ECONOMIC GROWTH AND THE ENVIRONMENT

Theodore Panayotou

Harvard University and Cyprus International Institute of Management

I. Introduction

Will the world be able to sustain economic growth indefinitely without running into resource constraints or despoiling the environment beyond repair? What is the relationship between a steady increase in incomes and environmental quality? Are there trade-offs between the goals of achieving high and sustainable rates of economic growth and attaining high standards of environmental quality. For some social and physical scientists such as Georgescu-Roegen (1971), Meadows et al. (1972), growing economic activity (production and consumption) requires larger inputs of energy and material, and generates larger quantities of waste byproducts. Increased extraction of natural resources, accumulation of waste, and concentration of pollutants would overwhelm the carrying capacity of the biosphere and result in the degradation of environmental quality and a decline in human welfare, despite rising incomes (Daly 1977). Furthermore, it is argued that degradation of the resource base would eventually put economic activity itself at risk. To save the environment and even economic activity from itself, economic growth must cease and the world must make a transition to a steady-state economy.

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At the other extreme, are those who argue that the fastest road to environmental improvement is along the path of economic growth: with higher incomes comes increased demand for goods and services that are less material-intensive, as well as demand for improved environmental quality that leads to the adoption of environmental protection measures. As Beckerman (1992) puts it, "The strong correlation between incomes, and the extent to which environmental protection measures are adopted, demonstrates that in the longer run, the surest way to improve your environment is to become rich," (quoted by Rothman 1998, pp. 178). Some went as far as claiming that environmental regulation, by reducing economic growth, may actually reduce environmental quality (Barlett 1994).

Yet, others (e.g., Shafik and Bandyopadhyay (1992), Panayotou (1993), Grossman and Krueger (1993) and Selden and Song (1994)) have hypothesized that the relationship between economic growth and environmental quality, whether positive or negative, is not fixed along a country's development path; indeed it may change sign from positive to negative as a country reaches a level of income at which people demand and afford more efficient infrastructure and a cleaner environment. The implied inverted-U relationship between environmental degradation and economic growth came to be known as the "Environmental Kuznets Curve," by analogy with the income-inequality relationship postulated by Kuznets (1965, 1966). At low levels of development, both the quantity and the intensity of environmental degradation are limited to the impacts of subsistence economic activity on the resource base and to limited quantities of biodegradable wastes. As agriculture and resource extraction intensify and industrialization takes off, both resource depletion and waste generation accelerate. At higher levels of development, structural change towards information-based industries and services, more efficient technologies, and increased demand for environmental quality result in leveling-off and a steady decline of environmental degradation (Panayotou 1993), as seen in the Figure 1 below:

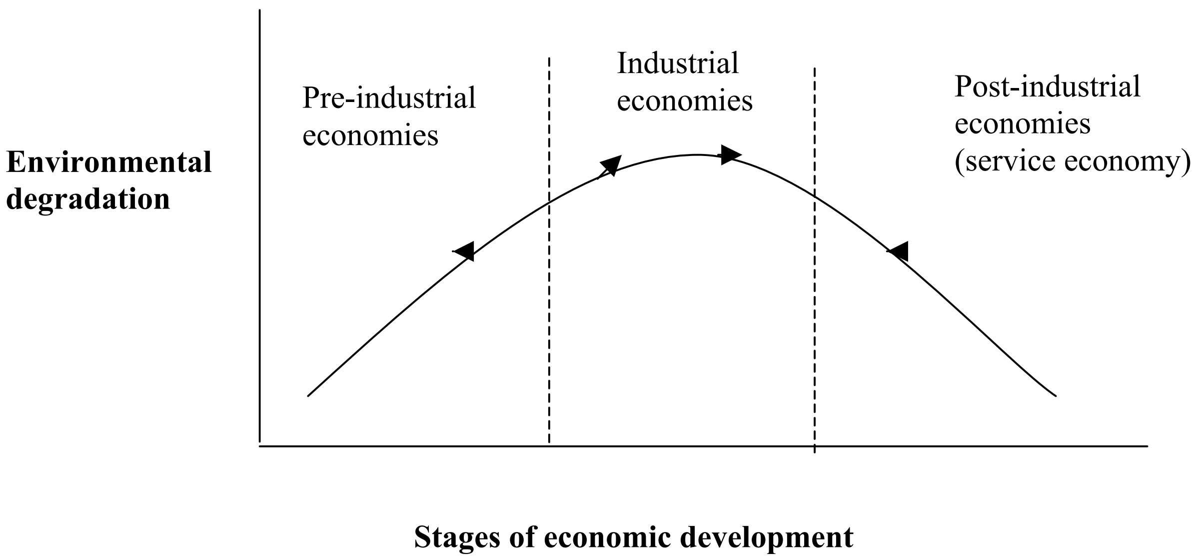


Figure 1: The Environmental Kuznets Curve: a development-environment relationship

The issue of whether environmental degradation (a) increases monotonically, (b) decreases monotonically, or (c) first increases and then declines along a country's development path, has critical implications for policy. A monotonic increase of environmental degradation with economic growth calls for strict environmental regulations and even limits on economic growth to ensure a sustainable scale of economic activity within the ecological life-support system (Arrow et al. 1995) A monotonic decrease of environmental degradation along a country's development path suggests that policies that accelerate economic growth lead also to rapid environmental improvements and no explicit environmental policies are needed; indeed, they may be counterproductive if they slow down economic growth and thereby delay environmental improvement.

Finally, if the Environmental Kuznets Curve hypothesis is supported by evidence, development policies have the potential of being environmentally benign over the long run, (at high incomes), but they are also capable of significant environmental damage in the short-to-medium run (at low-to-medium-level incomes). In this case, several issues arise: (1) at what level of per capita income is the turning point? (2) How much damage would have taken place, and how can they be avoided? (3) Would any ecological thresholds be violated and irreversible damages take place before environmental degradation turns down, and how can they be avoided? (4) Is environmental improvement at higher income levels automatic, or does it require conscious institutional and policy reforms? and (5) how to accelerate the development process so that developing economies and economies in transition can experience the same improved economic and environmental conditions enjoyed by developed market economies?

The objective of this paper is to examine the empirical relationship between economic growth and the environment in different stages of economic development and explore how economic growth might be decoupled from environmental pressures. Particular attention is paid to the role of structural change, technological change and economic and environmental policies in the process of decoupling and the reconciliation of economic and environmental objectives. We then examine the experience of the ECE region in fostering environmentally friendly growth. Whether and how it has been possible to decouple economic growth from environmental pressures in the ECE region. What has been the role of structural change, technological change and policy instruments in this decoupling for the two major groups of countries that constitute the ECE region, the developed market economies and the economies in transition.

II. Empirical Models of Environment and Growth

The environment-growth debate in the empirical literature has centered on the following five questions. First, does the often-hypothesized inverted-U shaped relationship between income and environmental degradation, known as the Environmental Kuznets Curve actually exist, and how robust and general is it? Second, what is the role other factors, such as population growth, income distribution, international trade and time-and-space-dependent (rather than income-dependent) variables? Third, how relevant is a statistical relationship estimated from cross-country or panel data to an individual country's environmental trajectory and to the likely path of present day developing countries and transition economies. Fourth, what are the implications of ecological thresholds and irreversible damages for the inverted-U shaped relationship between environmental degradation and economic growth? Can a static statistical relationship be interpreted in terms of carrying capacity, ecosystem resilience and sustainability? Finally, what is the role of environmental policy both in explaining the shape of the income-environment relationship, and in lowering the environmental price of economic growth and ensuring more sustainable outcomes?

Empirical models of environment and growth consist usually of reduced form single-equation specifications relating an environmental impact indicator to a measure of income per capita. Some models use emissions of a particular pollutant (e.g. SO_2, CO_2, or particulates) as dependent variables while others use ambient concentrations of various pollutants as recorded by monitoring stations; yet other studies employ composite indexes of environmental degradation. The common independent variable of most models is income per capita, but some studies use income data converted into purchasing power parity (PPP) while others use incomes at market exchange rates. Different studies control for different variables, such as population density, openness to trade, income distribution, geographical and institutional variables. The functional specification is usually quadratic; log quadratic or cubic in income and environmental degradation. They are estimated econometrically using cross-section or panel data and many test for country and time fixed effects. The ad hoc specifications and reduced form of these models turns them into a "black box" that shrouds the underlying determinants of environmental quality and circumscribes their usefulness in policy formulation. There have been some recent efforts to study the theoretical underpinnings of the environment-income relationship and some modest attempts to decompose the income-environment relationship into its constituent scale, composition and abatement effects. However, as Stern (1998) has concluded, there has been no explicit empirical testing of the theoretical models and still we do not have a rigorous and systematic decomposition analysis.

We proceed with an overview of the theoretical microfoundations of the empirical models, followed by a survey of studies whose primary purpose is to estimate the income-environment relationship. We then survey attempts at decomposition analysis followed by studies that are focusing on mediating or conditioning variables such international trade as well as on ecological and sustainability considerations and issues of political economy and policy.

Finally, we review the experience of the ECE region in terms of the growth and environment relationship and efforts to decouple the two.

III Theoretical Underpinnings of Empirical Models

The characteristics of production and abatement technology, and of preferences and their evolution with income growth, underlie the shape of the income-environment relationship. Some authors focus on production technology shifts brought about by structural changes accompanying economic growth (Grossman and Krueger 1993, Panayotou 1993). Others have emphasized the characteristics of abatement technology (Selden and Song 1995, Andreoni and Levinson 1998. And yet others have focused on the properties of preferences and especially the income elasticity for environmental quality (McConnell 1997, Kriström and Rivera 1995, Antle and Heidebrink 1995). A few authors have formulated complete growth models with plausible assumptions about the properties of both technology and preferences from which they derive Environmental Kuznets Curves (Lopez 1994, Selden and Song 1995). In this section, we will briefly review the main theoretical strands of the KC literature.

