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Demystifying the environmental Kuznets curve: turning a black box into a policy tool*

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ABSTRACT: The reduced-form approach to the income–environment relationship has been a useful first step towards answering the question of how economic growth affects the environment. However, without an explicit consideration of the underlying determinants of environmental quality, the scope for policy intervention is unduly circumscribed. In this paper a modest attempt is made to incorporate explicit policy considerations into the income–environment relationship and to explore its determinants as a step towards a better understanding of this relationship and its potential as a policy tool. The role of the *rate* of economic growth and population density is also explored. A main finding is that at least in the case of ambient SO_2 levels, policies and institutions can significantly reduce environmental degradation at low income levels and speed up improvements at higher income levels, thereby flattening the EKC and reducing the environmental price of economic growth.

1. Introduction

Casual observation suggests that cities in the newly industrializing countries such as Bangkok, Shanghai and Mexico City are more polluted today than they were 20–30 years ago, while cities in industrial countries, such as New York, London and Tokyo are cleaner than 20–30 years ago. This apparent paradox raises the question: do higher income levels imply a worse or better environment? Several researchers, such as Shafik and Bandyopadhay (1992), Hettige, Lucas and Wheeler (1992), Panayotou (1993, 1995), Selden and Song (1994), Grossman and Krueger (1995), Vincent (1996) and others, have found that for several pollutants there is an inverted U-shaped relationship between income and pollution. This relationship came to be known as the environmental Kuznets curve (EKC) because of its similarity to the inverted U-shaped relationship between inequality and income levels advanced by Simon Kuznets (1955).

The EKC literature, critically reviewed by Stern, Common and Barbier (1996), has raised more questions than it has answered. Does an inverted U-shape income–environment relationship (when it exists) imply that

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environmental degradation is a 'growing-up' problem that will go away automatically, i.e., no policy intervention is necessary? Is the level of income the only development-related variable that matters, or does the speed with which each level of income is reached (i.e., the growth rate) make a difference?

What is the role of structure versus the scale of the economy or the effect of environmental expenditures and regulations versus the quality of institutions? These are questions that cannot be answered by the simple reduced-form approach to the environmental Kuznets curve. While parsimonious in data and estimation complexity, the conventional approach is basically a 'black box': it hides more than it reveals since income level is used as a catch-all surrogate variable for all the changes that take place with economic development.

While several authors such as Grossman and Krueger (1995), Arrow *et al.* (1995) and Kaufmann *et al.* (1995) have identified the need for a more structural and analytic approach to the income–environment relationship and the explicit inclusion of policy variables, we know of no study that has empirically attempted such a decomposition. This paper is a modest attempt to include both policy variables and the rate of economic growth, first in a reduced-form equation and then in a decomposition equation that breaks down the net income effect into its constituent scale, structure and abatement effects. A more formal approach through the specification and estimation of structural equations and solution back to recover the EKC parameters and obtain the net effect of income changes on pollution is taken by a parallel study by Islam, Vincent and Panayotou (1997). The present paper's focus is on the policy scope and potential of a more analytic and structural approach to the income–environment relationship than its technical detail. From being a black box that lends itself to misinterpretation, EKC has the potential to become a policy tool by focusing attention on the structural changes of supply and demand for commodities and amenities throughout the development process and on the role of policies and institutions in exacerbating or mitigating the environmental externalities of economic growth.

In the following two sections, we make the case for inclusion of the growth rate and of policy variables in both reduced-form and structural specifications of EKC. In Sections 4, 5, and 6 we discuss respectively the methodology, data, and empirical findings of both reduced-form and 'decomposed' EKC estimations for ambient SO_2 levels using panel data for 30 countries.

2. Growth and policy variables

There is no clear *a priori* expectation as to the direction in which the rate of economic growth affects the income–environment relationship. Conventionally it is assumed that the income–environment relationship is not affected by the rate of economic growth. It is the level of income rather than its time rate of change that influences environmental quality. The same level of environmental quality results at each level of income per capita, regardless of how rapidly or slowly this income level is reached. A rapid rate of economic growth, however, may result in lower levels of

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ambient environmental quality if the flow of emissions exceeds the rate at which it is assimilated by the environment, thus resulting in larger concentrations and possible damage to the environment's assimilative capacity. For example, if a certain environment can assimilate 100 tons of SO_2 a year but the flow of emissions is 300 tons a year, we can expect faster accumulation (and hence higher concentrations) than when emissions are only 150 tons a year.

Of course, a greater level of abatement effort can offset the 'extra' accumulation of pollutants by enhancing or complementing the environment's absorptive capacity. However, there is no reason to presume that a faster growth will automatically result in higher pollution abatement effort than the level corresponding to the income per capita attained. Environmental and social changes take place at different speeds. Shifts in people's preference functions and in social norms are slow adaptive processes that may fall more behind a fast rate of environmental degradation than a slower one which allows time for adaptation and adjustment. Indeed, one reason for the observed inverted-U relationship between environmental degradation and income is the discrepancy between the rates of economic and social change, with the latter almost always trailing the former. The faster economic change (and corresponding environmental change) is, the larger is likely to be the gap between the two.[1]

In the conventional reduced-form or 'black-box' formulation of the income–environment relationship, in which demand and supply, scale and composition factors are lumped together (see Section 3), it is not possible to disentangle the effects of growth on pollution levels and abatement effort. Therefore, there is no clear *a priori* expectation as to the direction in which economic growth affects the income–environment relationship. Our own hypothesis is that economic growth, or the time rate of change of income as distinct from its level, is a significant factor affecting the income–environment relationship, but the direction of the net effect depends on the relative magnitudes of the opposing effects discussed above.

