Environmental Kuznets Curve

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Glossary

cointegration Classical regression analysis assumes that the error term in a regression is normally and independently distributed. An extreme violation of this condition is when the error term is a random walk. Such a regression is termed a spurious regression and the results are not reliable. It usually indicates that a required variable with random walk behavior has been omitted from the model or that the variables in the model follow random walks and are not related to each other.

consistent estimation May show bias and inefficiency, but both are reduced toward zero as the sample size increases.

developed economies Countries with high income levels; typically have an income per capita greater than U.S. $10,000, life expectancy greater than 70 years, and literacy rates greater than 95%.

developing economies Countries with low- and middle-income levels; equivalent to the term "Third World."

econometrics The specialized branch of mathematical statistics applied to the analysis of economic data.

economic growth An increase in economy-wide economic production usually measured by an increase in gross domestic product; also, the process of the economy growing over time.

environmental degradation Any human-caused deterioration in environmental quality.

externality When a production or consumption activity has unintended damaging effects, such as pollution, on other firms or individuals and no compensation is paid by the producer or consumer to the affected parties (negative externality); when activities have beneficial effects for others, such as freely available research results, and the recipients do not pay the generator of the effect (positive externality).

heteroskedasticity When the variance of the error term in a regression model varies systematically across observations or cases.

income elasticity The percentage increase in some variable when income increases by 1%.

income per capita Usually computed as the gross national product of a country for one year divided by the total population.

integrated variable A random walk is an integrated variable—the current value is equal to the previous period's value plus a random shock. This means that the effect of these shocks on the future does not decline over time. Rather, the current value of the variable is an integration of all past shocks.

omitted variables bias Occurs when variables that should be in a regression model are omitted and they are correlated with those variables that are included.

panel data A data set that includes observations of a number of individuals, countries, firms, and the like over a number of time periods such as months or years.

simultaneity bias When there is mutual feedback between two variables and ordinary regression analysis cannot provide consistent estimates of model parameters.

sustainable development If the current average well-being of people could be maintained into the indefinite future.

technological change The invention and introduction of new methods of production as well as new products.

The environmental Kuznets curve is a hypothesized relationship among various indicators of environmental degradation and income per capita. During the early stages of economic growth, degradation and pollution increase, but beyond some level of income per capita (which will vary for different indicators) the trend reverses, so that at high income levels economic growth leads to environmental improvement. This implies that the environmental impact indicator is an inverted U-shaped function of income per capita. Typically, the logarithm of the indicator is modeled as a quadratic function of the logarithm of income.

1. INTRODUCTION

An example of an estimated environmental Kuznets curve (EKC) is shown in Fig. 1. The EKC is named for Simon Kuznets, who hypothesized that income inequality first rises and then falls as economic development proceeds. Emissions of various pollutants, such as carbon dioxide, sulfur, and nitrogen oxides, are tightly coupled to the use of energy. Hence, the EKC is a model of the relationship among energy use, economic growth, and the environment.

The EKC is an essentially empirical phenomenon, but most of the EKC literature is statistically weak. It is very easy to do bad econometrics, and the history of the EKC exemplifies what can go wrong. The EKC idea rose to prominence because few paid sufficient attention to the relevant diagnostic statistics. Little or no attention has been paid to the statistical properties of the data used such as serial dependence and random walk trends in time series, and few tests of model adequacy have been carried out or presented. However, one of the main purposes of doing econometrics is to test which apparent relationships are valid and which are spurious correlations.

When we do take such statistics into account and use appropriate techniques, we find that the EKC does not exist. Instead, we get a more realistic view of the effect of economic growth and technological changes on environmental quality. It seems that most indicators of environmental degradation are monotonically rising in income, although the "income elasticity" is less than 1.0 and is not a simple function of income alone. Time-related effects, intended to model technological change common to all countries, reduce environmental impacts in countries at all levels of income. However, in rapidly growing middle-income countries, the scale effect, which increases pollution and other degradation, overwhelms the time effect. In wealthy countries, growth is slower and pollution reduction efforts can overcome the scale effect. This is the origin of the apparent EKC effect.