The model by Lopez (1994) consists of two production sectors, with weak separability between pollution and other factors of production (labor and capital), constant returns to scale and technical change and prices that are exogenously determined. When producers free ride on the environment or pay fixed pollution prices, growth results inescapably in higher pollution levels. When producers pay the full marginal social cost of pollution they generate, the pollution-income relationship depends on the properties of technology and of preferences. With homothetic preferences pollution levels still increase monotonically with income but with non-homothetic preferences, the faster the marginal utility declines with consumption levels and the higher the elasticity of substitution between pollution and other inputs, the less pollution will increase with output growth. Empirically plausible values for these two parameters result in an inverted-U-shaped relationship between pollution and income. This tends to explain why in the case of pollutants such as SO_2 and particulates, where the damage is more evident to consumers and, hence, pollution prices are near their marginal social costs, turning points have been obtained at relatively low-income levels. In contrast, turning points are found at much higher income levels, or not at all for pollutants such as CO_2, from which damage is less immediate and less evident to the consumers, and hence under priced, if priced at all.

Selden and Song (1995), using Forster's (1973) growth and pollution model with utility function that is additively separable between consumption and pollution derive an inverted-U path for pollution and a J-curve for abatement that starts when a given capital stock is achieved; i.e. expenditure on pollution abatement is zero until "development has created enough consumption and enough environmental damage to merit expenditures on abatement" (Selden and Song 1995 p. 164). Two sets of factors contribute to early and rapid increase in abatement: (a) on the technology side, large direct effects of growth on pollution and high marginal effectiveness of abatement, and (b) on the demand side, (preferences) rapidly declining marginal utility of consumption and rapidly rising marginal concern over mounting pollution levels. To the extent that development reduces the carrying capacity of the environment, the abatement effort must increase at an increasing rate to offset the effects of growth on pollution.

A number of empirical EKC models have emphasized the role of the income elasticity of demand for environmental quality as the theoretical underpinning of inverted-U shaped relationship between pollution and income (Beckerman 1992, Antle and Heiderbrink 1995, Chadhuri and Pfaf 1996). Arrow et al. (1995) state that because the inverted-U shaped curve "is consistent with the notion that people spent proportionately more on environmental quality as their income rises, economists have conjectured that the curve applies to environmental quality generally" (p. 520). A number of earlier studies (Boercherding and Deaton 1972), Bergstrom and Goodman 1973, and Walters 1975) found income elasticities for environmental improvements greater than one. Kriström (1995) reviewed evidence from CVM studies (Lombrer et al. 1991 and Carson et al. 1994) that found income elasticities for environmental quality much less than one. Does the finding of a low-income elasticity of demand for environmental quality present a problem for EKC models?

McConnell (1997) examines the role of the income elasticity of demand for environmental quality in EKC models by adapting a static model of an infinitely lived household in which pollution is generated by consumption and reduced by abatement. He finds that the higher the income elasticity of demand for environmental quality, the slower the growth of pollution when positive, and the faster the decline when negative, but there is no special role assigned to income elasticity equal or greater to one. In fact, pollution can decline even with zero or negative income elasticity of demand, as when preferences are non-additive or pollution reduces output (e.g. reduced labor productivity due to health damages, material damage due to acid rain deposition or loss of crop output due to agricultural externalities). He concludes that preferences consistent with a positive income elasticity of demand for environmental quality, while helpful, are neither necessary nor sufficient for an inverted-U shaped relationship between pollution and income. McConnell found little microeconomic evidence in non-valuation studies that supports a major role for responsiveness of preferences to income changes in macroeconomic EKC models.

Kriström (1998, 2000) interpreting the EKC as an equilibrium relationship in which technology and preference parameters determine its exact shape, proposed a simple model consisting of: (a) a utility function of a representative consumer increasing in consumption and decreasing in pollution; and (b) a production function with pollution and technology parameters as inputs. Technological progress is assumed to be exogenous. He interprets the EKC as an expansion path resulting from maximizing welfare subject to a technology constraint at each point in time; along the optimal path the marginal willingness to pay (MWTP) for environmental quality equals its marginal supply costs (in terms of forgone output). Along the expansion path the marginal utility of consumption, which is initially high, declines and the marginal disutility of pollution (MWTP for environmental quality) is initially low and rises. Technological progress makes possible more production at each level of environmental quality, which creates both substitution and income effects. The substitution effect is positive for both consumption and pollution. The substitution effect dominates at low-income levels and the income effect dominates at high-income levels producing an inverted-U shaped relationship between pollution and income. Of course, the exact shape of the relationship and the turning point, if any, depend on the interplay of the technology and preference parameters, which differ among pollutants and circumstances.

In overlapping generation models by John and Pecchenino (1994,1995), John et al. (1995) and Jones and Mannelli (1995) pollution is generated by consumption activities and is only partially internalized as the current generation considers the impact of pollution on its own welfare but not on the welfare of future generations. In these models, the economy is characterized by declining environmental quality when consumption levels are low, but given sufficient returns to environmental maintenance, environmental quality recovers and may even improve absolutely with economic growth.

Andreoni and Levinson (1998) derived inverted-U shaped pollution-income curves from a simple model with two commodities, one good and one bad, which are bundled together. Income increases result in increased consumption of the good, which generates more of the bad. This presents consumers with a trade-off: by sacrificing some consumption of the good they can spend some of their income on abatement to reduce the ill effects of the bad. When increasing returns characterize the abatement technology, high-income individuals (or countries), giving rise to an optimal pollution-income path that is inverted-U shaped. The abatement technology is characterized by increasing returns when it requires lumpy investment or when the lower marginal cost technology required large fixed costs (e.g. scrubbers or treatment plants); poor economies are not large enough or polluted enough to obtain a worthwhile return on such investments and end up using low fixed cost, high marginal-cost technologies, while rich economies are large enough and polluted enough to make effective use of high fixed-cost, low marginal-cost technologies. Different pollutants have different abatement technologies and correspondingly the income environment relationship may or may not be inverted-U shaped. The authors argue that similar results are obtained from other "good-bad" combinations e.g. driving a vehicle associated with mortality risk which can be abated by investments in safety equipment: "both the poor who drive very little and the rich, who invest in safe cars face lower risk from driving than middle-income people". Indeed, empirically, Khan (1998) found such an inverted-U shaped relationship between hydrocarbon emissions and household income in California, and Chaudhuri and Pfaf (1998) between indoor pollution and household income in Pakistan.

IV. The Basic Environmental Kuznets Curve

The 1990s have seen the advent of the Environmental Kuznets Curve (EKC) hypothesis and an explosion of studies that tested it for a variety of pollutants. In this section, we review the basic EKC studies that focus on the income-environment relationship; in subsequent sections we review studies that focus on mediating or conditioning variables. Appendix Table 1 Summarize the empirical studies of the EKC hypothesis and their findings and Appendix Figure 1 depicts these findings in a diagrammatic form. The first set of empirical EKC studies appeared independently in three working papers by: Grossman and Krueger (1991), in an NBER working paper as part of a study of the likely environmental impacts of NAFTA; by Shafik and Bandyobadhyay (1992) for the World Bank's 1992 World Development Report; and by Panayotou (1992) in a Development Discussion Paper as part of a study for the International Labor Office. It is reassuring that these early studies found turning points for several pollutants (SO_2, NO_x, and SPM) in a similar income range of $3,000 - $5,000 per capita.

Grossman and Krueger (1993, 1994) estimated EKCs for SO_2, dark matter (smoke) and suspended particles using GEMS (Global Environmental Monitoring System) data for 52 cities in 32 counties during the period 1977-88, and in per capita

GDP data in purchasing power parity (PPP) terms. For SO_2 and dark matter, they found turning points at $4,000-$5,000 per capita; suspended particles continually declined at even low-income levels. However, at income levels over $10,000-$15,000 all three pollutants began to increase again, a finding which may be an artifact of the cubic equation used in the estimation and the limited number of observations at high-income levels.

Shafik and Bandyopadhyay (1992) estimated EKCs for 10 different indicators for environmental degradation, including lack of clean water and sanitation, deforestation, municipal waste, and sulfur oxides and carbon emissions. Their sample includes observations for up to 149 countries during 1960-90 and their functional specification log-linear, log quadratic and logarithmic cubic polynomial functional forms. They found that lack of clean water and sanitation declined uniformly with increasing incomes and over time; water pollution, municipal waste and carbon emissions increase; and deforestation is independent of income levels. In contrast, air pollutants conform to the EKC hypothesis with turning points at income levels between $300 and $4000. Panayotou (1992, 1993, and 1995), using cross section data and a translog specification found similar results for these pollutants, with turning points at income levels ranging from $3000 to $5000. (The lower figures are due to the use of official exchange rates rather than PPP rates).

Panayotou also found that deforestation also conforms to the EKC hypothesis, with a turning point around $800 per capita; controlling for income deforestation is significantly greater in tropical, and in densely populated countries. Cropper and Griffiths (1994), on the other hand, using panel data for 64 countries over a 30-year period, obtained a turning point for deforestation in Africa and Latin America between $4700 and $5400 (In PPP terms). These turning points are a multiple of those found by Panayotou and by Shafik and Bandyopadhyay's studies, a possible consequence of Cropper and Griffith's use of panel data. A study by Antle and Heidebrink (1995), which used cross-section data, found turning points of $1,200 (1985 prices) for national parks and $2,000 for afforestation. On the other hand, Bhattari and Hammig (2000), who used panel data on deforestation for 21 countries in Latin America, found EKC with a turning point of $6,800. Furthermore, while earlier studies have controlled for institutional factors, such as the level of indebtedness, and found them to have the expected signs, negative and positive respectively (Bhattarai and Hammig 2000).

