Environmental Kuznets Curves:
A Review of Findings, Methods, and Policy Implications

Bruce Yandle, Madhusudan Bhattarai, and Maya Vijayaraghavan

Introduction

Since 1991, when economists first reported a systematic relationship between income changes and environmental quality, the Environmental Kuznets Curve (EKC) has become standard fare in technical conversations about environmental policy (Grossman and Krueger 1991). EKCs are statistical artifacts that summarize a few important aspects of collective human behavior in two-dimensional space. A chart showing an Environmental Kuznets Curve reveals how a specific measurement of environmental quality changes as the income of a nation or other large human community changes. When first unveiled, EKCs revealed a surprising outcome. The early estimates showed that some important indicators of environmental quality such as the concentrations of sulfur dioxide and particulates in the air actually improved as incomes and levels of consumption went up. This happy outcome occurred when incomes were higher. Before that point, however, at lower income levels, environmental quality deteriorated as incomes began to rise.

These results quickly generated a two-fold response from among scholars. The first response came in the form of efforts to replicate and extend the initial findings. Along with these efforts came the second response, a serious probing of data, methods of estimation, and the extent to which the EKC could be generalized. As a result, we now know far more about linkages between an economy and its environment than we did before 1991, but there is still a lot we do not know.

The advent of EKCs raises many questions: How did the name Environmental Kuznets Curve originate? Why Kuznets? What have we learned about the statistical relationships between various measures of environmental quality and income? Do all aspects of environmental quality deteriorate or improve systematically with economic development? Does the degree of property rights and contract enforcement make a difference? What about other institutions and their feedback on the economy?

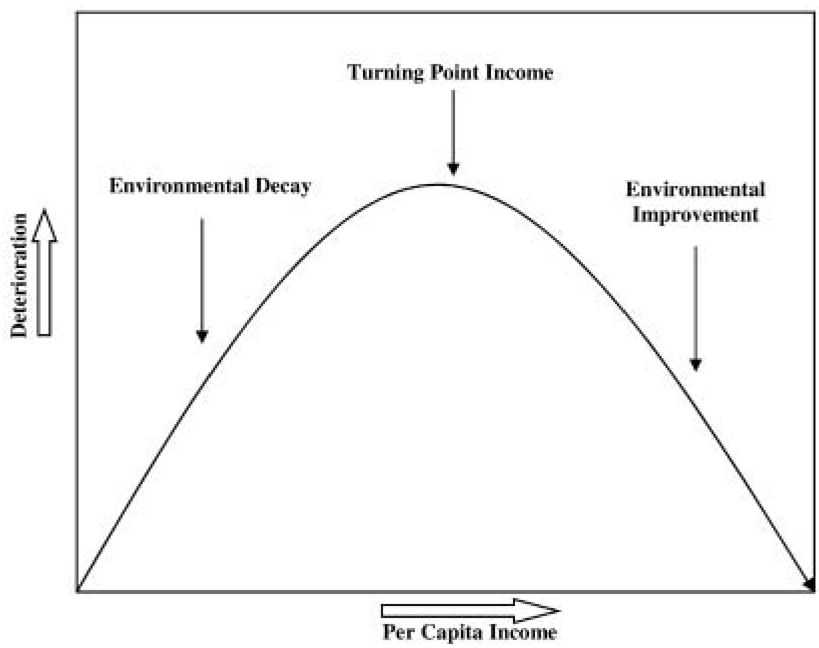
This study addresses some of the questions raised about EKCs. The major focus of this paper is to review the main findings and methodologies of studies that have made significant contributions to the EKC literature. To the authors' knowledge, there have been more than 100 peer-reviewed EKC publications since Grossman and Krueger's path-breaking work. A review and synthesis of the methods used and findings of all these studies is beyond the scope of this study. However, we do review a substantial sampling of EKC research and findings.

Background

At the 67th annual meeting of the American Economic Association in 1954, Simon Kuznets delivered the presidential address, "Economic Growth and Income Inequality." He suggested that as per capita income increases, income inequality also increases at first but then, after some turning point, starts declining (Kuznets 1955, 23–24). Kuznets believed that the distribution of income becomes more unequal at early stages of income growth but that the distribution eventually moves back toward greater equality as economic growth continues. This changing relationship between per capita income and income inequality, now observed empirically, can be represented by a bell-shaped curve (or inverted U-shaped curve) now known as the Kuznets Curve, for which Simon Kuznets was awarded the Nobel prize in economics in 1971. The Kuznets curve hypothesis posits that initially, at lower levels of per capita income, income distribution is skewed toward higher income levels. Inequality is high. As incomes rise, skewness is reduced. Income inequality is relatively lower.

In 1991, the Kuznets Curve took on a new existence. It became a vehicle for describing the relationship between levels of environmental quality, such as the concentration of sulfur dioxide emissions, and related measures of per capita income, both temporally and across spatial settings. As economists were able to marshal data on the environment for larger samples of countries and income levels, evidence began to mount that as countries develop, certain measures of the quality of life might initially deteriorate but then improve. Specifically, there is evidence that the level of environmental degradation for some pollutants and conventionally measured per capita income follows the same inverted-U-shaped relationship as does income inequality and per capita income in the original Kuznets curve. With only slight modification, the original Kuznets Curve figure can be converted to the Environmental Kuznets Curve, as shown in figure 1.

Figure 1: A Typical EKC Diagram



The logic of the EKC relationship is intuitively appealing. At the low levels of per capita income found in pre-industrial and agrarian economies, where most economic activity is subsistence farming, one might expect rather pristine environmental conditions, relatively unaffected by economic activities—at least for those pollutants associated with industrial activity. The EKC statistical relationship suggests that as development and industrialization progress, environmental damage increases due to greater use of natural resources, more emission of pollutants, the operation of less efficient and relatively dirty technologies, the high priority given to increases in material output, and disregard for—or ignorance of—the environmental consequences of growth. However, as economic growth continues and life expectancies increase, cleaner water, improved air quality, and a generally cleaner habitat become more valuable as people make choices at the margin about how to spend their incomes. Much later, in the post-industrial stage, cleaner technologies and a shift to information and service-based activities combine with a growing ability and willingness to enhance environmental quality (Lindmark 2002; Munasinghe 1999).[1]

Generally speaking, the transition from lower to higher levels of per capita income occurs over a long period of time, perhaps as much as a century, if not more. But the transition from destruction to enhancement of the environment may take place in a much briefer time period. For example, a population may be just at the enhancement threshold when rising incomes from trade expansion (or development) generate the necessary demand for environmental improvement. While an expansion of export production may initially degrade the environment, the later income effects can lead to environmental improvements—sometimes quickly.

Emerging Theory

According to Barbier (1997), the origins of the EKC hypothesis are somewhat cloudy and appear to be the product of numerous studies conducted simultaneously in the early 1990s. Most sources point to the analysis by Grossman and Krueger (1991) of air quality measures in a cross-section of countries for different years. Their study was part of a wider investigation into the claim that the economic growth accompanying the North American Free Trade Agreement (NAFTA) would foster environmental degradation. Grossman and Krueger identified the turning point where higher incomes yield improved air quality. At the time of the study, per capita income in Mexico fell into the zone where air quality improves.

An early EKC study by Shafik (1994) reported similar findings. This paper was originally a background paper (Shafik and Bandyopadhyay 1992) for the World Bank's inquiry into growth and environment relationships for the Bank's 1992 *World Development Report*. Then, Panayotou (1995) offered perhaps the earliest and most detailed explanation of a possible Kuznets-type U-shape relationship between the rate of environmental degradation and the level of economic development.

The recognition that pollution may decline as incomes grows goes back at least as far as 1971. Vernon Ruttan, in his presidential address to the American Agricultural Economics Association, hypothesized the luxury nature of environmental quality when he said:

> In relatively high-income economies the income elasticity of demand for commodities and services related to sustenance is low and declines as income continues to rise, while the income elasticity of demand for more effective disposal of residuals and for environmental amenities is high and continues to rise. This is in sharp contrast to the situation in poor countries where the income elasticity of demand is high for sustenance and low for environmental amenities. (Ruttan 1971, 707–8)

Based on Ruttan's hypothesis, Antle and Heidebrink (1995) developed an environmental transition hypothesis reflecting the trade-off between the environment and economic development.[2] They agreed that the demand for environmental quality rises once an income threshold is reached, but they assumed that the inputs that form environmental quality, such as water and air quality, are generally unpriced common-access resources until then. Giving only implicit recognition to the evolution of property rights, Antle and Heidebrink (1995, 605) concluded: "Economic growth is likely to be accompanied by environmental degradation at low income levels, but as income grows the demand for environmental protection also tends to increase, leading to a development path characterized by both economic growth and environmental quality improvements." Without explaining how property rights enter the picture, they developed a theoretical model that assigned prices to environmental and market goods.

