ECONOMIC GROWTH AND THE ENVIRONMENT

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ABSTRACT

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. 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.

Keywords: economic growth, population growth, environmental Kuznets curve

INTRODUCTION

It is commonly argued that we need economic growth to ensure the well-being of the economy and improve standards of living. Further, the promotion of economic growth worldwide is seen as the way to lift developing countries out of poverty. But what are the effects of economic growth on the environment? Some economists argue that economic growth will eventually lead to an improvement in the environment, despite some past increases in environmental degradation correlated with economic growth. But to what extent does economic growth promote resource depletion and increase in waste production and hence increased damage to the environment? To what extent does it damage the basic ecosystems on which we all depend? To what extent does it cause reduction of biodiversity?

In this essay, I will not attempt a comprehensive evaluation of this whole set of ideas. Rather, I will attempt just a partial exploration by studying the work surrounding what has become known as the Environmental Kuznets Curve Hypothesis. Readers interested in a general exploration of the implications of economic growth in our finite world could not do better than read the masterful analysis made by Herman Daly, formerly senior economist in the environment department of the World Bank, in the September 2005 issue of the Scientific American magazine

Kuznets was a USA economist of Russian extraction. In 1955 he advanced the hypothesis that during the process of industrialisation of presently developed nations, income inequality in society initially increased, later ceased to increase and eventually began to decrease (Kuznets, 1955). This sequence was tied up with the gradual process of urbanisation. The hypothesis goes roughly like this.

The average per capita income of the rural population has usually been lower than that of the urban population. Now at the beginning of the process of industrialisation, the urban population was relatively small, and its income distribution was more unequal than that of the rural agricultural population. This would be particularly so when the urban population was being swelled fairly rapidly by immigrants from the rural areas and abroad. Then in urban areas there would be a full range from "low-income positions of recent entrants to the economic peaks of the established top-income groups". So as the weight of population moved from rural to urban areas, income inequality increased. But as industrialisation proceeded, the economic position of the lower-income groups (measured by per capita income) in urban areas, improved for various reasons which Kuznets details, such as the growing political power of the urban lower-income groups, and income inequality in urban areas decreased. Since the majority of the population came to be located in urban areas, income inequality decreased nationally.

Kuznets also gave a supplementary argument which supports the above conclusion. He argued that in the early stages of the emergence of the industrial system, the agricultural and industrial revolutions, together with the rapid rise of population (caused by the rapid decline in death rates while birth rates were maintained), would have had a shattering, dislocating effect on society. But it would be the lower income groups which bore the brunt of this dislocation. In contrast, in the early stages, there were factors favouring the upper income groups – they were bolstered by gains out of new industries with a rapid rate of creation of new fortunes. These processes would have led to a widening income inequality in society. However, one "would expect these forces to be relatively stronger in the earlier phases of industrialization than in the later when the pace of industrial growth slackens".

Overall then, Kuznets postulated that over time during the development of modern industrial economies, income inequality first rose, then leveled off and subsequently declined. However, this change must be viewed against the background of overall economic growth and the fact that average per capita income rose over time (except during catastrophic periods such as wars). So that if one plots income inequality against per capita income one gets a bell shaped, or inverted U-shaped curve (actually Kuznets did not give such a curve in his paper).

It is worthwhile now, when so much current interest is on the poverty of "developing nations", especially in Africa, to note that Kuznets cautioned against accepting the idea that developing nations might experience the same trajectory. And for those of us who are interested in the manifold effect of population growth, Kuznets noted that the "long swing" (the name he gave to the changing relationship we have just mentioned) occurred alongside the long swing of the demographic transition: "For the older countries a long swing is observed in the rate of growth of population – the upward phase represented by acceleration in the rate of growth reflecting the early reduction in the death rate which was not offset by a decline in the birth rate (and in some cases was accompanied by a rise in the birth rate); and the downward phase represented by a shrinking in the rate of growth reflecting the more pronounced downward trend in the birth rate". And Kuznets asks the question, is there a possible relation between these two different swings?

Now the demographic transition, mentioned above, involves two key processes, reduction in mortality and reduction in fertility. Only if the latter occurs will population growth rate eventually decline allowing the completion of the Demographic Transition. And developing countries vary a great deal in the extent that fertility has declined in recent decades. In particular, fertility has not declined very much in many African countries. It is indeed uncertain whether or not these countries will ever complete the Demographic Transition. So if Kuznets conjecture on the possible relationship between the long swing in income inequality and the Demographic Transition is correct, we may share Kuznets doubt that developing nations might experience the income inequality trajectory producing the inverted U–shaped curve. We will return later to what the future holds in store for developing nations.

Now during the 1990s several workers found evidence suggesting that with some indicators of environmental degradation (mainly indicators of atmospheric pollution), in the early stages of economic growth (with average income rising from a low level) environmental degradation increases, but at some stage in economic growth (at some income level) pollution ceases to increase and subsequently decreases. Graphically, this relationship shows an inverted U-shaped curve when degradation per capita (y axis) is plotted against GDP per capita (x axis). The resemblance of this relationship to the one studied by Kuznets led to the curve being named the Environmental Kuznets Curve (EKC). Generalizing to total environmental degradation, the hypothesis was born that environmental quality deteriorates in the early stages of economic growth but improves at later stages; further, there is a causal connection between economic growth (usually measured by income per capita) and this pathway of change of environmental quality. The hypothesis was named the EKC hypothesis.

To many, the EKC hypothesis suggested that far from causing yet more serious environmental degradation, continued economic growth was the best way to ensure that this did not take place.

THE EKC HYPOTHESIS

The hypothesis states there is an inverted U-shaped relationship between some indicators of environmental damage and economic growth. So during economic growth, environmental degradation will initially increase, but eventually decrease. If one then plots an **indicator** of environmental damage against **GDP per capita**, one gets an inverted U-shaped curve with a 'turning point' **(TP)**. The hypothesis implies that rising income itself is the primary cause of decreasing environmental quality at low incomes and improving environmental quality at higher incomes (Moomaw and Unruh, 1997).

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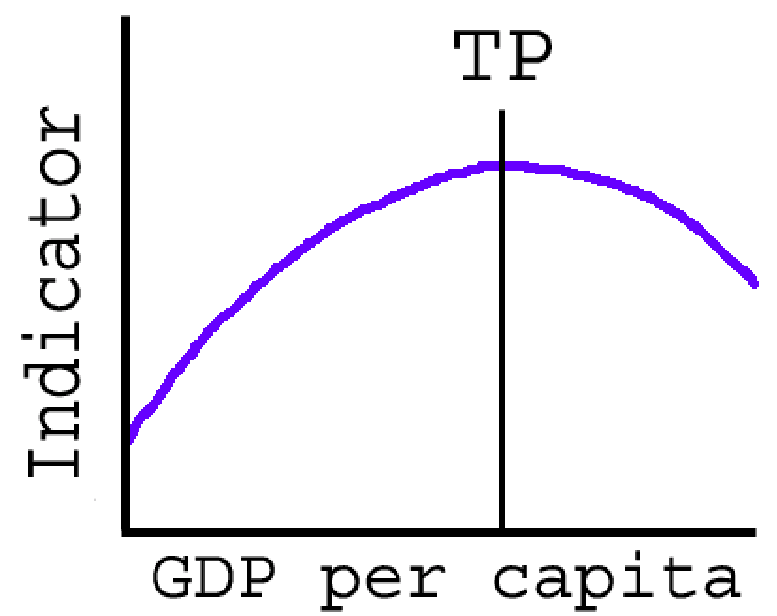
The EKC hypothesis



What could be the mechanism or mechanisms by which the relationship between environmental degradation and income is produced? The commonest explanation advanced, according to Dinda (2004) is that "when a country achieves a sufficiently high standard of living, people attach increasing value to environmental amenities". In other words, as people become wealthier, they have more time to think about other things than mere survival, time to think about environmental conditions, and, being more wealthy, they have more clout to influence local and national governments to take action to improve the environment. This leads to environmental legislation being enacted and new institutions designed to protect the environment (for example, Arrow et al, 1995).

Another causal factor is the phenomenon of structural change in economies. The history of industrialized countries is one of economic change from rural agricultural, to urban industrial society, with increased environmental degradation ('dark satanic mills'). But subsequent movement from an energy intensive industrial economy towards a less energy intensive service based economy leads to a reduction in environmental degradation. Also, as a country becomes more wealthy, it can afford to spend more on research and development, which leads to the development of improved technologies and thus subsequent reduced environmental impact (Canas, 2003; Dinda, ibid).

We shall see later that there are other causal factors.

A NOTE ON TERMINOLOGY

Readers of the EKC literature will find a number of technical terms being used. The following notes on some of these terms will help those readers who are not familiar with them.

Elasticity

'Elasticity', a much used term in economics, concerns the relationship between a dependent and an independent variable. One reads statements of the form 'the a elasticity of b'. Here, 'a' is the independent variable, 'b' the dependent variable. A common example in economics is the *price elasticity of demand* . This concerns how demand for some product changes with price. Here price is the independent variable, demand is the dependent variable. Price elasticity of demand is the percentage change in quantity demanded in *response* to a percentage change in price.

Associated terms are 'elastic' and 'inelastic'. Here we are concerned with just how responsive change in the dependent variable is to change in the independent variable. Consider again price elasticity. When the % change in demand is greater than the % change in price, demand is relatively responsive to price and is called elastic. But when % change in demand is less than the % change in price, demand is relatively unresponsive to price and is called inelastic. Where the ratio of the two % changes is 1, i.e. a 1% change in a leads to an approximately 1% increase in b, then demand is 'unit elastic'. Cramer (1998) provides an example of an elasticity less than one in his study of the impact of population growth on harmful gaseous emissions. Some pollutants had an elasticity of about 0.75 to 0.8; that is, a 10% increase in population produces an increase in emissions of 7.5% to 8%.

Now for some examples of elasticities more relevant to the present essay. *Affluence elasticity of impact* "refers to the responsiveness of an impact to a change in an economic measurement of affluence, e.g. GDP per capita" (York et al 2003a). So we can have the affluence elasticity of *environmental* impact. *Population elasticity* is "the proportional change in pollution or environmental impact per given proportional change in population" (Cole and Neumayer, 2004).

Scale, technological and composition effects

Three other terms crop up frequently in the EKC literature that indicate how economic growth may affect the quality of the environment: 'scale effects', 'technological effects' and 'composition effects'.

Scale effects. Increasing output in the economy requires more input, so more natural resources used, and is accompanied by more waste production and emissions. The scale effect means economic growth has a negative (adverse) effect on the environment.

Technological effects . The damage to the environment caused by economic activity partly depends on the technologies used in resource extraction, manufacture and disposal of products, and in the ability through technical innovation to change materials used to manufacture a given product from materials demanding greater resource use to materials demanding less.

Composition effects . This refers to change in the balance between different sectors of the economy, for example, a decrease in manufacturing (major use of natural resources) and an increase in service industries (less use of natural resources). Such changes alter the overall impact of the economy on the environment.

Ecological Footprint

The Ecological Footprint may be defined as follows:

The ecological footprint of a specified population or economy can be defined as the area of ecologically productive land (and water) in various classes - cropland, pasture, forests, etc. - that would be required on a continuous basis a) to provide all the energy/material resources consumed, and b) to absorb all the wastes discharged by that population with prevailing technology, wherever on Earth that land is located.

Readers might like to read our companion essay "How many people can the earth support? Part Two. Ecological Footprints", for further explanation of the footprint concept.

