies (e.g., Cropper and Griffiths, 1994; Seldon and Song, 1994) found much higher turning points for some of these indicators which reduces the chance of this misinterpretation.

(g) Aggravation of other environmental problems

It is 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 sulphur and nitrogen oxides

emissions means that no metals would be processed from sulphate ores using technologies that generate sulphur gases and no coal or oil, etc. would be burnt. Such a state of technology is way off in the future. So the average impact will not be zero for some time to come. The marginal impact can well be negative at least for a range of incomes until abatement costs start rising sharply. From then on total impact will again start to rise. Also all services require large expenditures of energy and materials so that a shift to consumption of services will only partially aid in averting an upturn in environmental impacts.

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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 (see above). Satisfying the material needs of people requires the use and disturbance of energy flows and materials. The enhanced greenhouse effect is one of the most serious threats to global sustainability (Common, 1995), but almost no one suggests that an inverted U-shaped curve applies for the greenhouses gases[9] nor for energy use per capita (Suri and Chapman, 1997). EKCs for global pollutants with long-term costs and perhaps for some resource stocks tend to be monotonically increasing while those with local impacts tend to have the inverted U-shape (Arrow *et al.*, 1995). 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. Estimation of EKCs for total energy use are an attempt to capture environmental impact whatever its nature (e.g., Suri and Chapman, 1997).

4.2 Suggestions for alternative approaches

In their concluding comments, Stern *et al.* (1996) argued that:

> 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. (p. 1159)

There have been no attempts to estimate structural models or to test the theoretical models discussed in section 2. However, there have been several studies of individual countries. Vincent (1997) examines the experience of Malaysia and Carson *et al.* (1997) look at variation across US states, while de Bruyn *et al.* (1997) examine the experience of four OECD countries (see below). Unruh and Moomaw (1997) use a qualitative historical approach and testing for structural breaks in regressions to look at events in individual countries around the oil price shocks (see below). Vincent (1997) compared Selden and Song's predictions for a country with the income level of Malaysia with the actual data for Malaysia with mixed results. In particular, sulphur emissions fell sharply in the 1980s rather than rising as predicted. This was due to a sudden shift to power generation using domestic natural gas. Ambient measurements of total suspended particulates and various water pollution indicators are available for about 15 years for most of the states of peninsular Malaysia whose income levels vary widely but overlap temporally due to rapid economic growth. All the indicators show rising monotonic or insignificant relations with income and population density. Shafik (1994) and Grossman and

[9] Schmalensee *et al.* (1995) present results showing a within-sample turning point for the carbon dioxide EKC. This paper is discussed in section 3 above.

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Krueger (1991) both found declining concentrations over this income range. Carson *et al.* (1997) argue that a study of a single country eliminates the problems associated with comparing data from different countries. The richest US states have more than double the income of the poorest. The variation among US counties is even greater. On the other hand, institutional factors and other variables are fairly common across the states. All EKCs for a variety of pollutants for both US states and counties were declining in income. This relationship was significant even when industrial employment mix variables were added to the regression. As mining and mineral processing are very capital-intensive activities this is not so surprising and perhaps gross product originating on an industry basis should have been used. It turns out that the poorest US states such as Louisiana, West Virginia, New Mexico, Utah, etc. are often states with important resource extraction and processing industries, while the richest states such as Connecticut, New Jersey, Massachusetts, and New York are states with an orientation towards the service sector and high tech industries. Trade specialization among these states might explain even more of the variation in emissions across states than worldwide trade specialization might explain variation in emissions among countries.

Pearson (1994) reiterates the points in Stern *et al.*'s (1994) critique but emphasized the need for empirical work to investigate the determinants of the EKC relationship in terms of structural change, policy variables, etc. even if in a single equation framework. This is the direction in which most of the recent literature seems to be moving. As will be seen below, although recent EKC studies have looked at the role of additional explanatory variables, in most cases this has not been a systematic effort to explain the underlying determinants of the EKC relationship, but, rather, each study examines separately the role of possible conditioning variables in influencing the EKC relationship. Though these studies are interesting and useful as initial explorations, there is the danger of omitted variables bias.