In contrast, the effect of good policies on environmental quality is expected to be unambiguously positive. An inverted-U relationship between certain pollutants and income levels is an empirical observation. It may also be to a degree inevitable and even optimal as natural and environmental resources are run down to accumulate human and human-made capital and subsequently built up as sources of environmental amenities as the demand for such amenities rises with income levels.[2] However, the height or degree of convexity of the curve is largely a function of policies and markets. Where there exist policy distortions such as energy subsidies or policy failures in the sense of unmitigated market failures, for example undefined property rights or externalities, the deterioration of the

[1] There is extensive literature on the consequences of social and institutional change trailing economic change; see, for example, Huntington (1968).

[2] Even without the rise of demand for environmental amenities, the stocks of renewable natural resources are likely to recover at least partially when the economy diversifies and the centre of economic gravity moves from the primary sectors to industry and services.

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environment (at low income levels) per unit of per capita GDP increase is higher than it would be otherwise. This arises from the fact that implicit in the income–environment relationship is an efficiency factor, e.g., pollution per unit of output, which is amenable to policy manipulation. For example, energy subsidies may result in higher energy intensity of GDP and, other things equal, a higher level of emissions, a lower level of environmental quality and a steeper environmental Kuznets curve. Similarly, the open-access status of many natural resources, such as forests and fisheries, would result in higher rates of depletion per unit of GDP than would have prevailed under a more secure property rights regime (see Figure 1). A steeper rise in the curve reflects excessive resource intensity and waste generation. A steeper fall (likely but not inevitable) as environmental awareness rises and institutions improve with economic growth reflects stronger pressures to reduce environmental degradation when it has reached high levels and when policies are seen to be responsible.

The improvement of the environment with income growth, however, 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 (or reduced degradation) materialize or not, when and how depends critically on government policies, social institutions and the completeness and functioning of markets.

Policies and markets determine the 'environmental price' of economic growth and, in the presence of ecological thresholds, they largely determine the reversibility of environmental damage (see Figure 1). For example, deforestation in the tropics is difficult to reverse once the topsoil

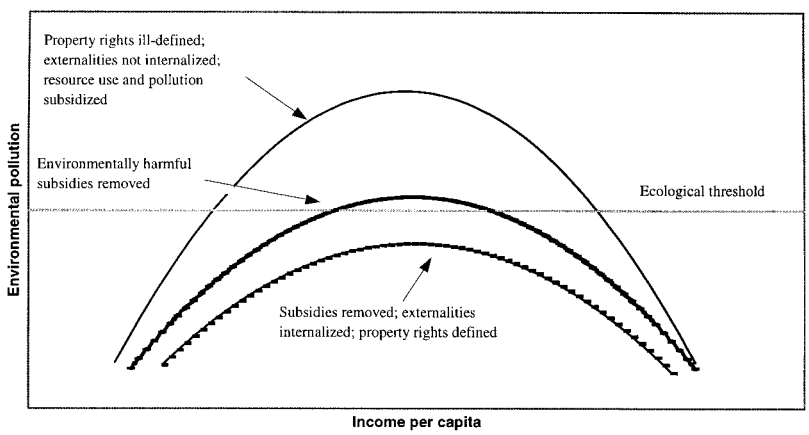


Figure 1. *The income–environment relationship under different policy and institutional scenarios; the environmental Kuznets curve is flattened out by removing environmentally harmful subsidies, internalizing externalities and ensuring a clear definition of and enforcement of property rights over natural resources. (Source: Panayotou, 1993, 1995, 1997)*

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is washed away. Policies and markets also determine the responsiveness of the supply of environmental quality to the higher future demand and, hence, the future prospects for environmental improvement. Better policies, such as removal of distortionary subsidies and introduction of more secure property rights over resources and pollution taxes (or other efficient instruments) to internalize externalities, are expected to reduce the 'environmental price' of economic growth, thereby flattening out the income–environment relationship and possibly achieving an earlier turning point. Furthermore, the institutional framework might affect the ability to monitor environmental degradation, thereby increasing the speed of social changes and lowering their gap with environmental changes. Thus, the effects of better economic and environmental policies on environmental quality are expected to be unambiguously positive.

3. Inside the black box: scale, composition and abatement effects

The environmental Kuznets curve is a reduced form function that gives the 'net effect' of income on the environment. Or, more accurately, income acts as an omnibus variable or a surrogate for a variety of underlying influences, the separate effects of which are obscured. As such, the EKC, in its reduced form, is a 'black box' that hides more than it reveals. We are left without any clue as to why the observed relationship exists and how to influence it. Without an explicit consideration of the underlying determinants of environmental quality, the scope for policy intervention is unduly circumscribed. Therefore, estimation of a reduced-form EKC should only be a first step in our effort to understand the environment–development relationship, not the endpoint.

As a first step towards a more analytical approach to the income–environment relationship, initially we recognize that environmental quality is the outcome of the interplay of emissions and abatement (or depletion and regeneration in the case of renewable resources), and then we identify the different types of effects that income has on environmental quality, or rather the different effects of economic development that are transmitted through the income variable. This enables us to identify the determinants of environmental quality:

- the scale of economic activity;
- the composition (or structure) of economic activity;
- the effect of income on the demand and supply of pollution abatement effort (what we might term the 'pure' income effects).

The larger the *scale* of economic activity per unit of area, all else equal, the higher the level of environmental degradation (pollution, resource depletion) is likely to be, since increased economic activity results in increased levels of resource use and waste generation, if nothing else changes. Since income is acting as an indicator of economic activity, we would expect a positive relationship between environmental degradation and income, while controlling for all other income-related effects. We represent the scale of economic activity by GDP per unit of area. This formulation applies only to concentrations of pollutants, not to per capita emissions, which are unlikely to be affected by the density of production.

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The *composition* of economic activity influences environmental quality because of the differential pollution (and resource-using) intensity of different sectors of the economy. The primary sector (agriculture, fisheries, forestry, and mining) tends to be more resource-intensive than either the secondary (industry) or tertiary (services) sectors. Industry (especially manufacturing), on the other hand, tends to be more pollution-intensive than either agriculture or services. Since the structure of the economy (sectoral composition of output) changes with economic growth, part of the effect of increases in income per capita on environmental degradation reflects the effects of the changing composition of output. We represent economic structure by the share of industry in GDP and expect a positive relationship with environmental degradation. Since the share of industry in GDP first rises with economic growth and then declines[3] as the country moves from the pre-industrial to the post-industrial stage of development, we expect an inverted-U shaped relationship between environmental pollution and income level while controlling for all other influences transmitted through income.