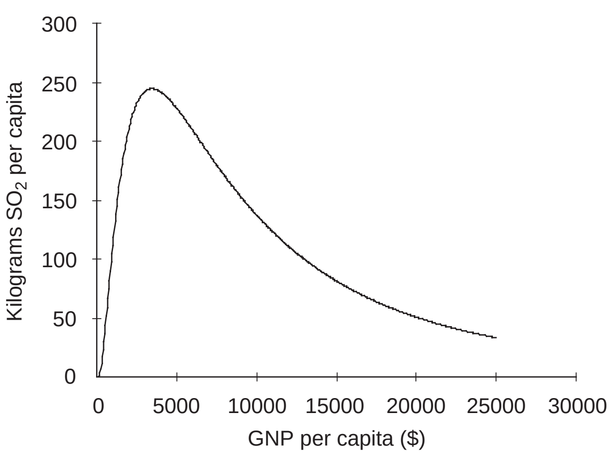

FIGURE 1 Environmental Kuznets curve for sulfur emissions. Data from Panayotou (1993) and Stern *et al.* (1996).

The econometric results are supported by recent evidence that, in fact, pollution problems are being addressed and remedied in developing economies.

This article follows the development of the EKC concept in approximately chronological order. Sections II and III review in more detail the theory behind the EKC and the econometric methods used in EKC studies. Sections IV to VI review some EKC analyses and their critiques. Section VII discusses the recent evidence from Dasgupta and colleagues and others that has changed the way in which we view the EKC. The final two sections discuss an alternative approach, decomposition of emissions, and summarize the findings.

2. THEORETICAL BACKGROUND

The EKC concept emerged during the early 1990s with Grossman and Krueger's pathbreaking study of the potential impacts of the North American Free Trade Agreement (NAFTA) and Shafik and Bandyopadhyay's background study for the *World Development Report 1992*. However, the idea that economic growth is necessary for environmental quality to be maintained or improved is an essential part of the sustainable development argument promulgated by the World Commission on Environment and Development in *Our Common Future*.

The EKC theme was popularized by the International Bank for Reconstruction and Development's (IBRD) *World Development Report 1992,* which argued that "the view that greater economic activity inevitably hurts the environment is based on static assumptions about technology, tastes, and environmental investments" and that "as incomes rise, the demand for improvements in environmental quality will increase, as will the resources available for investment." Others have expounded this position even more forcefully, with Beckerman claiming that "there is clear evidence that, although economic growth usually leads to environmental degradation in the early stages of the process, in the end the best—and probably the only—way to attain a decent environment in most countries is to become rich." However, the EKC has never been shown to apply to all pollutants or environmental impacts, and recent evidence challenges the notion of the EKC in general. The remainder of this section discusses the economic factors that drive changes in environmental impacts and that may be responsible for rising or declining environmental degradation over the course of economic development.

If there were no change in the structure or technology of the economy, pure growth in the scale of the economy would result in a proportional growth in pollution and other environmental impacts. This is called the scale effect. The traditional view that economic development and environmental quality are conflicting goals reflects the scale effect alone. Panayotou, a proponent of the EKC hypothesis, argued,

> *At higher levels of development, structural change towards information-intensive industries and services, coupled with increased environmental awareness, enforcement of environmental regulations, better technology, and higher environmental expenditures, result in leveling off and gradual decline of environmental degradation.*

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

1. Scale of production implies expanding production, with the mix of products produced, the mix of production inputs used, and the state of technology all held constant.
2. Different industries have different pollution intensities, and the output mix typically changes over the course of economic development.
3. Changes in input mix involve the substitution of less environmentally damaging inputs to production for more damaging inputs and vice versa.
4. Improvements in the state of technology involve changes in both (a) production efficiency in terms of using less, *ceteris paribus*, of the polluting inputs per unit of output and (b) emissions-specific changes in process that result in less pollutant being emitted per unit of input.