In the early stage of development, the price of environmental goods is low, and large amounts are used. With continued resource use and rising scarcity, the price of environmental use rises. Deterioration ends and improvement follows. Antle and Heidebrink did not explicitly recognize that the rising price of environmental quality or services can stem from the emergence of markets, property rights and other fundamental changes in institutions, but their model is consistent with this possibility.

Thus, one theory to explain the EKC's U-shape is that environmental quality becomes a luxury good at higher levels of income.[3] Stated more formally, this means that the income elasticity of demand for environmental resources varies with the level of income. At the threshold where further income increases yield environmental improvement, income elasticity of demand is greater than one; environmental quality is a luxury good. However, some form of exclusive property rights must exist if environmental quality is to be preserved or improved (Anderson and Leal 2001). This means there is a story about evolving property rights embedded in the classic EKC relationship (Yandle and Morriss 2001), but only a few studies have addressed the income-induced institutional change explanation for EKCs.

When attempting to explain EKC turning points, it is appealing to think that at some income level environmental quality becomes a normal good rather than a luxury good and that this leads to a reshuffling of consumer demand favoring environmental protection. But like most economic models, this one assumes a world where other things are held constant. Since EKCs seem to be generated over rather long periods of time, holding other things constant becomes quite a challenge. For this reason, Goklany's (1999) historical trend analysis of over a century of air pollution levels in the United States, the Mather, Needle, and Fairbairn (1999) documentation of four centuries of forest land use changes in the Western United States, and Lindmark's (2002) historical examination of carbon dioxide emissions in Sweden are important for discussions on EKCs. (We will discuss empirical studies later.)

Andreoni and Levinson (2001) combine basic supply and demand theory to explain the familiar inverted U. They assume economies of scale in pollution control, so that recovery of environmental quality is less costly for larger economies, a factor contributing to environmental improvement as income rises. But on the demand side, the marginal willingness to pay for environmental quality declines with income—although it does not fall to zero when incomes rise to the highest levels. The Andreoni-Levinson theory is accompanied by supporting evidence in their examination of the U.S. pollution control experience.

Roca (2003) goes beyond the theories of consumer or community behavior. Recognizing that decisions about environmental quality are largely political, not individual, Roca discusses the EKC turning points in terms of political economy. He reminds us that interest group politics may be the determining factor that leads to a change from deterioration of environmental quality to improvement. He argues that the ability of a highly organized group of environmentalists to spread the costs of environmental protection across a large part of society may not be explained by income growth alone. He refers to the possibilities that one politically organized group may displace costs such that the costs fall outside the politically powerful. Of course, it is still possible for the income effect to be the driving mechanism that energizes the special interest groups' political action. In an earlier study, Torras and Boyce (1998) also explored income-induced changes in the political decision making process in a nation and their implications for the EKC and environmental management in general.

Focusing on changing technologies and factor prices that affect energy consumption, capital-labor ratios and therefore emissions, Kadekodi and Agarwal (2001) build a capital-labor substitution theory that explains when and why the EKC turning point occurs. They then raise doubts about the existence of EKCs, arguing, without the benefit of empirical data, that the EKC's inverted-U shape derives from prices, energy shocks, and movement to capital intensive industries. As we shall see, later empirical research that addresses the capital-labor relationship (Cole 2003) dispels some of Kadekodi and Agarwal's concerns.

Spangenberg (2001) offers another EKC critique. Arguing at a conceptual level, Spangenberg calls attention to the fact that the most frequently examined pollutants—sulfur and nitrogen oxides and suspended particulates—are associated with the production of energy and that changing relative prices leads to the adoption of cleaner energy sources. Never denying the fact that EKC estimates do indeed reveal an inverted-U shape, Spangenberg calls for a more comprehensive way of measuring environmental use or impact. He suggests that researchers adopt total resource throughput as a way to overcome the energy substitution difficulty. Canas, Ferrao, and Conceicao (2003), to be discussed later, performed just the kind of investigation that Spangenberg recommended. They found strong support for the EKC inverted U.

Following the tack that Spangenberg suggested, Bruvoll and Medin (2003) examine the factors that contribute to emissions from all sectors of the Norwegian economy, except ocean shipping, for the years 1980, 1987, and 1989–1996. They do not estimate EKCs but rather examine emissions and how they have changed. To do this, the investigators establish eight sectors for their analysis and focus on energy use for multiple energy types. Taking a close look at changing emission levels of lead, sulfur dioxide, nitrogen oxide, carbon dioxide, particulates and four other air pollutants, the two investigators decompose the change into shares explained by eight factors. These include population size, scale of production, composition of output, energy intensity and mix, and techniques used to convert energy and produce goods and services.

The Bruvoll and Medin 1980–1996 analysis of changing emissions shows that increases in the scale of production add 52 percent to the level of each emission studied. This increase is offset by substitutions to cleaner energy forms and changing techniques for using energy for sulfur dioxide, lead, and carbon monoxide. Inverted-U Kuznets curve would likely be observed for these pollutants. This is not the case for the other pollutants studied, however.[4]

The Accumulated Empirical Evidence

Empirical analyses of the EKC first focused on two critical topics: 1) whether a given indicator of environmental degradation displays an inverted-U relationship in association with rising levels of per capita income and 2) the calculation of the threshold where environmental quality improves with rising per capita income (Barbier 1997). With accumulated evidence showing support for the inverted U-EKC, a second tier of research, all in the spirit of good science, moved to test the foundations of earlier work. Researchers obtained additional data sets and used additional statistical techniques. They also extended the search to include more work on deforestation, biodiversity conservation, and indicators of environmental amenity other than air and water pollution. This section briefly summarizes the findings of selected EKC studies. Here, the emphases are more on methods used, key findings, and each study's distinct contributions to the EKC literature.

Air and Water Quality Measures

Since Grossman and Krueger (1991) were the first to model the relationship between environmental quality and economic growth, their methodology is worth further description. They analyzed the EKC relationship in the context of the much-debated North American Free Trade Agreement (NAFTA). At the time, many people feared that opening markets with Mexico would invite a race to the bottom—companies would try to find the lowest environmental standards they could get away with. Environmentally intensive factories, it was said, would rush across the border to escape the stricter environmental standards of Canada and the United States.

Grossman and Krueger used an EKC-based hypothesis to argue that a NAFTA-based trade expansion would protect the environment. To address the hypothesis, they developed a cross-country panel of comparable measures of air pollution in various urban areas and explored the relationship between economic growth and air quality. They used the data from UN agencies and Global Environmental Monitoring System (GEMS).[5] Their samples included 42 countries for sulfur dioxide, 19 countries for smoke or dark matter, and 21 for suspended particulates, representing both developing and developed countries.

After adjusting for the effect of geographic characteristics of different cities, time-trend effects in the levels of pollution, and the location and type of the pollution measurement device, Grossman and Krueger (1991) found EKC patterns of relationship for the ambient levels of both sulfur dioxide and dark matter (smoke) suspended in the air. The turning point came when per capita GDP was in the range of $4,000 to $5,000 measured in 1985 U.S. dollars, which is approximately $6,700 to $8,450 in 2003 dollars. Unlike the relationship found for sulfur dioxide and smoke, no turning point was found for suspended particulates. In this case, the relationship between pollution and GDP was monotonically increasing. As GDP per capita rose, so did this form of pollution.[6]

Selden and Song (1994) examined the two air pollutants studied by Grossman and Krueger, along with oxides of nitrogen and carbon monoxide. They used GEMS data across countries and across time to model the relationship between per capita GDP and the air pollutants.[7] Broadly speaking, their results lend support to the existence of an EKC relationship for all four air pollutants. The EKC turning point (in 1985 U.S. dollars) for sulfur dioxide was nearly $9,000, and in the vicinity of $10,000 for suspended particulate matter. (In 2003 dollars, the figures would be about $15,200 and $16,900.) Both the figures are significantly higher than the estimates from Grossman and Krueger.

Seldon and Song attribute the higher turning points in their results to their use of aggregate air-quality data, which includes readings from both rural and urban areas, rather than the urban data used by Grossman and Krueger. They expect urban air quality to improve before aggregate data reveal improvement. The turning-point income they found for oxides of nitrogen was over $10,000, while carbon monoxide peaked when income levels were a little over $15,000 (or approximately $16,900 and $25,300 in 2003 U.S. dollars).

Cole, Rayner, and Bates (1997) examined the relationship between per capita income and a wide range of environmental indicators using cross-country panel data sets. The environmental indicators used in this analysis are: carbon dioxide, carbonated fluorocarbons (CFCs) and halons, methane, nitrogen dioxide, sulfur dioxide, suspended particulates, carbon monoxide, as well as nitrates, municipal waste, energy consumption and traffic volumes. Data for the years 1970–92 cover ten OECD countries for nitrogen dioxide, eleven for sulfur dioxide, seven for suspended particulate matter and carbon monoxide, nine for nitrogen dioxide and sulfur dioxide from transport, seven for suspended particulate matter from transport, and twenty-four for traffic volumes. Data for concentration of nitrates covers the years 1975–90 for 30 rivers in fifteen OECD countries. Carbon dioxide data are for seven regions between the years 1960 and 1991.