While the generation of pollution is driven by the scale and composition of economic activity, the *abatement* of pollution is driven by demand and supply factors, both of which are influenced by income. On the demand side, at low income levels, people are more concerned with food and other material needs and less concerned with environmental quality. At higher income levels, people begin to demand higher levels of environmental quality to go along with their increased prosperity. This Engel's Law-type relationship between income and *demand for* environmental quality translates into an inverted-J curve between income and environmental degradation (Selden and Song 1995). In contrast to the inverted U-curve relationship of the reduced-form model, the inverted J-curve indicates a non-increasing relationship between environmental degradation and income once the scale and composition of output are controlled for. This is a reflection of the non-negative income elasticity of environmental quality that is visible in the J-curve but masked by scale and structural factors in the U-curve. On the supply side, low incomes mean that countries and individuals cannot afford much expenditure on pollution abatement even if the demand were there. Economic growth not only creates the demand for improved environmental quality, but it also makes the resources available to supply it. Higher incomes enable higher public expenditures on environmental infrastructure as well as environmental regulations that drive private sector expenditure on abatement technologies. What we can capture by the income variable (while controlling for scale and composition) is the locus of the equilibrium abatement levels (i.e., where the supply and demand for abatement, both income-dependent, are equal). Stripped of the scale and composition effects, the relationship between environmental degradation and income per capita is expected to be monotonically negative.

[3] As one reviewer pointed out, the share of services in GDP might be a better variable to use since it increases monotonically with GDP. We prefer, however, industry share in GDP because of the industry's direct link to SO_2 emissions.

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4. Methodology

The income–environment relationship is often studied by specifying and estimating flexible functional forms with quadratic and higher-order terms that relate ambient emission levels (concentrations) or emissions to income per capita and to other variables such as population density and site-specific variables. Since our interest here is to examine how policy and the growth rate of the economy (i.e., the speed with which per capita income reaches higher levels) affect the income–environment relationship, we employ the most basic model that includes only income per capita and population density and the variables of special interest. We chose ambient SO_2 levels as our dependent variable since most previous studies found it to exhibit a classic EKC relationship with income level. (In subsequent work we will repeat this exercise for pollutants that do not exhibit the classic EKC relationship to explore whether our approach makes a difference.) In order not to unduly constrain the relationship, we postulate a cubic functional form:

$$X_{it} = \alpha_0 + \alpha_Y Y_{it} + \alpha_{YY} Y^2_{it} + \alpha_{YYY} Y^3_{it} + \alpha_D D_{it} + \alpha_{DD} D^2_{it} + \alpha_{DDD} D^3_{it} + \alpha_G G_{it} + \alpha_{GY} G_{it} Y_{it} + \alpha_P P_{it} + \alpha_{PY} Y_{it} P_{it} + \alpha_t t + \epsilon_{it} \quad (1)$$

where X_{it} is the ambient SO_2 level in country i in year t, Y_{it} is the GDP per capita in country i in year t, D_{it} is the population density in country i in year t, $G_{it} = 100 + g$, where g is the annual growth rate of GDP per capita, P_{it} is the policy variable in country i in year t, ϵ_{it} is an error term and the αs are the parameters to be estimated.

By entering the growth rate and the policy variables both additively and multiplicatively with income, we are able to test whether they affect the EKC's slope or intercept or both. We have also included a linear time trend to capture exogenous (not income-induced) advances in technology and/or increases in environmental awareness. Since our dependent variable is in terms of median country concentrations of SO_2, we did not include variables representing characteristics of sites and methods of monitoring.[4] Since these location characteristics are unlikely to be correlated with income, their exclusion does not bias the coefficients of interest, but it does increase the residual variance in the relationship between ambient SO_2 and income.

As noted earlier, a major limitation of the reduced-form approach of equation (1) is its black-box structure: we do not know why the estimated relationship exists. Above, we identified four possible channels through which income per capita may affect the ambient environmental quality: the scale and composition of economic activity, which jointly determine the level of emissions, and the demand for and supply of environmental quality, which jointly determine the level of pollution abatement. We represent the scale of economic activity by GDP per unit of area, the

[4] We did not use city averages, as do Grossman and Kreuger (1995), because most explanatory variables, such as income, industry share, etc. are not available at the city level. Using country averages for some variables and city averages for others introduces its own distortions. Moreover, for SO_2, unlike particulates, country averages may be more appropriate.

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composition of economic activity by industry share and the equilibrium level of abatement by GDP per capita, which determines both the demand and supply for environmental quality. For both flexibility and comparability with equation (1), we chose a cubic functional form for all three channels:

$$X_{it} = \beta_0 + \beta_Y Q_{it} + \beta_{QQ} Q^2_{it} + \beta_{QQQ} Q^3_{it} + \beta_S S_{it} + \beta_{SS} S^2_{it} + \beta_{SSS} S^3_{it} + \beta_Y Y_{it} + \beta_{YY} Y^2_{it} + \beta_{YYY} Y^3_{it} + \beta_D D_{it} + \beta_{DD} D^2_{it} + \beta_{DDD} D^3_{it} + \beta_G G_{it} + \beta_{GQ} G_{it} Q_{it} + \beta_{GS} G_{it} S_{it} + \beta_{GY} G_{it} Y_{it} + \beta_P P_{it} + \beta_{PQ} P_{it} Q_{it} + \beta_{Ps} P_{it} S_{it} + \beta_{PY} P_{it} Y_{it} + \beta_t t + \epsilon_{it} \quad (2)$$

where X_{it}, Y_{it}, D_{it}, G_{it}, P_{it} and t are defined as in equation (1), Q_{it} is defined as GDP per square kilometre and represents the scale of economic activity,[5] S_{it} is defined as industry share in GDP and represents the structure or composition of economic activity, ϵ_{it} is an error term and the βs are the parameters to be estimated.