Evidence for the Kuznets curve relationship

Although several workers found empirical evidence for the Kuznets curve relationship for environmental degradation in the early 1990s, commentators are generally agreed that the key early paper was that by Grossman and Krueger (1991) on air quality measures. These authors found the EKC relationship for ambient levels of SO_2 and dark suspended matter (smoke), and estimated the turning point per capita GDPs.

One pollutant that several workers thought showed the Kuznets curve relationship was sulphur dioxide (SO_2). We take by way of example, the work of Beckerman (1992) who studied data on ambient concentrations of SO_2 in cities in 'low-income', 'middle-income' and 'high-income' countries. Data for the years 1977 to 1981 showed that the country groups could be arranged, from low to high concentrations in the order: Low-income: middle-income: high-income. But about ten years later, this order was reversed. This corresponded to a decrease in SO_2 concentrations of roughly 9 per cent per annum in the high-income countries and a 3.7 per cent rise in low-income countries. Beckerman also found that another pollutant, very damaging to human health, 'small particulate matter'(SPM) showed similar trends although even in the earlier years low-income countries had far higher SPM concentrations than did cities in middle- and high-income countries.

Beckerman also studied other indicators of the state of the human environment. In developing countries, bad sanitation (inadequate supplies of (clean) water and the absence of proper sewage disposal systems) has a very harmful effect on human health. Beckerman wrote that at that time, about one, or one and a half billion people were affected by water-related diseases in one form or another. So sanitation provides indicators of environmental health. Beckerman studied the relevant data for developing countries and found that higher average incomes tend to be associated with a higher proportion of the population having access to water and sewage disposal.

Beckerman's paper deals with damage to the environment in so far as factors directly affecting human health are concerned. It is important to note however what the paper did not deal with, did not cover. In the first place, although changes in CO_2 concentrations were discussed by Beckerman, he did not investigate the relationship between these changes and income. Now, increased CO_2 concentrations contribute to global warming, which will in the future, and most analysts think now does, cause an increase in severe weather events, damaging the economy, causing flooding, damaging homes and infrastructure, as with the recent Los Angeles disaster, and will submerge vast areas of low lying agricultural land in the future. In other words, rising CO_2 concentrations have an indirect effect on human health. Second, Beckerman did not deal with the much wider question, how has increased income related to overall environmental damage, which must include things like decline in natural ecosystems, damage to agricultural land, pollution of rivers and seas!

So we now leave this one particular paper and find out what other workers have concluded about the validity and extent of application of the EKC hypothesis.

AN ATTEMPT AT CONSENSUS

By the middle of the 1990s a considerable amount of analysis had been carried out. However drawing valid conclusions was hampered by limitations in the available data:

Two different types of data set had been used by investigators. The first, and most used type was 'cross-sectional' - examining the actual GDP/environmental indicator relationship at some point in time across a whole set of countries. The second type of data set provides time-series within countries: how the GDP/environmental indicator relationship has changed over time in individual countries. This second type of data set is the best type for investigating the Kuznets relationship; unfortunately, such historical data sets that were then available were usually of short time length, making it difficult to draw useful conclusions from this sort of data set alone.

Now there is an assumption made in drawing conclusions from cross-sectional data sets. This is that all the countries involved will eventually show the same time trajectory of change in the GDP/environmental indicator relationship. But there is no guarantee that countries in the early stages of per capita GDP growth will eventually develop in the same way that countries in much later stages of GDP growth have already developed. Analyses based on cross-sectional data must then be treated with caution, especially if not backed up by time-series based analyses.

Vincent (1997) comments on this issue. He points out that "virtually all the low-income observations come from developing countries, while all the high-income observations come from developed countries". This lack of overlap means that conclusions about a changing relationship between GDP and environmental change could be nothing more than statistical artefacts:
"'environmental Kuznets curves'…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".

Despite these difficulties, there was a growing opinion amongst workers in the field that some legitimate conclusions could be drawn about the EKC hypothesis, and in 1994 an important cooperative initiative was taken by the Royal Swedish Academy of Sciences when they organised a workshop on the subject of this hypothesis. One outcome of this meeting was an attempt by eleven scientists from the USA, Sweden and England to establish what was the general consensus about the significance of the EKC hypothesis. Their paper was published in the journal Science (Arrow et al. 1995). In the same year the Institute for Ecological Economics hosted a 'forum', inviting a selection of workers to contribute papers discussing various aspects of this supposed consensus, and subsequently these papers were published in various journals.

Arrow et al noted that the inverted U-shaped relationship between some measures of environmental quality and per capita income had been used as evidence to support the general proposition that economic growth is good for the environment. However, they point out that the inverted U-shaped curve had by then only been clearly shown to apply to a selected set of environmental pollutants (SO_2, NO_x (oxides of nitrogen), CO (carbon monoxide), suspended particulates), quality of sanitation and purity of water supplies. These are pollutants which involve local short-term costs for remediation. In contrast, the relationship had not been found at that time for pollutants or stocks of waste involving long-term and more dispersed costs such as CO_2. Further, while the curve had been found for some *emissions*, i.e. some outputs from the material economy, it had not been shown for *resource stocks* (inputs into the material economy).

The authors also note that the reduction of one pollutant in a given country might involve an increase in other pollutants in the same country or the transfer of pollutants to other countries. And finally, where emissions have declined with rising income, "the reductions have been due to local institutional reforms, such as environmental legislation and market-based incentives to reduce environmental impacts. But such reforms often ignore international and intergenerational consequences. Where the environmental costs of economic activity are borne by the poor, by future generations, or by other countries, the incentives to correct the problem are likely to be weak. The environmental consequences of growing economic activity may, accordingly, be very mixed".

The subsequently published papers in general supported the conclusion that the Kuznets curve relationship did exist for some indicators of environment degradation but not for other indicators. For example, Barbier (1997) reached this conclusion for the papers published in the special Kuznets issue of the journal Environment and Development Economics. He concluded the relationship was clear for some atmospheric pollutants, especially SO_2 and to a lesser extent solid particular matter. He notes however, that several studies have suggested the Kuznets relationship may not apply to CO_2 emissions.

We turn now to some of the individual publications that appeared in this overall discussion of the Kuznets hypothesis, papers which help to build up a more in-depth and general picture of the situation.

Moomaw and Unruh (1997) surveying previous work on $C0_2$ concluded that different workers had reached conflicting conclusions. They also note that some workers found an N-shaped, not an inverted U-shaped curve – CO_2 emissions did decline over a mid-range of incomes but as incomes continued to rise there was a re-establishment of the upward trend in CO_2 emissions.

Moomaw and Unruh in their own work studied the relationship between CO_2 emissions and per capita GDP in countries across the world from 1950 to 1992. They found that one group of countries ('Type 1') showed a relationship with some resemblance to the Kuznets curve. These were a subset of OECD (industrialized) countries. 'Type 2' countries showed a purely positive correlation between CO_2 and GDP, but when a country suffered 'economic contraction' the CO_2 emissions showed a 'backtracking' (reduction). This group of countries was dominated by the presence of centrally planned economies and some developing countries. 'Type 3' countries exhibited a 'chaotic' relationship – they showed no consistent relationship between CO_2 and GDP over the period studied. This set of countries was dominated by developing countries that had failed to generate consistent GDP growth. So the first conclusion that can be drawn is that even if the Kuznets relationship is found, it is not found in the majority of countries.

However, the authors found a very interesting feature of the plot between CO_2 emissions and per capita GDP. The 'turning point' in the relationship did not show as a smooth curve change, as in the Kuznets curve, but as a sudden, discontinuous transition. This leads to the suspicion that the primary relationship is not between GDP and CO_2, but between some other factor and CO_2. In fact the Authors found the data on the turning point relates much better to the oil price shocks of the 1970s and the policies that governments subsequently adopted.

Schindler (1996) looked at the global situation but with a focus on events in Canada. He noted that "typically, the U-shaped relationships are based on expenditures for environmental amenities, implying that higher spending will necessarily lead to better environmental quality". However, typically, expenditures on the environment do not increase until severe environmental degradation has already occurred. It is then that time-consuming, very costly – and often ineffectual - assessment, cleanup and restoration activities are undertaken. He gives various examples such as billions of dollars spent, with little gain, for the cleanup of St. Lawrence Great Lakes. Schindler then sardonically comments "it follows that environmentally responsible economic planning would prevent U-shaped relationships from occurring al all".

The paper by Cole et al (1997) shows even more clearly how tenuous a relationship between per capita income and environmental degradation often is. They looked into pollution with chlorofluorocarbons (CFCs) and halons. We know how there has been a massive reduction in the use of these chemicals. But this is not related to any gradual increase of per capita income. It is a consequence of the Montreal Protocol committing signatories to massive reductions in use of these chemicals. The authors comment that this example illustrates the potential effectiveness of international cooperation (actually they say "a multilateral response") to an environmental problem. But they add a rider: This sort of effective response may turn out to be unusual. It was possible "because of the relative ease with which cleaner alternatives to CFCs and halons have been developed, and hence their relatively low abatement costs".

Of considerable interest is the likely change in environmental degradation in developing countries. The EKC relationship may have been found with some indicators of environmental degradation in developed countries, but will developing countries show this relationship? A subsidiary question is; will developing countries attain the level of per capita wealth at which the turning point is likely to occur?

The paper by Vincent (1997) already mentioned gives us some insight into this question. This study concerned one developing country, Malaysia, which had already gone quite a long way on the path of economic development, and Malaysia's economy had been one of the fastest-growing in the world since the 1970s. Malaysia was a good country to study because it had more, and probably better data on environmental quality than perhaps any other country.

Vincent claims his study is the first such analysis of the pollution/income relationship over time for a developing country.

Vincent did two things. First for various air pollutants he compared Malaysian emission trends over 1987 – 1991 with the predictions made by some other workers (Selden and Song, 1994) from cross-sectional (across-countries) studies. Then, using data from the late 1970s into the early 1990s he looked into the pollution-income relationship for one air pollutant, total suspended particulates (TSP), using ambient air quality data, and several water-quality parameters such as biochemical oxygen demand.

Selden and Song had studied particulates, SO_x, NO_x and CO. All except CO showed the inverted U-shape relationship. And the turning points in the curve for the three pollutants showing the relationship were in the region of 10,000 US dollars. This figure is about at the dividing line between upper-middle-income and high-income countries in 1988. But this level is well above Malaysia's per capita GDP in the 1987-91 period. Selden and Song's results then suggest that Malaysia's air pollution emissions should have been rising during 1987-91. Vincent found that the emissions did indeed rise for particulates, NO_x and CO, but the increases were much smaller than predicted by Selden and Song's estimated relationships. However, SO_x declined considerably, and for a very simple reason: emissions by power plants declined sharply during the period in question. But this was not because of some new environmental policy. It was because big natural gas reserves had been found in Malaysia; and the government decided to reduce dependence on imported fuel oil by converting power plants to natural gas. If it had not discovered natural gas, or, if it had decided to export all the gas it produced instead of raising consumption by domestic power plants, emissions of SO_x would not have declined so steeply as they in fact did, if at all. "Geology and a desire for energy independence, not rising income and associated environmental policy responses, were responsible for the decline in SO_x emissions".

In the study of changes over time for TSP and water-quality parameters, Vincent found that the inverted U-shaped relationship was not found for any of the factors investigated. Either income was not significantly associated with the factor (three water-quality parameters) or it maintained a positive relationship (TSP and two water-quality parameters) – "rising income worsened pollution".