Returning to urban environmental quality, the mid-1990s have seen a large number of studies focusing on airborne pollutants, Selden and Song (1994) estimated EKCs for SO_2, No_x, and SPM and CO using longitudinal data on emissions in mostly developed countries. They found turning points of $8,700 for SO_2, $11,200 for No_x, $10,300 for SPM, and $5,600 for CO. These are much higher levels than Grossman and Krueger's, a discrepancy that which authors explain in terms of reduction of emissions lagging behind reduction in ambient concentrations. However, this reasoning does not explain the large difference of their results from those of Panayotou, who also uses emissions data; the use of longitudinal data versus cross-section may help explain part of the difference. Cole et al. (1997) estimated income-environment relationships for many environmental indicators, including total energy use, transport emissions of SO_2, SPM and NO_2, nitrates in water, traffic volumes, CFC emissions and methane. They found inverted-U shaped curves only for local air pollutants and CFCs and concluded that "meaningful EKCs exist only for local air pollutants, while indicators with a more global, more indirect, environmental impact either increase with income or else have high turning points with large standard errors" (p.441). This conclusion would lead one to expect that CO_2, the global pollutant *par excellance*, would increase monotonically with income, at least within any observable income range since the impacts of global warming are (totally) externalized to other countries and future generations. Indeed, earlier studies (e.g. Shafik and Bandopadhyay 1992) obtained such a result. Holtz-Eakin and Selden (1995) estimated EKCs for CO_2 using panel data, and found that CO_2 emissions per capita do not begin to decline until income per capita reaches $35,000, a result that confirms earlier findings by Shafik (1994).

However, more recent studies, using better data and more sophisticated estimation techniques, have obtained turning points for CO_2 emissions, while higher than those of local pollutants, still within the range of observable income levels. Schmalnesee et al. (1998) using a spline regression with ten piece-wise segments and the Holtz-Eakin and Selden data, have obtained an inverted-U shaped relationship between CO_2 emissions and income per capita in PPP$ (1985). They found negative CO_2 emission elasticities with respect to income per capita at the lowest and highest income splines, and a turning point in the range of $10, 000 to $17,000 per capita. Galeotti and Lanza (1999a,b) have tested alternative functional specifications for the CO_2-income relationship, including Gamma and Weibrill functions as well as quadratic and cubic functions. They found turning points between $15,000 and $22,000 depending on the specification and sample.

Another recent study by Panayotou, Sachs, and Peterson (1999), using a ten segment piece-wise spline function and panel data for 150 countries during 1960-92, have found results quite similar to those of Schmalensee et al. The income elasticity of emissions was low at the lowest income spline, and rose to a maximum at around $11,500 per capita (turning point) and turned negative at incomes of about $17,500. Finding an inverted-U shaped relationship for an invisible pollutant with much delayed effects and ample scope for a fee-riding behavior, is a bit puzzling but fully explainable by structural changes accompanying economic growth: from agriculture, to industry, to services, three sectors with different carbon emissions intensities.

V. Decomposition of the Income-Environment Relationship

The income-environment relationship specified and tested in much of the literature is a reduced form function that aims to capture the "net effect" of income on the environment. Income is used as an omnibus variable representing a variety of underlying influences, whose separate effects are obscured. For this reason, some authors termed the reduced form specification as a "black box" that hides more than it reveals; "without explicit consideration of the underlying determinants of environmental quality, the scope of policy intervention is unduly circumscribed." (Panayotou 1997, pp. 469). In order to understand why the observed relationship exists, and how we might influence it, more analytical and structural models of the income-environment relationships are needed. As a first step, it must be recognized that the observed environmental quality is the outcome of the interplay of emissions and abatement within a location specific context, and try to identify the different effects of economic development on environmental quality transmitted through the income variables.

Panayotou (1997) and Islam, Vincent, and Panayotou (1999) identify three distinct structural forces that affect the environment: (a) the scale of economic activity, (b) the composition or structure of economic activity and (c) the effect of income on the demand and supply of pollution abatement efforts. They name the respective effects on the environment: the scale or level effect, the structure or composition effect, and the pure income or abatement effect.

Algebraically:

$$\begin{bmatrix}\text{Ambient} \\ \text{Pollution} \\ \text{Level}\end{bmatrix} = \begin{bmatrix}\text{GDP per} \\ \text{Unit Of} \\ \text{Area}\end{bmatrix} \text{X} \begin{bmatrix}\text{Composition} \\ \text{of} \\ \text{GDP}\end{bmatrix} \text{X} \begin{bmatrix}\text{Abatement} \\ \text{Efforts}\end{bmatrix}$$

Kaufman et al. (1998) and Nguyen (1999) have identified analogous effects.

The scale effect on pollution, controlling for the other two effects, is expected to be a monotonically increasing function of income since the larger the scale of economic activity per unit of area the higher the level of pollution, all else equal. The structural change that accompanies economic growth affects environmental quality by changing the composition of economic activity toward sectors of higher or lower pollution intensity. At lower levels of income, the dominant shift is from agriculture to industry with a consequent increase of pollution intensity. At higher incomes, the dominant shift is for industry to services with a consequent decrease in pollution intensity. Hence, the changing share of industry in GDP may represent structural change. The composition effect is then likely to be a non-monotonic (inverted-U) function of GDP, i.e. as the share of industry first rises and then falls, environmental pollution will first rise and then fall with income growth, controlling for all other influences transmitted through income.

Stripped of its scale and composition effects, the income variable represents "pure" income effects on the demand and supply of environmental quality. On the demand side, at low incomes, income increases are directed towards food and shelter, and have little effect on the demand for environmental quality; while at higher income levels, income increases lead to higher demand for environmental quality since the latter is a normal (if not a superior) good. The Engel's curve for environmental quality translates into an inverted-J curve between income and environmental degradation (Selden and Song 1995); that is once the scale and composition effects of income growth are controlled for, pollution is a non-increasing function of income reflecting the non-negative elasticity for environmental quality. On the supply side, higher incomes make available the resources needed for increased private and public expenditures on pollution abatement, and induce stricter environmental regulations that internalize pollution externalities. The income variable (stripped of its scale and composition effects) captures the locus of the equilibrium abatement levels, where demand and supply, both income-dependent, are equal. Hence, the abatement effect is expected to be a monotonically decreasing function of income. Figure 2 below depicts these three effects based on Islam, Vincent, and Panayotou (1999):

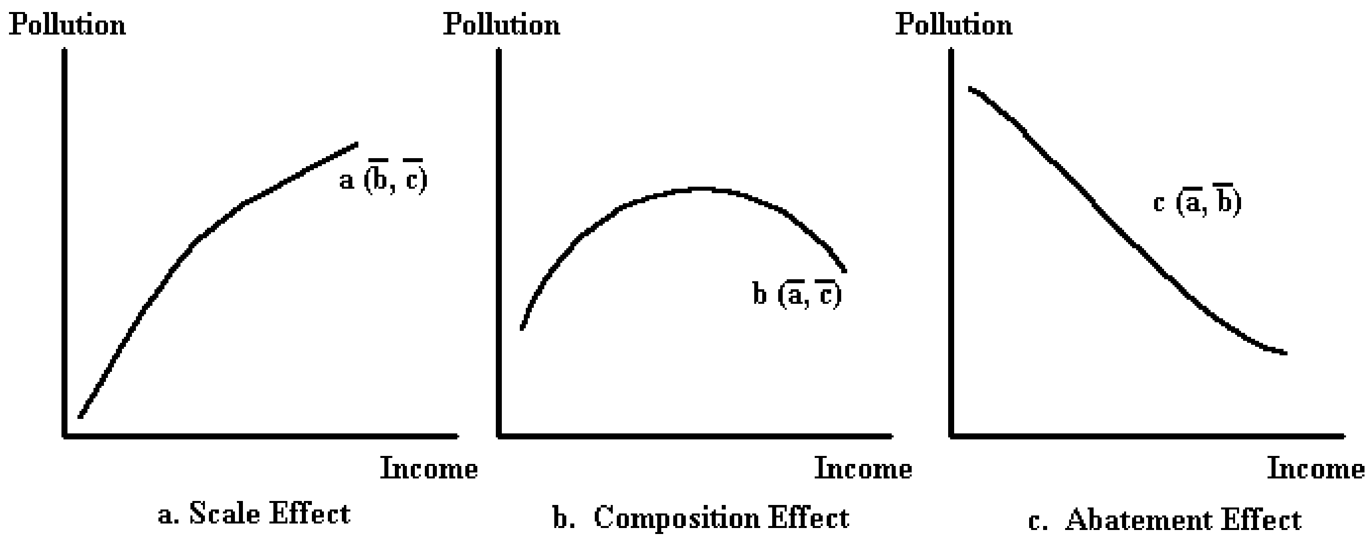


Figure 2. Decomposition of Income Effects on the Environment

Panayotou (1997) specified a cubic functional form for all decomposition effects, and included variables representing population density, economic growth rate, and a policy variable (quality of institutions). He tested the model with a panel data set for thirty countries; he used SO_2 data from GEMS and PPP-adjusted GDP figures from Summers and Heston (1991). The decomposition of the income variable into its constituent channels improved the overall fit dramatically, compared with the reduced form equation. The scale of the economy increases SO_2 concentrations monotonically, but at a diminishing rate, and it is particularly strong up to income levels of $3 million per square kilometer.

The composition effect leads to monotonically increasing SO_2 emissions with increasing industry share (from 20% to 43%) up to per capita income of $8,000; beyond this level and up to $17,000, industry share levels off and declines slightly (to 37%) with analogous effects on emissions. (A tail effect of rising industry share and SO_2 emissions at even higher income levels might be due to the very few observations of countries at this level of income). Income per capita now stripped of its scale and composition effects captures only the abatement effect on ambient emissions, which is expected to be negative, at least up to income levels of about $13,000 per capita (again a tail upturn is difficult to explain because of too few observations at the high end of income levels).