The scale of the economy is expected to enter with a positive sign since, other things (composition, abatement, etc.) being equal, the larger the volume of economic output, the higher the level of SO_2 emissions and hence the higher the level of ambient concentration. The industry share is also expected to enter with a positive sign since it is correlated with energy use, the main source of SO_2 emissions. Once scale and composition of output have been controlled for, GDP per capita is expected to enter with a negative sign, since increasing economic prosperity both results in high demand for pollution abatement and makes available the resources to supply it. We have also attempted inclusion of lagged GDP per capita (one- and three-year lagged) to capture permanent income effects and lagged response between GDP rise and enactment of environmental standards, but they were highly correlated with GDP per capita and were dropped.

As in equation (1), we included population density, the growth rate of the economy and an exogenous policy variable representing the quality of institutions and a linear time trend. The sign of population density is ambiguous since, on the one hand, more people per square kilometre would result in higher SO_2 emissions as a result of the use of coal and non-commercial fuels in cooking and heating, not fully captured by the scale of formal economic activity; on the other hand, densely populated countries are likely to be more concerned than less densely populated countries about abating SO_2 at every level of income. The inclusion of the growth rate aims to test the hypothesis that the relationship between ambient pollution levels and the three decomposition effects (scale, structure and abatement) are affected by how fast the economy grows. It is expected that a faster growth rate would result in somewhat higher levels of ambient SO_2 concentrations as the scale of the economy expands and somewhat slower improvement in environmental quality as income per capita rises.

[5] GDP per square kilometre is a good indicator for scale as long as output composition is fixed or controlled for. However GDP/km^2 may not fully reflect the scale of consumption if GDP and GNP differ significantly. International trade also makes a difference, as Stern *et al.* (1996) pointed out.

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The inclusion of the policy variable is less clear when income per capita, stripped of its scale and composition effects, is meant to capture the demand and supply (or rather the equilibrium level) of pollution abatement. However, we distinguish between endogenously and exogenously determined policy. Income per capita captures the endogenous or income-induced environmental regulations and public expenditures. Our policy variable allows for (a) non-income driven (or 'conscious') environmental policy and (b) for the quality of policy-related institutions: countries with the same level of income may consciously adopt more or less stringent environmental policies based on differences in educational level, quality of policy-making institutions and of bureaucracy, rule of law, etc. Another way of looking at it is that the income-per-capita variable captures the 'quantitative' aspects of policy (e.g., environmental expenditures), while our policy variable captures the 'qualitative' or institutional aspects. Thus, while we test for the interaction of the policy variables with all the channels of the income–environment relationship, we expect it to interact most significantly with the abatement channel. The expected sign of its impact on ambient SO_2 levels is unambiguously negative: better policies/institutions result in lower pollution levels.

Finally, a time-trend variable was also included, as in equation (1), to capture any time-related exogenous shifts in technology or preferences unrelated to income levels (or to any other of the included variables).

We estimated two versions of equations (1) and (2): fixed and random effects. The fixed-effects version treats differences in the intercepts as due to deterministic factors. The random-effects version treats those differences as being due to stochastic factors. Using the Hausman (1978) test we determined the preferred version by testing the null hypothesis that the random effects were uncorrelated with year and region. The random-effects model was preferred unless the null hypothesis was rejected at a significance level of five percent. The test statistics reported in Tables 2 and 3 below favour the use of the fixed-effects estimation.

5. The data and econometric issues

Our data set is an unbalanced panel of cross-section and time-series observations. The dependent variable in both equations (1) and (2) is defined as the country median of annual SO_2 concentrations ($\mu g/m^3$ or kg/km^3) averaged over all daily observations of the monitoring stations in the country, obtained from the Global Environmental Monitoring System (GEMS). The GEMS air monitoring project collects data on air quality in urban settings through monitoring stations located in a changing sample of cities in both developed and developing countries. Most cities have monitoring stations in more than one location, chosen to be representative of geographic conditions for an increasing number of countries. Our sample includes 30 developed and developing countries for the period 1982–94, which were the countries and the time span for which we had data on both SO_2 and our policy variable. We use country median data rather than individual station observations to minimize the bias from the skewed distribution of monitoring stations towards a few countries such as the USA. One potential problem with SO_2 is its propensity to travel over great distances and across

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borders; therefore, its local concentration levels may not simply relate to the country's scale and composition of economic activity and levels of pollution abatement, but also to the economic activity and abatement in other (neighbouring) countries. Capturing these efforts requires a detailed air circulation model, which is beyond the scope of this paper.

The GDP variable is taken from the World Bank (1995) *World Tables* and is measured in terms of 1985 constant US dollars. We did not use the purchasing-power-parity (PPP)-adjusted GDP figures from Summers and Heston (1991) because they were available only up to 1992, and we did not want to extrapolate our key independent variable to make it coterminous with our dependent variable that ran to 1994.[6] Since the World Bank's income data do not correspond to a common set of international prices and tend to understate the incomes of poor countries and overstate the income of rich countries, a certain bias is introduced in our results, which should be taken into account in comparing them with those of other studies that use PPP-adjusted income figures.

Population density, expressed in thousand persons per square kilometre is also taken from the *World Tables*. The scale of the economy, represented simply by GDP per square kilometre is constructed from the same GDP data in 1985 prices. The composition variable represented by share of industry in GDP was obtained by dividing industrial GDP by total GDP, both obtained from *World Tables*, as were the original growth rates of GDP by country. Finally, the policy variable is proxy for the quality of institutions. Ideally, we would have liked to have a variable representing the quality of environmental policies and institutions, which was both unavailable and difficult to construct country by country. We experimented instead with a set of five indicators of the quality of institutions in general: respect/enforcement of contracts, efficiency of bureaucracy, the efficacy of the rule of law, the extent of government corruption and the risk of appropriation obtained from Knack and Keefer (1995). Since these variables were highly correlated, we had to choose one of them; we chose the respect/enforcement of contracts, but the efficacy of the rule of law and the efficiency of bureaucracy also worked well, as did a composite index of all five variables. Table 1 provides summary statistics for the main variables used in the estimation of equations (1) and (2).