Ayers (1995) went further than Arrow and colleagues in being sceptical over the general proposition that economic growth is good for the environment. In fact he concluded the proposition was "false and pernicious nonsense". Remember that Arrow et al had noted that the relationship had not been found for resource depletion. Now Ayres notes that economic growth is historically closely correlated with increased consumption of energy and other resources. He also notes that "most of the environmental problems of regional and global concern are directly traceable to the unsustainable use of fossil fuels and/or other materials, such as toxic heavy metals and chlorinated chemicals". Further he notes a general consequence of the basic physical law of conservation of mass – "every material extracted from the environment is a potential waste…Except for materials used in construction, raw materials (and fuels) usually become wastes or pollutants within months or a few years at most".

O'Neill et al (1996) are equally sceptical. They consider that the empirical relationship that had been discussed by Arrow (ibid), between environmental quality and GDP adopts a trivial definition of environmental quality as it is only based on a subset of pollutants in a limited number of places. This is inadequate to encompass "the complex interactions between economic growth and the environment on which that growth depends".

Such a simplification of the total environmental situation ignores the importance of "basic ecosystem services: cleaning the water, purifying the air, decomposing wastes, maintaining CO_2 balance, permitting recovery from natural disturbances, filtering ultraviolet radiation, and providing sources of new medicines". In fact, "discussions of economic growth often ASSUME stable, resilient ecosystems that will continue to provide these life-support services".

The authors go on to assert that even if wealthy nations are able to reduce pollution, economic growth will impose increasing stress on ecosystems. And "total impact can be expected to increase as a function of GDP, considering cumulative depletion of resources, land use changes with implications for water quality and biodiversity, and rates of exploitation that exceed rates of replacement".

We now turn to a comprehensive assessment of the EKC relationship that was not made in response to the paper by Arrow (ibid) and the forum of the Institute for Ecological Economics (they are not mentioned).

A SKEPTICAL ASSESSMENT IN 1997

Ekins (1997) surveyed what he saw as key past investigations of the EKC hypothesis and went on to carry out analyses of his own. He starts by noting the optimistic conclusions of some other investigators which may sometimes go so far as to "create the impression that economic growth and the environment are not only not in conflict - economic growth is necessary to improve the environment. They invite an emphasis on achieving economic growth rather than on environmental policy, because economic growth is perceived to be able to achieve both economic and environmental objectives, whereas the environmental policy may impede economic growth. This turns the 'limits to growth' argument on its head. Instead of the environment setting limits to growth, these conclusions suggest that growth is a requirement of environmental improvement". As we will see, Ekins does not think these conclusions are valid.

Ekins notes that various workers have found evidence which they interpreted as showing the inverted U-shape between environmental indicator and income as follows: *Atmospheric pollutants*: SO_2, suspended particulates, $N0_{2.x}$, CO, even CO_2 although at turning points so extremely high that there is little practical relevance in the result. *Water pollutants and other pollutants*: fecal coliform bacteria, biological and chemical oxygen demand and nitrates. However, studies of some other indicators produced an N shaped curve, that is, at the highest income levels, the downward trend is reversed and further income increase is associated with increased environmental impact once more.

Land-based environmental degradation studies : The only one studied by more than one group of researchers was deforestation. Some workers found the EKC shape relationship, while two workers found no significant relationship with income.

However, when Ekins compared various studies he found what he concludes are serious inconsistencies. First, sometimes, for a given environmental indicator, different workers found different curve shapes or no significant relationship with income (e.g. with the pollutant cadmium).
Second, where, for a given indicator, different workers have found the EKC shaped relationship, turning point incomes varied widely (for example deforestation). Third. The results always depend on the mathematical equations used in the estimations. Sometimes plausible variant equations yield very different results.

Ekins general conclusions at this point in his paper were:

"None of the pollutants unequivocally shows an inverted-U relationship where studies have been done by more than one group of researchers".
And more generally:
"As a generally applicable notion, the EKC hypothesis can be deemed invalid".

Ekins also questions the reliability of the data used by some investigators; sometimes the data has been patchy, and possibly not always adequately representative of the situation in the country concerned. This conclusion was strengthened, Ekins observed, by one study in which the relationships between income and two different sets of per capita energy consumption data were studied by regression analysis, one set of data from the United Nations Development Programme, the other from the World Bank. The former analysis yielded an inverted-U relationship, the latter, a linearly increasing relationship.

Later in his paper, Ekins adopted the classical scientific way of testing a hypothesis, namely, testing whether or not expected consequences deduced from the hypothesis correspond to what actually happens.

Ekins argues that if the EKC hypothesis was generally valid, countries which have achieved an income exceeding the turning point income ("countries.already over the hump") should exhibit an overall improvement in the environment with time. So he examined what were then fairly recent studies by both the OECD and the European Commission of member countries environments. He found that while some progress had been made with some environmental indicators, there had been little progress on many more, and in fact some new problems had emerged. He writes "despite improvements in some indicators, notably of some air pollutants, these countries seem to be experiencing continuing, serious environmental degradation on all fronts". Such findings "seem almost completely to negate the EKC hypothesis". "What the wider environmental assessments indicate is the complete lack of justification of conclusions that seek to use the improvements that have occurred to argue that there exists any overall correlation between income growth and increasing environmental quality".

Ekins goes on to say that a study of OECD data by MacGillivray provides supporting evidence for this conclusion. That worker had constructed an overall measure of environmental performance based on 12 different indicators of the environment ranging from atmospheric pollutants to relative size of protected areas. MacGillivray found no strong relationship between environmental performance and income.

In a later section of his paper Ekins goes on to investigate whether or not any environmental improvements that might have taken place with rising income were necessary consequences of economic growth alone. Here he examines 1) scale effects -destructive of the environment, and 2) technological and 3) compositional effects - potentially both improving the environment. So the question about necessary consequences of economic growth becomes - will improvements brought about by 2 and 3 come about more or less automatically as part of the process of economic growth or will they require to be brought about by deliberate government policy?

Ekin's analysis of data from the G7 countries (USA , Canada , Japan , France , Germany , Italy and the UK - the world's richest nations) show that technological and compositional effects have taken place and that a combination of these effects "is able to counteract completely the (positive) scale effect on environmental impact".

So did the changes brought about by the technological and compositional effects arise automatically in the process of economic growth, or were they brought about by deliberate change in the policies of governments? While he did not carry out a full analysis in an attempt to answer this question, he advanced arguments which led him to believe in "the necessity of determined public policy to achieve environmental improvement in a context of rising incomes".

In the penultimate section of his paper Ekins discusses the implications of EKC studies for the future. He notes that in almost all cases where an EKC has been claimed, "most of the world's population lies on the upward-sloping part of the EKCs that have been estimated. This implies that, even if these EKCs are valid, income growth across the global population will increase environmental damage before it reduces it". And he notes this is same conclusion that other workers have made in the two studies that have projected EKC relationships into the future.

In his final conclusion section Ekin writes: "any improvements in environmental quality as incomes increase are likely to be a result of the enactment of environmental policy rather than endogenous changes in economic structure or technology". And:

"...insofar as the EKC studies permit any conclusions at all, they provide evidence of unsustainable development rather than the reverse".

ASSESSMENTS PUBLISHED IN 2004 AND OTHER RECENT EVIDENCE

Both Dinda (2004) and Yandle et al (2004) carried out surveys of the literature on the Environmental Kuznets Curve hypothesis and made their assessments of the evidence. Numerous other papers on this subject have also appeared in recent times. I here attempt to summarise main findings.

Criticisms of methodology and data sources in EKC studies

Ekins (ibid) has not been the only worker to criticise methods used and conclusions drawn in EKC studies. A useful review of criticisms made by various other workers is provided by

Cole (2003) and Cole and Neumayer (2005). Cole (2003) goes on to develop a series of modelling equations for exploring just how robust the claims of a basic Kuznets curve relationship actually are, and then applies these in investigating four pollutants: Air pollutants (sulphur dioxide, nitrogen oxides and carbon dioxide), and a water pollutant (biological oxygen demand, a measure of organic water pollution)

Cole considers his analyses provide strong support for the validity of an inverted U-shaped relationship between income and emissions as far as the three air pollutants are concerned. However, with biological oxygen demand the relationship seems to be U-shaped. And Cole and Neumayer (ibid) conclude from their analyses that "the EKC may be more robust than some studies have claimed".

Empirical evidence for the EKC relationship.

Following Dinda I divide environmental indicators into three groups:

Air quality indicators.

Local air quality indicators that have a direct effect on human health (SO_2, suspended particulate matter, CO, NO_x etc) generally show the inverted U-shaped relationship. And it seems that the turning point for *urban* air quality indicators is lower than the national aggregate level, partly because it is easier to improve urban air quality than to reduce national emissions.

In contrast, with indicators with a more global, indirect effect, like CO_2 and chlorinated fluorocarbons, concentrations usually increase monotonically with per capita income; if there is a turning point, it is at a level beyond the income level of most countries. Thus for CO_2, Lantz and Feng (2005) noted that some investigators found evidence for a strictly monotonic relationship between GDP/capita and CO_2. Other investigators found evidence supporting the existence of an EKC. But most of these investigators concluded "the CO_2-GDP/capita relationship is essentially monotonic since most countries are not expected to achieve the turning point even in the distant future".

Water quality indicators.

Three main sub-categories have been investigated: a) concentration of pathogens in water; b) amount of heavy metals and toxic chemicals discharged in water by human activities; c) measures of deterioration of the water oxygen regime (Vincent's water-quality parameters). Here the results are more mixed than for air quality indicators. Evidence for the EKC relationship was found for some indicators, for example, arsenic, cadmium, lead, nitrates, biological and chemical oxygen demand, and fecal coliform bacteria. But conflicting results about the shape and peak of the curve were often found. And some authors found the N-shaped curve mentioned in the previous section, instead of the inverted U-shaped relationship: during economic growth, the inverted-U curve develops, but beyond a certain income level, the relationship between environmental pressure and income reverts to being positive.

Other environmental indicators.

This embraces a wide variety of indicators: municipal solid wastes, urban sanitation, access to safe drinking water, energy use and traffic volumes etc. Dinda thinks that most of these indicators do not support the EKC. But Yandle et al (ibid) note evidence has been found using cross-sectional data for an inverted U-shaped relationship between water withdrawal for agriculture and per capita income. And in India the EKC has been found for changes in crop areas (as income increases, cropland declines, allowing more room for habitat).

On the other hand, Dinda concludes: "All studies find that environmental problems having direct impact on human health (such as access to urban sanitation and clean water) tend to improve steadily with economic growth. On contrary, when environmental problems can be externalized (as in the case of municipal solid wastes) curve does not even fall at high-income levels".

The evidence on deforestation is conflicting. And this illustrates a more general point: while the inverted U-shaped curve relationship has been found for some pollutants, the evidence for resource stocks, not clear back in 1995, as we saw earlier with Arrow et al (1995) is still not clear cut (Bhattarai and Hammig (2004). However, Yandle et al (ibid) who discuss several studies that directly or indirectly provide evidence about deforestation, seem on balance, to conclude that the evidence points to the existence of the Kuznets curve relationship at least in some areas of the world, although these authors do not make this conclusion explicit.

Finally, in their study of a much more comprehensive measure of environmental impacts, namely ecological footprints York et al (2003b) concluded: "the quadratic of GDP per capita is the opposite of what is necessary to generate an environmental Kuznets curve. The effect of GDP per capital, then, on the ecological footprint is monotonically positive within the range of observations - an increase in per capita GDP consistently leads to an increase in the ecological footprint.".