Aside from being able to explain a larger percentage of the variations of ambient emissions, what is the policy significance of such decomposition? Panayotou (1997) demonstrates how a policy variable interacts with the abatement effect of income growth to reduce ambient emissions: a 50% improvement in the efficacy of environmental policies / institutions at income levels between $10,000 and $20,000 reduces ambient SO_2 by half; at much lower income levels, the same policy change does not bring about the same improvement because the demand (and supply) for environmental quality are relatively dormant. Panayotou concludes that "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" (pp.482).

VI. International Trade

An alternative explanation for the downward sloping segment of the inverted-U shaped relationship between certain pollutants and income per capita may be found in the hypothesized propensity of countries as they get richer to spin-off pollution-intensive products to lower income countries with lower environmental standards, either through trade or direct investment in these countries. If this is true, the past is not a good predictor of the future: developing countries, as Grossman and Krueger (1995) noted, "will not always be able to find still poorer countries to serve as havens for the production of pollution-intensive goods" (p. 372). There is little evidence, however, that either the patterns of trade or the location of investment are significantly influenced by differential environmental standards among countries (see Tobey 1990, Grossman and Krueger 1993, Jaffe et al. 1995, and Panayotou and Vincent 1997). This is not to say that environmental dumping does not take place, but that it has not been significant enough to explain observed reductions of pollution in developed countries, despite continued economic growth. Hettige et al. (1992) observed that there is some evidence of "industrial displacement effect" on the dirtier industries, as a result of tightening of environmental regulations in the industrialized nations since 1970. Another contributing factor has been the "import protection" imposed by developing countries (p. 480). For example, countries with high tariffs and quota on chemicals have experienced faster growth of toxic intensity in their industrial production mix than those that followed outward oriented policies (Grossman and Krueger 1993).

International trade obscures the link between income and environment in a given country by delinking consumption from production within the country. This has let some authors to take a consumption, rather than production, approach to the income-environment relationship; income changes are seen to drive environmental degradation. Ekins (1997) argues that when consumption patterns do not shift to match shifts in production patterns, environmental effects are being displaced from one country to another, an opportunity that may not be available to today's least developed countries.

Ekins (1997) tested the EKC hypothesis using a consumption-based aggregate indicator of environmental impacts developed by the OECD to include: local and global pollutants, access to water and sanitation, imports of tropical timber, energy intensity, private road transport, water abstraction, nitrate fertilizer application, and threatened species, among others. Not surprisingly, he found no support for the EKC hypothesis; aggregation of so many dissimilar indicators into one may have eliminated any systematic co-variation with income.

Clearly, more work need to be done to fully understand the role of international trade in mediating the relationship between environment and economic growth. On the one hand, there appears to be little evidence in support of the pollution haven hypothesis; to the contrary, there is increasing evidence that open economies tend to be cleaner than closed economies. On the other hand, a growing body of ecological economics literature marshals evidence showing that, while the production patterns of developed countries may have grown cleaner over time, their consumption patterns continue to be as environmentally burdensome as ever. To resolve these issues, we need more analytical and disaggregated structural models than the standard reduced-form specifications.

VII. Thresholds, Irreversibility and the Quest for Sustainability

The finding of an Environmental Kuznets Curve or inverted-U shaped relationship between income per capita and environmental degradation exhibited by a subset of pollutants seems to suggest that countries can out-grow their environmental problems by simply emphasizing economic growth without the need for special attention to the environment itself. While the environment is certain to get worse before it gets better, it seems that channelling a country's limited resources to achieve rapid economic growth and move quickly through and out of the environmentally unfavorable stage of development makes good environmental sense, as well as good economic sense.

However, the EKC, despite its theoretic microfoundations, is ultimately an empirical relationship which as been found to exist for some pollutants but not for others. There is nothing inevitable or optimal about the shape and height of the curve. First, the downturn of EKC with higher incomes maybe delayed or advanced, weakened or strengthened by policy intervention. It is not the higher income *per se* which brings about the environmental improvement but the supply response and policy responsiveness to the growing demand for environmental quality, through enactment of environmental legislation and development of new institutions to protect the environment.

Second, since it may take decades for a low-income country to cross from the upward to the downward sloping part of the curve, the accumulated damages in the meanwhile may far exceed the present value of higher future growth, and a cleaner environment, especially given the higher discount rates of capital-constraint on low-income countries. Therefore, active environmental policy to mitigate emissions and resource depletion in the earlier stages of development may be justified on purely economic grounds. In the same vein, current prevention may be more cost effective than a future cure, even in present value terms; for example, safe disposal of hazardous waste as it is generated may be far less costly than future clean ups of scattered hazardous waste sites.

Third, the height of the EKC reflects the environmental price of economic growth: the steeper its upward section, the more environmental damage the country suffers for each increment in its income per capita. While this depends in part on income level (stages of development), the efficiency of markets and policies largely determines the height of the EKC curve. Where markets are riddled with failures (externalities, ill-defined property rights, etc.), or distorted with subsidies of environmentally destructive inputs, outputs, and processes, the environmental price of economic growth is likely to be significantly higher than otherwise. Economic inefficiency and unnecessary environmental degradation are two consequences of market and policy failures that are embodied to different degrees in empirically estimated EKCs. Perhaps more importantly, the higher the EKC, the more likely that critical ecological thresholds are crossed and irreversible changes taken place (Panayotou 1993). For example, tropical deforestation, the loss of biological diversity, extinction of species and destruction of fragile ecosystems and unique natural sites are either physically irreversible or prohibitively costly to reverse. Similarly, the economic and social consequences of damage to mental development and learning capacity from high lead levels in the blood of school-age children (due to lead emissions) are not easy to reverse, and certainly they are not reversed by switching to unleaded gasoline at later stages of development.

Panayotou (1993, 1995) argued that, while an inverted-U shaped relationship between environmental degradation and income per capita is an empirical reality for many pollutants and an inevitable result of structural and behavioral changes accompanying economic growth, it is not necessarily optimal: "In the presence of ecological thresholds that might be crossed irreversibly, and of complementarities between environmental protection and economic growth, a deep EK-Curve (implying high rates of resource depletion and pollution per unit of incremental GDP per capita) is neither economically nor environmentally optimal, because more of both could be obtainable with the same resources, if better managed." (Panayotou 1995, pp.30). In order to reduce the environmental price of economic growth and lower the EKC below ecological thresholds, as seen in Figure 4, the author recommends removal of environmentally harmful subsidies (e.g. on energy and transport), better-defined and enforced property rights, full cost pricing of resources to reflect growing scarcities, and internalization of environmental costs (e.g. through pollution taxes and tradable permits).

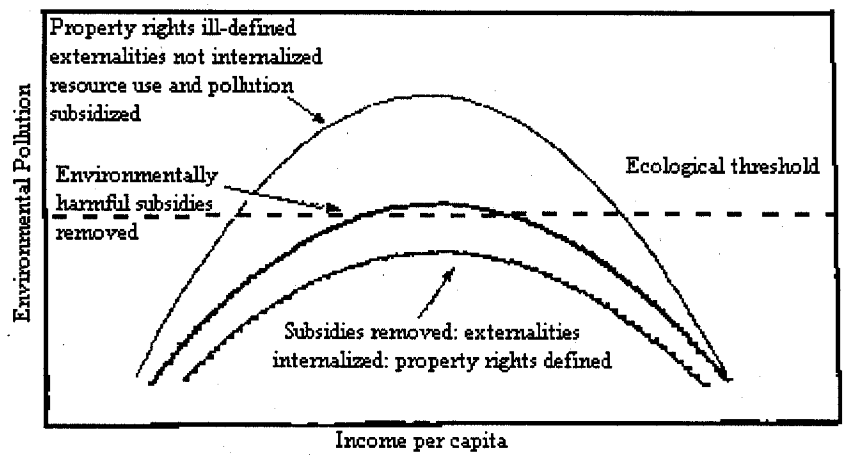


Figure 4. The income-environment relationship under different policy and institutional scenarios; the environmental Kuznets curve is flattened out by removing environmentally harmful subsidies, internalizing externalities and ensuring a clear definition of and enforcement of property rights over natural resources. (Source: Panayotou, 1993, 1995, 1997)

Munasighe (1995) is concerned that structural adjustment policies and other economy-wide reforms aimed to accelerate economic growth in poor countries might produce environmental impacts that violate safe ecological limits. He recommends adjustment of the timing and sequencing of policy reforms and complementary measures to address specific distortions and "tunnel through" the EKC while cautioning against the temptation of making major changes in economy-wide policies merely to achieve minor environmental (and social) gains" (p.124).

Arrow et al. (1995) called attention to the ever-expanding scale of economic activity, as a result of economic growth, against the finite limits of the carrying capacity of the planet, while recognizing that these limits are neither fixed nor static. In the absence of endogenously (within the economic system) generated signals of increasing scarcity (e.g. rising environmental resource prices), economic activity may expand at a pace and scale that overwhelms the much-more-slowly expanding carrying capacity of the planet resulting in irreversible damage to the productivity of the resource base, and unsustainability of economic growth itself. Sustainability of economic activity may also be undermined by the loss of ecosystem resilience that results from growth-driven reduction in diversity of organisms and heterogeneity of ecosystems. Discontinuous changes in ecosystem functions, irreversible loss of future options, new uncertainties, and increased vulnerability to natural disasters are a few avenues through which reduced ecosystem resilience may impair economic sustainability.

Arrow et al. (1995) argue for abetter understanding of ecosystem dynamics, and recommend reforms to improve the signals received by economic agents, including better-defined property rights and institutions that "provide the right incentives for protecting the resilience of ecological systems" (p.521). However, given the inherent uncertainties and discontinuities, they also counsel use of precaution to maintain diversity and resilience of ecosystems.