5. Empirical determinants of the EKC

Many of the most recent EKC studies have focused on examining possible determinants of the EKC relationship or on investigating the impact of various conditioning variables on the EKC relationship. A few studies claim to have achieved a decomposition of the EKC. Unruh and Moomaw (1997) and Moomaw and Unruh (1997) argue instead that historical events trigger reductions in emissions across countries at varying levels of income.

5.1 Conditioning variables

(a) Trade

Rock (1996) estimates regressions where the dependent variables are two indicators of toxic intensity of GDP also used by Lucas *et al.* (1992). The equations include a quadratic function in income per capita, the share of manufacturing in GDP, and four different indicators of trade orientation. A separate regression was estimated for each of the latter indicators. The inverted U-shape is present and pollution is rising with the share of manufacturing in GDP. A dummy variable for closed versus open

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economies shows that closed economies had lower toxic intensities of GDP, while the growth rate of exports and the growth rate of the share of exports in GDP are both positively related to the pollution indices.

Liddle (1996) examines changes in the consumption/production ratio of various metals and paper in the OECD countries. In most cases there is no clear trend. This result would be evidence against a major role for trade in determining the EKC. In contrast to Liddle, Suri and Chapman (1997) argue for an important role for trade in generating the EKC relationship. They show that the ratio of manufacturing exports to manufacturing imports has increased in many developing countries while it has decreased in many developed countries. They estimate an EKC for energy use per capita for the period 1970–1991 for 34 countries ranging from Bangladesh to the US in income levels. The EKC is a logarithmic quadratic with the addition of the following variables: M/MFG—imports of all manufactures as a share of domestic manufacturing production; X/MFG—exports of all manufactures as a share of domestic manufacturing production; and MFG/GDP—share of manufacturing in GDP. The estimates indicate an inverted U (turning point more than $50,000) with the expected signs for the auxiliary variables but only the coefficient for X/MFG among the auxiliary variables is significant. Exclusion of the quadratic term results in all the coefficients being significant showing that these variables covary strongly with squared GDP per capita. A number of variant models are also estimated. A model with an interaction term M GDP/MFG investigates whether the effect of imports on lowering energy use is greater as income rises. This seems to be the case and the M/MFG coefficient falls to zero. A third version with a dummy variable for high income countries in the interaction term provides a better fit. This is the best evidence so far that trade effects are one of the causes of the flattening or downward slope of the EKC, but this result was not found for a different sample of countries with carbon dioxide as the dependent variable (Cooke, 1997).

Rothman (1997) argues that one way to avoid the trade issue is to look at the environmental impacts generated by consumption rather than by the production activities in a country. To this end he estimates EKCs for expenditure on different categories of consumption goods. Only expenditure on food, beverages, and tobacco shows an inverted U-shape within the sample range of income. The other categories of expenditure are monotonically increasing including a number of resource intensive categories such as rent, fuel, and power. The data are calculated on the basis of international PPP prices but there is no guarantee that the prices of individual commodities within groups reflect their environmental impact or that the impact from a dollar's worth of each good consumed in the developed countries is equal to that in the developing countries.

(b) Political freedom

Torras and Boyce (1996) look at how various indicators of democracy may influence the formation of preferences and mediate between private preferences and public policy. They estimate cubic EKCs using the GEMS data analyzed by Grossman and Krueger (1994) and data on access to safe water and access to sanitation at the national level from the Human

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Development Report. In addition, the following variables are included in the regression: the Gini coefficient of income distribution, literacy, an index of civil liberties, and control variables similar to those used by Grossman and Krueger. On the whole, coefficients for the three 'democracy' indicators have the expected negative sign and are significant, especially for the developing countries. Literacy and rights have a more consistent effect than the Gini index possibly reflecting difficulties in measuring and comparing this index across countries. For the three atmospheric pollutants from the GEMS data the significance of the income terms declines when the democracy variables are added showing that they explain variation previously modelled by the EKC relationship. The pattern is mixed for the other dependent variables.

