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## **The Environmental Kuznets Curve: a Survey of the Literature**

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### **SUMMARY**

In the last few years, several studies have found an inverted-U relationship between per capita income and environmental degradation. This relationship, known as the environmental Kuznets curve (EKC), suggests that environmental degradation increases in the early stages of growth, but it eventually decreases as income exceeds a threshold level. The present paper reviews both early and recent contributions on this subject, discussing whether and to what extent such a curve can be empirically observed, and the policy implications that derive from the empirical evidence.

Keywords: environmental Kuznets curve, growth, pollution

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## NON TECHNICAL SUMMARY

In the last decade, there have been many attempts to evaluate the impact of economic growth on environmental quality. In the absence of a single criterion of environmental quality, various indicators of environmental degradation have been used in the literature for this purpose. Several of these indicators show an inverted-U relationship with income: environmental degradation gets worse in the early stages of growth, but eventually reaches a peak and starts declining as income exceeds a certain level. This relationship has been defined as the Environmental Kuznets Curve (EKC) after Simon Kuznets who first observed a similar relationship between income and inequality.

The present paper provides a critical survey of early and more recent contributions in this area to address the following questions: (i) Which environmental indicators follow an EKC pattern? (ii) When an EKC does apply, at what income level does environmental degradation start declining? (iii) To what extent can we rely on existing results to draw implications for policy makers?

Evidence of the existence of the EKC is far from clear-cut. Only some air quality indicators show a strong (but not overwhelming) evidence of an EKC. However, even when an EKC is empirically observed, there is still no agreement in the literature on the income level at which environmental degradation starts decreasing. Moreover, some recent contributions have questioned the existence of the EKC even for those indicators that seem to follow this pattern. In fact, given the lack of long time-series of environmental data, most studies have used a cross-country approach. However, this approach might be misleading since environmental degradation is generally increasing in developing countries and decreasing in industrialized ones. Therefore, EKC may merely reflect the juxtaposition of two opposite trends, rather than describe the evolution followed by a single economy over time. In fact, single-country studies that have examined the environment-income relationship over time find no evidence of an EKC.

This result, together with the existence of data problems and limitations in econometric techniques, casts serious doubts on the evidence in favor of the EKC. Therefore, policy makers should not take the alleged shape of the curve to conclude that environmental degradation will automatically fall in the long run as income becomes sufficiently high.

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## **I. Introduction**

The relationship between economic growth and environmental quality has been the object of a large debate in the economic literature for many years. This debate goes back to the controversy on the limits to growth at the end of the 1960s. At one extreme, environmentalists as well as the economists of the Club of Rome (Meadows et al. 1972) argued that the finiteness of environmental resources would prevent economic growth from continuing forever and urged a zero-growth or steady-state economy to avoid dramatic ecological scenarios in the future. At the other extreme, some economists (e.g. Beckerman 1992) claimed that technological progress and the substitutability of natural with man-made capital would reduce the dependence on natural resources and allow an everlasting growth path.

As Shafik (1994) has pointed out, in the past this debate lacked empirical evidence to support one argument or the other, remaining on a purely theoretical basis for a long time. This was mainly due to a lack of available environmental data for many years. However, it also reflected the difficulty of defining how to measure environmental quality. In the absence of a single criterion of environmental quality, several indicators of environmental degradation have been used to measure the impact of economic growth on the environment. However, different indicators yield different empirical results. The World Development Report (1992) was one of the first studies to emphasize this issue. As shown in the Report (World Bank, 1992, Figure 4 p. 11), some indicators of environmental degradation (e.g. carbon dioxide emissions and municipal solid wastes) increase with income, which implies that they worsen with economic growth. Other indicators (such as the lack of safe water and urban sanitation) fall as income rises, indicating that - in these cases - growth can improve environmental quality. Finally, many indicators (e.g. sulfur dioxide and nitrous oxide emissions) show an inverted-U relationship with income, so that environmental degradation gets worse in the early stages of growth, but eventually reaches a peak and starts declining as income passes a threshold level (see Figure 1). This inverted-U relationship has been defined as the Environmental Kuznets Curve (henceforth

EKC) after Simon Kuznets, as it resembles the shape of the relationship that the Nobel Prize economist first observed between income distribution and economic growth.<sup>2</sup>

The object of the present paper is to provide a critical survey of the literature on the growth-environment relationship, focusing on the impact of growth on environmental quality. To the best of my knowledge, no one has yet attempted to give an overview of the many contributions that exist in this area, taking both early and recent studies into account.<sup>3</sup> In particular, the current review intends to determine **whether and to what extent an EKC is empirically observed**. In addition, attention will be focused on the policy implications of the empirical evidence. The main conclusion from the analysis of the literature is that the evidence on the environment-income relationship is not yet clear-cut and several methodological pitfalls cast doubts on the results that have been presented so far. Policy makers should therefore avoid simplistic recommendations based on current evidence. More specifically, the possibility that environmental degradation may eventually fall as income grows (as suggested by the alleged decreasing portion of the EKC) does not necessarily mean that growth will automatically solve the problems it causes in the early stages of development. Much work remains to be done to get a deeper understanding of the environment-income relationship. In this regard, the present paper emphasizes the drawbacks of the cross-country studies that have been mainly used so far and the need to adopt a single-country approach, as suggested in some recent studies.

The structure of the paper is as follows. Section II investigates the effects of growth on environmental quality to establish the theoretical underpinnings of the EKC. Section III is divided in two parts. The first examines the empirical evidence on the EKC that emerges from the cross-country studies to determine: (i) for which environmental indicators such a curve

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2 It was probably Panayotou (1993) who first coined the term ‘environmental Kuznets curve’, although several contemporaneous studies observed this “bell-shaped” relationship between growth and environmental degradation in the early 1990s (Shafik 1994, Selden and Song 1994, Grossman 1995, Grossman and Krueger 1994). Notice that one can identify several versions of the EKC since there is no universally accepted measure of environmental degradation (see section IV.D for a more detailed discussion of this aspect).

3 Previous reviews have focused either on the early studies (Pearson 1994) or on part of the later contributions (Barbier 1997). Moreover, the literature review in Pearson is organized by studies, which is made possible by the small number of works that he examines. Given the difference in the results across the environmental indices, the present survey is organized by indicator, thus providing a different perspective with respect to former essays.

exists; (ii) at what income level environmental degradation starts decreasing. The second part explores how the evidence changes when we follow the evolution of the environment-income relationship in a single country over time rather than inferring it from cross-country analyses. Section IV draws attention to limits of current studies (both cross- and single-country) that restrict the reliability of the evidence in favor of the EKC. Section V discusses the policy implications emerging from the literature on the EKC, especially for the developing countries that are now on the upward part of the alleged curve. Some concluding remarks will follow.