Data on global emissions and total energy use are for 22 OECD countries between 1980 and 1992. CFCs and halons data include 1986 data for 38 countries, and 1990 data for 39 countries. Late 1980s data for methane emissions in 88 countries were used, while data for municipal waste came from 13 OECD countries. Energy use from transport covered 24 OECD countries from 1970–90. Emissions of nitrogen dioxide, sulfur dioxide and suspended particulates from the transport sector are considered separately. The range of meaningful turning points estimated by Cole, Rayner, and Bates (1997) is shown in Table 1.

Table 1: Selected Pollutants and Income

	EKC Turning Point	
Pollutant	**1985 US$**	**2003 US$**
Carbon Dioxide	$ 22,500 – $ 34,700	$ 37,000 – $ 57,000
Carbon Monoxide	9,900 – 10,100	16,300 – 16,600
Nitrates	15,600 – 25,000	25,600 – 41,000
Nitrogen Oxide (industrial)	14,700 – 15,100	24,800 – 25,500
Nitrogen Oxide (transport)	15,100 – 17,600	25,500 – 29,700
Sulfur dioxide	5,700 – 6,900	9,600 – 11,600
Sulfur dioxide (transport)	9,400 – 9,800	15,800 – 16,500
Suspended particulates (nontransport)	7,300 – 8,100	12,300 – 13,600
Suspended particulates (transport)	15,000 – 18,000	25,300 – 30,400

Note: The values in 2003 U.S. dollars are estimated by multiplying by 1.69. One 1985 US$ would be worth about $1.69 in 2003.
Source: Cole, Rayner, and Bates (1997).

Following closely on the heels of the Grossman and Krueger study, Shafik and Bandopadhyay (1992) estimated the relationship between economic growth and several key indicators of environmental quality reported in the World Bank's cross-country time-series data sets.[8] They found a consistently significant relationship between income and all indicators of environmental quality they examined. As income increases from low levels, quantities of sulfur dioxide, suspended particulate matter, and fecal coliform increase initially and then decrease once the economy reaches a certain level of income. The turning-point incomes in 1985 U.S. dollars for these pollutants are $3,700, $3,300 and $1,400 respectively.[9] (In 2003 U. S. dollars, the turning points would be about $6,200, $5,500 and $2,300.)

Data and Estimating Techniques

Some researchers were inspired by reports of EKC turning points to delve even deeper into the data and estimating techniques. Their search was part of an effort to examine the robustness of the findings, to test the strength of the statistical methods. The work by Harbaugh, Levinson, and Wilson (2002) is notable for the degree of care used in reexamining some important earlier findings. They focused on the initial work by Grossman and Krueger (1995) on sulfur dioxide, smoke, and total suspended particulates (TSP). They then gathered a combined World Bank-United Nations 1998 data set, which, along with the original Grossman-Krueger data, had added observations as well as corrections for errors in the original set. They made new estimates for the same years and locations as used by Grossman and Krueger. The inverted U for sulfur dioxide disappeared. The inverted U was supported for smoke, with a turning point of $6000 (1985 dollars), which is in the neighborhood of the Grossman-Krueger findings. Just as did Grossman and Krueger, the researchers found a monotonically decreasing relationship between TSP and rising per capita income.

By the mid-1990s, investigations of EKC relationships had generated enough consistent findings to give assurance that for many pollutants, richer is definitely cleaner. With more and more environmental data sets gathered, researchers could probe even deeper. Grossman and Krueger (1995) went back to the drawing board and conducted a more extensive empirical analysis. Once again, they modeled the relationship between per capita income and environmental quality using GEMS data sets. Only this time, while repeating an analysis of air quality, they focused heavily on water quality. The GEMS/Water project monitors various dimensions of water quality in river basins, lakes, and groundwater aquifers, but the data on lakes.

and groundwater are quite limited. Because of this, Grossman and Krueger focused their attention on river basins.[10]

Their 1995 study makes use of all variables that can be considered indicators of water quality, provided that they have anthropogenic constituents (not just "natural" pollutants) and that at least ten countries are represented in the sample. They found an EKC relationship for eleven of the fourteen indicators selected for the analysis. The estimated turning-point incomes (in 1985 and 2003 U.S. dollars) are shown in table 2.

Table 2: Water Pollution and Income

Pollutant	EKC Turning Point	
	1985 US$	2003 US$
Arsenic	$ 4,900	$ 8,300
Biological oxygen demand	7,600	12,800
Cadmium	5,000	8,400
Chemical oxygen demand	7,900	13,300
Dissolved oxygen	2,700	4,500
Fecal coliform	8,000	13,500
Nitrates	2,000	3,400
Lead	10,500	17,700
Smoke	6,200	10,500
Sulfur dioxide	4,100	6,900
Total coliform	3,000	5,000

Source: Grossman and Krueger (1995).

A study by Hettige, Lucas, and Wheeler (1992) explored the EKC phenomenon further. They developed a production toxic intensity index for 37 manufacturing sectors in 80 countries over the period from 1960 to 1988.[11] Instead of focusing on individual measures of environmental quality such as air quality, they generalized the environmental impact of manufacturing by determining if manufacturing became more or less "toxic" in relation to income. By applying their toxic intensity index in their statistical models, they were able to identify the extent to which polluting production did or did not shift from higher- to lower-income countries when incomes rose faster in one than the other location.

Their results indicate the existence of an EKC relationship for toxic intensity per unit of GDP. No evidence, however, was found for toxic intensity measured per unit of manufacturing output. When the mix of manufacturing was held constant, Hettige, Lucas, and Wheeler found that manufacturing in low-income countries was not more toxic, nor was manufacturing in high-income ones less toxic. Manufacturing, which is just one part of GDP, did not become cleaner or dirtier as income changed. Instead, manufacturing became smaller relative to services and trade in expanding economies. This suggests that higher income leads to a demand for a cleaner environment regardless of whether the environment has been damaged by a toxicity-intense manufacturing sector. They conclude that the GDP-based intensity result is due solely to a broad shift from industry toward lower-polluting services as development proceeds. They found the EKC pattern for the 1960s to be quite different from that of the later decades when toxic intensity in manufacturing in less-developed countries grew most quickly.

Hettige, Lucas, and Wheeler (1992) also extended their analysis to investigate the possibility that toxic displacement has been affected by the trade policies of less-developed countries. Their investigation indicates that the toxic intensity of manufacturing output in these countries rises when the governments protect their chemical manufacturing sector with tariffs and nontariff trade barriers. They also find that outward-oriented, high-growth countries have slow-growing or even declining toxic intensities of manufacturing, while toxic intensity increases more rapidly in inward-oriented economies—those with less trade.

The Role of Trade

The findings by Hettige et al. on trade policy and toxic intensity suggest a revised view of the displacement phenomenon or “pollution-haven” hypothesis—the argument that companies in developed countries sought to move to less-developed countries so they would be allowed to continue their pollution. Rapidly increasing toxic intensity does not seem to characterize all manufacturing in less-developed countries in the 1970s, when environmental regulation in industrialized countries became more strict. Rather, toxic intensity in manufacturing has grown much more rapidly in economies that are relatively closed to international trade.

Dean (2002) provides additional evidence that supports the notion that expanding trade can lead to improved environmental quality. Her study focuses on water pollution in China using 1987–1995 data. Dean's simultaneous equation estimating procedure accounts for how trade expansion leads to increased production that initially degrades the environment. Then, rising incomes that follow generate environmental improvements. The question, of course, is whether the income effects are large enough to offset the terms-of-trade effect. Dean's analysis of the Chinese experience supports the notion that expanding trade leads to improved water quality.[12]

Pointing out that the effect of trade on these matters has not been examined rigorously by EKC researchers, Cole (2003) notes that for a set of higher-income countries that buy goods in world markets, the race to the top—that is, rushing to improve the quality of life when incomes increase—can be associated with a race to the bottom—a race to relax environmental standards—for suppliers of goods to those richer countries.

Cole estimates EKCs for three kinds of emissions—sulfur dioxide, nitrogen oxide, carbon dioxide—and for biological oxygen demand (BOD), a common measure of water quality. He examines five annual observations for sulfur dioxide and nitrogen oxides for 26 countries, and annual observations covering 1975 to 1995 for 32 countries for carbon dioxide and BOD.

Applying some of the most rigorous standards seen in EKC empirical research, Cole finds the now common inverted-U shaped relationship for sulfur dioxide, nitrogen oxides, and carbon dioxide. He gets mixed and weak results when estimating the traditional EKC for BOD. Of key importance to the trade debate, Cole finds evidence that more intense trade activities lead to lower domestic emissions primarily for sulfur dioxide. However, he notes that the effects are so small as to be insignificant in most cases. Where statistically significant, the trade variable has an exceedingly small complementary effect on declining pollution. As Cole explains (2003, 575), his research generally supports the now common inverted-U story. His findings are particularly noteworthy because of the attention paid to different country samples, alternate functional forms, and variables that account for income distribution and politics. In a way, Goklany (2001) anticipated Cole's findings, which Grossman and Krueger (1991) also noted: Open economies improve their environments. More open economies have had higher growth rates of labor-intensive assembly activities that are also relatively low in toxic intensity. Highly protected economies have had more rapid growth of capital-intensive smokestack sectors.