These proximate variables may, in turn, be driven by changes in underlying variables such as environmental regulation, awareness, and education. A number of articles have developed theoretical models about how preferences and technology might interact to result in different time paths of environmental quality. The various studies make different simplifying assumptions about the economy. Most of these studies can generate an inverted U-shape curve of pollution intensity, but there is no inevitability about this. The result depends on the assumptions made and the value of particular parameters. It seems fairly easy to develop models that generate EKCs under appropriate assumptions, but none of these theoretical models has been empirically tested. Furthermore, if in fact the EKC for emissions is monotonic as recent evidence suggests, the ability of a model to produce an inverted U-shaped curve is not necessarily a desirable property.

3. ECONOMETRIC FRAMEWORK

The earliest EKCs were simple quadratic functions of the levels of income. However, economic activity inevitably implies the use of resources, and by the laws of thermodynamics, use of resources inevitably implies the production of waste. Regressions that allow levels of indicators to become zero or negative are inappropriate except in the case of deforestation where afforestation can occur. This restriction can be applied by using a logarithmic dependent variable. The standard EKC regression model is

$$\ln(E/P)_{it} = \alpha_i + \gamma_t + \beta_1 \ln(\mathrm{GDP}/P)_{it} + \beta_2[\ln(\mathrm{GDP}/P)]^2_{it} + \varepsilon_{it}, \qquad (1)$$

where E is emissions, P is population, GDP is gross domestic product, ε is a random error term, and ln indicates natural logarithms. The first two terms on the right-hand side are intercept parameters that vary across countries or regions i and years t. The assumption is that although the level of emissions per capita may differ over countries at any particular income level, the income elasticity is the same in all countries at a given income level. The time-specific intercepts are intended to account for time-varying omitted variables and stochastic shocks that are common to all countries.

The "turning point" level of income, where emissions or concentrations are at a maximum, can be found using the following formula:

$$\tau = \exp[-\beta_1/(2\beta_2)]. \qquad (2)$$

The model is usually estimated with panel data. Most studies attempt to estimate both the fixed effects and random effects models. The fixed effects model treats the α_i and γ_t as regression parameters, whereas the random effects model treats them as components of the random disturbance. If the effects

α_i and γ_t and the explanatory variables are correlated, the random effects model cannot be estimated consistently. Only the fixed effects model can be estimated consistently. A Hausman test can be used to test for inconsistency in the random effects estimate by comparing the fixed effects and random effects slope parameters. A significant difference indicates that the random effects model is estimated inconsistently due to correlation between the explanatory variables and the error components. Assuming that there are no other statistical problems, the fixed effects model can be estimated consistently, but the estimated parameters are conditional on the country and time effects in the selected sample of data. Therefore, they cannot be used to extrapolate to other samples of data. This means that an EKC estimated with fixed effects using only developed country data might say little about the future behavior of developing countries. Many studies compute the Hausman statistic and, finding that the random effects model cannot be estimated consistently, estimate the fixed effects model. But few have pondered the deeper implications of the failure of this test.

Tests for integrated variables designed for use with panel data find that sulfur and carbon emissions and GDP per capita are integrated variables. This means that we can rely only on regression results that exhibit the cointegration property. If EKC regressions do not cointegrate, the estimates will be spurious. Very few studies have reported any diagnostic statistics for integration of the variables or cointegration of the regressions, and so it is unclear what we can infer from the majority of EKC studies.

4. RESULTS OF EKC STUDIES

The key features differentiating the broad variety of EKC studies can be displayed by reviewing a few of the early studies and examining a single indicator (sulfur) in more detail. This section also discusses EKCs for total energy use, seen by some as a proxy indicator for all environmental impacts.

The early EKC studies appeared to indicate that local pollutants, such as smoke and sulfur emissions, were more likely to display an inverted U-shaped relation with income than were global impacts such as carbon dioxide. This picture fits environmental economics theory; local impacts are internalized in a single economy or region and are likely to give rise to environmental policies to correct the externalities on pollutees before such policies are applied to globally externalized problems.