## II. Conceptual background of the EKC: effects of growth on the environment

As Grossman (1995) first suggested, it is possible to distinguish three main channels whereby income growth affects the quality of the environment. In the first place, growth exhibits a **scale effect** on the environment: a larger scale of economic activity leads per se to increased environmental degradation. This occurs because increasing output requires that more inputs and thus more natural resources are used up in the production process. In addition, more output also implies increased wastes and emissions as by-product of the economic activity, which contributes to worsen the environmental quality. In the second place, income growth can have a positive impact on the environment through a **composition effect**: as income grows, the structure of the economy tends to change, gradually increasing the share of cleaner activities in the Gross Domestic Product. In fact, as Panayotou (1993, p.14) has pointed out, environmental degradation tends to increase as the structure of the economy changes from rural to urban, from agricultural to industrial, but it starts falling with the second structural change from energy-intensive heavy industry to services and technology-intensive industry. Finally, technological progress often occurs with economic growth since a wealthier country can afford to spend more on research and development.<sup>4</sup> This generally leads to the substitution of obsolete and dirty

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<sup>4</sup> For instance, Komen et al. (1997) examine data on 19 OECD countries between 1980 and 1994 and show that the income elasticity of public research and development expenditures for environmental protection is approximately equal to one. Notice that technological progress can be seen as both the cause and effect of economic growth.

technologies with cleaner ones, which also improves the quality of the environment. This is known as the **technique effect** of growth on the environment.

An inverted-U relationship between environmental degradation and per capita income suggests that the negative impact on the environment of the scale effect tends to prevail in the initial stages of growth, but that it will eventually be outweighed by the positive impact of the composition and technique effects that tend to lower the emission level. The **income elasticity of environmental demand** is often invoked in the literature as the main reason to explain this process. As income grows, people achieve a higher living standard and care more for the quality of the environment they live in. The demand for a better environment as income grows induces structural changes in the economy that tend to reduce environmental degradation. On one hand, increased environmental awareness and “greener” consumer demand contribute to shift production and technologies toward more environmental-friendly activities. On the other hand, they can induce the implementation of enhanced environmental policies by the government (such as stricter ecological regulations, better enforcement of existing policies and increased environmental expenditure). This also contributes to shift the economy towards less polluting sectors and technologies. Hence, the demand for a better environment and the resulting policy response are the main theoretical underpinnings behind the decreasing path of the EKC (Grossman, 1995 p.43).<sup>5</sup>

Another argument has been advanced in the literature to explain the bell-shaped environment-income pattern. It has been suggested (World Bank 1992, Unruh and Moomaw 1998) that the existence of an endogenous **self-regulatory market mechanism** for those natural resources that are traded in markets might prevent environmental degradation from continuing to grow with

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<sup>5</sup> Many authors have claimed that the environment is a luxury good, that is, environmental demand does not simply increase as people get richer, but grows faster than income. However, two recent contributions have challenged this interpretation. McConnell (1997) has proved that the assumption that the environment is a luxury good is neither a necessary nor a sufficient condition to obtain an EKC. In fact, he shows that pollution can decrease even if the demand for environmental quality is inelastic with respect to income. In the same way, under specific conditions, pollution may increase even if the demand for the environment is very elastic. Kristrom and Riera (1996) went even further, questioning the assumption that the environment is a luxury good. They estimated the income elasticity of environmental improvements in several European countries and found that in many cases this elasticity is less than one.



income. In fact, early stages of growth are often associated with heavy exploitation of natural resources due to the relative importance of the agricultural sector. This tends to reduce the stock of natural capital over time. The consequent increase in the price of natural resources reduces their exploitation at later stages of growth as well as the environmental degradation associated with it. Moreover, higher prices of natural resources also contribute to accelerate the shift toward less resource-intensive technologies (Torras and Boyce, 1998).<sup>6</sup> Hence, not only induced policy interventions, but also market signals can explain the alleged shape of the EKC.

### **III. Empirical evidence on the environment-income relationship**

The above discussion indicates the conceptual arguments that make the EKC conceivable from a theoretical viewpoint. We now ask whether empirical evidence really supports this pattern and what indicators follow it? Given the lack of long time-series of environmental data, most empirical studies have adopted a cross-country approach to address this question. The present section examines the results and main limitations of these studies and indicates the single-country approach as an alternative method for future research.

#### **A. Cross-country studies**

All the studies on the EKC address the following common questions: (i) is there an inverted-U relationship between income and environmental degradation? (ii) If so, at what income level does environmental degradation start declining? As we shall see, both questions have ambiguous answers.

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<sup>6</sup> As Unruh and Moomaw (1998) point out, the increase in the oil price that occurred during the 1970s promoted the shift to alternative sources of electric power production.

In the absence of a single environmental indicator, the estimated shape of the environment-income relationship and its possible turning point generally depend on the index considered. In this regard, it is possible to distinguish three main categories of environmental indicators that have been used in the literature: air quality, water quality and other environmental quality indicators.

As to **air quality indicators**, there is strong, but not overwhelming evidence of an EKC. A distinction is conventionally made in the literature between local and global air pollutants (e.g. Grossman 1995, Barbier 1997).<sup>7</sup> The measures of urban and **local** air quality (sulfur dioxide, suspended particulate matters, carbon monoxide and nitrous oxides) generally show an inverted-U relationship with income. This outcome, that emerged in all early studies, seems to be confirmed by more recent works (Cole et al., 1997). However, there are major differences across indicators as to the turning point of the curve: carbon monoxide and especially nitrous oxides show much higher turning points than sulfur dioxide and suspended particulate matters (see Table 1). Moreover, there are also large differences across studies that focus on the same indicator. For instance, Selden and Song (1994) estimate a turning point for suspended particulate matters three times higher than that found by Shafik (1994). Similar large differences occur in the case of sulphur dioxide (see Table 1).<sup>8</sup>

When emissions of air pollutants have little direct impact on the population the literature generally finds no evidence of an EKC. In particular, both early and recent studies find that emissions of **global** pollutants (such as carbon dioxide (CO<sub>2</sub>)) either monotonically increase with income or start declining at income levels well beyond the observed range. Moreover, Cole et al. (1997) have recently pointed out that even in studies that find a peak (however high) in the

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<sup>7</sup> Grossman (1995) was among the first to draw the distinction between local and global air pollutants, which is often adopted also in recent contributions. However, this distinction is not clear-cut: some local pollutants (e.g. sulfur dioxide (SO<sub>2</sub>)), may travel for hundreds of miles, so they can be considered both local and global air quality indicators.