Our EKC hypothesis, like those of previous studies, is derived from a simple model of the economy (in which there is no feedback from the environment to the economy). In other words, we assume unidirectional causality from the economy to the environment. However, there is growing evidence that environmental degradation limits growth possibilities, especially in developing countries. As Stern *et al.* (1996) pointed out in the presence of such simultaneity, estimating single-equation relationships introduces biases and may result in inconsistent estimates. This problem is particularly serious when resource depletion (e.g., deforestation) or degradation of the resource base (e.g., soil erosion) are involved, but pollution may also have productivity-related effects, either directly or through its

[6] A comparison of the results of regressions using PPP-adjusted GDP and GDP at official exchange rates for the years 1982 to 1992 indicated significant robustness.

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Table 1. *Summary statistics of main variables*

Variables	*Observations*	*Mean*	*Standard deviation*	*Minimum*	*Maximum*
SO_2 ($\mu g/m^3$)	193	14.63	12.74	0.3	54.1
GDP per capita ($1,000)	193	6.76	6.300	0.148	23.4
Population density ($1,000/km^2$)	193	0.184	0.658	0.002	5.4
Scale ($\$ \times 10^6/km^2$)	193	1.51	4.798	0.020	39.6
Industry share	182	0.34	0.072	0.194	0.56
Growth ($100 \times GDP_t/GDP_{t-1}$)	193	103.4	4.175	89.6	115.8
Policy	193	7.10	2.128	2	10

impact on health. In our formulation of the SO_2–income relationship we assume that these feedbacks are relatively small, since SO_2 is only one of many components of environmental quality (not necessarily correlated with the others). To the extent that this assumption does not approximate reality, our single-equation formulation has introduced biases in our estimates.

The use of observations that are aggregations over varying numbers of subunits to test the EKC hypothesis is likely to give rise to heteroscedasticity problems in estimation, rendering ordinary least squares (OLS) estimates inefficient as pointed out by Stern *et al.* (1996). While for our estimation we use generalized least squares we have also checked for heteroscedasticity in our data by performing the Goldfeld–Quandt test. We found that none of our variables is heteroscedastic as indicated by *F* values for individual variables in the range of 0.81 to 1.25 compared to a critical value of the F-test of 1.48 at 0.05 level.

Multicollinearity is another potential problem in our data, as it is for previous EKC studies. Our use of combined cross-section and time-series data reduces but does not eliminate this potential problem. While there are no sure methods of detecting multicollinearity in multivariable regressions, we check a number of possible indicators such as partial correlation coefficients. No multicollinearity was detected among any of our basic explanatory variables but there was some collinearity between lower- and higher-order terms of some variables, as one would expect with polynomial regressions. While the ideal approach would be to express the explanatory variables in terms of deviations from mean values or to use orthogonal polynomials (Draper and Smith, 1981) we chose the simpler and less satisfactory approach of dropping the insignificant forms of the variable. While this may lead to specification bias, this is thought not to be the case in our model, since all the theoretically essential variables still appear and there is no *a priori* theoretical reason why higher-order forms should also be included. Indeed, it is the objective of the EKC hypothesis to test whether such terms are indeed significant.

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6. Estimation results

The panel regression results for equation (1) are reported in Table 2. We estimated two models:

- the standard cubic equation with only income and population density as explanatory variables;
- the same model with the addition of the growth rate and policy variables.

For each model we estimated both fixed effects and random effects versions. In both cases the null hypotheses that the random effects were uncorrelated with year was rejected by the Hausman test and hence the fixed-effects estimation was favoured. All variables in Model I are statistically significant at least at the 10 per cent level and have the expected signs indicating the presence of an inverted U-shaped relationship between ambient SO_2 and income per capita within the range of income data. A similar relationship exists between SO_2 and population density. The overall fit of Model I is not high ($R^2 = 0.148$), implying that variables other than income and population density also matter.

In Model II we introduced our two variables of interest: GDP growth rate and a policy variable, represented by enforcement of contracts. The overall fit increased by over 60 per cent from 0.148 to 0.238. The square of population density became statistically insignificant; the constant became

Table 2. *Estimation results for SO_2 emissions: The role of population density, economic growth rate and policy variables (t-statistics in parentheses)*

	Model I		*Model II*	
	Fixed effects	*Random effects*	*Fixed effects*	*Random effects*
Constant	11.145	10.782	−30.185	−30.736
	(4.394)	(7.021)	(−1.285)	(−1.407)
GDP per capita	1.937	2.151	2.561	2.310
	(1.973)	(2.741)	(1.803)	(2.016)
(GDP per capita)^2	−0.295	−0.312	−0.241	−0.234
	(−2.941)	(−3.353)	(−1.709)	(−1.850)
(GDP per capita)^3	0.0098	0.0103	0.008	0.008
	(3.200)	(3.470)	(1.906)	(2.061)
Population density	52.668	50.131	39.424	35.330
	(7.478)	(7.491)	(4.284)	(4.062)
(Population density)^2	−23.484	−22.430	—	—
	(−6.138)	(−6.007)	—	—
(Population density)^3	2.556	2.442	−1.354	−1.208
	(4.536)	(4.381)	(−4.276)	(−3.996)
GDP growth rate	—	—	0.558	0.569
			(2.503)	(2.722)
Policy	—	—	−3.406	−3.294
			(−4.942)	(−5.306)
R^2	0.148	—	0.238	—
Hausman's χ^2	—	17.7	—	4.90
Probability $> \chi^2$	—	0.068	—	0.672
N	193	193	193	193

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negative and less significant as did all income terms though still significant at least at the 10 per cent level. Both the growth rate and the policy variables as additive terms were highly significant and had the expected signs. A 1 per cent increase in the growth rate results in 0.56 $\mu g/m^3$ increase in the ambient concentration of SO_2, while an improvement in the quality of institutions (enforcement of contracts) by one unit (or by 15 per cent) results in reduction of ambient SO_2 concentration by 3.4 $\mu g/m^3$. The multiplicative terms of the growth and policy variables and the linear time trend were not statistically significant and were dropped.

Figure 2 depicts the environmental Kuznets curve derived from Model II (fixed effects) and the effects of a higher growth, better policy, and a higher population density. The EKC for SO_2 attains a turning point at an income per capita just under US$5,000 (Figure 2b), a finding comparable with those of Grossman and Krueger (1993), Panayotou (1993, 1995) and

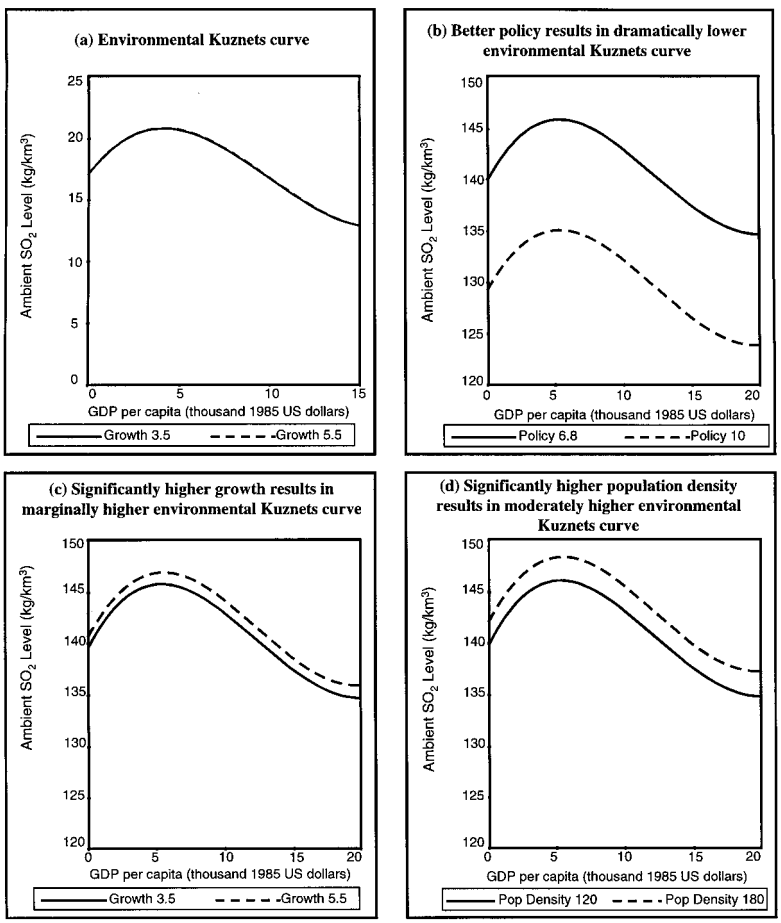


Figure 2. *Reduced-form environmental Kuznets curve: The role of growth, policy and population density*

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Shafik (1994). Between $5,000 and 15,000 per capita, ambient SO_2 concentration falls rapidly; it levels off between $15,000 and $20,000 and begins to turn up again, although as this is outside the range of data or at the extreme end where there are only very few observations (i.e., countries with over $20,000 per capita in 1985 prices), it should not be taken seriously.

As seen in Figures 2(b)–(d), better policy results in dramatically lower ambient SO_2 levels while faster growth and higher population density result in marginally to moderately higher ambient SO_2 levels. It might therefore be more effective to focus efforts for controlling pollution on improving policy rather than either on limiting economic growth or controlling population growth. While the cost (not just the effectiveness) of each option is also relevant, policy/institutional improvements are likely to have lower costs and more benefits associated with them than artificial restrictions on economic or population growth. This is as far as one can go with the black-box or reduced-form specification of equation (1).

The panel regression results for the decomposition of equation (2) are reported in Table 3. Again, the random-effects estimation was rejected by the Hausman test, and we therefore focus our discussion on the fixed-effects model, even though we report the results of both versions. All variables are the same as in equation (1) except that the income effect is decomposed into its constituent scale, composition (or structure) and abatement effects. First of all, it is noteworthy that the overall fit improved dramatically with the R^2, rising from 0.238 to 0.502. Income per capita, now stripped of its scale and structural-change effects, captures only the abatement effect. It is, as expected, negatively associated with ambient SO_2 levels up to US$13,000 per capita (Figure 3a). Beyond this point it turns up, but the significance of this 'tail' effect is uncertain because of the very few observations at the high end of income levels. It is also noteworthy that the cubic term is no longer significant.

As expected, the expansion of the scale of the economy increases ambient SO_2 concentrations, but it does so at a diminishing rate (see Figure 3b). The cubic term is only marginally significant and does not alter the monotonic relationship within the data range. The scale effect is particularly strong for income levels up to US$3 million per square kilometre.

The sectoral structure of the economy represented by industry share has the right signs, having a generally non-decreasing relationship with ambient SO_2 levels. It has, however, a peculiar cubic shape with rising portions at the tail ends and a fairly constant section in the middle for industry shares between 10 and 30 per cent. This is, in part, because the simple industry share term is not statistically significant except as it interacts with income per capita, implying that the greater the income-induced SO_2 abatement effect, the larger is the share of industry in GDP, apparently indicating more visibility of pollution sources and more opportunity (i.e., point sources, scale economies) to control it. The industry share rises from under 20 per cent to about 43 per cent when income per capita reaches US$8,000 and declines to about 37 per cent when income reaches US$17,000, beginning to rise again. If we ignore this tail effect, we see that the share of industry reaches its maximum at intermediate income levels, and this is when energy and emissions intensities are at their highest.

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Table 3. *Decomposition of the income–environment relationship into scale, composition and pure income effects (t-statistics in parentheses)*

	Fixed effects	*Random effects*
Constant	73.96	49.523
	(6.015)	(6.435)
GDP per capita	−11.391	−8.437
	(−2.906)	(−2.434)
(GDP per capita)^2	0.207	0.109
	(2.898)	(2.604)
(GDP per capita)^3	—	—
Population density	−765.60	−244.82
	(−5.102)	(−3.658)
(Population density)^2	3324.86	1328.68
	(4.773)	(3.162)
(Population density)^3	−4230.68	−1853.40
	(−4.284)	(−2.610)
Scale (= GDP/km^2)	37.010	12.433
	(4.830)	(2.050)
(Scale)^2	−6.359	−1.966
	(−3.275)	(−1.066)
(Scale)^3	0.280	0.620
	(1.724)	(0.381)
Industry share	—	—
(Industry share)^2	−472.24	−567.43
	(−2.804)	(−4.078)
(Industry share)^3	905.86	972.50
	(3.257)	(4.105)
(GDP) × (Industry share)	10.666	8.735
	(2.738)	(2.243)
(GDP per capita) × (growth)	0.052	0.0762
	(1.917)	(2.613)
(GDP per capita) × (policy)	−0.437	−0.540
	(−3.074)	(−3.661)
R^2	0.502	—
Hausman's χ^2	—	36.64
Probability > χ^2	—	0.002
N	182	182

Hence, the most relevant portion of the Figure 3c curve is between industry shares of 20 and 30 per cent. In this range, the SO_2–industry share relationship does have the expected J shape.

The statistical significance of the population density found in the reduced-form equation (1) survives the decomposition of the income variable, though it reverses signs. If all other factors are controlled for, low population densities of under 50 persons per square kilometre are associated with high ambient SO_2 levels (70 kg/km^3), presumably because, in sparsely populated countries, there is less pressure to control emissions; as population density rises to around 170 persons per square kilometre, SO_2 levels drop to their lowest level (45 kg/km^3) and begin to rise again as the household use of coal and informal fuels by a denser population overwhelms the population pressure for more pollution abatement (Figure 3d).

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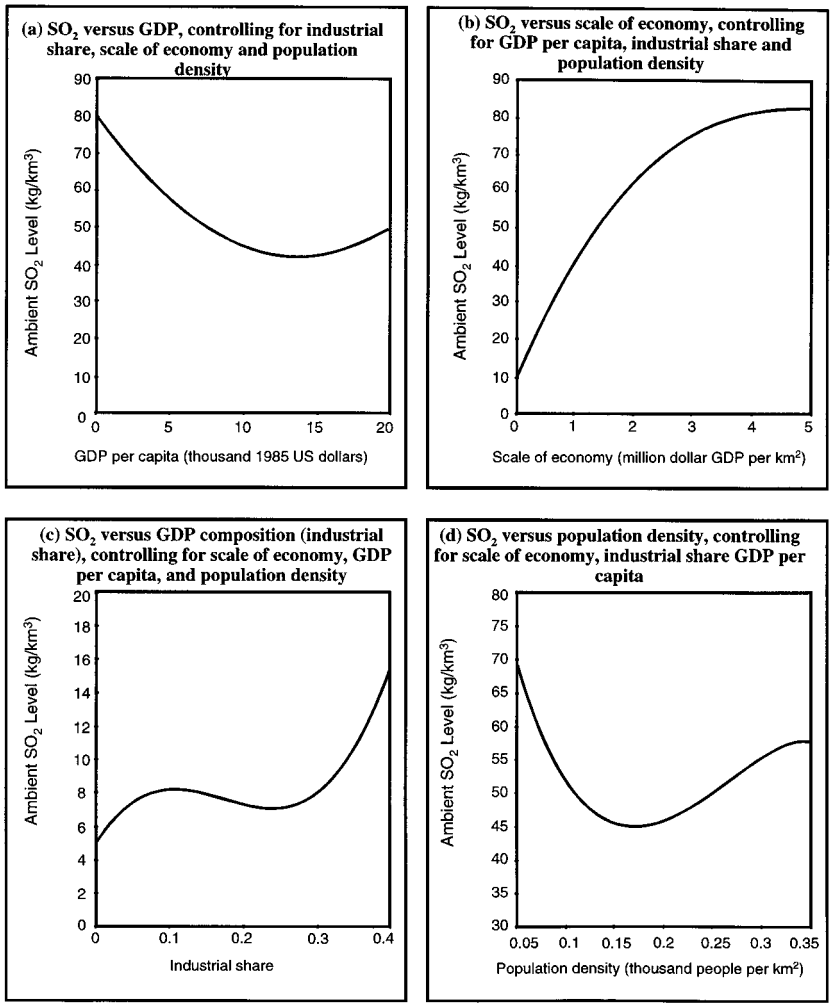


Figure 3. *Decomposing the environmental Kuznets curve*

The statistical significance and correct signs of the growth rate and policy variables have also survived the decomposition of the reduced-form function, but the channel of the effect of these two variables has changed from the intercept to the slope of the income–environment relationship. It is the multiplicative or interactive term of each of these variables with income per capita that is now significant, not the additive term. The multiplicative terms with scale and industry share were, however, insignificant. The positive interaction effect between GDP per capita and the GDP growth rate imply that higher growth rates result in slower improvements in environmental quality as income rises, everything else being held constant (Figure 4a). The reason may be that, under conditions of rapid growth, proportionately less of each income level is allocated to

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environmental expenditures than under conditions of slower (and evidently more sustainable) growth. Another reason could be that both the demand for improved environmental quality and the enactment of environmental regulations trail farther behind the economic changes with faster growth. It could also be that environmental regulations are less effective under conditions of rapid economic growth. Whatever the explanation, the effect is quite small, especially at low income levels, and can be easily offset by better policy.