Cole's research also added strength to the much earlier work by Suri and Chapman (1998) that focused on energy consumption. Specifically, they showed that as industrialized economies matured, they moved to services and then imported more manufactured goods from developing countries. The Suri-Chapman findings suggest that the global diffusion of manufacturing contributes to environmental improvements as incomes rise and development continues.

In addition to his detailed empirical work, Cole helpfully describes the accumulated criticisms leveled at EKC research and sets out to address most of them. Criticisms include 1) the claim that EKCs are generated by trade patterns, not by internally generated improvements, 2) the possibility that environmental degradation can be linked directly to income generation, as in developing countries, 3) the possibility that data problems and related statistical relationships generate spurious results, which is to say that what looks like an estimated EKC may in fact be a statistical mirage; and 4) the fact that some EKC estimates reveal the possibilities that a second period of environmental decay may follow a race to the top, which is to say that researchers need to use the appropriate mathematical form to test for the possibility of an S-shaped curve.

Although he addresses the criticisms, Cole remains concerned about how EKC results have been interpreted. These include 1) the concern that policy makers might assume that all forms of environmental degradation will be resolved by rising incomes, 2) that EKC evidence for one pollutant implies that all pollutants follow similar patterns, and 3) that widely different results can be obtained when median rather mean estimates of key variables are considered when estimating EKCs.

Time Path and Measures of Pollution

The growing body of EKC evidence that supports the notion of turning points has inspired researchers to probe deeper into the time path that may be followed by EKCs for a particular cross-section of countries. For example, if a turning point for sulfur dioxide emission concentrations is found for a sample of countries in 1990, is the income turning point about the same in 1980 and 1970? That is, is there evidence of technology change or other changes that might make the resulting EKCs more sensitive to income and therefore more likely to improve faster environmentally?

This question and other related ones inspired the work of Hill and Magnani (2002). Instead of turning to the World Bank data used by most investigators in the late 1990s, these two authors used 1994 United Nations data on actually monitored pollution levels across 156 countries along with 1985 constant dollar measures of the per capita income; the investigators examined carbon dioxide, sulfur dioxide, and nitrogen oxide levels. Any EKC turning-point findings could be viewed as a confirmation of earlier work. They tested the robustness of their findings for country and time period sub-samples and also for different definitions of income or welfare. They specifically substituted the U.N.-developed Human Development Index (HDI), which is an average of three different indicators that are computed in somewhat complex ways: life expectancy at birth, educational attainment, and real per capita GDP.

Hill and Magnani found the EKC inverted U for carbon dioxide, which is rather unusual since other researchers find a simple linear relationship between income and carbon dioxide emissions, and for three time periods. The maximum occurs at $9,000 in 1970, at $13,000 in 1980, and at $11,000 in 1990, all in 1985 dollars. (In 2003 dollars, the points are respectively $15,200, $22,000, and $18,600, respectively.) In short, there was variation in the income turning point across periods, with no apparent explanation as to why. Similar results were found for sulfur and nitrogen oxides. The inverted U is seen for sulfur dioxide with a maximum at $8,000 for 1975, $13,000 in 1980, $7,000 in 1985, and $8,000 in 1990, again in 1985 dollars. Similar turning points were seen for nitrogen oxide. It is worth noting that the income turning points they estimated are in the same neighborhood of earlier studies by Grossman and Krueger (1991, 1995) and others.

Hill and Magnani (2002) divided their sample of countries into three income groups and made EKC estimates for each of the pollutants for each sub-sample. They found the inverted-U EKC for the higher income group for carbon dioxide and nitrogen oxide. A turning point was found for sulfur dioxide for the middle-income group, but not for the low and high income groups. These and other statistical findings enabled the authors to infer that richer countries were reducing their levels of emissions when energy prices rose significantly, suggesting that energy price shocks also induced technology change. The same effect was not seen for the lower-income countries. Their EKC findings using the HDI welfare measure were not consistent with the GDP results. Although some evidence of turning points was observed, the index magnitudes were not readily translatable into GDP measures and, in some cases, occurred at the extreme edges of the sample values, which makes them suspect.

Taking a break from examining conventional pollutants, Canas, Ferrao, and Conceicao (2003) focused on DMI, direct material inputs into an economy. DMI is calculated on the basis of all materials used in raw or finished form, whether mined or obtained domestically or from imports. The EKC question is what happens to the use of raw materials as an industrial economy matures? Does some kind of efficiency-hunting force drive toward economizing on material quantities in the production of final goods and services? Using panel data for 16 industrialized countries and for years spanning 1960 to 1998, the team of researchers created the necessary DMI estimates and then made statistical estimates of EKCs. They found strong evidence for turning points. Their inverted-U estimate found the turning point at approximately $28,100 in 2003$. They also estimated an inverted-N shape, which implies that in an early period when incomes rise, the environment deteriorates, but then a turning point is reached. Following a period when environmental quality and incomes rise together, another turning point is reached where environmental decay accompanies rising income. The relevant turn, from positive to negative input use, occurred at $23,180. Generally speaking, the EKC estimates did not reveal dramatic turns but rather generated shapes that were more like inverted saucers than inverted Us.

Deforestation

An EKC study by Cropper and Griffiths (1994) began a move away from pollution to the study of deforestation as an environmental measure. They examined the effect of population pressures and income growth on deforestation in 64 developing countries in Africa, Asia, and Latin America, which together contain forest areas of over one million hectares. They found statistically significant EKCs for Latin America and Africa, but the per capita income levels in most countries in Latin America and Africa are lower than the respective peaks of their estimated EKCs ($5,420 and $4,760 in 1985 U.S. dollars), or about $9,100 and $7,900 in 2001 U.S. dollars. In other words, the turning points are yet to be achieved in the lower- income countries included in the sample.

In another study, Panayotou (1995) investigated the EKC relationship for deforestation, sulfur dioxide, oxides of nitrogen, and suspended particulate matter. He used mid-to-late 1980s data from 41 tropical, mostly developing countries for deforestation, and late-1980s data for 55 countries (both developed and developing) for emissions of sulfur dioxide and oxides of nitrogen. He found that the turning-point income for deforestation occurs much earlier (around $800 per capita or $1,300 in 2003 dollars) than for emissions ($3,000 or about $5,000 in 2003 dollars for sulfur dioxide, $4,500 or $7,600 in 2003 dollars for suspended particulates and $5,500 or $9,300 for oxides of nitrogen). According to Panayotou, this is because deforestation for either agricultural expansion or logging takes place at an earlier stage of development than heavy industrialization.

On the basis of his empirical work, Panayotou argued that environmental degradation overall (combined resource depletion and pollution) is worse at levels of income per capita under $1,000 (or about $1,600 in 2003 dollars). Between $1,000 and $3,000 (or about $5,000 in 2003 dollars), both the economy and environmental degradation undergo dramatic structural change from rural to urban and from the principal pursuit of agricultural production to industrial production. A second structural transformation begins to take place, he said, as countries surpass a per capita income of $10,000 (about $16,900 in 2003 dollars) and begin to shift from energy-intensive heavy industry into services and information-intensive industry.

In her approach to EKC modeling, Shafik (1994) expanded the variables considered. She hypothesized that there are four determinants of environmental quality in any country: 1) endowment such as climate or location; 2) per capita income, which reflects the structure of production, urbanization, and consumption patterns of private goods, including private environmental goods and services; 3) exogenous factors such as technology that are available to all countries but change over time; and 4) policies that reflect social decisions about the provision of environmental public goods depending on institutions and the sum of individual benefits relative to the sum of individuals' willingness to pay. Shafik then focused on the availability of clean water, access to urban sanitation, ambient levels of suspended particulate matter, ambient levels of sulfur oxides, changes in forest area between 1961–86, the annual rate of deforestation between 1962–86, dissolved oxygen in rivers, fecal coliforms in rivers, municipal waste per capita, and carbon emissions per capita.[13] Shafik's results were truly mixed. She found an EKC relationship between per capita income and sulfur dioxide and suspended particulate concentrations. However, the general EKC shape did not hold for carbon emissions per capita, dissolved oxygen in rivers, or forestation/deforestation.