The EKC relationship being unidirectional and without feedbacks from the environment to the economy does not address sustainability concerns, which would involve long lags and require a dynamic model with reciprocal causality. Moreover, as de Bruyn et al. (1998) pointed out "the outcomes of statistical analysis cannot be interpreted in terms of ecosystems resilience or carrying capacity" (p. 173). They make a modest attempt to introduce dynamics by formulating a growth model based on "intensity-of-use" analysis, which they estimate for CO_2, NO_x, and SO_2 in the Netherlands, the UK, USA, and West Germany. They find that the time patterns of emissions correlate with economic growth and attribute any reductions in emissions to structural and technological change. They then define "sustainable growth" as the rate of economic growth that leads to zero growth in emissions, i.e. any increase in emissions due to scale expansion is offset completely by structural change and technical progress.

Sustainable growth rates were calculated for each pollutant for the 4 countries (see Table 1). With few exceptions, these rates are significantly lower than the 3% annual growth rate for developed countries and 5% for developing countries that the Brundland Report (WCED 1987) considered sustainable.

Table 1

Sustainable growth rates using income levels of 1990

Country	CO_2 (%)	NO_x (%)	SO_2
Netherlands	1.8	2.1	11.2
UK	1.8	1.2	2.4
USA	0.3	2.6	3.8
West Germany	2.9	4.5	5.2

Source: de Bruyn et al.. 1998

VIII. Political Economy and Policy

Despite a general recognition that the empirical relationship between environmental degradation and income is neither net of policy effects nor immune to policy intervention, very few researchers attempted to include policy variables into either reduced-form or structural models. This is probably due to the lack of data on policy variables in general and environmental policy in particular. For example, Panayotou (1997), in one of the very few studies that attempted to incorporate policy variables, used as proxies the quality of institutions to represent environmental policies. He experimented with a set of five indicators of the quality of institutions in general: respect/enforcement of contracts, efficiency of bureaucracy, the rule of law, the extent of government corruption and the risk of appropriation obtained from Knack and Keefer (1995). Enforcement of contracts and a composite index of all five variables worked best. It was found that improvements in the quality of institutions (policies) by 10% resulted in reduction of SO_2 emissions by 15%. Having found a much smaller emissions elasticity with respect to the role of economic growth and the density of population, the author argues that the efforts of pro-environment reforms should focus on improving the quality of institutions and policies rather than attempting to slow down economic or population growth. Indeed, Panayotou found that improvements in policy institutions are likely to have higher payoffs at higher incomes, which also tend to be associated with improved monitoring possibilities.

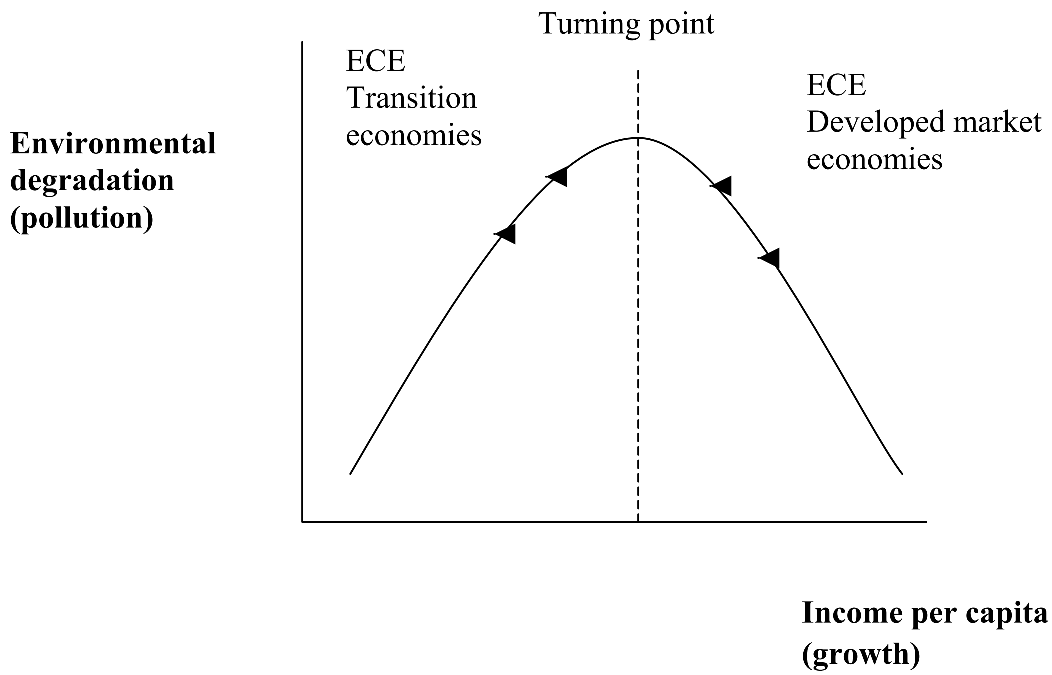
Nguyen (1999) found similar results for improvements in institutional capacity for controlling CO_2 emissions in France, Japan, Korea, Thailand, the United States, and Vietnam. Bhattarai and Hamigg (2000), using indicators of socio-political institutions from the Freedom House and from Knack and Keefer (1995), found that the quality of government institutions has statistically significant negative effects on deforestation, especially in developing countries with publicly managed forests. Strengthening of property rights institutions, such as tenure security and enforcement of contracts was also found to reduce deforestation pressures, all else equal.

While the study of the role of policy in mediating the environment-growth relationship is still in its infancy, the question arises as to what determines environmental policy itself. If it is not simply income-dependent but at least in part exogenous, what explains the difference in environmental policies of countries at similar levels of economic development? Torras and Boyce (1996) examine how various indicators of democracy affect the formation of preferences and mediate between individual preferences and public policy. They show, for example, that when democracy variables are included, income loses some of its significance in explaining variations in emissions.

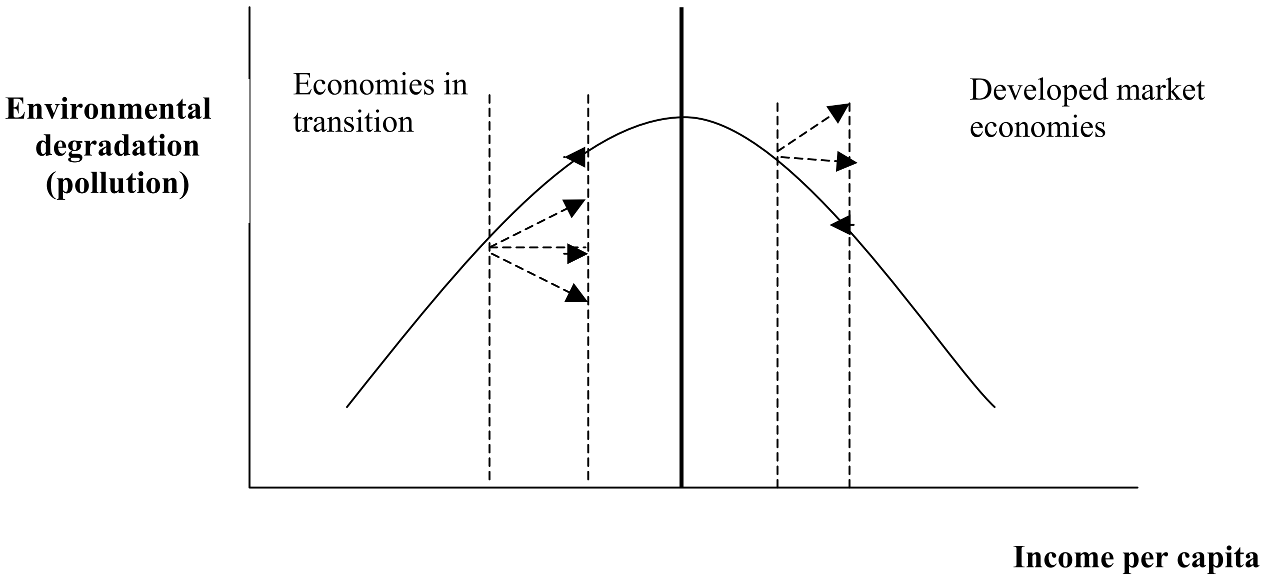
Deacon (1999) showed that the income-environment relationship varies across political systems and environmental quality tends to be lower in non-democratic regimes. Since only the elite-specific costs and benefits are usually considered in setting policies in such regimes, one would expect under investment in environmental quality and other public goods characterized by non-excludability of benefits. Deacon finds strong empirical evidence for his hypothesis in public investments in roads, public education, access to safe water and sanitation, and unleaded gasoline in a cross-section of 118 countries. Controlling for differences in income (undemocratic countries tend to be poorer) Deacon found statistically significant differences in the provision of public goods and environmental protection between the most democratic regime and each of the other regimes in 56 out of 65 cases, consistent with his hypothesis. Military and police expenditures is the major exception among public goods, as they tend to be higher in dictatorial regimes, apparently because they are viewed as conferring protection to the privileges of the elite. While Deacon's results are preliminary, they do suggest that political systems and political economy have autonomous influence on environmental quality, or at any rate mediate the income-environment relationship. The recent trends towards democratization should have beneficial effects on environmental quality (through a more complete accounting of benefits from public goods), as well as on economic growth, through introduction of the rule of law and more secure property rights, factors that may also benefit the environment.

IX. The ECE Region

The ECE region consists of 55 member countries evenly divided between developed market economies and economies in transition. In terms of level of development as represented by income per capita (an admittedly crude indicator) ECE countries range from very poor central Asian countries such as Tajikistan with per capita incomes under US$1000 to very wealthy countries in Europe and North America with incomes in excess of US$30,000. In general transitional countries have incomes below US$10,000 and developed market economies above US$15,000. It can thus be said that economies in transition find themselves to the left of the turning point of the Environmental Kuznets Curve (EKC), that is on the rising segment of the curve where growth comes at the price of increased environmental damage. In contrast, developed market economies find themselves to the right of the turning point and hence on the falling segment of the EKC.