(c) Density of economic activity

Kaufmann *et al.* (1997) and Shukla and Parikh (1992) examine the influence of the spatial intensity of economic activity (GDP/area) and city size, respectively, on ambient concentrations. Kaufmann *et al.* (1997) use ambient SO_2 concentrations for a panel of mostly developed and middle income countries (but including China) between 1974 and 1989. The estimated equation is:

$$C_{jt} = \alpha + \beta_1(Y/P)_{jt} + \beta_2(Y/P)_{jt}^2 + \beta_3(Y/A)_{jt} + \beta_4(Y/A)_{jt}^2 + \beta_5(S/\mathrm{GDP})_{jt} + \beta_6 t + \varepsilon_{jt} \quad (1)$$

where Y/P is GDP per capita, Y/A is GDP per area, and S/GDP is steel exports as a percentage of GDP which is intended to capture the effects of trade. The authors argue that this approach is superior to including population density as a RHS variable because the impact of population density would be expected to vary with the level of income per capita. Increases in density would have less impact when overall emissions were low than when they were high. This could instead be easily addressed by simply putting all variables in logarithms including the dependent variable or using the multiplicative approaches of Panayotou (1993) or Vincent (1997). In (1) the elasticity of emissions with respect to Y/P is in fact dependent on Y/A as the area of individual countries are fixed and therefore national Y/A cannot be held constant as Y/P increases:

$$\frac{\partial C_j}{\partial (Y/P)_j} = \beta_1 + 2\beta_2(Y/P)_j + \beta_3(P/A)_j + 2\beta_4(Y/P)_j(P/A)_j^2 \quad (2)$$

The model is estimated for both national average levels of Y/A and city specific levels of Y/A. The authors find that concentrations are a U-shape function of income per capita and an inverted U-shape function of income per area. The former result is obviously diametrically opposed to the standard EKC results for sulphur dioxide concentrations. However, the signs of the parameters in (2) are $\beta_1 < 0$, $\beta_2 > 0$, $\beta_3 > 0$, $\beta_4 < 0$. This implies a reverse shape N cross section as Y/P is increased—so that at high income levels emissions are declining. Similar results are reported by Panayotou (1997) who claims that the GDP per area variable represents 'scale'.

Shukla and Parikh (1992) were primarily interested in the relationship between city size and ambient pollution levels for SO_2, particulates, and

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Table 1. Econometric techniques

Authors	Date	Data type	Estimation technique	Dependent variable	Exchange rate	Cubic term	Regression diagnostics
Antle and Heidebrink	1995	C-S	OLS	Levels	Market	No	No
Carson *et al.*	1997	C-S	OLS, GLS, non-parametric fit	Levels	National Current	n.a.	Discussed but not presented
Cole *et al.*	1997	Panel, C-S	FE/GLS, OLS	Logs and Levels	PPP	No	*
Cropper and Griffiths	1994	Panel	FE	ΔLogs	PPP	No	No
de Bruyn *et al.*	1997	Time Series	OLS	ΔLogs	National Currency	n.a.	Yes
de Bruyn	1997	C-S	OLS	Logs	Market	No	Yes
Grossman and Krueger	1991	Panel	RE	Levels	PPP	Yes	No
Holtz-Eakin and Seldon	1995	Panel	FE	Logs and Levels	PPP	No	*
Horvath	1997	Longitudinal	FE	Levels	PPP	Yes	No
Kaufmann *et al.*	1997	Panel	OLS, FE, RE	Levels	PPP	No	Yes
Komen *et al.*	1997	Panel	OLS, FE, RE, AR	Levels	PPP	No	Yes
Liddle	1996	Panel	FE	Logs and Levels	PPP	No	Durbin-Watson
Moomaw and Unruh	1997	Time Series, C-S, and Panel	OLS, FE	Levels	PPP	Yes	No
Panayotou	1993	C-S	OLS	Logs	Market	No	No
Panayotou	1997	Panel	FE/RE	Levels	Market	Yes	Yes
Rock	1996	C-S	OLS	Levels	Market	No	No
Rothman	1997	C-S	OLS	Levels	PPP	No	No
Schmalensee *et al*	1955	Panel	FE, Spline Regression	Logs	PPP	n.a.	Yes
Selden and Song	1994	Panel	OLS, FE, RE	Levels	PPP	No	Yes
Shafik	1994	Panel, C-S	FE	Levels	PPP	Yes	No
Shukla and Parikh	1992	C-S	OLS	Levels	Market	No	No
Suri and Chapman	1997	Panel	FE, AR	Logs	PPP	No	No
Torras and Boyce	1997	Panel	OLS	Levels	PPP	Yes	No
Vincent	1997	Panel	FE, RE	Levels	National Currency	Yes	Yes
Westbrook	1995	Panel	FE, RE	Logs	Market	No	No