<sup>8</sup> The differences in these results can be explained by differences in the way pollution is measured as well as in sample size. For instance, Selden and Song (1994) measure the *flow* of emissions of local air quality indicators in 22 countries, whereas Shafik (1994) focus attention on the *stock* of the same indicators using a much larger

CO<sub>2</sub> curve, the alleged turning point has a very large standard error. This implies that estimates of the CO<sub>2</sub> turning point are quite unreliable, casting doubts on the possible downturn of the CO<sub>2</sub> curve.

For **water quality indicators**, empirical evidence of an EKC is even more mixed. However, when a bell-shaped curve does exist, the turning point for water pollutants is generally higher than for air pollutants. Three main categories of indicators are used as measures of water quality: (i) concentration of pathogens in the water (indirectly measured by faecal and total coliforms), (ii) amount of heavy metals and toxic chemicals discharged in the water by human activities (lead, cadmium, mercury, arsenic and nickel) and (iii) measures of deterioration of the water oxygen regime (dissolved oxygen, biological and/or chemical oxygen demand).<sup>9</sup> As Table 1 shows, there is evidence of an EKC for some indicators (especially in the latter category), but many studies reach conflicting results as to the shape and peak of the curve.<sup>10</sup> Several authors (Grossman and Krueger 1994, Shafik 1994, Grossman 1995) find evidence of an N-shaped curve for some indicators: as income grows water pollution first increases, then decreases and finally rises again (Figure 2). Thus, the inverted-U curve might correspond just to the first two portions of this more complex pattern. The existence of an N-shaped curve seems to imply that at very high income levels, the scale of the economic activity becomes so large that its negative impact on the environment cannot be counterbalanced by the positive impact of the composition and technology effects mentioned above.<sup>11</sup>

Finally, in the absence of a single definitive measure of environmental quality, many **other environmental indicators** have been used to test the EKC hypothesis. In general, for most of these indicators there seems to be little or no evidence of a Kuznets-type story. Both early and

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database (up to 149 countries).

<sup>9</sup> See Grossman (1995) for a detailed description of the environmental problems and health risks caused by each pollutant.

<sup>10</sup> Compare, for instance, the results obtained by Grossman (1995) and Grossman and Krueger (1994) with those achieved by Shafik (1994) (Table 1).

<sup>11</sup> Shafik (1994, p.765) has advanced the hypothesis that the increase in rivers pollution at high-income levels typical of an N-shaped curve might occur because "people no longer depend directly on rivers for water and

recent studies (Shafik 1994, Cole et al. 1998) find that environmental problems having direct impact on the population (such as access to urban sanitation and clean water) tend to improve steadily with growth. On the contrary, when environmental problems can be externalized (as in the case of municipal solid wastes) the curve does not even fall at high income levels. As to deforestation, the empirical evidence is controversial.<sup>12</sup> Some studies find an inverted-U curve for deforestation with the peak at relatively low income levels (e.g. Panayotou 1993), whereas others conclude that “per capita income appears to have little bearing on the rate of deforestation” (Shafik 1994, p.761). Finally, even when an EKC seems to apply (as in the case of traffic volume and energy use), the relative turning points are far beyond the observed income range.

Summing up, three main stylized facts that provide the answer to our initial questions seem to emerge from cross-country studies: (i) only some indicators (mainly air quality measures) follow an EKC; (ii) an EKC is more likely for pollutants with direct impact on the population rather than when their effects can be externalized;<sup>13</sup> (iii) in all cases in which an EKC is empirically observed, there is still no agreement in the literature on the income level at which environmental degradation starts decreasing.

### **B. From cross-country to single-country studies**

As shown above, cross-country studies suggest that the EKC may only be a valid description of the environment-income relationship for a subset of all possible indicators. However, Roberts and Grimes (1997) have recently questioned the existence of an EKC even for indicators that seem to follow this pattern. They observe that the relationship between per capita GDP and

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therefore may be less concerned about river water quality”.

<sup>12</sup> As Panayotou (1993) pointed out, the rate of deforestation is particularly important as a measure of environmental degradation for two reasons. Firstly, it can be taken as a proxy variable for the depletion of natural resources. Secondly, together with land use changes, deforestation accounts for about 17-23% of total anthropogenic carbon dioxide emissions (World Resource Institute 1996).

<sup>13</sup> This seems to reflect the existence of a free-rider problem. In fact, as Shafik (1994, p.770) argues, “where environmental problems can be externalized, there are few incentives to incur the substantial abatement costs associated.”

carbon intensity changed from linear in 1965 to an inverted-U in 1990.<sup>14</sup> How can we explain the modification in the curve shape over the last thirty years? Roberts and Grimes (1997, p.196) argue that the Kuznets-type curve that we observe for carbon intensity today is the result of environmental improvement in developed countries in these last decades and “not of individual countries passing through stages of development.” In fact, the data set shows that carbon intensity fell steadily among high income countries in the period 1965-90, but increased among middle- and low-income nations, with a marked increment in the latter group. Therefore, the EKC that emerges in the cross-section analysis “may simply reflect the juxtaposition of a positive relationship between pollution and income in developing countries with a fundamentally different, negative one in developed countries, not a single relationship that applies to both categories of countries” (Vincent 1997, p. 417). For this reason, Vincent (1997) claims that the cross-country version of the EKC is just a statistical artifact and should be abandoned. In fact, as Stern et al. (1994) have argued, “more could be learnt from examining the experiences of individual countries at varying levels of development as they develop over time.” These considerations have given rise to a new line of research based on single-country analysis. This econometric approach achieves some surprising results that cast serious doubts on the reliability of the indications emerging from cross-country studies.

Vincent (1997) examines the link between per capita income and a number of air and water pollutants in Malaysia from the late 70s to the early 90s. Two main conclusions emerge from this single-country study. First, cross-country analysis may fail to predict the income-environment relationship in single countries, as it occurs in the case of Malaysia. Second, none of the pollutants examined by Vincent shows an inverted-U relationship with income. Contrary to cross-section analysis, several measures indicate that increments in the income level may actually worsen environmental quality. It can be argued that the results achieved by Vincent hinge heavily on specific features of the country in question and cannot be extended to other countries. However, de Bruyn et al. (1998) reach similar conclusions following other individual

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<sup>14</sup> Carbon intensity is defined as carbon dioxide emissions per unit GDP. See section IV.D for discussion on the choice of the measure of environmental degradation.

countries over time. They investigate emissions of several air pollutants (sulfur dioxide, carbon dioxide and nitrous oxides) in four OECD countries (Netherlands, West Germany, UK and USA) between 1960 and 1993 and find them to be positively correlated with growth in almost every case.<sup>15</sup> However, these conclusions are questioned by Carson et al. (1997) who find the opposite result in a single-country study on the United States. Using data collected by the Environmental Protection Agency from the 50 US states, Carson et al. (1997) find that per capita emissions of air toxics decrease as per capita income increases.