The role of technology and changes in relative importance of different components of the economy

As a country becomes wealthier it can afford to spend more on research and development, leading to the development of improved environmental technologies. Here public spending on environmental research and development acts as a catalyst for private investment in developing new technologies. 'Dirty' and obsolete technologies are replaced by upgraded new and cleaner technologies. The consequence of such changes is that "a given amount of goods can be produced with successively reduced burdens on natural resources and the environment" (Dinda, ibid). In other words, methods of raw material extraction and manufacture of goods from these raw materials, become more efficient, as do methods of pollution abatement. This line of argument leads to the subject of 'dematerialization' which we take up in the next section of this essay.

While there is evidence that technological change has contributed to reducing environmental impact, a dissenting voice is that of Lantz and Feng (2005), who for Canada and the period 1970 to 2000 found a U-shaped (not an inverted U-shaped) relationship between CO_2 emissions and technology. The elasticities for 1970 and 2000 were -0.1 and 0.1 respectively. The turning point was in 1995. This result "may imply that technological changes have shifted from enhancing more environmentally friendly production techniques.to encouraging CO_2 enhancing production techniques".

It is worth noting at this point that technological development is a key reason for the optimism of economists of Julian Simon ilk over concerns about future resource depletion and economic growth. As we note in our earlier essay "How many people can the earth support? part 1", the argument goes: Pursuit of some particular resource leads in the short term to falling availability and consequent rise in prices. This however has two effects. First, it stimulates people to develop better extraction technology; second, it stimulates people to find/develop substitutes for the non-renewable resource. The result is that this leaves us better off than if the original problem had never arisen. We do not share Simon's optimism.

Now numerous workers have noted that during the course of economic development, the structure of the economy changes and this brings about changes in environmental impact. "Environmental degradation tends to increase as structure of the economy changes from rural to urban or agricultural to industrial, but it starts to fall with another structural change from energy intensive industry to services and knowledge based technology-intensive industry" (Dinda, ibid). So during economic development, there is initially an increase in energy intensive extractive and manufacturing industries and later a shift from these to less energy demanding industries such as services.

Quality of governance, regulation and institutions

We saw earlier an example of how regulation can very effectively reduce harmful emissions (CFCs and halogens, in that case as a result of international cooperation). And both Dinda and Yandle et al conclude that pollution grows unless environmental regulation is strengthened. Dinda also says that at the national level, social institutions tend to be strengthened by economic growth, although corruption may hinder this process. Yandle et al emphasize that strong institutions are essential if environmental regulation is to be enforced. And on the basis of work by Panayatou, they conclude that "the quality of policies and institutions in a country can significantly reduce environmental degradation at low-income levels and speed up improvements at higher-income levels".

And we also saw earlier that Ekins in his major review of the EKC concluded that "any improvements in environmental quality as incomes increase are likely to be a result of the enactment of environmental policy rather than endogenous changes in economic structure or technology".

In a recent important paper, Esty and Porter (2005) carried out a systematic analysis of a large array of factors that might affect a country's environmental performance as measured by levels of 1) urban particulates, 2) SO_2, 3) energy usage - energy per unit of GDP. For the latter the authors measured total energy consumption per unit of a countries GDP; high figures represent more energy consumed per unit of economic output, and thus greater economic inefficiency. Data came from a large number of countries which varied between measures dependent on availability. The array of factors investigated, that is the independent variables, were divided into two sets.

Set 1 was "environmental regulatory regime". This consists of "measures of various aspects of a country's environmental regulatory system, including standards, implementation and enforcement mechanisms, and associated institutions. These variables capture regulatory elements that directly affect pollution control and natural resource management".

Set 2 was "economic and legal context". This set "contains indicator's of a country's more general administrative, political, scientific, and technical capabilities and institutions. We thus include measures of the extent to which the rule of law is respected, property rights are protected, and the country exhibits technological strength".

For each of the three measures of environmental performance graphs was plotted of the measure (y axis) and GDP per capita (x axis). A clear pattern emerged: Richer countries (measured by GDP per capita) achieved better results than poor ones.

The data did not however reveal an inverted U-shaped curve (EKC). The authors think this "may be explained by the fact that our sample of countries contains relatively few countries in the 'early industrialization' stage of development, in which emissions and energy usage would be low and rising, especially for the air pollution measures".

Despite the general relationship between environmental performance and level of economic development as measured by GSP per capita, there were "wide variations in environmental performance among countries at similar levels of economic development".

And now we come to the heart of the debate about what are the factors that cause the EKC. For the authors say this suggests that "a country's income or development stage affects but does not alone determine environmental outcomes. Some rich countries seem to have learned how to advance environmental quality ahead of their economic progress; others have not".

These findings then provide the background, the justification, for the investigation of other factors that might be involved in improving environmental performance, which make up the bulk of this paper, with results as follows.

In the regression analyses, with both energy usage and particulates, the vast majority of the independent variables were significant, had the expected negative sign and accounted for a reasonable degree of explained variance. With both measures, two of the sub-sets of Set 1, namely regulatory structure and regulatory stringency were highly significant. And with Set 2, almost all the variables were significant and accounted for a substantial degree of explained variance. With SO_2, most of the independent variables were again significant, but the degree of explained variance was generally much lower.

The authors concluded :

".the statistical analysis presented suggests that environmental results vary not only with income levels as suggested by the environmental Kuznets Curve literature but also with both the sophistication of a nations regulatory regime and, perhaps more notably, its broader economic and social context".

As part of their overall investigation, the authors also looked at the question of the relationship between environmental performance and competitiveness. Does environmental regulatory stringency detract from or contribute to economic progress? They used an index measuring the overall regulatory regime and the World Economic Forum's Current

Competitiveness index, and found a strong positive correlation between regulatory regime and competitiveness. They conclude that the evidence supports the view that environmental progress can be made without sacrificing competitiveness.

Finally, Bhattarai and Hammig (2004), in a study of deforestation of tropical natural forests find that the quality of governance is an important determinant of forest resource preservation.

Property Rights

Both Dinda and Yandle et al emphasise that Property Rights are also important for securing environmental improvement. Ownership creates the incentive to conserve and to accumulate wealth that can be traded or passed to future generations. Dinda writes: “Countries with a high degree of private ownership and proper allocation of property rights have more efficient resource allocation, which helps to increase income and decrease environmental problems”. And he concludes: “thus, the EKC may be a proxy for a property rights model that begins with a commons and ends with private property rights”. Yandle et al say virtually the same thing in their paper.

Distribution of power, political rights and corruption

The distribution of power in the population also affects environmental trends. Torras and Boyce (1998) studied variables which may be regarded as proxies for power within a country - income inequality, literacy, political rights and civil liberties. The authors used air and water quality indicators - sulphur dioxide, smoke, heavy particles, dissolved oxygen and faecal coliform bacteria.

The results were mainly consistent with the hypothesis that greater inequality in the distribution of power leads to more pollution, but with results varying between high and low income countries. For example, with income inequality in relation to sulphur dioxide and smoke, “greater income inequality is associated with more pollution in the low-income countries, but not in the high-income countries”. Then with literacy, in both low- and high-income countries, literacy was statistically significantly associated with better environmental quality for several pollution indicators. With political rights, generally a higher rights score is associated with improvements in indicator quality, although this was stronger in low-income than in high-income countries. There were a few exceptions. Thus for example, in high-income countries the association between political rights and dissolved oxygen was in the opposite direction.

However, Cole (2003) found no evidence that the distribution of power determined pollution emissions. And York et al (2003a) who included measures of political rights and civil liberties among their independent variables in their study of impact on ecological footprints, failed to find any impact of these factors.

There is much evidence that corruption in governing elites and in powerful groups such as industrialists, and the corrupt actions of individual entrepreneurs, contributes to environmental deterioration. Such behaviour is sometimes termed 'rent-seeking' by economists. This refers to when individuals or groups, including government officials, seek to obtain goods or services, by influencing the development of government policy and other ways, at the expense of taxpayers/other consumers, that is without proper compensation. Lopez and Mitra (2000) give references for India , Indonesia and Thailand . They then go on to develop a theoretical analysis of this phenomenon.

To the authors' surprise, corruption is not likely to prevent the formation of a Kuznets curve relationship. However, the turning point in the Kuznets curve occurs at higher income and pollution levels.

The authors conclude their results are particularly significant for the larger developing countries such as China , India and Indonesia , which are experiencing explosive economic growth.

First: "Unless this growth process brings about a rapid reduction of corruption (an unlikely event given that institutions and cultural norms typically show extraordinary resilience), pollution will remain much higher in these countries than the levels reached in currently developed countries when their per capita incomes were comparable".

Second: In the newly industrialising nations, pollution is likely to go on increasing until per capita incomes reach much higher levels than the turning point income levels of developed nations. "That is, the empirically estimated Kuznets curves are not likely to be valid for the projection of patterns of pollution for the developing countries".

Esty and Porter (2005) also find that corruption is a significant causal factor of environmental deterioration through pollution.

International trade

So far we have treated countries as if they were all self-contained and isolated. In fact all countries engage in international trade. And this trade influences the economy, the affluence and the environment of countries. And this leads us to a very contentious hypothesis – **the Pollution Haven Hypothesis (PHH).** The argument here, based primarily on Dinda's paper, and simplified, goes like this.

We can think of countries divided into two groups. On the one hand, high income countries with considerable environmental regulation designed to limit environmental damage, and low income countries where environmental regulation is at best rudimentary. Pollution intensive production, for example, mining, is thus comparatively costly in high income countries. If we assume a certain degree of trade liberalisation, there will then be some degree of relocation of pollution intensive production from high income countries to low income countries. Consequently pollution rises in lax regulation countries and falls in countries with stringent environmental regulation. So on the global scale, the world's most pollution producing industries locate in the countries with the lowest environmental standards with the result that world pollution rises.

This hypothesis has obvious relevance to any discussion of the EKC relationship. For supposing that some environmental indicator in a wealthy country shows the Kuznets curve relationship over time, while this indicates a benefit for the country concerned, it may be associated with a consequential increased environmental degradation in some poor country or countries. Then at a global level, there is no environmental improvement.

Obviously the effects of international trade are much more complicated than this brief introduction to the PHH portrays. For example, the relocation of ‘dirty’ industries is associated with foreign direct investment and technology transfer which can stimulate economic development in underdeveloped countries, assist governments there to improve the efficiency of production and thus reduce pollution. Further, trade may raise income levels of people in poorer countries which can lead to demands from the public for more effective environmental protection as was mentioned in an earlier section. And Yandle et al appear to me to conclude that in general, with developing countries, environmental prospects are better in countries more open to international trade than countries closed to such trade.

As we said at the beginning, the Pollution Haven Hypothesis has proved to be very contentious, and continues to be debated. And while there is clear evidence of the sort of effect predicted by the hypothesis in some countries, this does not prove that the mechanism producing the effect is the one stated by the PHH, which depends partly on degrees of environmental regulation. Various other factors affect trade in ‘dirty’ goods, for example, abundance of capital, or degree of government corruption.

However, the recent work of Cole and Neumayer (2005) throws further light on the possible significance of the PHH. These authors consider the importance the 'composition effect' (see the earlier section on terminology) has had for pollution reduction in developed countries (DCs). If this composition effect has in fact made a very significant contribution to bringing about the inverted U-shaped relationship in DCs, and it has been achieved by exporting pollution intensive industries abroad, this does not augur well for future development in less developed countries (LDCs). For if the LDCs need to follow the same pollution-income path as the DCs “they will have no-one to whom they can pass their pollution-intensive industries”.