Notes: C-S: Cross-Section, OLS: Ordinary Least Squares, GLS: Generalized Least Squares, FE: Fixed Effects, RE: Random Effects, AR: autocorrelation correction applied, PPP: Purchasing Power Parity, *: results available from authors.

smoke. Using cross-sectional data from WRI (1989) they found that pollution rose with city size. However, when they added GDP per capita and its square to the regression an inverted U was found with respect to city size. The EKC relationship holding city size constant was, however, U-shaped, though few coefficients are significant at conventional levels except for those in the particulates regression. This finding is similar to the results of Kaufmann *et al.* (1997) and Panayotou (1997).

(d) Economic structure

Westbrook (1995), Suri and Chapman (1997), Rock (1996), Panayotou (1997), and Cooke (1997) all examine aspects of the output structure. Westbrook and Cooke both estimated models for carbon dioxide emissions and used a systematic breakdown of GDP into three or four major sectors. Suri and Chapman and Rock looked at the influence of the share in GDP of manufacturing on energy consumption and pollution intensity, respectively.

Westbrook (1995) used a panel of 56 developing countries between 1971 and 1991. The omission of developed countries restricts generality but many other EKCs omit developing or low income countries instead. Of most interest is a regression of log emissions per capita on GNP per capita and its square and the shares of GNP in agriculture and services. All the coefficients in the regression are significantly different from zero. The income relationship is an inverted U and as would be expected the signs of the industrial structure coefficients are negative reflecting the lower emissions of agriculture and services relative to the industrial sector. The implication is that though industrial structure is a significant explanatory factor other factors also contribute towards the inverted U relationship. Cooke's (1997) results (including both developed and developing countries) are very similar and Suri and Chapman (1997) and Rock ((1996) also find a positive coefficient for manufacturing. Panayotou (1997) finds similar results for the GEMS sulphur dioxide data set.

5.2 EKC decompositions

A few studies have attempted to decompose the EKC relationship into a number of more fundamental underlying components such as structural change, growth, scale, price, and other effects. De Bruyn *et al.* (1997) estimate the following regression individually for West Germany, The Netherlands, the UK, and the USA for groups of 17 to 29 observations over the period 1960–1993:

$$\Delta \ln E_{jt} = \beta_{0j} \Delta \ln Y_{jt} + \beta_{1j} + \beta_{2j} \ln Y_{jt-1} + \beta_{3j} \Delta \ln P_{jt} + \varepsilon_{jt} \qquad (3)$$

for CO_2, NO_x, and SO_2, E is emissions, Y is income, and P are energy prices. They interpret β_{0j} in terms of the scale effect. If $\beta_{1j} < 0$ and $\beta_{2j} = 0$ then they would attribute the declining emissions to exogenous technical change. If, however, $\beta_{2j} < 0$ then they would attribute the change to structural change and increased R&D efforts as income levels rise. β_{3j} would be expected to be less than unity in absolute value. In the cases examined, β_{0j} is positive and except in one case significant. β_{1j} is mostly zero or negative. β_{2j} is zero or negative and more significantly so for NO_x and for all three pollutants