In conclusion, all current single-country studies seem to suggest that **the EKC need not hold for individual countries over time**. However, different studies reach conflicting results as to the effects of growth on the environment. Therefore, further research is needed to understand the evolution of environmental degradation relative to income in a single country over time. In particular, both Vincent (1997) and Carson et al. (1997) are **cross-regional studies**, therefore they are also subject to the critiques to the cross-country approach mentioned above. In fact, cross-country studies implicitly assume that all countries will follow the same pattern in order to infer the environment-income relationship of a single country over time. As mentioned above, this assumption does not seem to be supported by empirical evidence. Similarly, in order to infer the environmental degradation of the whole country over time, cross-regional studies implicitly assume that all regions in a given nation will follow the same pattern. For some countries, however, regional differences can be very significant. Thus, the environment-income relationship may not only differ across nations, but also across regions of the same country.<sup>16</sup> Hence, although current single-country studies tend to go in the right direction, a time-series approach seems more appropriate than a cross-regional one to examine individual countries

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15 The only exception (out of the 12 cases that they observe) is sulfur dioxide emissions that decreased monotonically with per capita income in the Netherlands. In general, the growth parameter (which is taken by the authors as a measure of the size effect) is estimated to be around 1, so that – ceteris paribus – income and emissions tend to grow at the same speed. The impact of growth on emissions can be counteracted by the reduction of emissions due to technological and structural factors (i.e. the composition and technique effects mentioned above). However, the authors find that in some cases these effects turn out to be statistically insignificant, which explains why the size effect tends to prevail.

16 However, differences across regions are generally smaller than those across countries.

over time and this is the line of research that single-country analyses should develop in the future.

#### **IV. Limitations of current studies**

As many authors have underlined (e.g. Grossman and Krueger 1994), knowing the shape of the environment-income relationship could help policy makers to formulate appropriate environmental policy. However, current results do not seem completely reliable for this purpose. We already mentioned why cross-sectional studies (both cross-country and cross-region) limit the validity of the evidence at disposal. In this section, we look at some other drawbacks of the current literature that should induce to use the available results with particular caution for policy aims.

##### **A. Data problems**

The first and most obvious limitation of the studies on the EKC is the lack of good data on environmental indicators.<sup>17</sup> Even when such data is available, it appears to be unreliable in some low-income countries because of data collection problems. Moreover, the existence of definitional differences across countries raises problems of data comparability, casting serious doubts on the cross-country approach (Shafik 1994, Carson et al. 1997).

One important consequence of the lack of data is that many studies use **estimates rather than actual measures** of environmental indicators (see Table 1). Such estimates are based on rates of conversion from economic data “both of which can be unreliable, especially in developing countries” (Kaufmann et al., 1998). In some cases (e.g. carbon dioxide) the estimates are computed by applying emission coefficients to national consumption of various kinds of fuel. In other cases (e.g. sulphur dioxide and other air pollutants) they are calculated by multiplying this national consumption “by coefficients that reflect the contemporaneous abatement practices in each country” (Grossman 1995, p.24).

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<sup>17</sup> In general, environmental data is much scarcer than economic statistics. Even in OECD countries that have long time series, environmental indicators are only available from the 1970s.

Beyond **data quality and comparability**, current studies may also suffer from **sample selection bias**. In fact, monitoring stations that collect data on pollution are often situated where pollution is potentially more severe. Thus, for instance, most stations are in towns or along rivers suspected of high pollution. Therefore, the results are likely to reflect local conditions and, in some circumstances, pollution might be overestimated. On the other hand, most of the available data is from developed countries. However, a large contribution to global pollution comes from many developing countries for which data is not available. Hence, the sample selection made in cross-country studies may underestimate the level of pollution.

### **B. Reduced-form models**

Both cross- and single-country studies are based on **reduced form models**.<sup>18</sup> As de Bruyn et al. (1998) point out, these models enable economists to estimate the influence of income on environmental quality. However, they give no indication about the direction of causality, namely whether growth affects the environment or the other way around. In other words, reduced-form relationships “reflect correlation rather than a causal mechanism” (Cole et al. 1997, p.401). In reality, environmental quality is likely to have a feedback effect on income growth (Stern et al. 1994, Pearson 1994). As a matter of fact, the environment is a major factor of production in many underdeveloped countries that heavily rely on natural resources as a source of output. Therefore, environmental degradation in these countries is likely to reduce their capacity to produce and hence to grow. Moreover, several studies point out that high pollution levels may reduce worker productivity and thus economic output. Hence, a **simultaneous-equation model** may be more appropriate for understanding the environment-income relationship.<sup>19</sup>

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<sup>18</sup> As it is well known, this means that the current endogenous variable (environmental quality) is expressed only as a function of predetermined variables.

<sup>19</sup> A simultaneous-equation model is a system of equations in which environmental quality and income are both endogenous variables. To the best of my knowledge, there has only been one attempt (Dean 1996) to use this approach so far. However, Dean applies this method to investigate the impact of trade liberalization on environmental quality in developing countries, which goes beyond the scope of the present paper.



### C. Limitations of econometric techniques

Besides the problems mentioned so far, there are also other limitations to the validity of current EKC studies (both cross- and single-country). One of the main criticisms concerns the **choice of specific functional forms** to estimate the environment-income relationship. Most of the literature has examined reduced-forms in which the environmental indicator is a quadratic or cubic function of income. However, neither the quadratic nor the cubic function can be considered a realistic representation of the environment-income relationship.

As Cole et al. (1997) pointed out, a cubic function implies that environmental degradation will eventually tend to plus or minus infinity as income grows over time. Similarly, a quadratic concave function implies that environmental degradation could eventually tend to zero (or even become negative) at sufficiently high income levels, which is not supported by empirical evidence.<sup>20</sup> Another drawback of the quadratic function is that it is symmetrical, that is, the uphill portion of the curve has the same slope as the downhill part. This implies that, when income goes beyond some threshold level, environmental degradation will decrease at the same rate as it previously increased. This is also very unlikely, as many forms of environmental degradation can be extremely difficult to undo. For instance, most pollutants tend to accumulate and persist for a long time, so that they are generally much harder to mitigate than to produce. Hence, as Pearson (1994, p.212) argues, more sophisticated techniques of curve fitting should be investigated in the future so that our findings are not determined by the specific functional form chosen.