Following in the footsteps of Cropper and Griffiths (1994), Bhattarai and Hammig (2001) analyzed EKCs for deforestation for a sample of 66 countries from Latin America, Asia, and Africa. They found a statistically significant EKC relationship for Latin America and Africa. In contrast to the Arrow et al. (1995) assertion that an inverted U-shaped relationship is not feasible for stock resources like forest ecosystems), Bhattarai and Hammig (2004) validate the EKC relationship for deforestation of tropical natural forest cover. Unlike most previous studies that have used FAO (Food and Agriculture Organization) forest data sets on forest and wood lands, they used improved forest cover data across 64 countries that came from the World Resources Institute and GEMS data sets. The authors found that per capita income, governing institutions, human capital, and technical progress (linked with economic development and income growth) all had a bigger impact on reducing deforestation of tropical natural forest than did factors such as rural population pressures, which was a commonly cited main causal factor for deforestation in previous studies. Their turning point income level for tropical natural forest was in the range of $6,000 to $7,000 (1985 dollars) or $10,000 to $11,800 in 2003 dollars.

Barbier and Burgess (2001) focused indirectly on tropical deforestation in their EKC research by examining the expansion of agricultural land use. Their sample was made up entirely of tropical countries for the time period 1961–94. They found an EKC turning point of $5,445 (1987 dollars) or $8,700 in 2003 dollars for their full sample, which was composed of African, Latin American, and Asian sub-samples. Their EKC model adjusted for variables that include GDP growth, population growth, cereal yield, cropland share of land, agricultural exports, political corruption, property rights enforcement and political stability. Of these variables, population growth, cropland share, agricultural exports, and political stability all had a positive association with growth in agricultural land use. The other variables were not significant.

Ehrhardt-Martinez, Crenshaw, and Jenkins (2002) examined 1980 to 1995 data for a sample of 74 less-developed countries in Africa, Asia, and Latin America to estimate the EKC for deforestation. They found a strong inverted-U EKC with a turning point occurring at $1,150 in 1980 dollars ($2,354 in 2003 dollars).

In another deforestation paper, Lantz (2002) used the forest area clear cut annually for the years 1975 through 1999 for the five regions of Canada to examine the relationship between clear-cutting and income, and between clear-cutting and population and technology as proxied by a time trend. Lantz finds no inverted U for the traditional income/clear-cutting model. In brief, clear-cutting activity is negatively associated with GDP per capita; it does not rise and then fall, but falls continuously. However, he does find an inverted U for a model using population and clear-cutting. This suggests that the effects of higher incomes are captured in the population variable.

In a paper closely related to the study of deforestation, Bimonte (2002), using a 1996 sample of 36 European countries, examined the relationship between the share of land defined as protected areas in a country and the level of per capita income. Bimonte argued that something more comprehensive than emissions of air pollution (or even deforestation perhaps) was needed to get at fundamental concerns about and treatment of environmental assets. He also argued that if the EKC hypothesis should hold for emissions like sulfur dioxide, then the hypothesis should surely hold for something as fundamental as the share of land devoted to protected areas, such as parks. In his EKC model for protected areas, he also included the number of newspapers sold annually (per thousand population), and a Gini coefficient, which adjusted for income distribution. He predicted that newspaper sales, which proxied for the level of information, would be positively associated with the share of land devoted to protected area, all else equal, and that the more even the distribution of income, the more likely income effects would lead to efforts to conserve natural resources. Bimonte's estimate revealed the EKC inverted U for protected areas. Both the Gini index and newspaper sales were statistically significant in association with protected areas and of the predicted sign. Once again, the EKC hypothesis could not be rejected.

Extending the Model beyond Environmental Effects

Logic suggests that the EKC environmental-income relationship is part of a general phenomenon where rising incomes lead people to improve key dimensions of their lives. Indeed, given the accumulated data on the income-environment linkage, it would be surprising to observe no statistical linkage between income and health. After all, cleaner air and water are precursors to improved health and increased life expectancies. Gangadharan and Valenzuela (2001) examined 1996 data for 51 countries in an effort to isolate the two-stage effect between income, the environment, and human health. Their study examined a number of now conventional emissions in an effort to identify the linkages between income change, environmental change, and human health. The emissions they considered included carbon dioxide, sulfur dioxide, nitrogen oxides, and total suspended particulates. They also made estimates that linked GDP to energy consumption, assuming that, all else equal, increased energy consumption leads to environmental degradation. They used measures of infant mortality, life expectancy, and other variables in their analysis of health effects.

The results of the Gangadharan-Valenzuela estimate are rather weak. Of the environmental variables considered, the carbon dioxide estimate is the only one that shows a statistically significant relationship with GNP. When displayed graphically, the results of that estimate show an S-shaped, not an inverted-U shaped curve. The health effect estimates are much more interesting. These suggest that rising incomes do indeed lead to health improvements, but that the environmental effect associated with getting the higher income must be taken into account, especially in the early stages of income growth.

Extending the EKC analysis to irrigation and water sector development issues, Rock (1998) and, more recently, Goklany (2002) have shown an inverted U-shaped relationship between water withdrawal for agriculture and per capita income across countries. That is, as income increases, water withdrawals initially increase but then decline. Rock's statistical analysis across 68 countries finds the inverted U-shaped relationship for annual water withdrawals for agriculture use and for annual water withdrawals per capita, with the turning point income of $14,300 and $18,000, respectively. This suggests that the turning point for agricultural water withdrawal is much higher than that of the water and air pollution indicators. Goklany uses a more qualitative graphical and trend analysis on per capita water withdrawal for agriculture on a global scale to validate EKCs for water withdrawal for agricultural use. Similarly, Bhattarai (2004) found a statistically significant EKC growth pattern between irrigation development (measured by gross crop area irrigated) and the per capita income level in tropical countries from 1972 to 1991. The turning point income is $2,800 for the combined model with 64 tropical countries and about $5,500 for Asian countries in 1985 dollars. (These are respectively $4,700 and $9,200 in 2003 dollars.)

Kumar and Aggarwal (2001) focus on agricultural land-use patterns in 19 states in India. They studied changes in cropland areas, pasture, and forest cover in these states from 1963 to 1995. Their results clearly demonstrate the existence of EKCs for crop areas in India, with turning point income at around $200 (1970 dollars, or $753 in 2003 dollars). As income increases, cropland declines, allowing more room for habitat. This turning point is much lower than that reported by previous studies for other environmental pollutants (sulfur dioxide, oxides of nitrogen, BOD) and deforestation. Their results also show a turning point of $110 (in 1970 dollars or $400 in 2003 dollars) for change in forest area in India, but attribute this more to strict government rules and regulations governing the forest sector.

Property Rights and the Rule of Law

Beginning in 1997, attempts to incorporate explicit policy considerations to the EKC relationship were adopted. To understand the relevance of these studies, we should recognize that the movement along an Environmental Kuznets Curve can be thought of as movement through a set of property rights stations and their accompanying institutions. For example, in primitive societies managed by tradition or tribal rule, part of the resource base may be treated as a commons. The cost of defining and enforcing transferable private property rights is simply too large to do otherwise; the net gains are too small. With growing scarcity, however, a time comes when some aspects of the commons become defined as public or communal property.

As "propertyness" expands—and private property is the most incentive-enriched form—individuals have a greater incentive to manage, to conserve, and to accumulate wealth that can be traded or passed on to future generations. Under such circumstances, what might be viewed as a waste stream affecting the commons, or no-man's-land, is seen as an invasion of property. Those who impose uninvited costs are held accountable. A similar response can occur in tribal settings where social pressures that punish or reward treatment of communal property are effective.

Eventually, when scarce aspects of the environment are defined as property—either public property managed by government or private property managed by individuals—the community moves rapidly in the race to improve environmental life. The pace of this progress is determined partly by the extent to which environmental assets are protected by private property rights. Thus, the Environmental Kuznets Curve is a proxy for a property rights model that begins with a commons and ends with private property rights.

Yandle and Morriss (2001) explore the role of institutions of property rights and the rule of law in shaping the EKC relationship in an economy. The concept of property rights and the rule of law are also embedded in the terms governance and democracy that are used in some recent EKC studies (mostly for deforestation) such as Torras and Boyce (1998); Bhattarai and Hammig (2001, 2004); and Barbier and Burgess (2001).

Panayotou (1997) initiated the interest in institutions by studying the EKC relationship for sulfur dioxide across 30 countries using annual data from 1982 to 1994, both to gain a better understanding of the income-environment relationship and as a basis for conscious policy intervention. Panayotou found that faster economic growth and higher population density do increase moderately the environmental price of economic growth, but better policies can offset these effects and make economic growth more environmentally friendly and sustainable.

The policy variables used in the study are proxies for the quality of institutions. The author experimented with a set of five indicators of the quality of institutions in general: respect/enforcement of contracts, efficiency of the bureaucracy, the efficacy of the rule of law, the extent of government corruption, and the risk of appropriation, all obtained from Knack and Keefer (1995). Since all these variables were highly correlated, the author chose to use an index for the respect/enforcement of contracts. Panayatou's main finding is that the quality of policies and institutions in a country can significantly reduce environmental degradation at low-income levels and speed up improvements at higher-income levels. Policies such as more secure property rights under a rule of law and better enforcement of contracts and effective environmental regulations can help flatten the EKC, reducing the environmental damage from higher growth.