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in Germany. β_{3j} is insignificant except for carbon dioxide in the USA. Therefore, they conclude that structural change related to the income level is of importance. They argue that the decline in pollution seen in developed countries since the early 1970s is due to the slow rate of economic growth during this period. The on-going effects of the level of income in reducing pollution has not been overcome by the effects of growth in raising it. They also calculate the economic growth rates that are compatible with zero emissions growth holding energy prices constant. For CO_2 these are 1.8 per cent in the UK and The Netherlands, 2.9 per cent in Germany, and 0.3 per cent in the US where the price effect has had most influence in reducing emissions. Zero emissions growth rates are much higher for the other two pollutants but lowest for the UK which has the least effective legislation.

This model can also be interpreted as a type of error correction model (see Cuthbertson *et al*., 1992), though there is no tendency to return to an equilibrium between income and emissions if emissions are perturbed by exogenous shocks. The price and growth effects have the effect of permanently shifting the emissions–income relationship. When $Y_{jt-1} = \exp(-\beta_{1j}/\beta_{2j})$ and growth and price inflation are zero there is no tendency for emissions to change. Below this income level emissions tend to increase irrespective of the growth rate and above this level they tend to decline. The interpretation of β_{1j} and β_{2j} as technical and structural change parameters is therefore problematic.

De Bruyn (1997) carries out a Divisia index number decomposition (Ang, 1994) of sulphur dioxide emissions in West Germany and The Netherlands for the 1990s. The method requires sector by sector emissions on the same basis as national accounting data and therefore will be difficult to apply elsewhere. The results indicate only a small role for structural change in reducing emissions.

Panayotou (1997) also claims to carry out a decomposition of the EKC. He estimated a cubic regression (with some cross-product terms dropped) of ambient concentrations of sulphur dioxide on GDP per capita, GDP per square kilometre, industry shares, population density, the growth rate of GDP, and a quality of institutions variable. GDP per square kilometre is supposed to represent scale, industry shares, structural change, and GDP per capita—a pure income effect. The growth rate and population density terms are additional variables which are not seen as part of the decomposition per se. He argues that faster growth, higher population density, greater scale, and industrialization worsen levels of pollution, while income and institutional variables can offset this deterioration. The abatement effect is in fact tenuous as though sulphur dioxide concentrations fall with rising income up to about $15,000 per capita (market exchange rates), they rise with income at higher levels. This latter effect is statistically significant. This ‘decomposition’ is problematic as it mixes both proximate and underlying causes of the EKC and yet omits some important variables such as trade flows or orientation.

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5.3 Historical events

Unruh and Moomaw (1997) and Moomaw and Unruh (1997) argue that the EKC theory that income reduces emissions is incorrect and instead reductions in emissions have been triggered by specific events such as the 1973 oil crisis. As an example, they find that the transition to lower per capita emissions of CO_2 can happen at varying income levels and tends to happen fairly abruptly. In particular, the major changes in countries as different as Spain and the United States happened shortly after the oil price shocks of the 1970s. Moomaw and Unruh (1997) test for the existence of a structural break in 1973 in time series, cross-section, and panel CO_2-income regressions. In general, emissions per capita decline as income per capita rises after 1973 and rise as a function of income per capita before 1973. But these countries were selected on the basis that visual inspection of the EKC plot shows evidence of a structural break around 1973. Given this sampling bias, statistical testing adds very little.