The use of unrefined econometric techniques concerns not only the choice of regression models, but also the estimation method. This is another reason suggesting a cautious attitude to the empirical evidence of some studies. For instance, most of the early studies used **Ordinary Least Square (OLS) estimations** without correcting for heteroscedasticity and autocorrelation of the residuals. However, Carson et al. (1997) point out that the variance of the error terms may differ across countries or regions.<sup>21</sup> The residuals are also likely to be autocorrelated because of

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<sup>20</sup> In fact, there is no evidence that any country has environmental degradation close to zero.

<sup>21</sup> For instance, Carson et al. (1997) find strong evidence of heteroscedasticity for air emissions across the US

common shocks (e.g. the oil shock) that affect several countries simultaneously (Unruh and Moomaw 1998). In all these cases, OLS estimates of the standard errors turn out to be biased. However, this weakness mainly concerns the early studies and has been generally corrected in recent contributions by using Generalised-Least Square (GLS) estimates.

#### **D. Choice of the scaling factor of environmental degradation**

Another problem that arises in the empirical literature is the choice of the scaling factor to be used in the regression model. While all studies agree on using per capita GDP as the independent variable on the horizontal axis, one can distinguish three main variants in the literature for the dependent variable: (i) per capita emissions, (ii) total emissions, (iii) emission intensity (i.e. per unit of GDP).

These measures can have very different implications. This is evident if we look at a potentially different shape of the EKC. As Common (1995) noted, the Kuznets-type pattern with pollution that first increases and then decreases with income is consistent with two possible cases: (a) at sufficiently high income levels, the quadratic curve falls to zero (Figure 1), (b) at sufficiently high income levels, the curve tends to a lower bound  $k$  (Figure 3).<sup>22</sup>

We have already discussed case (a). As to case (b), if the vertical axis measures total emissions the shape of the curve implies that emissions will become constant at a sufficiently high-income level  $Y^*$ . However, if we measure emission intensity on the vertical axis, the existence of a lower bound implies that total emissions will not be constant, but will grow at the same rate as income so that emissions will tend to infinity in the long run.

In addition, each version of the EKC sheds light on aspects that do not emerge in the other two variants. For instance, the scatter diagram for cross-country CO<sub>2</sub> emission intensity in 1995 (Figure 4) reveals extremely high values of this variable in former Soviet Union countries.<sup>23</sup> On

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states, the variance of the residuals being a decreasing function of income.

<sup>22</sup> Common (1995) argues that case (b) is more interesting than (a) as it avoids the unrealistic implication that pollution eventually goes to zero or becomes negative.

<sup>23</sup> This occurs because former Soviet Union countries have both high CO<sub>2</sub> emissions and low incomes. The acronyms used in Figure 4 are as follows: UKR = Ukraine, AZR = Azerbaijan, KZK = Kazakhstan, UZB =

the contrary, the pollution impact of these regions does not emerge if we look at cross-country per capita emissions of CO<sub>2</sub> in the same year (Figure 5).<sup>24</sup> In this case, the outliers are mainly the oil producing countries that have high emissions and low population levels.

In general, the correct choice of EKC version should depend on the environmental indicator considered. For instance, the EKC in terms of per capita emissions is probably more correct than the other two versions when the main source of environmental depreciation is overexploitation of natural resources caused by population growth, whereas the emission intensity version provides a deeper insight when pollution is due mainly to heavy industry.

Some studies (Shafik 1994, Kaufman et al. 1998) have proposed pollutant concentration as an alternative indicator of environmental degradation. This is probably the most appropriate indicator when one examines global pollutants since their stock contributes to global warming more than their emissions (the so-called “stock externality” problem). This casts further doubts on the evidence in favor of the EKC. In fact, a convex relationship often emerges in studies that measure concentration rather than emissions of global pollutants (Kaufman et al. 1998 for SO<sub>2</sub>, Shafik 1994 for CO<sub>2</sub>).

## **V. Policy implications**

The shape of the environment-income relationship has critical policy implications. The alleged form of the EKC has lead some authors to conclude that current environmental degradation might be only a temporary phenomenon and that it is possible to “grow out” of the environmental problems in the long run (Beckerman 1992). If so, policy-makers should promote faster growth rates to overcome the income turning point as soon as possible. However, even if we neglect the flaws of the empirical studies and accept the EKC as a stylized fact for the sake of the argument, there are several reasons to question this conclusion.

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Uzbekistan, RUS = Russia.

<sup>24</sup> The following acronyms have been used in Figure 5: LUX = Luxembourg, ARE = United Arab Emirates, BHR = Bahrain, SGP = Singapore, CHE = Switzerland.

As Panayotou (1993) has underlined, a policy that devotes most resources to growth is not necessarily an optimal one. In fact, achieving the downturn of the EKC may be a very long process that takes decades, the more so the longer one waits to intervene.<sup>25</sup> In fact, emissions and the consequent environmental degradation often tend to accumulate over time. Therefore, delaying intervention to later stages of growth may result in prohibitively high abatement costs. If so, environmental damage that is physically reversible could become economically irreversible.

In addition, the literature has largely been concerned with the income level at which the turning point occurs. However, the height of the curve may be even more important. If emissions or concentrations at the vertex of the parabola are above some threshold level, we may enter that “shadow area” where the damage is unknown and potentially irreversible (Figure 6). This implies that environmental degradation may become irreversible before we reach the top of the curve. If so, it might be impossible to exploit the decreasing path of the EKC at a future date. This possibility should not be neglected, especially because empirical evidence suggests that the EKC is not stable, but tends to shift and change in shape with time (Roberts and Grimes 1997). For all these reasons, a policy of “wait and see” based on acritical faith in the EKC may have vast negative effects on the environment in the future. On the contrary, we should intervene to “tunnel through” the curve (Munasinghe 1998), building a bridge between the upward and downward portions of the EKC, without letting environmental problems reach their peak level. As Panayotou (1993) has argued, several policies can be implemented to flatten out the curve. For instance, eliminating policy distortions (e.g. energy and agrochemical subsidies) or enforcing property rights over natural resources may both serve this purpose.<sup>26</sup>

These considerations are particularly important for developing countries currently on the upward part of the curve. There is good reason to believe that these countries may not be able to

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<sup>25</sup> Selden and Song (1994) estimate that global emissions of all air pollutants that show an EKC in the cross-section analysis will keep on growing in future decades. This is what one would expect, since countries now on the upward portion of the curve often have the fastest rates of economic and population growth. Therefore, “emissions will not return to current levels before the end of the next century unless concerted actions are taken” (Selden and Song 1994, p.161).

follow the same path as developed countries in the past. In the first place, as Unruh and Moomaw (1998, p.222) have claimed:

“...it is not certain whether ‘stages of economic growth’ is a deterministic process that all countries must pass through, or a description of the development history of a specific group of countries in the 19th and 20th centuries that may or may not be repeated in the future”.