So Cole and Neumayer try to isolate the effect that compositional changes have in fact had in four DCs - USA, Canada, Japan and the UK, for the period 1970-96. They say their results suggest “that composition changes have reduced air pollution emissions, particularly SO_2, CO (carbon monoxide) and SPM (suspended particulate matter), by a significant amount over the period of consideration”. For example, with the UK and SPM, the emissions from manufacturing in 1996 were 11.3% lower than if the composition of production in 1996 had been the same as that in 1970.

Now export by DCs of pollution intensive industries abroad does not mean that DCs do not need the products of these industries; in fact, they import these products from LDCs. So the authors go on to investigate the importance of imports of pollution intensive products for the four presently developed countries considered.

They find evidence for the DCs that “the share of developing country imports in pollution-intensive consumption has increased over the period 1978-96”. “Thus it would appear that developed country demand for pollution-intensive output is increasingly being satisfied by imports from abroad...”. So “...the now rich countries have become clean at least partly by exporting the dirty production of products to other, poorer countries. This implies that the current poor countries will not be able to replicate fully this experience”.

The authors then go on to the forecasting of future pollution trends in LDCs. They examine predicted changes in income levels for LDCs up to 2100, and consider these in relation to estimated turning point incomes for various pollutants made by themselves but principally by other workers. They find that for most developing countries pollution is likely to get worse for many years to come. The results are worst for Africa. There, for virtually all pollutants, pollution is forecast to continue to rise for most of the present century and frequently even beyond 2100!

I will not pursue the implications of the PHH further here, leading as it would into an extended discussion of the pros and cons of free trade and globalisation; however we will briefly return to the topic in our section below on dematerialization. Readers who would like to explore further the PHH might like to study Taylor (2005).

Prospects for the developing world

We have just seen that Cole and Neumayer adduce considerable evidence justifying a very pessimistic view about the possibility of many LDCs achieving pollution reduction during at least many decades to come. Dinda (2004), partly through the work of Vincent (1997) which I mentioned earlier, seems also to be pessimistic about LDC prospects for pollution reduction. He noted that most developing countries had not yet reached income levels high enough to show the turning point in the Kuznets curve. And considering the world as a whole, the majority of the world population had standards of living substantially below the estimated turning points. In so far as there is any possibility then, of LDCs reducing pollution in the foreseeable future, or indeed reducing other environmental impacts, this will be unlikely to happen without considerable improvement in other factors we have considered in this section, such as regulation. And I have yet to consider properly the effects of continued human population growth, which is dealt with in a later section.

Dematerialization and delinking of environmental impacts

We mentioned that back in 1995, Arrow et al had concluded that the EKC relationship had not been shown for resource stocks. However, it was round about this time that a renewed interest was shown in 'materials flow analysis' (the analysis of the throughput of materials in the economy). Much work focused on 'dematerialization' and 'intensity of material use'.

Dematerialization refers to the absolute or relative reduction in the quantity of materials used in the economy in producing a unit of economic output (it also refers to reduction of quantity of waste produced). A common indicator of dematerialization is *intensity of material use* - this is the quantity of material used per unit of economic output. Another technical term used in this work is *de-linking*, i.e. the de-linking or decoupling of environmental impacts from economic growth. Such de-linking may be either relative (weak) or absolute (strong). In weak de-linking environmental stress *intensity* falls. But total environmental stress can still increase, although at a lower rate than the rate of growth of the economy. In strong de-linking, total environmental stress decreases over time.

However, dematerialization is quite a complicated matter. Thus one might be tempted to conclude that dematerialization at the production end in the pathway of production - use - disposal of individual units of a particular product (for example individual motor vehicles) is necessarily a good thing. But things are not as simple as that, as was pointed out by Herman et al. (1990): "The ease of manufacture of a particular product in smaller and lighter units may result in lower production cost and cheaper products of lower quality, which will be replaced rather than repaired on breaking down. Although a smaller amount of waste will be generated on a per unit basis, more units will be produced and disposed, and there may be an overall increase in waste generation at both the production and consumption end". In other words, if we think of motor vehicle production, reducing the weight (and hence resources used in manufacture) of individual cars (dematerialization on a unit basis) may in fact be accompanied by a rise in total material use in car manufacture because more cars are produced: produced not because more people are buying cars, but simply because users are discarding cars more frequently and hence purchasing new cars more frequently.

Then again, take the matter of the amount of carbon steel used in a nations economy. For the USA, and the period 1970 to 1982, the total amount of carbon steel used per year was very considerably reduced both in motor vehicle manufacture and construction. Yet data for the period 1978 to 1988 for the motor industry showed that while there was a massive decrease in the use of plain carbon steel, this was partly offset by increased use of lightweight, high strength alloys and synthetics. Nevertheless, during the same time period, adding up the weights of all materials used in car construction, there was a big reduction in total weight: The weight for a typical USA car fell from 3,569.5 to 3,167.0 pounds. Herman et al. also examine energy consumption in a selection of countries.They found what they think is clear evidence for a decrease in energy intensity in most of the countries studied.

Moving on now from Herman et al in 1990 to work published a decade later, we find that a considerable amount of work was carried out in the intervening period on material flow analysis, especially in industrialised countries, despite some remaining problems of data availability, and results were conceptualised in terms of *linking.* And coming back to the Environmental Kuznets Curve, we note that this curve is produced with both weak and strong de-linking, with GDP per capita plotted on the horizontal (x) axis. With *weak de-linking*, the environmental intensity of the economy is plotted on the vertical (y) axis. With *strong de-linking*, environmental stress or environmental stress per capita is plotted on the vertical axis (Vehmas et al, 2003).

Generally speaking, much evidence has been found to support the view that weak de-linking has been taking place in industrialised countries (Vehmas, ibid; Canas, 2003). Stated in different terms, the productivity of materials and energy has been increasing. If we now restrict ourselves to the European Union, the general trend over the period 1980 to 2000 has been one of weak de-linking. However, if results for individual EU countries are examined closely, and the period 1980 to 2000 divided into the two component decades, we find that the general trend for the first of these decades was weak de-linking, while in the second of these two decades there was a general trend to strong de-linking (decrease in absolute material flows) in some countries. However, in some countries, in the late 1990s, this decrease in absolute material flows stagnated, and some increase in flows took place (re-linking). And Vehmas (ibid) concluded, in relation to the right side of the inverted U-shaped Kuznets curve, that "the decreasing trend in material flows or material flows per capita cannot be expected to be a continuous one in any country". In this connection they note that "the possibilities for improving environmental efficiencies may have a technological (e.g. thermodynamic) or economic upper limit".

Now earlier in this essay (the section on International Trade and the Pollution Haven Hypothesis) we noted that through international trade environmental improvement in high income countries, that is, the industrialised countries, might have taken place at least partly at the expense of poorer countries. And we can then ask the question specifically in relation to material flows, to what extent has de-linking in the industrialised countries been achieved at the expense of poorer countries? This question was addressed by Fischer-Kowalski and Amann (2001).

These authors concur with the view that de-linking has been occurring in industrialised countries. In their words "we have been able to demonstrate that a certain reduction in material intensity during recent decades seems to have been ubiquitous among affluent industrial countries, both on an overall level and on a per capita level ". But they then go on to enquire - what are the possible explanations? They list three:

1. Technological change (driven they say by the desire for cost reduction and profitablity, but we add pressure from concerned citizens).

2. "Change in consumption patterns away from materially intensive commodities towards labour intensive services".

3. "Change in the international division of labour characterized by the externalization of the most materially intensive processes of raw material extraction and industrial production to the 'peripheral' countries of the 'south'".

Now there is, we think, general agreement that the first and second of these causes have led to a reduction of material intensity. But Fischer-Kowalski and Amann concluded that the third explanation has also played a significant part.

THE INFLUENCE OF POPULATION GROWTH AND OTHER DEMOGRAPHIC VARIABLES

So far we have largely ignored the effects of population growth on environmental impact. Now one might expect impact to increase with population growth, simply because the more people there are, the more people there are to feed, house and provide services for, the greater the energy need. Consequently the more people there are, the greater the depletion of resources and the greater the production of pollutants and other waste products.

It is indeed indisputable, if one takes a historical view, that mans activities have caused very extensive environmental degradation on our planet and population growth has been one causal factor. If we look at degradation of the land resource, we know for example, that vast areas of once fertile land in the Indus and Euphrates rivers region were turned into desert by successive civilizations. Globally, and considering just the last 1000 years, the land area that has been degraded by man's activities has amounted to 2000 million hectares (2000Mha). "Rapid population growth and consequent expansion of agriculture on marginal lands plus mismanagement of good land has accelerated the annual loss to 5-6 Mha" (Qiguo, 1994).

But population growth need not always cause increased environmental degradation. Thus, existing degradation can stimulate the development of technology to mitigate degradation, stimulate the development and implementation of more environmentally friendly agricultural methods and positive restorative activities like re-afforestation; all these developments mediated by, or enhanced by the increased cooperation of people faced with environmental threat and their power to influence the authorities to do something about the situation. And as authorities come to realise the seriousness of the situation they may create institutions which mitigate environmental degradation.

Now it is worth noting at this point that Simon Kuznets himself, back in 1967, made an interesting exploration of the relationships between economic growth, technological social and political change, and population growth, which can serve as a backdrop to what follows. Noting that there had often been a loose association between population growth and economic growth, he wrote:
“That modern economic growth meant a striking accelerated rise not only in product per capita but also in population does not imply that the latter was a necessary condition for the former”. However this economic development was primarily in present day industrialised countries. And Kuznets wrote: “"But today and in areas with conditions quite different from those that characterized the presently developed countries in their past, rapid population growth may be an obstacle to, rather than a condition of, an adequate rise in per capita product”.

That is not all that Kuznets had to say on the subject in this very important analytical paper. He is fully aware of the potential of technological development to lift populations in the poorer developing countries onto the pathway of adequate economic development. For example, he notes that technological development has already gone a long way in developed, industrialised nations, and development of new technologies is becoming progressively more expensive there. Yet at the time Kuznets was writing, even the older, “tried and true" technologies developed in the industrialised world had not been applied in the poorer countries. He speaks of the "advantages of economic backwardness that the underdeveloped countries possess”!
He writes:
“If their low productivity is due to failure to exploit modern technology effectively, the accessibility of most modern knowledge and technical know-how means a large stock of tested technology, material and social, available for future exploitation”.

His own detailed analysis in this paper provides the analytical underpinning to what may seem intuitively obvious - purely economic solutions to our problems are themselves inadequate. He goes on to examine the various social and political changes that must take place if the 'advantages of economic backwardness' are to bear fruit. And as far as continued population growth is concerned, he advises against expecting too much from possible population control efforts. This is not to deny the importance of population control.

Kuznets summarises this line of thinking when he writes that underdeveloped countries need a whole set of economic, political and social institutions if they are to solve their growth problems, if they are to take advantage of their economic backwardness.
“But, this set of policies, if successful, would also indirectly spread population control far enough to make it really effective in the long run. The changes in social and economic structure (and in the international situation) would provide reasonable assurance to future parents that their children will profit from fewer siblings, both in terms of survival and in terms of the effective return on their better education, training and health”, and so on.

Now Kuznets goes on to examine the relationship between population growth and total product growth across countries provided by a very limited available data set (it excludes

Communist countries and is only for a brief post-World War Two period). To cut a long story short, he concludes that “the rate of population growth among the underdeveloped countries has no uniform effect on growth in per capita product”.