Grossman and Krueger produced the first EKC study as part of a study of the potential environmental impacts of NAFTA. They estimated EKCs for SO_2, dark matter (fine smoke), and suspended particles (SPM) using the GEMS data set. This data set is a panel of ambient measurements from a number of locations in cities around the world. Each regression involved a cubic function in levels (not logarithms) of purchasing power parity adjusted (PPP) 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 approximately \$4000 to \$5000, whereas the concentration of suspended particles appeared to decline even at low income levels.

Shafik and Bandyopadhyay's study was particularly influential in that the results were used in the *World Development Report 1992*. They estimated EKCs for 10 different indicators using three different functional forms. Lack of clean water and lack of urban sanitation were found to decline uniformly with increasing income and over time. Deforestation regressions showed no relation between income and deforestation. River quality tended to worsen with increasing income. However, local air pollutant concentrations conformed to the EKC hypothesis, with turning points between \$3000 and \$4000. Finally, both municipal waste and carbon emissions per capita increased unambiguously with rising income.

Selden and Song estimated EKCs for four emissions series—SO_2, NO_x, SPM, and CO—using longitudinal data from World Resources. The data were primarily from developed countries. The estimated turning points all were very high compared with those in the two earlier studies. For the fixed effects version of their model, the estimated turning points were as follows (converted to 1990 U.S. dollars using the U.S. GDP implicit price deflator): SO_2, \$10,391; NO_x, \$13,383; SPM, \$12,275; and CO, \$7,114. This study showed that the turning point for emissions was likely to be higher than that for ambient concentrations. During the initial stages of economic development, urban and industrial development tends to become more concentrated in a smaller number of cities that also have rising central population densities, with the reverse happening during the later stages of development. So, it is possible for peak ambient pollution concentrations to fall as income rises, even if total national emissions are rising.

Table I summarizes several studies of sulfur emissions and concentrations, listed in order of estimated

TABLE I

Sulfur EKC Studies

Author(s)	Turning point (1990 U.S. dollars)	Emissions or concentrations	Purchasing power parity	Additional variables	Data source for sulfur	Time period	Countries/ cities
Panayotou (1993)	3,137	Emissions	No	—	Own estimates	1987–1988	55 developed and developing countries
Shafik and Bandyopadhyay (1992)	4,379	Concentrations	Yes	Time trend, locational dummies	GEMS	1972–1988	47 cities in 31 countries
Torras and Boyce (1998)	4,641	Concentrations	Yes	Income inequality, literacy, political and civil rights, urbanization, locational dummies	GEMS	1977–1991	Unknown number of cities in 42 countries
Grossman and Krueger (1994)	4,772–5,965	Concentrations	No	Locational dummies, population density, trend	GEMS	1977, 1982, 1988	Up to 52 cities in up to 32 countries
Panayotou (1997)	5,965	Concentrations	No	Population density, policy variables	GEMS	1982–1984	Cities in 30 developed and developing countries
Cole *et al*. (1997)	8,232	Emissions	Yes	Country dummy, technology level	OECD	1970–1992	11 OECD countries
Selden and Song (1994)	10,391–10,620	Emissions	Yes	Population density	WRI: primarily OECD source	1979–1987	22 OECD and 8 developing countries
Kaufmann *et al*. (1997)	14,730	Concentrations	Yes	GDP/Area, steel exports/GDP	UN	1974–1989	13 developed and 10 developing countries
List and Gallet (1999)	22,675	Emissions	N/A	—	U.S. EPA	1929–1994	U.S. states
Stern and Common (2001)	101,166	Emissions	Yes	Time and country effects	ASL	1960–1990	73 developed and developing countries

income turning points. On the whole, the emissions-based studies have higher turning points than do the concentrations-based studies. Among the emissions-based estimates, both Selden and Song and Cole and colleagues used databases that are dominated by, or consist solely of, emissions from Organization for Economic and Cooperative Development (OECD) countries. Their estimated turning points were \$10,391 and \$8,232, respectively. List and Gallet used data for 1929 to 1994 for the 50 U.S. states. Their estimated turning point is the second highest in Table I. Income per capita in their sample ranged from \$1,162 to \$22,462 (in 1987 U.S. dollars). This is a wider range of income levels than was found in the OECD-based panels for recent decades. This suggests that including more low-income data points in the sample might yield a higher turning point. Stern and Common estimated the turning point at more than \$100,000. They used an emissions database produced for the U.S. Department of Energy by ASL that covers a greater range of income levels and includes more data points than do any of the other sulfur EKC studies.