However, it is also possible for low-income countries to experience environmental improvement along the path of economic growth if they succeed to decouple environmental pollution and resource use from economic growth. This could be done through structured change, technological change or policy change, or combination of all three. The systemic change that formerly planned economies are undergoing involves a process of decoupling as previously unpriced or mispriced resources are brought into the domain of markets, but such decoupling is only temporary. Sustained decoupling can only take place with full-cost pricing that is inclusive of environmental externalities. In a manner quite analogous, developed market economies often re-couple environment and growth through environmentally harmful subsidies for sectors such as energy and transport.



The above caveat notwithstanding developing and transitional economies are bound to pay a higher environmental price for economic growth, than developed economies if for no other reason because a) their rate of population growth is generally higher since their demographic transition is not yet complete and b) their rate of economic growth tends to be higher because they are in the process of convergence (catching up with more advanced countries). The process of convergence does involve significant technological and structural changes. However, the decoupling effect of these changes may be offset by scale of effects, unless it is reinforced by conscious and aggressive environmental policies. The demand for such policies, however, tends to be income elastic and thus in low-income ECE countries such demand is likely to be limited. Hence, some form of exogenous inducement (e.g. aid form developed ECE countries) may be necessary to induce faster decoupling of income growth and environment in low-income countries.

A similar dichotomy between ECE economies in transition and ECE developed market economies exists with regard to technological change. While developed economies are adapting emerging technologies, that contribute to decoupling of economic growth from pressures on the environment and natural resources, transition economies are still catching up with environment-intensive technologies of the past which dominate the transport, energy and industry sector and cause many environmental problems. Again, in the same way that developed ECE counties can help reinforce the slow shift of consumer's preference in transitional ECE countries away from environment-intensive products and towards more environmental protection, they can also help accelerate their transition to the new environment –friendly technologies such as renewable energy and transport. Ultimately however, the extent to which more efficient technologies will be adapted depends on the relative prices between different sources of energy, types of fuels and modes of transport, which are determined by markets and governments policies.

X. The State of Growth and Environment in the Region

In the last decade, the developed market economies of the ECE region have experienced significant growth in CDP per capita and in industrial production accompanied by structural changes and a shift from energy and material intensive industry to services, leading to a reduction of emissions and energy intensity per unit of GDP by more than 25% in the past 20 years. The economies in transition are beginning to recover from the economic collapse of the 1990's and to grow again but at varying rates. Despite improvements in energy efficiency and levels energy consumption per capita lower than the developed market economies, their energy intensities of GDP is three to four times higher due to the large share of heavy industry and obsolete technology.

Environmental pressures form increasing consumption are expected to intensify in the coming years despite the shift from heavy industry to services and the reduction of energy and material intensity of consumer goods. The consumption patterns of economies in transition are expected to follow the same path as they have in the developed market economies. Technology cooperation can tap an existing large potential for the introduction of cleaner technology and less damaging production.

Energy efficiency improvement in developed market economies in the ECE region are being offset by the growth of demand for energy which is satisfied mostly by polluting fossil fuels and only to a small extent by renewable sources. Economies in transition on the other hand have huge potential for reducing energy intensity and increasing energy efficiency. Restructuring of industrial production could improve energy efficiency, reduce pollution and gradually replace obsolete technology. Technology transfer from advanced market economies can play a key role in this regard.

Transport in ECE developed market economies is characterized by increasing congestion and car-related pollution and an environmentally harmful shift from rail and other public transport to car and air travel. Low road transport prices and inefficient public transport systems discourage behavioural changes towards more sustainable modes and patterns of transport. In ECE economies in transition the earlier scarcity of private cars and the reliance on public transport is being increasingly replaced by growing use of cars (many of which are older and more polluting) at the expense of a cleaner rail and less-energy intensive public transport system.

XI. Policy Response

In the OECD countries we observe a strong decoupling of emissions of local air pollutants from economic growth. OECD countries have achieved a strong decoupling between energy use and economic growth over the past 20 years, with the economy growing by 17% between 1980 and 1998 and energy use falling by the about the same percentage. Water and resource use continued to grow but at a rate slower than GDP growth reflecting a weak decoupling of the two. Thus decoupling of emissions in OECD and generally the developed ECE countries has been accomplished through a combination of technological change and a strong environmental policy. The latter consisting of "greening" of fiscal policy, removing subsidies to environmentally harmful activities and the use of economic instruments to internalise environmental cost.

A number of EU policy initiatives, such as the Broad Economic Policy Guidelines 2001, among others have promoted a gradual but steady and credible change in the level and structure of the tax rates until external costs are fully reflected in prices, to cope with most of the fundamental structural problem in all developed countries, the unsustainable patterns of production and consumption. In the energy markets these guidelines aim to uses taxes and other market-based instruments to rebalance prices in favour of reusable energy sources and technologies. Other EU initiatives in this direction are the European Climate Change Programme (ECCP), the directive establishing an EU framework for emissions trading, and the Integrated Product Policy (IPP) all of which aim at realigning price relations and stimulating investments in new technologies that promote sustainable development. Member states are encouraged to improve market functioning by addressing market failures such as externalities through "increased use of market-based systems in pursuit of environmental objectives as they provide flexibility to industry to reduce pollution in a cost effective way, as well as encourage technological innovations". Economic instruments such as gradual but steady and credible change in the level and structure of tax rates until external costs are fully reflected in prices are promoted as the most efficient means of decoupling economic growth from pollution, as they alter price relations and thereby also drive changes in technology and consumer behaviour (preference) that lie behind the growth-environment relationship. As exemplified by the energy and transport sectors, the EU decoupling policy consists of demand management through full-cost pricing and development of more environmentally friendly alternatives by promoting technological innovations.

Since 1990 all economies in transition have made efforts to restructure their energy and transport sectors along market principles and to raise energy prices closer to economic and international levels. However because of the political sensitivity of energy pricing and the lagging reforms in many transition economies a gap of 20-85% continues to persist between energy prices in economies in transition. For example electricity prices for households in Eastern Europe are only 50 percent of those of the European Union; for industrial consumers, electricity prices are closer to their economic and international levels being 20% lower than those of the EU. The United Nations Economic Commission for Europe has repeatedly called upon its members to raise the prices of various energy sources to their full economic costs and adapt economic instruments to internalise the costs to human health and the environment associated with energy production and consumption. The aim is to decouple emissions from energy use and energy use from economic growth.

Conclusion

The ECE Region includes most of the most developed market economies in the world and most of the economies in transition. These two groups of countries are at different stages and levels of development and economic-environmental policy integration, yet both groups have, for different reasons, experienced a degree of decoupling of environment and growth. The decoupling in the developed market economies has been the result of structural change towards a service economy, of technological change towards less material-and energy-intensive production, and the adoption of new economic and environmental policies e.g. green fiscal reform, environmental change and permits and commercial and central regulations) to internalise environmental externalities. In the economies in transition, decoupling has been largely the result of industrial restructuring and market reforms to bring prices of energy, material and other resource inputs closer to their economic and international costs.

Despite significant progress towards sustainable development developed countries are still experiencing unsustainable consumption patterns as evidenced by the continued growth of municipal waste and CO^2 emissions. As transition economies begin to recover and grow again their emissions and resource use are also growing though less than proportionately. Their GDP energy-intensity, though declining, continues to be several times that of the developed countries while their consumption patterns are tracing the same path as that of their developed counterparts. Further decoupling of growth and environment and progress towards sustainable development calls for action on many fronts by both groups of countries as well as cooperation between them especially in technology transfer:

a. Use of an effective mix of economic instruments such as taxes, charges and tradable permits to correct market and policy failures and to internalise environmental and social costs and induce changes in the composition of consumption and production.

b. Improvement in resource use efficiency and "dematerialization" of the economy

c. Change in the content of economies growth and this involves adjustments costs which tend to be greater the faster is the rate of change in relative prices; in particular those who lose need to be compensated by those who benefit

d. Introduction of specific policies to preserve the living standards of those directly affected by the required adjustment and to avoid unemployment and social disruption; issues of inequality and social exclusion must be addressed.

e. Education for sustainable development to encourage industrial and collective responsibility and thereby induce behaviorable changes

f. Strengthening democracy and the citizens rights so that there is free expression of preferences and civil society can play a full and active role in the formulation of policies which can induce changes in consumption and production patterns.

The experience of the developed market economies of the ECE region holds valuable lessons for the East European and Central Asian economies in transition. First, the transition from a trade-off to a complementary relationship between economic growth and environmental quality is both a long process and one that requires active policy interventions in terms of a.) integration of economic and environmental policies (e.g. greening of fiscal policy), b.) the phasing out of environmentally harmful subsidies and the introduction of policy instruments for the internalisation of environmental costs. Second, the battle that can be won on the production side through structural change and technological progress can be lost on the consumption side through wasteful and unsustainable consumption patterns that do not yield to behaviorable changes that are slow to come about when environmental damage is remote in space or time as in the case of climate change. Third, industrial restructuring and market pricing are no guarantees for decoupling of economic growth from environmental pressures; in the presence of environmental externalities the pricing in sectors such as energy and transport (but also agriculture and industry) should go beyond economic and international costs to account for social costs that have been traditionally left outside the scope of markets and international trade. Last, while command and control regulations have been quite effective in decoupling environment and growth and bringing about significant improvements in environmental quality in the developed market economies of the ECE region, this has been accomplished at an unnecessarily high cost in terms of both the inflexibility of response and the slowness of adjustment to change as well as the lack of incentives for innovation and for going beyond compliance. As the more recent experience of OECD countries demonstrates, coupling command and control regulations with a healthy dose of economic instruments is a more cost-effective and flexible means to decouple economic growth from environmental pressures and pursue sustainable development.