However, he goes on to point out the qualifications that must apply to his analyses. In the first place, he notes that his analyses concern only one index of economic growth, output per capita. So they did not take into account other important and desirable aspects of economic growth - employment opportunities, equity of distribution of the product, and “an optimum combination of individual freedom and social responsibility”. So even if growth in per capita product was not impeded by a higher rate of population increase, the latter might create other serious problems of adjustment, such as providing employment for the increasing number of people entering the employment ages of life.

In the second place, Kuznets had only explored population and economic growth of whole national populations. So this ignored any differences in the rate of population increase among various economic groups within a country.

Kuznets notes that even a moderate proportionate reduction in consumption to compensate for a higher rate of population increase would hit the poorer more than the richer groups, even if group differentials in the rate of increase in numbers were not *systematically* related to economic and social status. But in fact the evidence suggests that in underdeveloped countries there is a negative correlation between fertility and income for families classed by income size. Since the fertility differentials are too large to be offset by plausible mortality differentials, Kuznets thinks we can assume a higher rate of natural increase for the lower income and social status groups than for the higher groups. All this makes problems for the economic advancement of the poor, for preventing economic and social inequality widening, and for ensuring an adequate upward flow of potential human talent from the lower classes.

Developed nations have solved this problem of inequality by a variety of institutional changes. Yet even here, “the problems may be accentuated when a rise in the over-all rate of population growth means a greater differential between the lower and upper economic and social groups, and acceleration in the growth of the former; or when technological changes, requiring more education and investment in human capital, may impede upward economic and social mobility that in the long run is indispensable to the efficiency of the economic society”.

The problems arising from population increase differentials between classes are more acute for underdeveloped countries with their lower overall per capita income and smaller economic reserves than for developed countries. “If a high rate of population increase would bring about an even wider income inequality than now exists in the underdeveloped countries, the consequences in the way of misery, failure of unity, and loss of political viability might indeed be dire” (Kuznets, 1967).

We will not attempt here to make any assessment of the whole economic and social picture conjured up by Kuznets. But we just note that as far as the supposed negative relationship between income and fertility is concerned, the study of Schoumaker (2004) on 25 sub-Saharan countries showed that in all the countries studied, the poorest women had a much higher fertility than the better off women, although economic status was not measured by income and expenditure, but indirectly by an index based on asset ownership and housing characteristics. Readers who wish to explore further the range of issues raised by Kuznets might like to consult Birdsall et al (2001) and Bhaskar and Glyn (Eds.) (1995). Rather, we will look at some specific research which provides evidence that population is either positively or negatively related to some forms of environmental degradation, with particular reference to work on the Kuznets curve. We start with work on agricultural and natural resources, then move on to studies on emissions and ecological footprints.

Research providing evidence on the relationship between population growth and environmental deterioration.

There are numerous studies which provide evidence about the relationships of human population growth to changes in agriculture and natural resources. Focusing on rural population growth, Pender (2001) concludes that the evidence is mixed. Sometimes population growth seems to have had beneficial environmental effects; but other studies have found that population growth has been associated with various aspects of resource degradation.

Now one of the biggest studies carried out in this subject area is that by Tiffen and colleagues (Tiffen et al.,1994). And Pender, in a brief introductory paragraph, on which the paragraph above is based, takes this publication as his example of beneficial population growth effects.

As the purpose of this essay is to explore the Kuznets relationship, we will not attempt to evaluate all the studies made on population growth and environmental degradation. However, we will begin by examining the Tiffen et al work as it illustrates that positive population growth effects are sometimes not unalloyed, and because it can act as a useful prelude to the investigations we will report on subsequently.

The book by Tiffen et al (1994) concerns just one district in Kenya , the Machakos district, which lies south-east of Nairobi on the edge of the highlands, the period covered by the study being 1930 to 1990. Over many years previously, many changes had taken place through human activities leading to very severe soil erosion.

During the study period, there was a large increase in land under cultivation, largely at the expense of grazing lands. And there was a big increase in non staple (subsistence) crops - fruit and vegetables and non-food cash crops such as coffee. Agricultural incomes are now much more supplemented by non-farm work. This has partly come about through the large increase in the output of non-subsistence products that has led to the creation of jobs in marketing, processing and “the satisfaction of new consumer demands”. There is now also a much greater effort at conservation. Important here has been the evolution of self-help groups, which had already existed at the start of the study period. Churches, cooperatives and NGOs now play a much more significant role in society. And people are now much more able to pool knowledge and capital, for both private and commercial projects.

Erosion has been reduced, but has by no means ceased. On cultivated land, improved terracing has reduced erosion, although such erosion remains very variable across the district. The greater part of total soil erosion has been on grazing land, and some reduction of erosion has taken place there through land demarcation and land registration. Some of the large old erosion gullies are now vegetated, partly as a result of conservation measures on the higher valley slopes. Agricultural output, both on a per capita basis and on a per hectare basis has increased. And while there had been a wood fuel crisis at the beginning of the study period, there were more trees growing at the end of the period than at the beginning. In grazing lands in northern Machakos, there was an increased "woodiness". But here the authors conclude this was not caused by shrub regrowth under heavy cattle grazing but to the managed regeneration of canopy trees, which protect the ground from erosion-causing rainsplash. On grazing lands, the authors conclude there is no evidence of irreversible land degradation during the study period.

All these positive changes have taken place during continued massive human population growth: The population was in the region of 240,000 to 260,000 in 1932. By 1989 the population had risen to 1,393,000. These facts are reflected in the title of the book: "More people, less erosion. Environmental recovery in Kenya".

Yet the somewhat rosy picture created by the trends just mentioned do not alone give an accurate summary of changes in the Machakos district.

Thus the authors say that it is possible that the rate of erosion on grazing lands has decreased not only because of better management, but also because of the removal of the most easily erodable material before the study period began! And there still remain, scattered through the district, some completely bare areas. And despite what was said earlier about tree canopy development in parts of northern Machakos, there has been considerable bush encroachment in some grazing areas, and the authors admit this threatens to reduce the value of the grazing land for cattle.

Now the Authors note that fertility losses caused by erosion are as important as the physical removal of soil. And fertility has declined in Machakos during the study period. Two approaches were used to study fertility changes.
In the first, soils were studied at 30 sites and the fertility in 1977 compared with the fertility in 1990. Carbon is an indicator of organic matter. It was very low in 1977 and declined considerably by 1900. Available phosphorus was generally low both in 1977 and in 1990, which at many sites indicates "a rather acute deficiency". There seems to have been no significant trend in nitrogen over the study period.

The second approach was to examine a series of sites in 1990, spread over three types of land. Group 1 sites were sites uncultivated for 60 years. Group 2 sites had been fallow for 20 years and were at the time of sampling used as grazing land. Group 3 sites had been under cultivation for 40-60 years or more without any known additions of fertilizer and little manuring. The nature of fertility changes in the district are then inferred from between-group comparisons. The analyses showed a definite trend of decline at every site from Group1 to Group 3. The only exception was available phosphorus, which was deficient in all groups. The authors attach particular significance to the sharp fall in the nitrogen and carbon contents to very low levels from the uncultivated group 1 sites (a big fall 1-2 and 2-3).

Under the pressure of population growth with subdivision of the land through inheritance, farm size has fallen and by the end of the study period there was no free land for occupation, although even back in 1939, 655 holdings were already of uneconomic size in the north. "Income generation must now come from still greater intensification on an already small farm in a difficult farming environment, or the development of new occupations in the processing and servicing sectors of the economy". And while the extent of landlessness is not known, in the Eastern Province, the authors, referring to a study which showed 7% of rural households were landless in 1975-1976 write “landlessness may have increased since then, for population growth has cut the inherited share of some to a house-sized plot, and new farm land is not available”. And in the Kangundo-Matungulu area , “from the 1930s to 1990, the population density had increased fivefold, but the price of land had increased twenty-fold in this part of the district, a sure indication of increasing land scarcity, as well as increased land productivity”.

So we think that the title of the book is misleading, and seems to reflect the authors' pre-conceived perceptions about the effects of population growth rather than a balanced assessment of the evidence. And we note also that the book does not deal with the effects of mans activities on overall plant and animal species diversity.

One resource that can be threatened by population growth is fuel wood. And we now turn to a study of a different district of Kenya and fuel wood production, which was carried out to test for the presence of a Kuznets (type) relationship for fuel wood. It should be pointed out at this juncture that the Kuznets curve refers specifically to relations between indicators of environmental deterioration and (independent variable) a measure of economic growth, usually per capita GDP. But some authors, as is the case here, use the term Kuznets curve more loosely to indicate some relationship whereby an indicator of environmental degradation shows first an increase then later a decrease when plotted against some other independent variable.

Patel et al (1995) studied smallholder wood production and population pressure in the central section of the Murang district in Kenya , in the highlands north of Nairobi . Wood trees are grown here in woodlots, on land borders, or (intercropping) in fields of maize and beans (maize and beans are the stable food crops, but vegetables and non-food cash crops are also grown). Both wood trees and fruit trees are used for erosion control on steep slopes.

In this district there had been considerable environmental degradation: Soil erosion has long been recognised to be a serious problem, being caused by a combination of factors - high rainfall, steep slopes and intensive cultivation. At the same time, population pressure has led to farm size reduction through inheritance.

The research method involved modelling simulations based on data collected in five rounds of surveys in 1991/92 of 115 randomly selected households. In this work, number of trees is the dependent variable. The independent variables used were land area, fruit trees (which might be a proxy for the amount of highly sloped land), labour and expenditure per capita (the latter was a proxy for income).

The elasticities associated with each independent variable were:
Land: 0.36; Fruit trees: 0.19; Labour: 0.4; Expenditure per capita: 0.24.
While the expenditure variable was important in size (as measured by its elasticity), it was not significant, but the other variables were significant.

As far as the land variable is concerned, households with greater land area are likely to have more trees. However, the elasticity of the expected value of the number of trees grown with respect to land is less than one, indicating that households with less land grow more trees per acre, if the other variables are held constant. The elasticity further implies, say the authors that if the other variables are held constant the number of trees per acre will increase as land is subdivided - the predominant form of land transaction.

However, the other variables are not constant as land is divided. Further investigation by the authors nevertheless suggested that with decrease in parcel size, while the expected number of trees per household falls, the expected number of trees per acre rises. Indeed, the authors say they expect to see an increase in total tree cover as farm size decreases even to one-fourth of its present level. They conclude that the results are analogous to the EKC where environmental degradation is shown to worsen, then improve, as per capita incomes improve. And their more general conclusion was:
“The existence of a persistent fuelwood 'gap', and the notion that population pressure will lead to declining tree cover, are not supported by the analysis. A simulation model indicates that as land continues to be subdivided tree cover may actually rise, a result consistent with other evidence of an 'environmental Kuznets curve'”.

However, the authors caution against being too optimistic about eventual environmental consequences. They say “there still exist at least three potential market failures that would give rise to suboptimal tree stocks in East Africa”.

First, trees are very important for preventing soil erosion in watershed management. Clearing such trees to exploit the land for more profitable crops can then have disastrous consequences. Indeed in another part of Kenya the resultant reductions in overall productivity led to ethnic tensions and violence.

Second, individual farmers, who own just a small part of an overall land slope, cannot individually effectively counteract large scale erosion. For it is not just a question of the number of trees, but also the arrangement of the trees on the whole slope. But that demands cooperation between households, and this might not be forthcoming.

“Third, while the number and arrangement of trees is critical, the composition of tree species is also important. Evidence of an 'environmental Kuznets curve' may be reassuring in terms of number of trees. But to the extent that the path implies a loss of diversity, there is reason for concern”. And in the study area there has in fact been a massive loss of tree diversity, with tree planting being mainly of two or three exotic species. “These high concentrations of exotic species increase the likelihood of disease or pest infestations that can have catastrophic results, such as cyprus blight that has plagued both Kenyan and Tanzanian highlands in recent years”.