The recent studies that use more representative samples of data found that there is a monotonic relation between sulfur emissions and income, just as there is between carbon dioxide and income. Interestingly, an estimate of a carbon EKC for a panel data set of OECD countries found an inverted U-shaped EKC in the sample as a whole. The turning point was at only 54% of maximal GDP in the sample. A study using a spline regression implied a within-sample turning point for carbon for high-income countries. All of these studies suggest that the differences in turning points that have been found for various pollutants may be due, at least in part, to the different samples used.

In an attempt to capture all environmental impacts of whatever type, a number of researchers estimated EKCs for total energy use. In each case, they found that energy use per capita increases monotonically with income per capita. This result does not preclude the possibility that energy intensity (i.e., energy used per dollar of GDP produced) declines with rising income or even follows an inverted U-shaped path.

A number of studies built on the basic EKC model by introducing additional explanatory variables intended to model underlying or proximate factors such as "political freedom," output structure, and trade. On the whole, the included variables turned out to be significant at traditional significance levels. However, testing different variables individually is subject to the problem of potential omitted variables bias. Furthermore, these studies did not report cointegration statistics that might indicate whether omitted variables bias was likely to be a problem or not. Therefore, it is not really clear what can be inferred from this body of work.

The only robust conclusions from the EKC literature appear to be that concentrations of pollutants may decline from middle-income levels and that emissions tend to be monotonic in income. Emissions may decline over time in countries at many different levels of development. Given the likely poor statistical properties of most EKC models, it is hard to come to any conclusions about the roles of other additional variables such as trade. Too few quality studies of other indicators apart from air pollution have been conducted to come to any firm conclusions about those impacts as well.

5. THEORETICAL CRITIQUE OF THE EKC

A number of critical surveys of the EKC literature have been published. This section discusses the criticisms that were made of the EKC on theoretical, rather than methodological, grounds.

The key criticism of Arrow and colleagues and others was that the EKC model, as presented in the *World Development Report 1992* and elsewhere, assumes that there is no feedback from environmental damage to economic production given that income is assumed to be an exogenous variable. The assumption is that environmental damage does not reduce economic activity sufficiently to stop the growth process and that any irreversibility is not severe enough to reduce the level of income in the future. In other words, there is an assumption that the economy is sustainable. However, if higher levels of economic activity are not sustainable, attempting to grow fast during the early stages of development, when environmental degradation is rising, may prove to be counterproductive.

It is clear that the levels of many pollutants per unit of output in specific processes have declined in developed countries over time with technological innovations and increasingly stringent environmental regulations. However, the mix of effluent has shifted from sulfur and nitrogen oxides to carbon dioxide and solid waste, so that aggregate waste is still high and per capita waste might not have declined. Economic activity is inevitably environmentally disruptive in some way. Satisfying the material needs of people requires the use and disturbance of energy flows and materials. Therefore, an effort to reduce some environmental impacts might just aggravate other problems. Estimation of EKCs for total energy use is an attempt to capture environmental impact regardless of its nature.

Various critics argued that if there was an EKC-type relationship, it might be partly or largely a result of the effects of trade on the distribution of polluting industries. The Heckshe–Ohlin trade theory, the central theory of trade in modern economics, suggests that, under free trade, developing countries would specialize in the production of goods that are intensive in the production inputs they are endowed with in relative abundance: labor and natural resources. The developed countries would specialize in human capital and manufactured capital-intensive activities. Part of the reductions in environmental degradation levels in developed countries and part of the increases in environmental degradation levels in middle-income countries may reflect this specialization. Environmental regulation in developed countries might further encourage polluting activities to gravitate toward developing countries.

These effects would exaggerate any apparent decline in pollution intensity with rising income along the EKC. In our finite world, the poor countries of today would be unable to find other countries from which to import resource-intensive products as they themselves become wealthy. When the poorer countries apply similar levels of environmental regulation, they would face the more difficult task of abating these activities rather than outsourcing them to other countries. There are no clear solutions to the impact of trade on pollution from the empirical EKC literature.

Some early EKC studies showed that a number of indicators—SO_2 emissions, NO_x, and deforestation—peak at income levels around the current world mean per capita income. A cursory glance at the available econometric estimates might have led one to believe that, given likely future levels of mean income per capita, environmental degradation should decline from this point onward. However, income is not normally distributed but rather very skewed, with much larger numbers of people below mean income per capita than above it. Therefore, it is median income, rather than mean income, that is the relevant variable. Both Selden and Song and Stern and colleagues performed simulations that, assuming that the EKC relationship is valid, showed that global environmental degradation was set to rise for a long time to come. More recent estimates showed that the turning point is higher; therefore, there should be no room for confusion on this issue.

6. ECONOMETRIC CRITIQUE OF THE EKC

Econometric criticisms of the EKC concern four main issues: heteroskedasticity, simultaneity, omitted variables bias, and cointegration issues.

Heteroskedasticity may be important in the context of cross-sectional regressions of grouped data. Data for a country are a sum or mean of observations for all of the regions, firms, or households within that country. Smaller residuals may be associated with countries with higher total GDPs and populations. Taking heteroskedasticity into account in the estimation stage seems to significantly improve the goodness of fit of globally aggregated fitted emissions to actual emissions.

Simultaneity may arise because increasing energy use drives increasing income, but increasing income may also increase the demand for energy in consumption activities. In addition, if environmental degradation is sufficiently severe, it may reduce national income, whereas the scale effect implies that increased income causes increased environmental degradation. A Hausman-type statistical test for regressor exogeneity can be used to directly address the simultaneity issue. No evidence of simultaneity has been found using such a test. In any case, simultaneity bias is less serious in models involving integrated variables than in the traditional stationary econometric model. The Granger causality test can be used to test the direction of causality between two variables. In tests of causality between CO_2 emissions and income in various individual countries and regions, the overall pattern that emerges is that causality runs from income to emissions or that there is no significant relationship in developing countries, whereas causality runs from emissions to income in developed countries. However, in each case, the relationship is positive, so that there is no EKC-type effect.

Three lines of evidence suggest that the EKC is an incomplete model and that estimates of the EKC in levels can suffer from significant omitted variables bias: (1) differences between the parameters of the random effects and fixed effects models tested using the Hausman test, (2) differences between the estimated coefficients in different subsamples, and (3) tests for serial correlation. Hausman-type test statistics show a significant difference in the parameter estimates for estimated random effects and fixed effects models in the majority of EKC studies. This indicates that the regressors—the level and square of the logarithm of income per capita—are correlated with the country effects and time effects, indicating that the regressors are likely correlated with omitted variables and that the regression coefficients are biased. As expected, given the Hausman test results, parameter estimates turn out to be dependent on the sample used, with the global and developing country estimates of emissions EKCs for sulfur and carbon showing a turning point at extremely high income levels and the developed country estimates showing a within-sample turning point. In the cases where serial correlation in the residuals was tested, a very high level was found, indicating misspecification in terms of either omitted variables or missing dynamics.

Tests for integrated variables designed for use with panel data indicate that sulfur emissions per capita, carbon emissions per capita, and GDP per capita are integrated. This means that we can rely only on regression results that exhibit the cointegration property. Results for cointegration are less clear-cut than those for integration in the individual time series. For sulfur emissions in 74 countries from 1960 to 1990, approximately half of the individual country EKC regressions cointegrate, but many of these have parameters with "incorrect signs." Some panel cointegration tests indicate cointegration in all countries, and some accept the non-cointegration hypothesis. But even when cointegration is found, the forms of the EKC relationship vary radically across countries, with many countries having U-shaped EKCs. A common cointegrating vector in all countries is strongly rejected.