The results that show a strong relationship between property rights enforcement and environmental quality are consistent with findings by Norton (2002) that document a related linkage between property rights and income. Norton's survey of literature and his own work show that strong property rights institutions support markets, which expand incomes and wealth. This means that there are two major forces at play in a process that yields environmental protection. Property rights enforcement leads to higher income levels, which in turn generate demand for environmental quality. Strong property rights institutions also provide a legal basis for taking action against those who generate pollution that degrade property values. They also provide incentives for investing in natural resource management where payoffs generally do not come for many years.

Following in the footsteps of Panayotou (1995), Qin (1998) included property rights considerations when he estimated EKCs for two common measures of environmental quality, sulfur dioxide emissions and levels of dissolved oxygen in rivers. Along with the two traditionally shaped EKCs, Qin also derived a monotonically increasing EKC for carbon emissions.[14] The proxy variables Qin used for the quality of institutions is the index of property rights obtained from Business Environmental Risk Intelligence data. These data are provided by the Institutional Reform and the Informal Sector at the University of Maryland and developed by Knack and Keefer (1995). They range continuously from 0 to 4, with a higher score for greater enforceability of laws governing property rights. Enforceability measures the relative degree to which contractual agreements are honored and complications presented by language and mentality differences are mitigated.

Qin found the point estimate for turning-point income for sulfur dioxide to be $7,798 in 1985 purchasing-power-parity-adjusted dollars (about $12,900 in 2003 dollars.) The property rights variable was significant, and corresponded to a flatter EKC as the index rose. The turning-point income for dissolved oxygen in rivers was estimated at $3,249 per capita GDP in 1985 purchasing power parity adjusted dollars (about $5,400 in 2003 dollars). The results for the property rights variable were similar to that of sulfur dioxide. The evidence again says that property rights enforcement matters.

Using the annual percentage change in forest area between the years 1972 to 1991 as an indicator of environmental quality, Bhattarai (2000) analyzed the EKC relationship for tropical deforestation across 66 countries in Latin America, Asia, and Africa. The study quantifies the relationship between deforestation and income, controlling for political and governing institutions, macroeconomic policy, and demographic factors. The results from his empirical analysis suggest that underlying political and civil liberties and governing institutional factors (the rule of law, quality of the bureaucracy, level of corruption in government, enforcement of property rights) are relatively more important in explaining the process of tropical deforestation in the recent past than other frequently cited factors in the literature—for example, population growth and shifting cultivation. The study suggests that improvements in political institutions and governance and the establishment of the rule of law significantly reduce deforestation. In a related way, macroeconomic policies that lead to increased indebtedness and higher black market premiums on foreign exchange (measures of trade and exchange rate policies) will increase the process of deforestation (also see Bhattarai and Hammig 2001, 2004).

Goklany (1999) was also interested in the forces underlying changes in pollution but he took a more direct policy analysis approach rather than engaging in statistical analysis for the purpose of estimating an EKC. He examined long-term air quality and emissions data for each of the original five traditional "criteria" air pollutants or their precursors in the United States—sulfur dioxide, particulate matter, carbon monoxide, nitrogen oxides, and ozone or one of its precursors, volatile organic compounds, and to a lesser extent, lead. His data covered the period before and after major environmental laws shifted control of air pollution to the federal government.

Specifically, Goklany examined three separate sets of indicators for each air pollutant. The first set consists of national emissions estimates, which are available from 1900 onward for sulfur dioxide, nitrogen oxides, and volatile organic compounds; from 1940 for particulate matter and carbon monoxide; and from 1970 for lead. The second set of indicators is composed of outdoor air quality measurements. These include ambient concentrations in the outdoor air, which are usually better indicators for the environmental, health, social, and economic impacts of air pollution than are total emissions. Based upon available data, Goklany developed qualitative trends in national air quality for the various pollutants. These were established from 1957 forward for particulate matter, from the 1960s for sulfur dioxide and carbon monoxide, and from the 1970s for ozone/volatile organic compounds and nitrogen oxides.

The final set of indicators consisted of estimates from 1940 to 1990 of residential combustion emissions per occupied household. Those estimates served as crude proxies for indoor air pollutants, which should serve as a better indicator of the public health impact of various air pollutants than outdoor air quality.

Goklany's findings indicate that before society reaches an environmental transition for a specific pollutant—that is, during the early phases of economic and technological development—"the race to the top of the quality of life" may superficially resemble a "race to the bottom"—or a race to relax environmental standards. But once a society gets past the transition, the race to the top of the quality of life begins to look more like a race to top environmental quality.

This could, in fact, create a not-in-my-backyard (NIMBY) situation. Goklany suggests that the apparent race to the bottom and the NIMBY effect are two aspects of the same effort to improve the quality of life. During the apparent race to the bottom, people are improving their lives in ways not clearly "environmental"; during the NIMBY phase, they are improving their lives by keeping out polluters since they are unwilling to pay the costs of controlling the pollution. The former occurs before the turning point while the latter occurs after.

Goklany also examines whether the data support the contention that, prior to the national control effected by the Clean Air Act Amendments of 1970 in the United States, there had been little progress in improving air quality and that states had been engaged in a race to the bottom. His findings do not support those claims, which were used to justify the 1970 nationalization of environmental protection in the United States.

In another study, Goklany (2002) qualitatively demonstrates an EKC pattern for water withdrawal for agriculture across the globe and he asserts that absence of private property rights in water compared to land is the main reason for the almost flat level of water productivity compared to land productivity, which has risen sharply in the latter half of the twentieth century. Bhattarai (2004) finds a much stronger effect of the quality of the underlying governing institutions (combination of democracy, rule of law, and civil liberty) on the level of irrigation development across tropical countries. The effects of these institutions were much bigger than that of population and other structural factors.

Conclusion

As this paper indicates, there is no single relationship that fits all pollutants for all places and times. There are families of relationships; in many cases the inverted-U EKC best approximates the link between environmental change and income growth. The acceptance of the EKC hypothesis for select pollutants has important policy implications. First, the relationship implies a certain inevitability of environmental degradation along a country's early development path, especially during the take-off process of industrialization. Second, the conventional EKC suggests that as the development process picks up, and when a certain level of per capita income is reached, economic growth helps to undo the damage done in earlier years. If economic growth is good for the environment, policies that stimulate growth (trade liberalization, economic restructuring, and price reform) should be good for the environment.

But there is more to the improved environment story than rising income. Improvement of the environment with income growth is not automatic but depends on policies and institutions. GDP growth creates the conditions for environmental improvement by raising the demand for improved environmental quality and makes the resources available for supplying it. Whether environmental quality improvements materialize or not, and when and how, depend critically on government policies, social institutions and the completeness and functioning of markets. It is for this reason, among others, that Arrow et al. (1995) emphasize the importance of getting the institutions right in rich and poor countries. Along these lines, Torras and Boyce (1998) show empirically that, all else equal, when ordinary people have political power, civil rights as well as economic rights, air and water quality improves in richer and poorer countries.

Better policies, such as the removal of distorting subsidies and the introduction of more secure property rights over resources will cause the race to the bottom to end sooner, and environmental improvements to come about at lower cost. Because market forces will ultimately determine the price of environmental quality, policies that allow market forces to operate are expected to be unambiguously positive. The search for meaningful environmental protection is a search for ways to enhance property rights and markets.

Unfortunately, we still know too little about how property rights institutions evolve in the development process, and there are still far too few EKC studies that take institutions into account. It is our hope that this type of research will form the wave of the future.

Notes

1. A major motivation for examining the linkages between income and the environment is the search for better policies for developing countries. If the EKC hypothesis is empirically verified, the early stages of economic development, when the poor are more adversely affected by environmental degradation, could be even more onerous for low-income groups than Kuznets originally predicted based on inequality alone. This finding would require appropriate policy responses, especially on the social side (Munasinghe 1999). Second, if environmental damage is a structurally determined and inevitable result of initial growth, then attempts to avoid such damage in the early stages of development may be futile (Munasinghe 1999). For these reasons, these EKC studies carry huge public policy implications.

2. Focusing on the marginal benefits and marginal costs of reducing pollution, Munasinghe (1999) concludes that in the early stages of development the perceived marginal benefits of environmental protection are simply too small for decision makers to forgo the benefits of economic development. Other theoretical studies include Antle and Heidebrink (1995); Andreoni and Levinson (2001); Bousquet and Favard (2001); Bulte and van Soest (2001); Dasgupta et al. (2002); Gawande, Berrens, and Bohara (2001); Lieb (2002); Levinson (2002); Pasche (2002); Roca (2003).

3. The concept of environmental quality as a luxury good is also deeply embedded in the post-materialist thesis in environmental sociology (Martinez-Alier 1995). According to this view, the modern environmental movement is explained by the decreasing marginal utility of material goods and services (relative to environmental amenities) due to a relative abundant supply of material goods. This approach is not limited to environmental quality; increasing emphasis on issues such as human rights, animal rights, and feminism has

appeared in industrial economies only when societal income has risen to a certain level. Hence, when poverty vanishes, people (or society) will start to worry about quality of life and environmental amenities, eventually producing the EKC relationship. However, the transition to the environmental stage is much more complex than this. Similarly, the notion of "too poor to be green" suggests that the poor either lack awareness (no preference for environmental amenities), have other more immediate necessities, or do not have enough income to invest in environmental improvement. It is possible that all these conditions occur simultaneously. Hence, the changes in the socio-political factors underlying the EKC may be too complex to be captured by a simple analytical model.

4. Stern (2002) takes an input/output approach to study sulfur dioxide emissions for 64 countries across the years 1973 to 1990. He finds that although the mix of inputs and outputs are significant in explaining emissions for individual countries they have little effect in explaining overall global emissions. Scale of production and technical change explain the most. Stern has weak results in an effort to estimate an inverted-U EKC. One of his estimates shows the traditional shape with the turning point occurring at $8,394 in 1990 dollars. This is in the neighborhood of other sulfur dioxide studies.

5. The Global Environmental Monitoring System is part of the United Nations Environment Program. Information on the environmental quality data across the sites (countries) are found at http://www.wri.org/wri/statistics/unep-gle.html.

6. Discovering turning points requires a data set that contains per capita income or GDP that ranges from very low to high levels. Without this range of incomes, one might observe a monotonically rising or falling relationship between pollution concentrations and income rather than a curve. The appropriate range of incomes is not always available for higher-income countries, such as the United States. If an EKC relationship is observed, it will likely be for the rightmost part of the curve, that portion where rising income levels are associated with environmental improvement. This result is found in work by Carson, Jeon, and McCubbin (1997). They used U.S. state-level emissions for seven major air pollutants: greenhouse gases, air toxics, carbon monoxide, nitrogen oxides, sulfur dioxide, volatile organic carbon, and particulate matter less than ten microns in diameter. In their initial analysis, the authors examined the 1990 state-level per capita emissions for greenhouse gases converted to pounds of equivalent carbon dioxide, air toxics, and point-source emissions of carbon monoxide, oxides of nitrogen, sulfur dioxide, volatile organic carbon, and particulate matter. They found that emissions per capita decrease with increasing per capita income for all seven major classes of air pollutants. In this respect, their results are consistent with those from cross-countries level studies that find an EKC. Hilton and Levinson (1998) found a more complete EKC in

their work on auto lead oxide emissions across the developed world. There is a related EKC identification problem when data are examined for all countries worldwide. The heterogeneity of the sample makes it extraordinarily difficult to account for institutional differences. See Stern and Common (2001).

7. The GEMS data used in the paper are obtained from the World Resources Institute. There are 22 high-income, six middle-income and two low-income countries in the sample. Clearly, less developed countries are under-represented in the sample.

8. Most of the variables cited in this paper are included in the environmental data appendix to the *World Development Report, 1992* (World Bank 1992).

9. Shafik and Bandyopadhyay (1992) also explore the impact of political and civil liberties on environmental quality. They use Gastil indexes that measure the level of political and civil liberties. The political rights index measures rights to participate meaningfully in the political process for 108–119 countries for 1973 and 1975 to 1986 on a scale of one to seven where lower numbers indicate greater political rights (detailed discussions of these indexes are found at http://www.worldbank.org/growth/index.html).

10. In choosing where to locate its monitoring stations, GEMS/Water has given priority to rivers that are major sources of water supply to municipalities, irrigation, livestock, and selected industries. A number of stations were included to monitor international rivers and rivers discharging into oceans and seas. Again, the project aimed for representative global coverage. The available water data cover the period from 1979 to 1990. By January 1990 the project had the active participation of 287 river stations in 58 different countries. Each such station reports thirteen basic chemical, physical, and microbiological variables.

11. For each country and year, Hettige, Lucas, and Wheeler (1992) have used UN industrial data to calculate shares of total manufactured output for 37 sectors defined on the international standard industrial classification (ISIC). To obtain country-specific toxic-intensity indexes, they have multiplied these shares by U.S. sectoral toxic intensities, estimated as total pounds of toxic release per dollar's worth of output. The sectoral intensities have been calculated from a sample of 15,000 U.S. plants which they have obtained by merging data from two sources: the U.S. Environmental Protection Agency's (EPA's) 1987 Toxic Release Inventory, which provides plant-level release estimates for 320 toxic substances, and the 1987 Census of Manufactures, which provides plant-level data on output value. They pool the country-specific toxic-intensity indexes with time-series estimates of income per capita to test two broad hypotheses: 1) industrial pollution intensity follows an inverse U-shaped pattern as development proceeds; and 2) OECD environmental regulation has significantly displaced toxic industrial production toward less-regulated LDC's. The rationale for the latter hypothesis is founded on relative

production cost. The former is based on the general notion of three stages of industrial development dominated by 1) agricultural processing and light assembly, which are (relatively) low in toxic intensity, 2) heavy industry (e.g., metals, chemicals, paper), which has high toxic intensity, and 3) high-technology industry (e.g., microelectronics, pharmaceuticals), which is again lower in toxic intensity. In part this is perceived as a natural evolution and in part a response to growing pressure for environmental regulation at higher incomes.

12. In their investigation of actions that shape EKCs, Dasgupta et al. (2002) examine trade and foreign direct investment. They report some interesting simple relationships between measurements of air pollution in China, Mexico and Brazil and foreign direct investment across 1987–1995. In all three cases, emissions went down with increases in investment.

13. Data and countries covered are the same as in Shafik and Bandopadhyay (1992).

14. The data for sulfur dioxide emissions were from GEMS, and the sample included data from 1981–86 for 14 countries. From GEMS/Water stations, three three-year-aggregated annual median dissolved oxygen levels in 15 countries for 1979–81, 1982–85 and 1986–88 were computed. The data for carbon dioxide were taken from World Resources Institute (1990). These are the cross-country annual carbon dioxide emissions from fossil fuel consumption and cement industries in 41 countries in 1987.

References

Andreoni, James, and Arik Levinson. 2001. The Simple Analytics of the Environmental Kuznets Curve. *Journal of Public Economics* 80(1): 269–86.

Anderson, Terry L., and Donald R. Leal. 2001. *Free Market Environmentalism*. New York: Palgrave.

Antle, John M., and Greg Heidebrink. 1995. Environment and Development: Theory and International Evidence. *Economic Development and Cultural Change* 43(3): 603–25.

Arrow, Kenneth, Bert Bolin, Robert Costanza, Partha Dasgupta, Carl Folke, C. S. Holling, Bengt-Owe Jansson, Simon Levin, Karl-Gôran Mäler, Charles Perrings, David Pimentel. 1995. Economic Growth, Carrying Capacity, and the Environment. *Science* 268(April 28): 520–21.

Barbier, Edward B. 1997. Introduction to the Environmental Kuznets Curve Special Issue. *Environment and Development Economics* 2(4):

369–81.

Barbier, Edward B., and J. C. Burgess. 2001. The Economics of Tropical Deforestation. *Journal of Economic Surveys* 15(3): 413–33.

Bhattarai, Madhusudan. 2000. The Environmental Kuznets Curve for Deforestation in Latin America, Africa, and Asia: Macroeconomic and Institutional Perspectives. Dissertation, Clemson University, Clemson, SC, December.

———. 2004. Irrigation Kuznets Curve, Governance and Dynamics of Irrigation Development: A Cross-country Analysis from 1972–91. Research Report 73. International Water Management Institute, Colombo, Sri Lanka.

Bhattarai, M. and Michael Hammig. 2001. Institutions and the Environmental Kuznets Curve for deforestation: A Cross-country Analysis for Latin America, Africa, and Asia. *World Development* 29(6): 995–1010.

———. 2004. Governance, Economic Policy, and the Environmental Kuznets Curve for Natural Tropical Forests. *Environmental and Development Economics* 9(3), June, forthcoming.

Bimonte, Salvatore. 2002. Information Access, Income Distribution, and the Environmental Kuznets Curve. *Ecological Economics* 41(202): 145–56.

Bousquet, Alain, and Pascal Favard. 2001. Heterogeneite des Agents et la Relation Pollution-Revenu. *Revue Economique* 52(6): 1185–203.

Bruvoll, Annegrete, and Hege Medin. 2003. Factors behind the Environmental Kuznets Curve. *Environmental and Resource Economics 24*(2): 27–48.

Bulte, Erwin H., and Daan P. van Soest. 2001. Environmental Degradation in Developing Countries: Households and the (Reverse) Environmental Kuznets Curve. *Journal of Development Economics* 65: 225–35.

Canas, Angela, Paulo Ferrao, and Pedro Conceicao. 2003. A New Environmental Kuznets Curve? Relationship between Direct Material Input and Income per Capita: Evidence from Industrialized Countries. *Ecological Economics* 46(3): 217–29.