In the second place, the environmental conditions in which the South is developing today are much different from the ones faced by the North in the past. In fact, the stock of greenhouse gases inherited by today’s developing countries is certainly higher than that met by the developed countries in the early stages of their development. As the so-called "stock externality" issue suggests, it is this stock, rather than the current flow of emissions, that contributes most to global warming and the damage that this creates. Hence, if we could measure actual environmental degradation rather than emissions on the vertical axis, the EKC of the newly developing countries might shift upward with respect to the EKC of the industrialized ones for a given income level.

Finally, Roberts and Grimes (1997) indicate another reason why the South may be unable to take the path followed by the North. Some of the environmental improvements in the North were made possible by relocating its most polluting, energy-intensive industries in the South (Hettige, Lucas and Wheeler 1992). However, the South will be unable to find in turn some other countries where these industries can be shifted in the future. Moreover, even if we transferred the least polluting and most energy-saving technologies from North to South, this might not necessarily improve the environmental quality in the latter unless other socio-economic reforms are undertaken. Quoting Roberts and Grimes (1997, p.196):

“even identical industries operating in non-wealthy countries face obstacles making them less efficient in energy and carbon terms, such as poor roads, inefficient energy sources and local shortages of well-educated high-tech workers”.

These considerations call for an international environmental policy that is different from the one recently developed in the Kyoto agreements. The North now has the whole burden of

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26 See Panayotou (1993) for a thorough discussion of these environmental policies.

cutting emissions, while the South has been left free to pollute. This policy reflects the belief (partially nourished by a misinterpretation of the EKC) that the developing countries first need to grow which will automatically lead them to address their environmental problems in the future. However, increasing pollution in the developing countries may have adverse effects on developed nations. As a matter of fact, issues such as global warming affect all countries irrespectively of the nation where emissions occur: one unit of pollutant contributes equally to the greenhouse effect wherever it is emitted. Therefore, if negative externalities from the South to the North are strong enough, the curve of the environmental damage due to pollution could rise again in the wealthiest countries.

As stated by Roberts and Grimes (1997), sustainability should be addressed at all levels of development if we are to avoid this risk. This does not mean introducing the North's high environmental standard also in the South from the beginning, but ensuring that environmental interventions accompany the financing policies of the development assistance agencies in the South. This is particularly important if we do not want developing countries to simply mimic the past experience of industrialized nations, but rather to learn from it.

## **VI. Conclusions**

In the last few years, there has been renewed interest in the relationship between income growth and environmental quality. A remarkable number of new contributions have investigated this relationship empirically, correcting for some of the drawbacks of early studies. Despite the use of more sophisticated econometric techniques, there is still no clear-cut evidence to support the existence of the EKC. As shown by this review of the empirical evidence, for most environmental indicators there is no agreement among different studies on the shape of the environment-income relationship. The lack of consensus concerns not only the turning point of the EKC, but also its very existence. Moreover, even when an inverted-U relationship does appear, it might be an artificial result of the cross-country approach. This approach seems inadequate to predict the future evolution of the environment-income relationship: industrialized countries may have moved along an inverted-U pattern in the past, but this does

not imply that developing countries will or should follow the same pattern today. Therefore, future research should use time-series analysis to determine the pollution trajectories of each country over time, improving on the lines indicated by recent single-country studies. This is particularly important for developing countries, many of which are in tropical areas where the fauna and flora have generally low resilience. A misdirected growth policy based on acritical faith in the EKC could have large and potentially irreversible effects in these nations, ruling out the possibility to run along the decreasing part of the curve in the future.