In contrast, the effect of better policies/institutions on the income-induced environmental improvement is very large: A 50 per cent

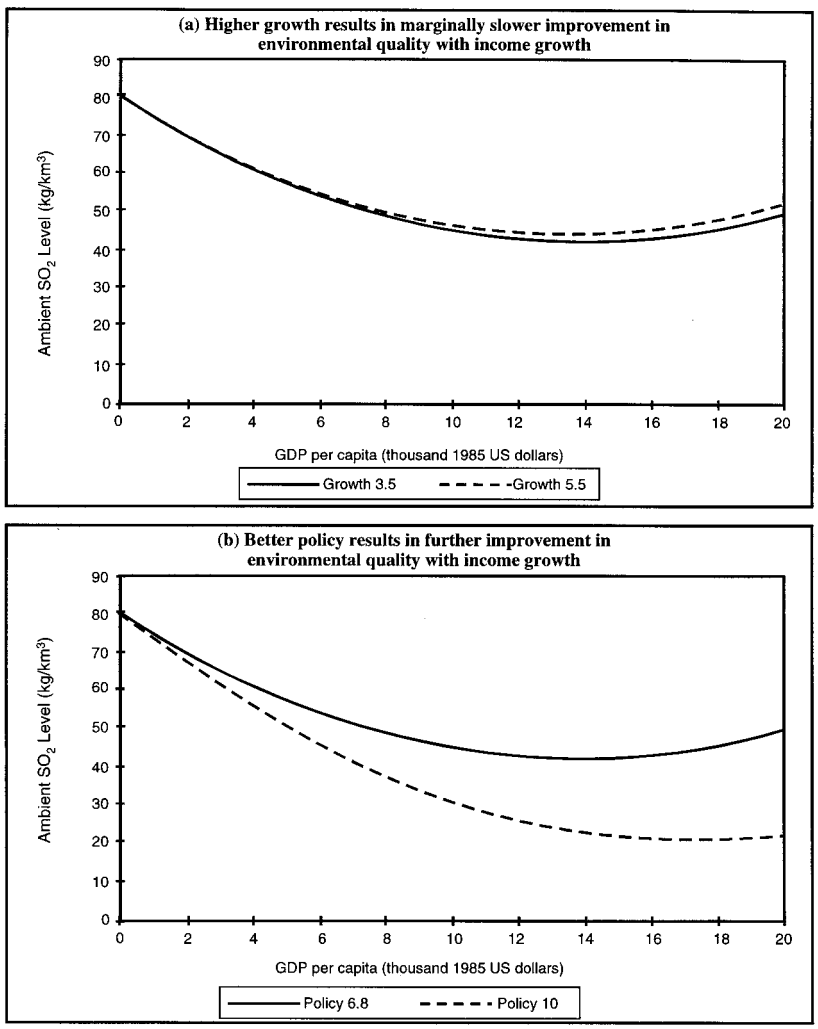


Figure 4. *Effects of higher growth rates and better policies on income-induced environmental improvement*

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improvement in the efficacy of environmental policies/institutions at income levels between US$10,000 and US$20,000 can reduce ambient SO_2 concentrations by half (Figure 4b). One would expect that improved policy would have greater impact at lower rather than higher levels of income. However, since income in the decomposition equation represents abatement effort, which takes off at higher income levels, improvement of policy institutions is likely to have much higher payoff at higher rather than lower incomes in making abatement efforts more effective in controlling ambient SO_2 levels. Furthermore, as noted earlier, higher incomes tend to be associated with improved monitoring possibilities and hence accelerate the speed of social adjustments, which in turn lowers the gap between the speed of environmental change and social change. Further work is needed to fully unravel the relationship between income-induced and autonomous environmental policies, but this would require more data on environmental policies and the efficacy of environmental institutions than we have been able to obtain thus far.

A main policy implication of this paper is that genuine environmental policy would enable a harmonization between economic growth and environmental quality. This is clearly the case for pollutants such as SO_2 that exhibit an EKC relationship. The challenge is to use the same methodology of decomposition to first uncover the reasons why EKC does not hold for certain other pollutants and then analyse the determinants and formulate policy recommendations for these other pollutants.

7. Conclusions

The reduced-form approach to the investigation of the relationship between income levels and environmental quality has been a useful first step towards answering the question of how economic growth affects the environment. This approach spared us the more difficult specification of structural equations and the more demanding data requirements of a more analytic approach, while it gave us a better understanding of the net effect of income (and by extension all that it represents) on the environment. However, without an explicit consideration of the underlying determinants of environmental quality, the scope for policy intervention is unduly circumscribed. Furthermore, the inverted U-shaped relationship that emerged between several pollutants and the environment has led in some cases to unintended and misleading interpretations that countries can grow out of their environmental problems without conscious environmental policies.

In this paper we have made a modest attempt to incorporate explicit policy considerations into the environmental Kuznets curve and to explore its determinants as a step towards both better understanding of the income–environment relationship and as a basis for conscious policy intervention. We have also explored whether the rate of economic growth, that is the speed with which higher levels of income are attained, makes a difference to the income–environment relationship. Our main finding is that the quality of policies and institutions can significantly reduce environmental degradation at low income levels and speed up improvements at higher income levels. In other words, better policies, such as more

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secure property rights and better enforcement of contracts and effective environmental regulations, can help flatten the EKC and reduce the environmental price of economic growth. Faster economic growth and higher population density (beyond a certain point) do increase moderately the environmental price of economic growth, but better policies can easily offset these effects and make economic growth more environmentally friendly and sustainable (by flattening the EKC as not to violate any ecological thresholds).

The decomposition of the EKC has revealed that those who argue that economic growth increases pollution levels are only partially right as they focus only on the scale and industrialization effects and ignore the abatement effect of higher incomes. The reverse is true of those who see economic growth as an adequate way out of environmental problems. When all effects are considered, the relationship between growth and the environment turns out to be much more complex with wide scope for active policy intervention to bring about more desirable and (in the presence of market failures) more efficient economic and environmental outcomes.

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