6. Progress on the EKC?

There are several promising signs in recent EKC papers. In particular, there is a concentration on investigating empirical determinants of the EKC. Also, four studies have looked at historical events (Unruh and Moomaw, 1997) or estimated EKCs for individual countries (Vincent, 1997; de Bruyn *et al.*, 1997; Carson *et al.*, 1997). Econometric practice does not seem to have improved (see below). In particular, the paper by Cole *et al.* (1997) claims to address the statistical issues raised by Stern *et al.* (1996) such as investigating the simultaneity issue in a statistical sense. However, the deeper issues of irreversibility raised by Arrow *et al.* (1995) have not been adequately addressed. EKCs for energy use have been estimated addressing the issue of the shifting nature of environmental impact. The different natures of EKCs and impact projections seems to be better understood than was shown by the World Bank Development Report in 1992 (e.g., Rothman, 1997). Differences between EKCs for ambient concentrations and emissions have also been extensively discussed.

Econometric technique is one aspect of the many studies that can be summarized quantitatively. Table 1 summarizes the key points concerning the econometric techniques used by the 25 studies that employ econometrics. The studies vary in terms of the type of data that they use. De Bruyn *et al.* (1997) estimate separate time series regressions for each country hence the appropriateness of OLS, national currencies, and the omission of a cubic term. The Vincent study is for the States of Malaysia and the Carson *et al.* study for US States; hence the use of the national currency. Of the other studies, only the Schmalensee *et al.* (1995) study uses all of what I consider the more sophisticated techniques (Stern *et al.*, 1996). Table 2 summarizes these data in terms of the proportion of studies using the more sophisticated techniques. In the entire sample, use of panel data and fixed effects, or GLS estimation are the most widely adopted techniques, while testing of cubic terms is the least adopted. Adoption of all the techniques except use of logarithmic dependent variables has increased from the pre-1997 sample to the post-1997 sample. The use of logarithmic dependent variables as opposed to a dependent variable in levels declined between

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Table 2. *Summary of econometric techniques*

Time Period	Panel or longitudinal data	FE, RE, GLS	Logarithmic dependent variable	PPP exchange rate	Cubic term	Regression diagnostics
All studies	71%	71%	40%	68%	32%	48%
Pre-1997	67%	67%	46%	58%	18%	33%
1997	75%	75%	33%	80%	45%	62%
Number of relevant studies	24	24	25	22	22	25

Note: For each variable the figure is the per cent using the technique in question of all the relevant papers.

the two time periods. There is certainly an increase in sophistication over time.

7. Conclusions

There has been progress in understanding the scope and determinants of the EKC in the last few years and some progress in methods of investigation. Evidence continues to accumulate that the inverted U-shape relation only applies to a subset of impacts, and that overall impact, perhaps approximately indicated by per capita energy use (Suri and Chapman, 1996), rises throughout the relevant income range. The current crop of studies shows surprisingly little interest in looking at whether impacts begin to rise again at high income levels for those indicators where a mid-income turning point has been identified.

Knowledge has advanced furthest in terms of understanding the determinants of the EKC. It is clear that structural change and technological progress are of importance. Torras and Boyce (1996) show the importance of 'democracy'—a variable that is also a correlate of development—in lowering emissions. There is, however, increasing evidence that the EKC is partly determined by trade relations. If this is so, the poorest countries of today will find it more difficult than today's developed countries to reduce the environmental impact as income rises. Some studies present more disaggregated evidence that is of interest in evaluating the performance of individual countries and the influence of particular events. Change may occur quite rapidly in crisis periods such as the oil price shocks of the 1970s or the CFC negotiations of the 1980s. Some of the empirical relationships that have been uncovered may not be robust—though this is not yet known—the issue of omitted variables bias has not been adequately raised.

Despite such progress we know little about other issues. There has not been any explicit empirical testing of the theoretical models surveyed in section 2. De Bruyn *et al.* (1997), de Bruyn (1997), and Panayotou (1997) have attempted to decompose the EKC into proximate causes. However, the de Bruyn (1997) study is very limited in scope in terms of countries and

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time periods studied and neither de Bruyn *et al.* (1997) nor Panayotou (1997) carry out a rigorous and systematic decomposition.

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