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ENVIRONMENTAL DEGRADATION

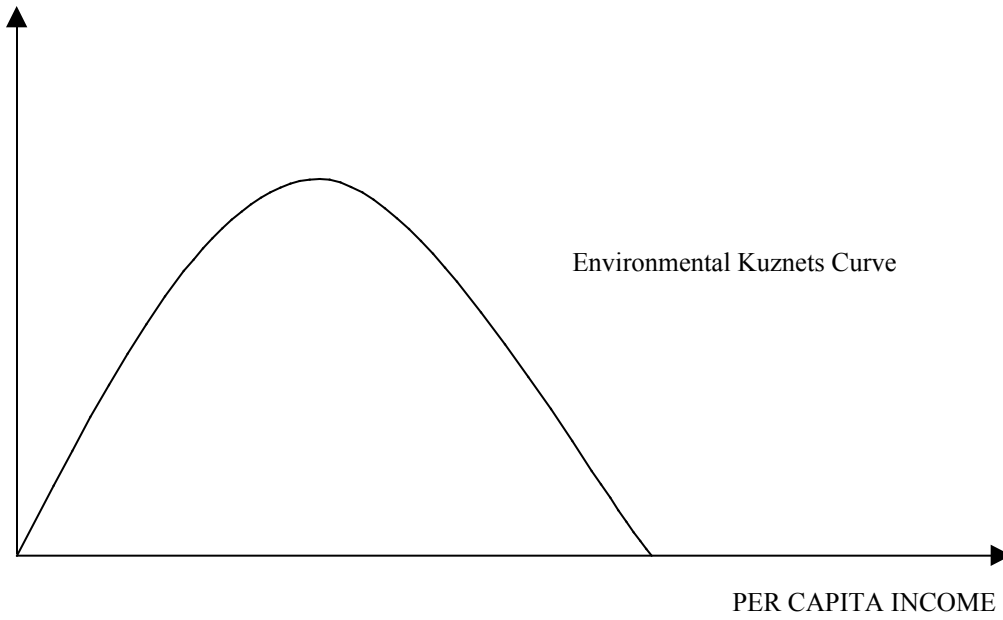


FIGURE 1: inverted-U (quadratic) curve

ENVIRONMENTAL DEGRADATION

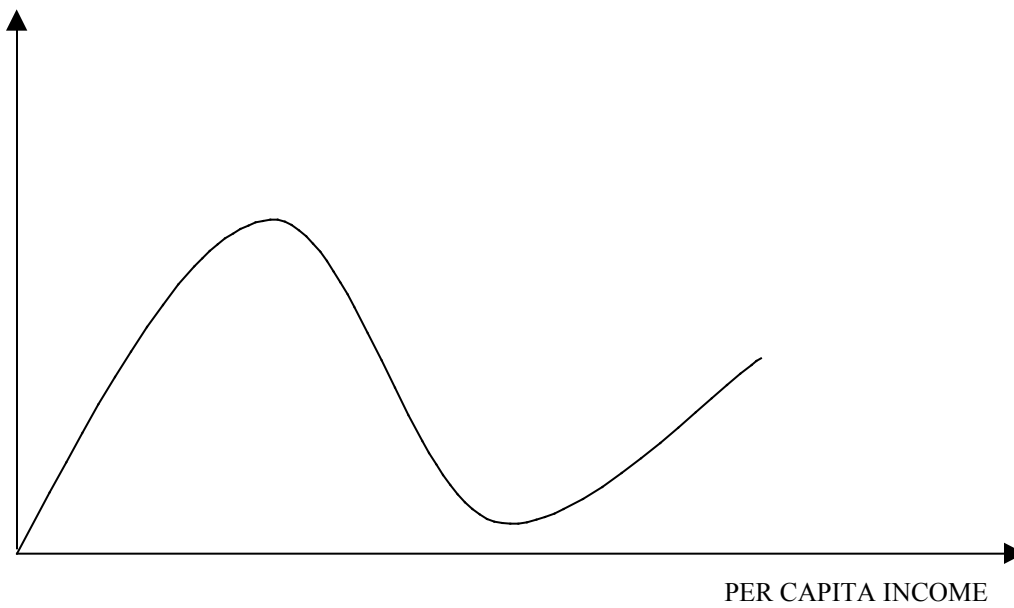


FIGURE 2: N-shaped (cubic) curve

ENVIRONMENTAL DEGRADATION

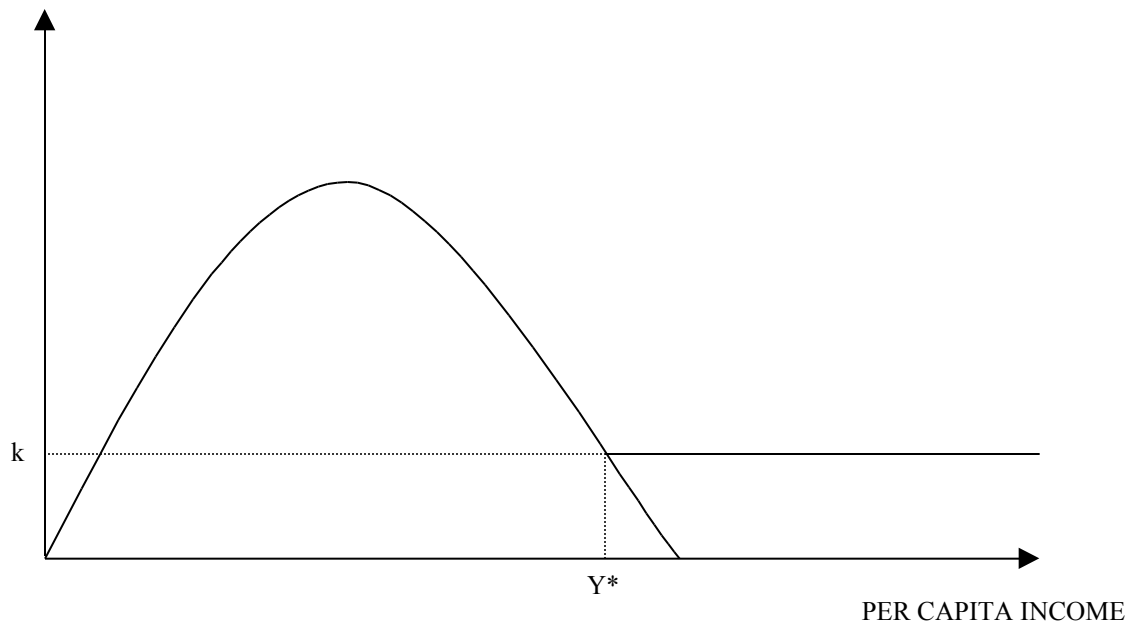


FIGURE 3: Environmental Kuznets Curve with lower bound  
*Source: Common, 1995*

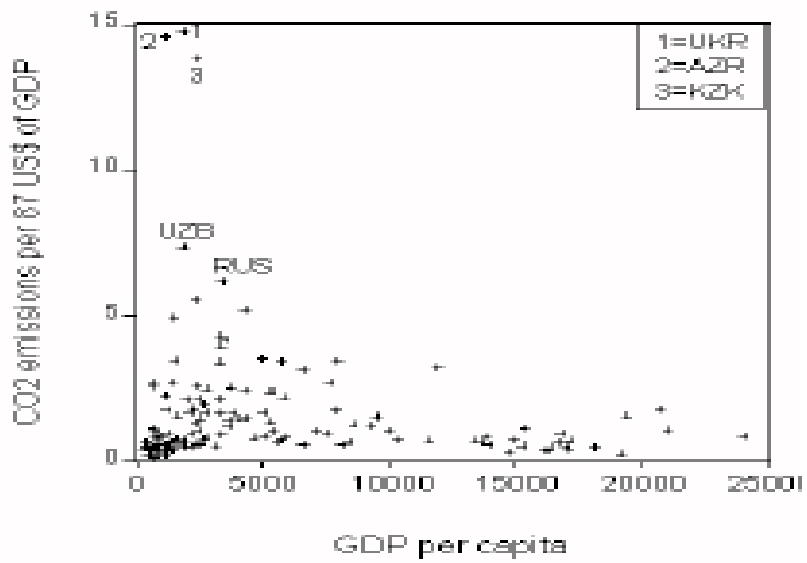


FIGURE 4: 1995 CO2 emission intensity

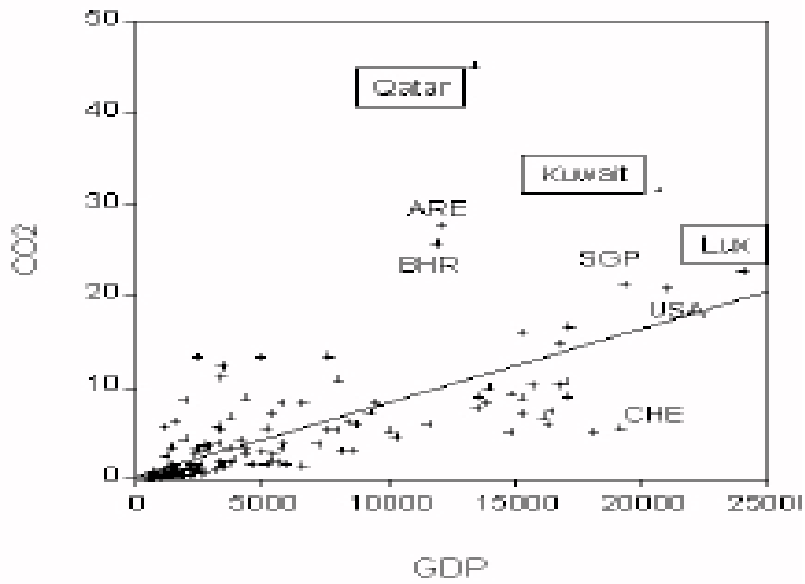


FIGURE 5: 1995 CO2 per capita emissions

ENVIRONMENTAL DEGRADATION

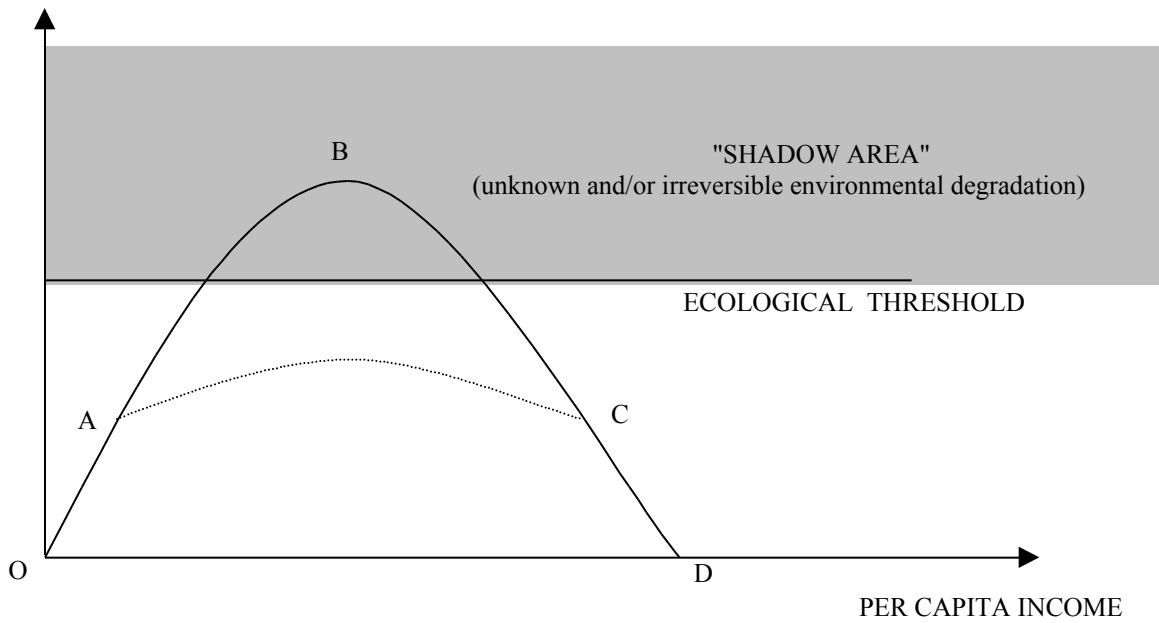


FIGURE 6: "Tunneling through" the EKC  
Source: *Munasinghe 1998*



		G 95	GK 94	HLW 97	P 93	SS 94	S 94	TB 98 w/o	TB 98 w/	KDGP98	CRB 97	HES 95	CJM 97	V 97	
I n d i c a t o r s	u a l i t y	NITRATES	EKC (\$10524)								EKC (\$15600)				
		AMMONIACAL NITROGEN												MI	
		pH												MI	
	O t h e r s	DEFORESTAT.				EKC (\$823-1200)		Y not signific.							
		MSW						MI				MI			
		LACK SANITAT.						MD	N-shaped	MI					
		LACK SAFE H2O						MD	N-shaped	N-shaped					
		TOXIC INTENS.			EKC (\$12790) or MI <sup>(2)</sup>										
		TOT. ENERGY USE										EKC (\$34700)			
		TRANSPORT ENERGY USE										EKC (\$4million)			
	TRAFFIC VOLUMES										EKC (\$65300)				

**INDICATORS LEGEND:** SO<sub>2</sub>=sulphur dioxide, SPM=suspended particulate matters, NO<sub>x</sub>=nitrogen oxides, CO=carbon monoxide, CO<sub>2</sub>=carbon dioxide, CFC=chlorofluorocarbons, GHG=greenhouse gases,

VOC=volatile organic carbon, PM10=particulate matters less than 10 microns in diameter, DO=dissolved oxygen, COD=chemical oxygen demand, BOD=biochemical oxygen demand,

TC=total coliforms, FC=faecal coliforms, MSW=municipal solid wastes