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Appendix
Table 1. A Summary of Empirical Studies of the Environmental Kuznets Curve (EKC) Hypothesis.

Author and explanatory indicator	*Dependent Variable*	*Relation Shape*	*Turning Point (GDP/per)*	*Remarks*
I	*II*	*III*	*IV*	*V*
Shafik & Bandyopadhyay (1992) GDP/per US$ 1985 ppp	Lack of clean water Lack of urban sanitation Level of particulate matters, Sulfur oxides(SO2) Changes in forest area Annual rate of deforestation Dissolved oxygen in rivers Municipal waste per capita Carbon emissions per capita	Linear downward Linear downward Quadratic Quadratic U-inverted Quadratic Quadratic U-inverted Quadratic Quadratic Quadratic U-inverted	Decline monotonically Decline monotonically na 3000 na 2000 na na 4000	Sample includes 149 countries for the period 1960-1990
Hettige, Lucas &Wheeler (1992) GDP/per US$ 1985	Toxic Intensity by GDP Toxic Intensity by par industrial output	Quadratic U-inverted Quadratic	12790 na	Global; Toxic intensity of 80 countries; Logarithm
Holtz-Eakin & Selden (1992) GDP/per US$ 1985	CO2	Quadratic U-inverted Cubic N-normal	35400 28010	Global; Emissions per Capita
Panayotou (1993) GDP/per US$ 1985	SO2 NOx PES Deforestation rate	Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted	3000 5500 4500 1200	Global; Emissions per Capita Deforestation
Grossman and Krueger. (1993) GDP/per US$ 1985 ppp	SO2 SPM Smoke	Cubic N-normal Cubic N-normal Cubic N-normal	a) 4107 b)14000 Decreasing a) 5000 b) 10000	Global; Data of GEMS Urban concentration of pollutants
Shafik (1994) GDP/per US$ 1985 ppp Time series	Lack of safe water Lack of urban sanitation Annual deforestation Total deforestation Dissolved oxygen in rivers Fecal coliform in rivers Ambient SPM Ambient SO2 Municipal waste per capita Carbon emission per capita	Linear downward Linear downward Quadratic U-inverted Quadratic U-inverted Linear downward Cubic N-normal Quadratic U-inverted Quadratic U-inverted Linear upward Linear upward	na na na a) 1375 b)11500 3280 3670 na na	Global; Data of the World Bank (WDR 1992, environ-mental data appendix) Linear, quadratic et cubic logarithm are tested

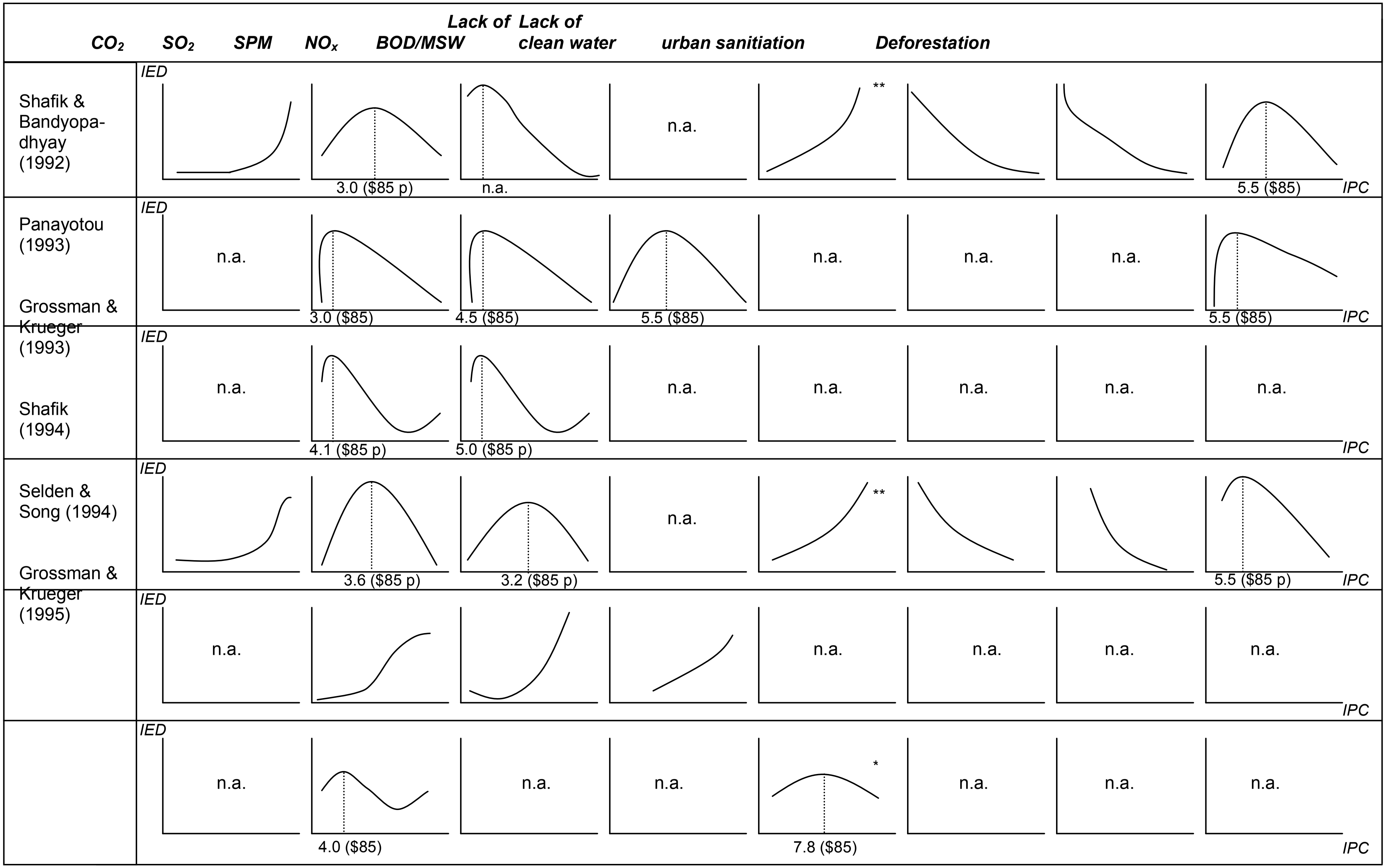
Selden and Song (1994) GDP/per US$ 1985 Population density	Estimation by random effect: - SO2 - SPM - Nox - CO Estimation by fixed effect: - SO2 - SPM - Nox - CO	 Cubic N-normal Cubic N-normal Cubic N-normal Cubic N-normal Cubic N-normal Cubic N-normal Cubic N-normal Cubic N-normal	 10700 9600 21800 19100 8900 9800 12000 6200	Global Data from WRI 1991 30 countries in the sample
Cropper and Griffiths (1994) GDP/per US$ 1985 Wood price Density of rural population	Deforestation rate	Quadratic, Africa, U-inverted L. America, U-inverted Asia, na	 4760 5420 na	Regional: 64 countries in the sample Deforestation observed during 1961-1991 Data from FAO
Kazuki (1995) GDP/per. Yen 70	Deforestation SO2 NOx	Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted	446 $70 1295 $70 1587 $70	Japan; Annual concentration in ppm; Yen is converted to Dollar
Antle and Heidebrink (1995) GDP/per US$ 1985	Total area of parks and protected areas (PARKS) Deforestation (DEFOR) Afforestation (AFFOR), Total forest area (FOR)	Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted	U-shape pattern U-shape pattern U-shape pattern	Data from World Development Report 1987, Environmental Data report and from the World Resource 1990-91
Grossman and Krueger (1995) GDP/per US$ 1985 et Mean GDP/ per	Sulfur dioxide (SO2) Smoke Heavy particles Dissolved oxygen Biological oxygen demand (BOD) Chemical oxygen demand (COD) Concentration of nitrates Fecal coliform Total coliform Concentration of lead Cadmium Arsenic Mercury Nickel	Cubic N-normal Cubic N-normal Cubic N-normal Cubic N-normal Cubic N-normal Cubic N-normal Cubic N-normal Cubic N-normal Cubic N-normal Cubic N-normal Cubic N-normal Cubic N-normal Cubic N-normal Cubic N-normal	a)4053 b)14000 6151 Decreasing 2703(*) 7623 7853 10524 7955 3043 1887 11632 4900 5047 4113	Global; Data are from GEMS Pollutant concentration in cities and rivers
Rock (1996) GDP US$ 1985	Heavy metals	Quadratic U-inverted	10800	Emissions of heavy metals
Panayotou (1997) GDP/per US$ 1985 ppp Population density; Industrial share; GDP growth; Policy	SO2	Cubic N-normal	a) 5000 b) 15000	The sample includes 30 developed and developing country for the period 1982-94
Roberts and Grimes (1997) GDP/per US$ 1987	CO2	Quadratic U-inverted	na	Data come from World Bank and from the Carbon Dioxide Information and Analysis Center (CDIAC)
Schmalensee, Stoker and Judson. (1997)	CO2	Log –linear	10000	National level panel data set for 47 countries from 1950 to 1990