We note here that the authors concerns about loss of diversity narrowly focus on the productivity of land for humans. But such conversion of mixed woodland or woodland savanna, disturbing the natural balance of species that evolved over millions of years - a balance which prevents pest infestations, has been a widespread feature of development in many countries, and this means a widespread reduction of tree species diversity, and diversity of associated species of other organisms, and an accelerated rate of (local) species extinction.

While studies such as those Tiffen et al and Patel et al provide valuable insights into the relationship between population growth and environmental degradation, their significance is limited by the fact that they only deal with a small part of a country. They tell us very little about what is going on elsewhere in the countries concerned. It is quite conceivable that even if environmental degradation was reversed in a district, this might be paralleled by accelerated environmental deterioration elsewhere in the same country. So while such studies illuminate mechanisms, whole country studies are more valuable for telling us about overall environmental change, especially as the sovereign state is the basic political unit responsible for the determination of environmental policies, laws and institutions. As Dietz and Rosa (1997) say of their own work: "Our unit of analysis was the nation-state because it is the principal collective actor in generating environmental impacts and in developing policies in response to them".

The work of Cropper and Griffiths (1994) investigates the effect of population growth and other variables on deforestation across 64 countries and across continents (Africa, Asia, Latin America (Central and South America). Because deforestation is primarily a problem of developing countries these authors limit themselves to non-OECD countries. They develop an equation which allows them to investigate the following independent variables: Per-capita income; per capita income squared; percentage change in per capita income; price of tropical logs; percentage change in population; rural population density; time trend. The dependent variable is the annual rate of deforestation.

They find that only the results for Africa and Latin America are statistically significant. Their results suggest "first, that a hump-shaped relationship exists between per capita income and deforestation" (in other words, producing a Kuznets type curve). Second, that "rural population density shifts this relationship upwards". That is to say, the turning point in the curve is at higher rates of deforestation as rural population density rises. And quantifying the effect of rural population density, the authors claim that "an increase in rural population density of 100 persons per 1,000 hectares raises the rate of deforestation by 0.33 percentage points in Africa". The grimness of the situation in Africa is seen by comparing Kenya and Malawi .

Kenya had a rural population density of 0.3 persons per hectare, and a peak deforestation rate of 1.91 percent per year. In contrast, Malawi had a rural population density of 0.7 persons per hectare and a peak deforestation rate of 3.21 per cent per year. Now put this information along side the fact that massive population growth is projected to continue for a long time in most sub-Saharan countries, and one realises how serious is the situation.

But there was another "disquieting" feature of the relationship between deforestation and per capita income. The levels of income at which rates of deforestation peak "are such that most of our observations fall to the left of the peak". In other words for most of the countries, income levels were below the curve's turning point income.

Why then the lack of significance with results for Asia ? The authors note that while destruction of natural forests has been massive in Asia, there has also been, in contrast to Africa and Latin America, the development of vast tree plantations. However, an increase in the price of tropical logs is likely to speed up both destruction of natural forests and increase of plantations. If it had been possible then to separate these two types of forest in the analyses, the authors think they would have found a similar relationship for the deforestation of natural forests as they had found for forests in Africa and Latin America .

We now turn to work on emissions (atmospheric pollutants) and ecological footprints. We note to begin with, that as far as pollutants are concerned, "empirical studies which explicitly examine the link between population and pollution in a systematic quantitative manner are very few in number" (Cole and Neumayer, 2004).

As we mentioned in an earlier section, Selden and Song (1994) found evidence supporting the EKC hypothesis for some pollutants (suspended particulate matter, sulphur dioxide, oxides of nitrogen and carbon monoxide). They went on to model possible future trends in global emissions, and concluded that emissions would rise over the foreseeable future. They also note that the fastest population growth is likely to occur among countries which are on the upward -sloping portions of the emissions-GDP per capita curve, that is on the left side of the curve in the figure shown early in this essay. However these authors brought population density into their analysis and find that modelling future changes to 2050, when population density was included in the modelling, lower forecasts were obtained than if population density was not included. They concluded that: "Intuitively, while the direct effect of greater population is to increase pollution (holding emissions per capita constant), this may be at least partially offset if increased population density causes per capita emissions to decline".

It should however be noted that Selden and Song are very careful to point out reasons why their forecasts should be treated with caution such as the fact that no attempt was made to build into the analyses possible future changes in technology and their implications for emissions.

A number of workers have found evidence that population growth causes an increase in emissions. We start with one investigation which gives a good idea of the complexity of interactions between population growth and other variables.

Cramer (1998) studied the relationship between population growth and air quality in California in recent decades, attempting to disaggregate the relationship by 13 different source categories and five pollutants. The source categories were:

Residential, Services, Commerce	Natural Sources
Waste Burning	Passenger Vehicles
Solvent Use, Cleaning, Surfaces	Trucks, Buses
Petroluem Production	Off-Road Vehicles
Industrial Processes	Other Transport
Agricultural Processes	Equipment
Miscellaneous Processes	

The pollutants studied were reactive organic gases (ROG) and oxides of nitrogen (NO_x) (the precursors of ozone), oxides of sulphur, carbon monoxide (CO), and particulate matter.

Population growth had been unusually rapid in California . In earlier decades this was mainly due to inter-state migration. In recent decades it was due mainly to immigration from other countries and relatively high fertility of some immigrant groups. While population growth caused increases in some pollutants, "despite the population growth, air quality actually has improved since the early 1980s due to aggressive regulatory efforts".

The effects of population growth were found to vary considerably between pollution sources. In general, population growth had a large, usually significant effect on emissions from source categories like “Residential, Services, Commerce” and “On-road Vehicles”, sources with consumption and commercial activities one would expect to be tied directly to population growth. So population growth increased emissions for such source categories. In contrast, population growth had insignificant effects on emissions from source categories related to management and economic production such as “Waste Burning” or “Industrial Processes”.

The effect of population growth was found to vary between pollutants - a large effect on ROG, NO_x and CO, but little effect on small particles and SO_x. While the effect of population growth varied between pollutants, and for a base year of 1990, Cramer found that with pollutants sensitive to population growth the overall impact of that growth had “an elasticity of about 0.75 to 0.8; that is, a 10% increase in population produces an increase in emissions of 7.5% to 8%”. They conclude that “this is a substantial impact, but..the elasticity is considerably less than unity; a doubling of population does not double pollution...”. This result stands in contrast to results with carbon dioxide we look at in some following work

It is clear that the relationship between population growth and pollution is a very complex one. But as Cramer shows, the complexity does not stop with the factors analysed above. For example, population growth may increase emissions by stimulating residential construction, but such impact may be mitigated by the conversion of agricultural land and decline in agricultural practices: the population regression coefficients for most emissions from agricultural processes are small but negative; because in California , most residential expansion makes use of agricultural land, so population growth reduces agricultural activities.

Carbon dioxide is a pollutant commonly studied, and results for this pollutant are obviously important through the effect of CO_2 in global warming. Now the majority of investigations seem to have found that population growth causes a roughly proportional increase in CO_2 emissions, i.e. the population elasticity of emissions was roughly one, at least over the range of incomes experienced or likely to be experienced by the majority of nations as we will now see. Some investigations made use of the Impact equation (IPAT): Environmental Impact = Population × Affluence × Technology.

Dietz and Rosa (1997) used a modified version of the IPAT equation in a study of the effects of population and affluence on CO_2 emissions, in a cross-country study (over a hundred nations) using 1989 data. They found that “the impacts of population are roughly proportional to its size across the range of population sizes that will characterize most nations over the next few decades”. Only at income levels above what the overwhelming majority of nations are likely to reach in the next quarter century would the downturn of the Kuznets curve occur. And they comment “this contradicts the views of those who are complacent about population growth”.

Bruvoll and Medin (2003) studied a large array of atmospheric pollutants, including CO_2 in Norway over the period 1980 -1996 in a study of the causal factors (“driving forces”) of the EKC using a decomposition analysis model. While their investigation was not primarily into the effects of population growth, they included population growth as one of the causal factors. They found that keeping all other factors constant, the growth of the Norwegian population (seven per cent) contributed to a corresponding growth in all emissions.

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York et al (2003a) also used a modified version of the IPAT equation to study CO_2 emissions and the energy footprint in a cross-nation study of 146 nations for CO_2 and 138 nations for the energy footprint, exploring a series of models of relationships. Their investigation was also not primarily to investigate the effects of population, but rather an attempt to improve methods of analysis of the anthropogenic forces of global environmental change. However, useful results on the influence of population growth were among the outcomes. They concluded:
"Population clearly appears to be a major driver of both CO_2 emissions and the energy footprint. In all six models the coefficient for population is not significantly different from 1.0, indicating that the population elasticity of impact for both CO_2 and the energy footprint is unit elastic. Thus, a change in population corresponds to a proportional change in both measures of impact".

Now the authors also included the extent of urbanisation and the predominant latitude of each country as variables in their analysis. The former variable was included since it has been suggested that environmental impacts may follow an environmental Kuznets curve relative to urbanization rather than economic development per se. Latitude was included as an indicator of climate effects. The findings here were that urbanization monotonically increases both CO_2 and energy impacts. And nations in non-tropical regions had higher impacts than nations in tropical regions, controlling for other factors.

York et al (2003b) again used a modified version of the IPAT equation to examine the impacts of a whole array of variables on the ecological footprint across most nations. So the ecological footprint is the dependent variable. They developed a series of analytical models in which different groups of independent variables are incorporated.

The authors concluded that population size has a roughly proportional effect on the ecological footprint. A 1% population increase caused a 0.98% increase in ecological footprint with other factors held constant. Also, the larger the proportion of a nations population of ages between 15 and 65, i.e. the working age groups, the larger the footprint. Further, "impacts are higher in nations with more land area per capita, suggesting that resource availability and/or density influences resource demand". And, conforming a conclusion of their other 2003 paper (2003a), impacts also increased the further a nation was from the tropics.

The authors also draw attention to the fact that the various driving forces have a multiplicative effect. Now since they also found that increases in GDP consistently lead to increases in impacts, a key consequence of the multiplicative relationship "is that because of high levels of consumption in affluent nations, even a slow rate of population growth in these nations is at least as great a threat to the environment as is a rapid rate of population growth in less developed nations".
So quoting from other authors "if the Chinese try to eat as much meat and eggs and drive as many cars (per capita) as the Americans the biosphere will fry", the authors point out "that a slow, but steady, growth in the American population, at current consumption levels, may equally challenge the biosphere".

I personally doubt this conclusion. My reason is this. People in developing countries aspire to the same high standard of living as is presently enjoyed by people in developed, industrial countries. They wish to attain to our level of affluence, and are moving in that direction in countries like China. Since population growth is massive in most developing countries, you have a big increase in both P and A in I=PAT and the multiplicative relationship holds there as elsewhere.

Shi (2003) studied the impact of population pressure on global CO_2 emissions. The data was a time-series for 93 countries for the period 1975-1996. For the 93 countries as a whole, Shi found there was an overall upward trend in emissions during this period (total increase during the period of 61.18%). Population during the same period grew by 42.82%. So a 1% rise in population gave a bigger percentage increase in emissions (1.4%) (but see the criticism of this high elasticity by Cole and Neumayer - the next paper we consider below).

Shi went on to see how country per capita income levels might affect the population - CO_2 emissions relationship.
Dividing the 93 countries into four income categories, these were the findings in relation to a one percent rise in population.