**AUTHORS LEGEND:** G 95=Grossman (1995), GK 95=Grossman and Krueger (1994), HLW 97=Hettige, Lucas and Wheeler (1997), P 93=Panayotou (1993), SS 94=Selden and Song (1994),

S 94=Shafik 1994, TB 98w/o=Torras and Boyce (1998) without inequality, TB 98w/=Torras and Boyce (1998) with inequality, KDGP 98=Kaufmann, Davidsdottir, Garnham and Pauly (1998),

CRB 97=Cole, Rayner, Bates (1997), HES 95=Holtz-Eakin and Selden (1995), CJM 97=Carson, Jeon and McCubbin (1997), V 97=Vincent (1997)

**RESULTS LEGEND:** EKC=environmental Kuznets curve. MI=monotonically increasing. MD=monotonically decreasing. Inverted-S shape=environmental degradation first rises, then levels off and finally increases again as income grows. Inverted-N shape=environmental degradation first falls, then rises and finally decreases again as income grows. Y not signific.=income not statistically significant.

N-shaped=environmental degradation first rises, then falls and finally rises again. Income level at the turning point in brackets. Minimum and maximum income levels given when several estimates are performed.

In CRB 97 values refer instead to turning points without and with transport sector. All values are in 1985US\$ unless otherwise specified.

**NOTES:** (1) The study by de Bruyn et al. (1998) is not included among single-country contributions in the table since the authors adopt a different econometric model, taking growth rather than

per capita income as explanatory variable. (2) EKC when emission intensity measured per unit GDP, MI when emission intensity measured per unit industrial output. (3) U-shaped with respect to income,

EKC with respect to spatial intensity of economic activity (turning point at \$6.7million with national spatial intensity, \$154million with city-specific spatial intensity).