7. OTHER EVIDENCE

Dasgupta and colleagues present evidence that environmental improvements are possible in developing countries and that peak levels of environmental degradation will be lower than those in countries that developed earlier. They present data that show declines in various pollutants in developing countries over time. They show that although regulation of pollution increases with income, the greatest increases occur from low- to middle-income levels. In addition, diminishing returns to increased regulation would be expected, although better enforcement at higher income levels would also be expected. There is also informal or decentralized regulation in developing countries. Furthermore, liberalization of developing economies over the past two decades has encouraged more efficient use of inputs and less subsidization of environmentally damaging activities. Multinational companies respond to investor and consumer pressure in their home countries and raise standards in the countries in which they invest. Furthermore, better methods of regulating pollution, such as market instruments, are having an impact even in developing countries. Better information on pollution is available, encouraging government to regulate and empowering local communities. Those who argue that there is no regulatory capacity in developing countries would seem to be wrong.

Much of Dasgupta and colleagues' evidence is from China. Other researchers of environmental and economic developments in China came to similar conclusions. For example, China is adopting European Union standards for pollution emissions from cars with an approximately 8- to 10-year lag. Clearly, China's income per capita is far more than 10 years behind that of Western Europe. Furthermore, China has reduced sulfur emissions and even carbon emissions during recent years. Ambient air pollution has been reduced in several major cities, and with the exception of some encouragement of road transport, the government is making a sustained effort in the direction of environmentally friendly policies and sustainable development.

8. DECOMPOSING EMISSIONS

As an alternative to the EKC, an increasing number of studies carry out decompositions of emissions into the proximate sources of emissions changes described in section II. The usual approach is to use index numbers and detailed sectoral information on fuel use, production, emissions, and so on that, unfortunately, is unavailable for most countries. Econometric decomposition models may require less detailed data. Decomposition models represent the relations between energy use and the environment more explicitly than do EKC models.

The conclusion from the studies conducted so far is that the main means by which emissions of pollutants can be reduced is by time-related technique effects, particularly those directed specifically at emissions reduction, although productivity growth or declining energy intensity has a role to play, particularly in the case of carbon emissions where specific emissions reduction technologies do not yet exist. Estimates of emissions-specific reductions for sulfur range from approximately 20% globally over a 20-year period to 50 to 60% in West Germany and The Netherlands during the 1980s alone.

Although the contributions of structural change in the output mix of the economy and shifts in fuel composition may be important in some countries and at some times, their average effect seems less important quantitatively. Those studies that include developing countries find that technological changes are occurring in both developing and developed countries. Innovations may first be adopted preferentially in higher income countries but seem to be adopted in developing countries with relatively short lags. This is seen, for example, regarding lead in gasoline, where most developed countries had substantially reduced the average lead content of gasoline by the early 1990s but many poorer countries also had low lead contents. Lead content was much more variable at low income levels than at high income levels.

9. CONCLUSIONS

The evidence presented in this article shows that the statistical analysis on which the EKC is based is not robust. There is little evidence for a common inverted U-shaped pathway that countries follow as their incomes rise. There may be an inverted U-shaped relation between urban ambient concentrations of some pollutants and income, although this should be tested with more rigorous time series or panel data methods. It seems unlikely that the EKC is a complete model of emissions or concentrations.

The true form of the emissions–income relationship is likely to be monotonic, but the curve shifts down over time. Some evidence shows that a particular innovation is likely to be adopted preferentially in high-income countries first with a short lag before it is adopted in the majority of poorer countries. However, emissions may be declining simultaneously in low- and high-income countries over time, *ceteris paribus,* although the particular innovations typically adopted at any one time could be different in various countries.

It seems that structural factors on both the input and output sides do play a role in modifying the gross scale effect, although on the whole they are less influential than time-related effects. The income elasticity of emissions is likely to be less than 1.0 but not negative in wealthy countries, as proposed by the EKC hypothesis.

In slower growing economies, emissions-reducing technological change can overcome the scale effect of rising income per capita on emissions. As a result, substantial reductions in sulfur emissions per capita were observed in many developed countries during the past few decades. In faster growing middle-income economies, the effects of rising income overwhelmed the contribution of technological change in reducing emissions.

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