Carson, Richard T., Yongil Jeon, and Donald R. McCubbin. 1997. The Relationship between Air Pollution Emissions and Income: U.S. Data.

Environment and Development Economics 2(4): 433–50.

Cole, M. A. 2003. Development, Trade, and the Environment: How Robust is the Environmental Kuznets Curve? *Environment and Development Economics* 8(4): 557–79.

Cole, M. A., A. J. Rayner, and J. M. Bates. 1997. The Environmental Kuznets Curve: An Empirical Analysis. *Environment and Development Economics* 2(4): 401–16.

Cropper, Maureen, and Charles Griffiths. 1994. The Interaction of Population Growth and Environmental Quality. *American Economic Review Papers and Proceedings* 84(2): 250–54

Dasgupta, Susmita, Benoit Laplante, Hua Wang, and David Wheeler. 2002. Confronting the Environmental Kuznets Curve. *Journal of Economic Perspectives* 16(1): 147–68.

Dean, Judith M. 2002. Does Trade Liberalization Harm the Environment? A New Test. *Canadian Journal of Economics* 35(4): 819–42.

Ehrhardt-Martinez, Karen, Edward M. Crenshaw, and J. Craig Jenkins. 2002. Deforestation and the Environmental Kuznets Curve: A Cross-National Investigation of Intervening Mechanisms. *Social Science Quarterly* 83(1): 226–43.

Gangadharan, Lata, and Rebecca Valenzuela. 2001. Interrelationships between Income, Health and the Environment: Extending the Environmental Kuznets Curve Hypothesis. *Ecological Economics* 36(3): 513–31.

Gawande, Kishore, Robert P. Berrens, and Alok K. Bohara. 2001. A Consumption-Based Theory of the Environmental Kuznets Curve. *Ecological Economics* 37(3): 101–12.

Goklany, Indur M. 1999. *Clearing the Air: The Real Story of the War on Air Pollution*. Washington, DC: Cato Institute.

———. 2001. Economic Growth and the State of Humanity. *PERC Policy Series*, PS-21. Bozeman, MT: PERC, April. Available: www.perc.org/publications/policyseries/econgrowth.html.

———. 2002. Comparing Twentieth Century Trends in U.S. and Global Agricultural Water and Land Use. *Water International* 27(3): 321–29.

Grossman, Gene M., and Alan B. Krueger. 1991. Environmental Impact of a North American Free Trade Agreement. Working paper 3914.

National Bureau of Economic Research, Cambridge, MA.
———. 1995. Economic Growth and the Environment. *Quarterly Journal of Economics* 110: 353–77.
Harbaugh, William T., Arik Levinson and David Molloy Wilson. 2002. Reexamining the Empirical Evidence for an Environmental Kuznets Curve. *Review of Economics and Statistics* 84(3): 541–51.
Hill, Robert J., and Elisabetta Magnani. 2002. An Exploration of the Conceptual and Empirical Basis of the Environmental Kuznets Curve. *Australian Economic Papers* 41(2): 239–54.
Hettige, Hemamala, Robert E. B. Lucas, and David Wheeler. 1992. The Toxic Intensity of Industrial Production: Global Patterns, Trends, and Trade Policy. *American Economic Review* 82(2): 478–81.
Hilton, F. G. Hank, and Arik Levinson. 1998. Factoring the Environmental Kuznets Curve: Evidence from Automotive Lead Emissions. *Journal of Environmental Economics and Management* 35: 126–41.
Kadekodi, Gopal K., and M. M. Agarwal. 2001. Why an Inverted U-shaped Environmental Kuznets Curve May Not Exist. In *The Sustainability of Long-Run Growth*, ed. M. Munashinge, O. Sunkel, and C. de Miguel. Cheltenham, UK: Edward Elgar: 274–85.
Knack, S., and P. Keefer. 1995. Institutions and Economic Performance: Cross-country Tests Using Alternative Institutional Measures. *Economics and Politics* 7(3): 207–27.
Kumar, P, and S. S. Aggarwal. 2001. Does Environmental Kuznets Curve Exist for Changing Land Use: Empirical Evidence from Major States of India? A selected paper presented at the conference "Path to Sustainability: Theory and Practice" organized by the US society for Ecological Economics at Durban, Minnesota, July 11–13.
Kuznets, Simon. 1955. Economic Growth and Income Inequality. *American Economic Review* 45(1): 1–28.
Lantz, Van. 2002. Is there an Environmental Kuznets Curve for Clear-cutting in Canadian Forests? *Journal of Forest Economics* 8(3): 199–212.
Levinson, Arik. 2002. The Ups and Downs of the Environmental Kuznets Curve, ed. John A. List and Aart de Zeeuw. In Recent Advances in Environmental Economics. Cheltenham, UK: New Horizons in

Environmental Economics, 119–41.

Lieb, Christopher M. 2002. The Environmental Kuznets Curve and Satiation: A Simple Static Model. *Environment and Development Economics* 7(1): 429–48

Lindmark, Magnus. 2002. An EKC-Pattern in Historical Perspective: Carbon Dioxide Emissions, Technology, Fuel Prices, and Growth in Sweden 1870–1997. *Ecological Economics* 42(2): 333–47

Martinez-Alier, J. 1995. The Environment as a Luxury Good or 'Too Poor to Be Green?' *Economie Appliquée* 48: 215–30.

Mather, A. S., C. L. Needle, and J. Fairbairn. 1999. The Environmental Kuznets Curve and Forest Trends. *Geography* 84: 55–65.

Munasinghe, Mohan. 1999. Is Environmental Degradation an Inevitable Consequence of Economic Growth: Tunneling through the Environmental Kuznets Curve. *Ecological Economics* 29(1): 89–109.

Norton, Seth. 2002. Population Growth, Economic Freedom, and the Rule of Law. *PERC Policy Series*, PS-24. Bozeman, MT: PERC, February. Available: http://www.perc.org/publications/policyseries/economic_freedom.php?s=2.

Panayotou, Theodore 1995. Environmental Degradation at Different Stages of Economic Development. In *Beyond Rio: The Environmental Crisis and Sustainable Livelihoods in the Third World*, ed. I. Ahmed and J. A. Doeleman. London: Macmillan, 13–36.

———. 1997. Demystifying the Environmental Kuznets Curve: Turning a Black Box into a Policy Tool. *Environment and Development Economics* 2: 465–84.

Pasche, Markus. 2002. Technical Progress, Structural Change, and the Environmental Kuznets Curve. *Ecological Economics* 42(3): 381–89.

Qin, Xiang Dong. 1998. Economic Development and Environmental Quality: A Look at the Environmental Kuznets Curve. Dissertation, Clemson University, Clemson, SC.

Roca, Jordi. 2003. Do Individual Preferences Explain the Environmental Kuznets Curve? *Ecological Economics* 45(2): 3–10.

Rock, M. T. 1998. Freshwater Use, Freshwater Scarcity, and Socioeconomic Development. *Journal of Environment and Development* 7(3):

278–301.

Ruttan, Vernon W. 1971. Technology and the Environment. *American Journal of Agricultural Economics* 53: 707–17.

Seldon, Thomas M., and Daqing Song. 1994. Environmental Quality and Development: Is There a Kuznets Curve for Air Pollution Emissions? *Journal of Environmental Economics and Management* 27: 147–62.

Shafik, Nemat. 1994. Economic Development and Environmental Quality: An Econometric Analysis. *Oxford Economic Papers* 46: 757–77.

Shafik, Nemat, and Sushenjit Bandyopadhyay. 1992. Economic Growth and Environmental Quality: Time Series and Cross Section Evidence. Working paper. World Bank, Washington, DC.

Spangenberg, Joachim. 2001. The Environmental Kuznets Curve: A Methodological Artefact? *Population and Environment 23*(2): 175–85.

Stern, David I. 2002. Explaining Changes in Global Sulfur Emissions: An Econometric Decomposition Approach. *Ecological Economics* 42(2): 201–30.

Stern, David I., and Michael S. Common. 2001. Is There an Environmental Kuznets Curve for Sulfur? *Journal of Environmental Economics and Management* 41: 162–78.

Suri, Vivek, and Duane Chapman. 1998. Economic Growth, Trade, and Energy: Implications for the Environmental Kuznets Curve. *Ecological Economics* 25: 195–208.

Torras, Mariano, and James K. Boyce. 1998. Income, Inequality, and Pollution: A Reassessment of the Environmental Kuznets Curve. *Ecological Economics* 25(2): 147–60.

World Bank. 1992. *World Development Report, 1992*. New York: Oxford University Press.

World Resources Institute. 1990. *World Resources 1990–91*. New York: Oxford University Press.

Yandle, Bruce, and Andrew Morriss. 2001. The Technologies of Property Rights: Choice Among Alternative Solutions to Tragedies of the Commons. *Ecology Law Quarterly* 28(1): 123–68.