GDP/per US$ 1985 ppp				
Cole, Rayner and Bates (1997)	Nitrogen oxides (NOx) Sulfur dioxide (SO2 SPM CO NOx of transport sector SO2 of transport sector SPM of transport sector Nitrates Carbon dioxide (CO2) Energy consumption CFCs and halons Methane (NH4) Municipal waste Transport energy use Traffic volume	Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted	15100 (14700) ** 5700 (6900) 8100 (7300) 10100 (9900) 15100 (17600) 9400 (9800) 15000 (18000) 15600 (25000) 25100 (62700) 22500 (34700) 15400 (12600) na na 400000 (4 mill.) 108200 (65300)	Cross-country/region data from OECD countries.
Vincent J. (1997) GDP/per RM78 Population density	SPM Biochemical oxygen demand (BOD) Chemical oxygen demand (COD) Ammoniac nitrogen pH Solid particles in rivers	Cubic N-inverted Cubic N-inverted Cubic N-inverted Cubic, na Cubic, na Cubic, na	na (increasing) na (decreasing) na (increasing) na (no form) na (no form) na (no form)	Malaysia Use the data set with observations from the late 1970's into the early 1990's.
Hettige, Mani and Wheeler (1997)	Industrial Water Pollution	Linear upward	na	Factor level-data on industrial water pollution from twelve countries
Carson , Jeon and McCubbin (1997) GDP/per US$ 1982	Greenhouse gases, Air toxics,90 Carbon monoxide Nitrogen oxides Sulfur dioxide Volatile organic carbon Particulate matter Air toxics,88-94	Linear downward Linear downward Linear downward Linear downward Linear downward Linear downward Linear downward Linear downward	Decreasing Decreasing Decreasing Decreasing Decreasing Decreasing Decreasing Decreasing	Data come from the 50 US states
Moomaw and Unruh (1997) GDP/per US$ 1985	CO2 (panel) CO2 (for each country)	Cubic N-normal Linear downward	12813 18333 na	Data are from the Oak Ridge National Laboratory and from the Penn World Tables
Komen, Gerking & Folmer (1997) GDP/per US$ 1991	PRD	Linear upward	na	19 countries of OECD
Ravallion, Heil and Jalan (1997) GDP/per US$ 1985 ppp	Carbon Emissions	Cubic N-normal	U-shape pattern	Data are from the Oak Ridge National Laboratory and from UN statistical division
Torras and Boyce (1998) GDP/per US$ 1985 ppp	SO2 Smoke Heavy particles Dissolved Oxygen Fecal coliform Access to safe water Access to sanitation	Cubic N-normal Cubic N-normal Cubic N-normal Cubic N-normal Cubic N-normal Cubic N-normal Cubic N-normal	3890 4350 Decreasing Increasing Increasing 11255 10957	Data cover the period 1977-1991 and are taken from GEMS
Unruh and Moomaw (1998) GDP/per US$ 1985 ppp	Carbon dioxide (CO2) emissions	Cubic N-normal	na	Data is obtained from Summers and Heston (1994), for 16 countries
Suri and Chapman (1998) GDP/per US$ 1985 ppp	Consumption of primary commercial energy per capita,	Quadratic U-inverted	55000	Data consist of observations on 33 countries over the period 1971-1990.

	expressed in terms of oil equivalents			Data are from IEA
Bruyn, Bergh and Opschoor (1998) Economic growth rate	CO2 NOx SO2	Linear logarithm Linear logarithm Linear logarithm	na na na	Data from the Netherlands, Western Germany, the UK and the USA, For various time intervals between 1960 and 1993
Rothman (1998) GDP/per US$ 1985 ppp	Food, beverages and tobacco Garment and footwear Gross rent, fuel and power Medical care and services Other commodities	Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted	12889 35263 23278 47171	Data from United Nation International Comparison Programme
Kaufman, Davidsdottir, Garnham and Pauly (1998) GDP/per US$ 1985	SO2 (cross-section) SO2 (fixed effects) SO2 (random effects)	Quadratic U-inverted Quadratic U-inverted Quadratic U-inverted	11577 12500 12175	Data are from UN Statistical Yearbook 1993. Panel of international data for 23 countries
Chaudhuri and Pfaff (1998)	Indoor air pollution	Quadratic U-inverted	na	The micro data come from the Pakistan Integrated Household Survey (PIHS) 1991
Kahn (1998)	Vehicle hydrocarbon emissions	Quadratic U-inverted	35000	Data from the Random Roadside Test, created by the California Department of Consumer Affairs Bureau of Automotive Repairs
Islam, Vincent and Panayotou (1999)	Suspended particulate matter (SPM)	Quadratic U-inverted	na	GEMS data on suspended particulate matter. The data contain 901 observations from 23 countries for the period 1977-88
Panayotou, Sachs & Peterson (1999) GDP/per US$ 1985 ppp	Carbon dioxide (CO)	Quadratic U-inverted	12000	The study combined time series and cross-section national level data to construct a panel with 3,869 observations for the period 1960-92
Galeotti and Lanza (1999)	Carbon dioxide (CO2)	Quadratic U-inverted	13260	New data set developed by IEA that covers the period between 1960-1995
Bhattarai & Hammig (2000) GDP/per US$ 1998 ppp	Deforestation	Quadratic U-inverted	6800	Data from FAO, WRI and the UNEP for 1980, 1990 and 1995. National Income, exchange rates and trade data are taken from the Penn World Tables, from Summers and Heston (1991).

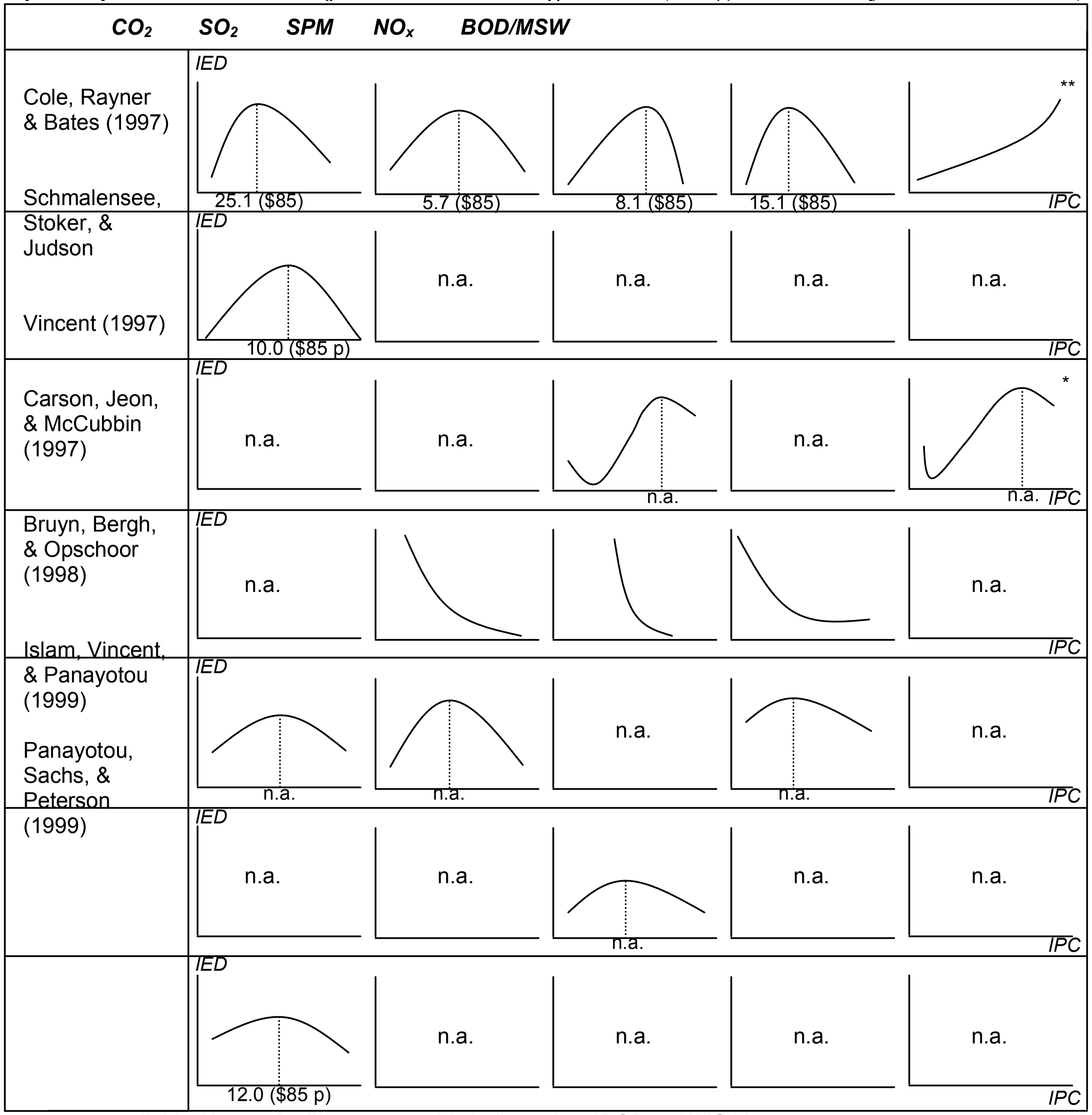
Appendix

Figure 1. ***Empirical Relationship Between Income per Capita (IPC) and Selected Indicators of Environmental Degradation (IED), Estimated by Selected Studies***



n.a. = not available (the study did not cover this indicator) *BOD **MSW

Figure 1. (cont.) ***Empirical Relationship Between Income per Capita (IPC) and Selected Indicators of Environmental Degradation (IED), Estimated by Selected Studies (1)***



n.a. = not available (the study did not cover this indicator) *BOD **MSW

Notes:

CO_2 = Carbon Dioxide
SO_2 = Sulfure Dioxide
SPM = Suspended Particulate Matter
NO_x = Nitrogen Oxides
BOD = Biochemical Oxygen Demand
MSW = Municipal Solid Waste

Turning Points:
First two digits mean thousands, ei 7.6
($85) = GDP/per capita in US $ of 1995
($85 p) = GDP/per capita given in PPP based on US $ of 1985

(1)
The studies in this page did not cover “Lack of clean water,” “Lack of urban sanitation,” and “Deforestation.”