Percentage increase in emissions			
low income	lower-middle income	upper-middle income	high income
1.58	1.97	1.42	0.83

In other words, in lower-middle income countries the elasticity of emissions with respect to population is nearly two, while in high income countries it is less than one.

Since developing countries have relatively low per capita incomes compared with developed countries,we see that the impact of population growth on emissions is bigger in developing than in developed countries. This conclusion with carbon dioxide stands somewhat in contrast with the conclusion of York et al (2003b) for ecological footprints, mentioned above. And we note that most future population growth will be in developing countries.

Shi's overall conclusion is that population growth has had a severe adverse effect globally on emissions over the last two decades.

Shi went on to prepare forecasts of global emissions up to 2025, using the United Nations low, medium and high population growth variant projections for population data. The 1990 global population was 5.266 billion and total carbon emissions were 6 gigatons. With the low variant projection, global CO_2 emissions will reach about 12.4 Gt of carbon. With the high variant, the figure is 14.2 Gt of carbon. The implications for global warming are terrible.

Cole and Neumayer (2004) made a study of the relationship of demographic factors to CO_2 and SO_2 emissions, : for CO_2, they worked with data from 86 countries over a period of 24 years (1975-1998); with SO_2, the data came from 54 countries and twenty years (1971 - 1990). There were important differences between the results for the two pollutants.

With CO_2, population increases were matched by proportional increases in emissions: the elasticity of emissions with respect to population were approximately unity over the entire range of country population sizes. The authors comment that their results of unit elasticity with CO_2 confirm the results of Dietz et al (1997) and York et al (2003a). They also question the validity of Shi's much higher elasticity estimates on statistical methodology grounds.

The authors also found, first that a higher urbanization rate increased emissions, a result consistent with the findings of York et al (2003a) we mentioned earlier; second that lower average household size increased emissions.

With SO_2, results were different: there was a U-shaped relationship with population. Population - emission elasticity was negative for very small populations but rose rapidly as population increased. The turning point was about 5.4 million people. So "population generates an increase in emissions for all populations over 5.4 million". Now only a quarter of all countries in the sample have a population below this threshold, so for most countries, an increase in population causes an increase in emissions. Further, urbanization and household size did not make significant contributions to change in SO_2 emissions.

What do the authors think are the reasons for the differences between the two pollutants? "The most likely explanation is that SO_2 and CO_2 emissions differ in their sources. CO_2 emissions are generated by a great variety of economic and consumption activities that are influenced by demographic factors. SO_2 emissions, in contrast, mainly derive from stationary sources and from the production of electricity in particular. On the whole, more SO_2 emissions will be generated for more people, but other demographic factors will not affect emissions".

However, they acknowledge that other "deeper" factors may be at work. Settlement patterns might change at higher population levels in such a way that countries may have to resort to lower quality energy sources. And when population growth rates are high, the resultant pressures on societies may swamp the abilities of those societies to plan and adapt in ways that could reduce the environmental impacts of energy supply.

What about the future? The authors conclude that with both pollutants, **"demographic trends suggest that a rising share of global emissions will be accounted for by developing countries"**(our bold text). The reasons are:

- Continued global population growth, which is mainly in developing countries.
- With CO_2, urbanisation will increase; currently it is on average 56% in developing countries compared with 78% in developed countries.
- Also with CO_2, in developing countries, average household size should fall, as young people are likely to move away earlier from their family home, marry at a later age and their parents increasingly live in separate homes.
- With SO_2, and remembering the low country population size of the turning point, developing countries populations are, on average, much larger than developed countries populations.

In contrast, in developed countries, population growth has slowed down considerably or stopped and urbanization and change in household size are not likely to progress much further.

Finally, Lantz and Feng (2005) made a major study of the impact of population, as well as income and technology on CO_2 emissions. They used panel data from five Canada regions for the period 1970 - 2000. In addition to a basic mathematical model, where GDP per capita is regressed against CO_2, the authors developed alternative models where they add population density and technology as variables (models 1 and 2) in a way that does not assume a linear relationship between these added variables and various measures of environmental degradation (they criticise earlier work by some authors which assumed linear relationships between dependent and independent variables).

These authors found that population has put increasing pressure on CO_2 emissions in Canada . They think their results imply population growth tends to increase fossil fuel use to support increasing demands for goods and services, although to a lesser degree as population continues to grow; thus population elasticities were 0.8 and 0.6 in 1970 and 2000 respectively. While they find evidence for an inverted U-shaped curve for population (i.e. a Kuznets type curve), the turning point occurs at 58 million - far above the then actual population of 30 million.

Summary of this section

Intuitively, one would expect population growth to cause increased environmental degradation, but in the wider environmental literature, which I have not attempted to fully assess, results on this relationship are mixed. If however, we confine ourselves to EKC and EKC-related literature, the focus of the present essay, the following main conclusions seem justified.

As far as CO_2 is concerned, population growth has been one factor causing an increase in emissions. This growth in emissions is thought by most workers to be proportional to population growth. If a inverted U-shaped relationship exists, it is at higher incomes than exist in the majority of countries today and at least in the near future. Urbanisation of the population causes increased emissions. And the greater the proportion of the population that is in the working age groups, the larger the population effect. Also average household size was found in one investigation to be a significant factor (the smaller the average houshold size, the larger the emissions).

Now in developing countries the trends in these demographic factors will continue, whilst there will be little change in developed countries. Combined with the fact that most future population growth will take place in developing countries, the implication is that a rising share of global emissions in the future will be attributable to developing countries. And the variation in population elasticity of CO_2 emissions between poor and rich nations reported in one investigation are consistent with this conclusion.

There is less evidence concerning other pollutants, but is seems that population growth has been one causal factor of the growth in emissions of suspended particulate matter, NO_x, CO and SO_2. For all except SO_2, there seems to be evidence for an inverted U-shaped relationship, but there is conflicting evidence with SO_2 where the relationship may be U-shaped. But for all four pollutants, most countries have average incomes that seem to imply population growth will continue to cause increased emissions for quite a while yet at least. Again, for SO_2 at least, it seems likely that a rising share of global emissions will come from developing countries, because they have a higher population growth rate than developed countries and on average developing countries are larger than developed countries.

Turning to a more comprehensive measure of environmental impact, namely the ecological footprint, population growth is a major force driving up the total footprint and the energy component of that footprint, population growth having a roughly proportional effect. Urbanization and age structure have similar effects as have been found with CO_2. Bearing in mind the multiplicative effects indicated by the IPAT equation, the high level of affluence in developed countries implies that even a small rate of population growth (from whatever cause) in these countries will mean that population growth there will continue to play a major role in increasing the global footprint.

Now the environmental indicators that have been studied in EKC literature on population influences, by no means cover the whole range of factors which contribute to environmental degradation. Strictly speaking then, we cannot generalise to a quantitative view on the influence of population growth on likely total future global environmental degradation. But whatever the influence population growth turns out to have on these other factors, we can conclude that population growth will be a major cause of further global environmental deterioration. And even if per capita environmental degradation was to decrease with rising income, population growth, especially in developing nations, is likely to override, to swamp, the beneficial effect of this reduction on a country's total environmental degradation.

Conclusions

Despite concerns over adequacy of data sources and criticisms of methodology, it is generally agreed that an inverted U-shaped relationship (the EKC) between economic growth, usually measured as per capita GDP, and some indicators of environmental quality has been found. And the causes of this EKC have been largely unravelled. To some extent, technological improvements, and shifts in relative importance of sectors of the economy, especially the movement away from energy intensive manufacturing industries to service industries (composition effects), which have been normal elements of economic growth, have been causal factors. Economic growth then, has been a causal factor of the EKC.

But economic growth per se does not alone produce the EKC. Combinations of other factors seem to be essential for the EKC to develop. These include various aspects of a country's environmental regulatory system, including standards, implementation and enforcement mechanisms, and associated institutions. Property rights also are important. A high general administrative, political, scientific and technical capability, seems also to be a hallmark of countries where the EKC relationship has developed. On the other hand, and although the evidence is somewhat conflicting, corruption, a high degree of income inequality, low level of literacy, lack of political rights and civil liberties, may impede the development of the EKC relationship.

Environmental indicators that have shown the EKC relationship are primarily pollutants, especially air quality indicators. And these are primarily pollutants which have a direct effect on human health rather than pollutants that have little direct impact on health. Some water quality indicators have shown the EKC, but for some others an N-shaped rather than an inverted U-shaped relationship has been detected.

Leaving aside pollutants and water quality indicators, a wide variety of other environmental indicators do not show evidence of the EKC. Environmental problems having a direct impact on human health, such as access to urban sanitation and clean water, usually tend to improve steadily with economic growth, according to Dinda (2004), who also observes however, that when environmental problems can be externalized, as with municipal solid wastes, improvement may not occur even at high income levels.

It is when we come to look at indicators of resource use that we especially find a dearth of evidence for the EKC. Perhaps the most studied resource is forests, and here the evidence on deforestation is conflicting, although it seems likely that the EKC relationship may have been found in some parts of the world.

If we are interested in the global significance of EKCs, it is worth remembering that the existence of an EKC demonstrated on data from individual countries, does not necessarily mean that the beneficial effect for the particular indicator concerned applies to global levels of environmental degradation, i.e. does not necessarily imply global benefit. For it does seem to be generally agreed that there is at least some truth in the Pollution Haven Hypothesis (PHH). However, since opinions seem still to be divided on the significance of the PHH, one should perhaps not stress its possible significance.

More important, if we are looking at the total global environmental situation, is the realisation of how limited is the extent that the EKC relationship has actually been found. Consider some aspects of this total environmental situation: reduction and degradation of natural habitats, including forests (not withstanding the possible existence of the EKC in some places as already mentioned), reduction of species diversity including extinction of species, salinization of soils, soil erosion, drastic reduction of ocean fish stocks, etc. And, recalling a comment of O'Neill et al (1996), we note that EKC analyses say little about basic ecosystem services: "cleaning the water, purifying the air, decomposing wastes, maintaining CO_2 balance, permitting recovery from natural disturbances, filtering ultraviolet radiation.". The limited known occurrence of the EKC does not then offer us much comfort about future global environmental trends.

And we also note how O'Neill et al assert that even if wealthy nations are able to reduce pollution, economic growth will impose increasing stress on ecosystems. And "total impact can be expected to increase as a function of GDP, considering cumulative depletion of resources, land use changes with implications for water quality and biodiversity, and rates of exploitation that exceed rates of replacement".

We must also remember, as Schindler (1996) observed for Canada, that generally speaking governments do not begin to commit themselves to major expenditures on the environment until environmental damage has already become very serious. It is then that time-consuming, very costly - and often ineffectual - assessment, cleanup and restoration activities are undertaken. Probably the same thing applies to the development and implementation of environmental policies.

If we approach environmental deterioration through the related concept of material flow analysis, the conclusions are not really more encouraging. In industrialized countries, a week de-linking of environmental intensity from economic growth has taken place, but there is little evidence of any long persistence of strong de-linking. And once again, such studies do not encompass the totality of environmental degradation.

For the EKC effect to occur, a nation needs to have achieved a per capita income higher than the turning point income of the curve. Yet most developing nations still have per capita incomes corresponding to the left (degradation increasing) side of the curve. Achieving a downturn in degradation will then require considerable economic growth. Whether this will be achieved by some of the poorest nations is very doubtful. We also have to bear in mind that in so far as the export of pollution-intensive industries is an important factor for pollution reduction, developing countries are unlikley to have this option. