Environmental Kuznets curves:

Empirical relationships between environmental quality and economic development*

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Abstract

This lecture discusses relationships between environmental and resource qualities and loads, and economic development, theoretically and empirically. We start in section 2 with a list of theoretical arguments that may or may not justify a tendency for environmental quality to first deteriorate, and subsequently improve, as per-capita incomes grow. In section 3 we go on to consider the empirical evidence on these issues, related to the concept of "environmental Kuzents curves" (EKC). This evidence indicates that estimated EKC relationships appear to largely hold for local pollution indicies, but less so for environmental and resource variables where effects occur on a global scale, such as biodiversity and carbon emissions. We discuss reasons for these differences, and their possible long-run implications.

1. Introduction

The relationship between economic development and environmental and resource loads on our planet is a central issue, perhaps the overriding issue for mankind for the century that lies ahead of us. Inevitably, it seems, we will face further surges in economic output, which are likely to raise material consumption in the richer part of the world, and even more so in the poorer part so as to bring living standards there closer to levels enjoyed by us. In addition world population is bound to increase, possibly double from its current level of about 6 billion. A crucial question is then whether such development patterns are at all possible without necessarily damaging the very basis for our existence, the Earth itself, beyond repair. In a book just about to be published, one of the world's most influential biologists today, Edward O. Wilson, seriously questions the Earth's ability to sustain a population much beyond 10 billion, let alone bring this population up to living standards remotely close to our own.[1] In his opinion we are approaching the limits of the Earth's carrying capacity, in several respects such as freshwater resources and the exploitation of its photosynthetic capacity. The perhaps most interesting aspect of the book, at least from the point of view of an economist such as myself, is however his idea that science and technology may, somehow, circumvent many or most of these problems, provided that we are sufficiently lucky and diligent in its development and application to the central environmental and resource problems facing us. Presuming that population growth halts and global population reaches a maximum of around 10 billion, as currently projected by the United Nations' Population Division, catastrophical environmental degradation and resource depletion may conceivably be avoided, given that we are sufficiently careful in applying appropriate technologies in appropriate ways.

At the very center of such a discussion stands the concept of the "environmental Kuznets curve" (or simply EKC in the following). This concept is named after the Nobel price winning economist Simon Kuznets (he received the 1971 price mainly for his work on economic accounting), who hypothesized that the relationship between income inequality and income level would follow an inverted U-shaped curve.[2] The adaptation of Kuznets' basic concept to environmental and resource economics involves the intellectual idea that economic development need not necessarily involve increased environmental degradation, and combines this with the empirical observation that environmental improvements may be possible together with material economic progress. It is here sufficient to remember the London smog, which during the 19th century, on a regular basis, seriously worsened the health situation of the London population during periods of unfavourable meteorological conditions. Such episodes are today history and remind us that, in many respects and places, environmental conditions have been worse in previous times than they are today.

EKC curves can be defined for inclusive or specific measures of environmental and resource conditions or states. An inclusive measure might involve the construction of a general index for environmental quality, or resource availability, and study the relationship between economic development and this index. More specific measures might depart from relationships for particular pollutants or resources. Most practical applications to date have considered such more specific

[1] See Wilson (2002), excerpts of which are published in the February, 2002, issue of Scientific American.
[2] See Kuznets (1955).

measures. Considering a particular pollutant, an EKC relationship then in this context implies that the level of this pollutant will increase when per capita incomes rise, but only up to a certain point. When incomes rise beyond this point, pollution will level off and eventually start decreasing.

Starting in the early 1990s, a number of researchers have attempted to estimate EKC curves for individual pollutants and resource indicies, as will be documented below. Central in this early work was efforts made by the World Bank related to the World Development Report 1992, which was to heavily devoted to this issue. We have later seen a virtual explosion of studies dealing with the EKC issue; some of this literature will be considered more carefully in the following.

As in all economic analysis, also the EKC concept requires a theoretical basis. Our exposition in the following, in section 2, will start summarizing some of the theoretical ideas invoked to explain this phenomenon. In section 3 we will go through some of the most important relevant literature, while section 4 concludes.

2. Theoretical perspectives on EKC curves

Traditionally, among economists and laypeople alike, a dominant view is that "more development", in the form of higher levels of income and standards of living, almost by definition is bound to lead to greater environmental deterioration. Such a view of the development process may be natural considering the types and magnitudes of environmental deterioration that has followed from increased economic activity over the last centuries. The basic idea behind the Kuznets curve concept is however that this is not a valid view of the development process, at least not as a general law or claim. A number of economic forces may serve to counteract a negative relationship between economic development and environmental degradation. We will here briefly sum up some of the most important of these.

1. As per-capita incomes grow, there is a tendency for a larger share of total demand to consist of services, and a smaller fraction to consist of manufactured goods, agricultural products and raw materials. Services are generally less energy and resource intensive than goods, in their production and consumption. As society switches more and more to services, energy and resource intensity of production and consumption, and thus environmental and resource burdens, are likely to grow less rapidly than output. This argument however does not by itself explain a reduction in environmental and resource burdens as incomes grow, unless the volume of goods consumption is actually reduced; it can only explain a lower environmental and resource intensity, per unit of output volume. The latter does not seem likely as a general tendency.
2. General technological progress leads to greater efficiency in the use of energy and materials. Thus a given amount of goods can be produced with successively reduced burdens on natural resources and the environment. One aspect of this progress may be better and more efficient reuse and recycling of materials, which (coupled with their greater efficiency in use) can yield large resource savings.[3]
3. As incomes grow, population preferences change, and then also the value placed by the population on preservation and a clean environment. It is generally recognized that the income elasticity of environmental and resource

[3] For an example of an analysis underlining such factors see Bruvoll and Medin (2001), who study components behind development patterns for air pollution in Norway, and where technical change plays a central role in reducing the pollution intensity of output over time.

goods are in excess of unity, i.e., preservation and environment are "luxury goods". In democratic societies this will be manifested in the political process by greater pressure in the direction of preserving and improving the environment, at least locally in the country in question. Among practical implications of such forces are stricter government rules regulating resource and environmental conditions, higher taxation of polluting discharges, taxation of particular resource inputs of products, and subsidized investments and research with the aim to combat pollution and high resource use.[4]

4. A point related to the previous one is that certain political variables may change together with economic development, and also work in the direction of lower environmental and resource burdens. One such factor is that a more educated population may lead to pressure for democratic reform in initially undemocratic societies. If there then is a tendency for more democratic societies to be more environment and resource friendly (e.g. because undemocratic societies are dominated by business leaders with less environmental interest), there may be a reinforcing effect on the degree of "environmental friendliness" of such a society.[5] This effect is separate from point 3 where the idea was that basic preferences shifted in the direction of more environmental friendliness. Here the point is rather that, for a given degree of environmental friendliness within the population, such preferences will to a greater degree be manifested in political action to preserve the

[4] A number of empirical studies confirm that such relationships exist. An example is De Bruyn (1997) who shows the impact on sulfur emissions via stricter environmental policy when incomes improve.
[5] Torras and Boyce (1996, 1998) emphasize such factors, and also find such effects using the same data as Grossman and Krueger (1995) discussed below. These effects are particularly strong for the group of developing countries.

environment when society becomes more democratic, which in turn is more likely when incomes grow higher.

5. Since different countries are at different levels of income, and thus (in line with point 3 above) have different degrees of aversion against pollution and high resource use, there may be room for mutually gainful trades between countries, in such a way that environmentally burdening production may tend to be located in low-income countries, while the consumption of such goods largely takes place in higher-income countries. Such activities, sometimes associated with the term "environmental dumping" may in case tend to reduce the resource and pollution loads in the rich countries, at the expense of higher such loads in lower-income countries. Statistically, it will appear in the form of relatively lower environmental loads on high-income countries, and higher loads on low-income countries.

Out of these five types of arguments the first can most likely not by itself explain a tendency to reduce the <u>absolute</u> environmental and resource burdens for high-income countries, unless <u>overall goods consumption</u> drops with income in such countries. The latter appears unlikely. Points 1-4 however interact and may have considerable overall force. Arguments described under point 2 imply that lower environmental burdens are by-products of a general technological level, which may be highly important for explaining differences in environmental and resource burdens between rich and poor countries. It is well known, and amply analysed and documented in particular the recent "endogenous growth" literature, that there are enormous divergencies in the degree to which advance technologies are applied across countries.[6] Indeed, a central aspect of being underdeveloped is just the inability to apply advance technologies, with their more efficient use of resources and les pollution intensity.

The third and to some degree the fourth arguments are particularly important for explaining possible tendencies for local (by this we mean national or lower levels) burdens of pollution and resource use to drop with income. The preferences of a given population for better environment, and the political implementation of such preferences, will usually lead to action that affects the environmental and resource situation in that country, but not necessarily much beyond. In particular, it does not guarantee action in cases with great conflict of interest among countries. Great biases in favour of solving local versus global environmental problems should then tend to indicate that the preference argument is quantitatively important.

Note also that if the fifth argument is important, one should perhaps expect high-income countries to have fewer environmental problems than low- or middle-income countries, as implied by the EKC principle, but still, perhaps, that average environmental quality deteriorates as all countries' incomes grow. This will have implications for interpretations of different types of empirical EKC relationships. In particular, cross-section studies at a given point of time may yield higher environmental quality in high-income than in low-income countries; still, time-series studies for given economies, that grow over time and retain their position in the world income distribution may yield that environmental quality deteriorates with income. A comparison of these two types of data may then help to indicate the importance of this argument.

[6] For relevant references see e.g. Aghion and Howitt (1998), Barro and Sala I Martin (1995), and Romer (1990).

Note finally in this section that theoretical models have been developed which yield the basic EKC result, namely an inverted U-shaped curve between a comprehensive environmental degradation measure and income, under fairly general conditions (Lopez (1994), Selden and Song (1995), John and Pecchenino (1994), McConnell (1997), Stokey (1998)).[7] Most of these theoretical models emphasize the effects of income increases on preferences for environmental and resource goods, and effects of directed technological progress (in the sense that more demand for environmental goods tends to promote resource- and environmental-friendly technical progress). A common problem empasized by these models is the interaction between environmental quality and resource abundance, technical progress and economic growth. This in turn points to a set of methodological problems in interpreting EKC relationships, namely that economic income, technical progress and environmental quality all tend to be simultaneously determined, perhaps by other, underlying, variables. We will come back to this problem in the discussion below.

3. Empirical issues

The EKC issue is essentially empirical. An important set of empirical issues relates to how to define a relevant measure of environmental and resource quality. Most researchers attacking this problem have not attempted to derive one single comprehensive measure, but instead found it more useful to attempt to derive individual EKC relationships for each of a number of narrower measures. Three main groups of such variables can be identified: first, variables representing general living conditions which are strongly related to environmental and resource goods; secondly,

[7] See also the surveys of related theoretical literature by Ekins (1997) and Stagl (1999).

ambient environmental and resource qualities at the local or average national level; and thirdly, environmental or resource variables in any given country that impact strongly on other countries. The seminal World Bank study (World Bank (1992)), which to a major degree built on Shafik and Bandyopadhyay (1992), focused on the following ten issues: lack of clean water, lack of urban sanitation, ambient levels of suspended particulate matter, ambient sulphur oxides, change in forest area (between 1961 and 1986), annual observations of deforestation (over the same period), faecal coliform in rivers, municipal waste per capita, and carbon emissions per capita. The two first of these most reasonably belong to category 1 mentioned above; carbon emissions to the third category; while the rest belong to the second category (except that the forest variables perhaps belong to both the two latter categories). Another influential study, Grossman and Krueger (1995), focused on three types of group 2 variables, namely three measures of ambient air quality, six measures of water quality, and five measures of heavy metals concentrations. A third large influential study, Selden and Song (1994), consider four different ambient air quality variables, i.e. also variables of type 2. Overall, it is fair to say that variables of type 2 (representing national levels of ambient recipient or resource quality) have received the most attention in the EKC literature. We will also draw attention to two surveys, by Barbier (1997) and by Stern (1998), from which many of the data presented below have been extracted.

We will now examine results from some influential available studies for specific environmental and resource variables, and start with national air pollution indicies in table 1. 5 different measures are included in the table, namely sulphur dioxide, smoke, heavy particles, NO_x and CO. The first of these stems mostly from heavy industry and power generation, the two last largely from road traffic, while the remaining two may be caused by both of these sources. We see that the studies surveyed are almost unanimous in finding that overall national air pollution levels peak at a certain per capital output, i.e., when per capita output exceeds the stated peak level, pollution drops. For sulphur dioxide this result is however not entirely clear in the most recent studies (by List and Gallet and by Stern and Common). If these data indicate a peak, it is in case at a too high income level to make the results reliable. "By and large", however, these studies show that air pollution peaks.

Table 2 considers 6 measures of national water pollution. The Grossman and Krueger (1995) study covers all these, and indicates peaks in every case, which occur from a low of 2700 USD per capita for dissolved oxygen, to a high of 10000 USD per capita for nitrates (for the latter, Cole et.al. has a higher peak point, of 15600 USD). The Shafik and Bandyopnadhyay (1992) study however by contrast does not find any peak for dissolved oxygen.

The Grossman and Krueger study also provides estimated EKC curves for 5 different heavy metals, reproduced in table 3, and also here in all cases find peaks; the lowest occurs for lead, at 1900 USD/capita, and the highest at 11600 USD/capita, for cadmium. Two other studies, Hettige et.a.l (1992) and Rock (1996), give results for general (unspecified) metals concentrations and general toxicity respectively, and here find peak points in the range 10000-13000 USD.

Table 1: Summary of EKC studies for national air pollution indicies. All figures in USD

Study	Sulphur Dioxide	Smoke	Heavy Particles	NO_x	CO
Grossman-Krueger (1995)	Peak at 4050, trough at 14000	Peaks at 6150 USD	Monotonically Decreasing		
Shafik and Bahdyopadhyay (1992); Shafik (1994)	Peaks at 3300		Peaks at 3-3500		
Panayotou (1995)	Peaks at 3000		Peaks at 4500	Peaks at 5500	
Selden and Song (1994)	Peaks at 8700		Peaks at 10300	Peaks at 11200	Peaks at 6000
Cole et.al. (1997)	Peaks at 6900		Peaks at 7300	Peaks at 14700	Peaks at 9900
List and Gallet (1999)	Variable, peaks at 22000 (US only)				
Stern and Common (2001)	Peaks at 9000 (OECD), 30-100000 (world)				

Note: Figures are not always comparable; mostly in 1990-1995 USD at PPP rates.

Table 2: Summary of EKC studies for national water pollution indicies.

Study	(Minus) dissolved oxygen	BOD	COD	Faecal coliform	Total coliform	Nitrates
Grossman and Kruger (1995)	Peaks at 2700	Peaks at 7600	Peaks at 7800	Peaks at 8000	Peaks at 3100	Peaks a 10000
Shafik and Bandyopadhyay (1992)	Increases uniformly					
Cole et.al. (1997)						Peaks at 15600

Table 3: Summary of EKC studies for national concentrations of heavy metals

Study	General	Toxicity	Lead	Cadmium	Arsenic	Mercury
Grossman-Krueger (1995)			Peaks at 1900	Peaks at 11600	Peaks at 4900	Peaks at 5100
Hettige et.al. (1992)		Peaks at 12800				
Rock (1996)	Peaks at 10800					

Our last table, table 4, sums up a number of studies dealing with other variables. These fall in three main categories. First, we have two variables that characterize general living conditions influenced heavily by environmental conditions, namely lack of water and sewage connections, and amount of municipal waste. Here Shafik and Bandyopadhyay (1992) find a uniform tendency for water and sewage coverage to increase with income, but on the contrary, for municipal waste to increase with income. The latter result is of courses contrary to the EKC principle, but may indicate that the municipal waste problem has not yet reached sufficient proportions for the individual countries, to warrant efforts of the magnitude necessary to reduce the waste amount. The second type of variable is the deforestation rate, where results are mixed: Panayotou (1995) finds a peak at a very low income level, Cropper and Griffiths (1994) at somewhat higher levels, while Shafik and Bandyopadhyay (1992) find no relation to income for this variable.

The last variables included in our table are per capita energy use and CO_2 emissions, which are strongly related considering virtually all countries reliance on fossil-fuel energy consumption. Here there is more reason for worry: while some of the studies imply peaks (but Shafik (1994) at a very high level of 35000 USD), other studies indicate that no peak exists, at least has not as of yet been reached.

Table 4: Summary of EKC studies for other environmental and resource indicies

Study	Lacks water and sewage connections	Municipal waste per capita	Defores-tation rate	Per-capita energy use	Per capita CO_2 emissions
Shafik and Bandyopadhyay (1992)	Uniformly decreasing	Uniformly increasing	No relation to income		
Cropper and Griffiths (1994)			Peaks at 4800 (Africa), 5400 Latin America)		
Shafik (1994)					Peaks at 35000
Antle and Heidebrink (1995)			Peaks at 2050		
Holtz-Eakin and Selden (1995)					Uniforml y increasin g
Moomaw and Unruh (1997)					Peaks at 12800
Panayotou (1995)			Peaks at 900		
Horvath (1997)				Uniformly increasing	
Schmalensee et.al. (1995)					Increases to 700, decreases from 10000 (1985 USD)

In presenting and discussing these tables we have not gone into the "deeper" issues of underlying causality, or more generally how to interpret the relationships, and neither the related econometric problems arising under alternative such assumptions. It is not immediately clear how an EKC relationship should be interpreted, as a causal relationship or as a (spurious or non-spurious) correlation, and whether it means the same in all countries and for all relevant variables. These are complex issues, and there is here only room for indication of some of the problems involved. First it must be recognized that environmental and resource endowments are determined simultaneously with economic output. An environmental endowment can be viewed as a factor of production, whereby a larger endowment contributes to a larger output. Moreover, output as normally measured can be increased in a given year by running down the current stock of resources (consuming the production factor so to speak, as in the case of Norway extracting North Sea petroleum, or Brazil extracting its rain forest). Such issues on the one hand calls for more sophisticated models where environmental loads, income, and other variables are determined simultaneously. It also calls for an analytical distinction between stock and flow variables in EKC analysis. Environmental quality is partly a flow concept (as for the current amount of air pollution emitted in a given city), and partly a stock concept (as for the amount of heavy metals accumulated in groundwater and soil, or the accumulated stock of atmospheric carbon dioxide). This distinction and the analytical confusion resulting from not making it, was stressed forcefully by Trygve Haavelmo more than 30 years ago,[8] but plays a small role in current formal modelling of EKC relationships.

The econometric problems with deriving EKC relationships are numerous and will not be dealt with further here.[9] They are related both to the simultaneity and stock-versus-flow issues touched on above, as well as to the issues of time-series versus cross-section (or panel data) EKC relationships; these obviously have quite different interpretations and significance.

[8] See Haavelmo (1971).

[9] See Stern (1998) for a discussion of different econometric approaches to the estimation of EKC curves, and an overview of the main relevant studies.

4. EKC curves: Where do we stand?

We have in this note gone through a number of theoretical and empirical issues related to the EKC concept. An underlying question is what the available theoretical and empirical knowledge can tell us about the expected quality of the Earth in periods to come. Subject to the possible theoretical and econometric pitfalls indicated by our discussion, a few rather robust conclusions seem to stand out. Perhaps most clearly, when we consider purely local environmental indicators or measures of life quality for local populations, these generally appear to improve with income. In the data surveyed, such relationships seem to be robust for most air and water pollution variables, heavy metal pollution levels, and coverage of tap water and sanitation. These are variables well under control by local and national governments, and the theoretical factors 1-4, studied in section 2 above, then come to play in a beneficial way. Apparently, factor 5 on our list of theoretical arguments, which involved the possibility of "environmental dumping", seems to play a smaller quantitative role, at least so far.

The second main result is that when considering environmental and resource indicators that only make sense to define on a supernational level, the situation is far more problematic, for various reasons. First, coordinated action across countries is much more difficult, both because of direct coordination problems and because different countries may feel they have different interests and stakes. Secondly, some of the environmental and resource variables that can be defined only on a global scale, such as the factors behind global warming and biodiversity, have important irreversibility properties that make improvements over time in relevant state variables very difficult of impossible. There is for instance little one can do to "repair" the damage done by species that have already disappeared from the Amazon rain forest, Antarctic ice caps that have already melted or coral reefs that have already vanished; or to lower already increased atmospheric carbon dioxide levels. In short, many of the overall global environmental and resource measures cannot possibly be improved through higher incomes. Perhaps equally problematic, some of these global indicators seem to be essential inputs for increased economic development, at least for the time being. This certainly applies to global water resources, including groundwater aquifiers, and to fossil fuels causing increased carbon emissions.[10] This situation might change, but at least today one does not see much indication of this.

Important questions are what the developments described here imply in terms of future developments, and what are their policy implications. One should not underestimate humankind's ability for adaptation and progress, and thus our ability (at least in a technical sense) to overcome the main environmental, resource and ecological problems that lie ahead. First, the derived EKC curves clearly give room for optimism concerning future developments of "ordinary" environmental quality variables such as air and water quality measures, locally and nationally. Here peaks, in the form of maximum per capita environmental loads as functions of per capita income, generally seem to be found. True enough, these peaks seem to occur at per capita incomes well beyond those of at least the poorer countries in the world today, which implies that conditions here, in very many countries, will get worse before they get better. But the hope and expectation is that further technological progress, with sufficient trickle-down to poorer countries, will be able to move the top points

[10] True enough, some authors point to the purely technical possibilities of increased production without increasing these loads; see e.g. Anderson (2000). As an example, it is true that our current energy demand can be met several times over through proper exploitation of solar power alone. These presentations however ignore basic economic incentive effects whereby production costs are several times higher for such energy

of the respective "humps" toward the left. Then matters are different when considering many important global variables, such as greenhouse gas concentrations and biodiversity, as already pointed out above. The "solution" of such problems (to the degree that at all they can be solved) requires concerted efforts on a global scale, in the form of directed technical progress and cross-border cooperation, which are so far unprecedented, and which require very long planning horizons, perhaps covering hundreds or even thousands of years. If we return to the discussion by Wilson (2002) referred to in the introduction, the implementation of such efforts may be too much to hope for. As a biologist, Wilson views human nature as having been formed by our requirements for evolutionary adaptation. In his view it does not lie in human nature to explicitly consider a perspective of more than, say, 2-3 generations when a current generation is planning for the future. If such a view is correct, it may be difficult to picture national or supernational government bodies actually adopting much longer horizons than this, when taking future action on environmental and resource issues.

Such a perspective implies problems with the future management of issues such as biodiversity and long-term climate change. The entire scientific community, including both social and natural scientists, here have a big job ahead.

types, at least currently. Much has been spoken over solar energy during the last 30 years; little has however been done.

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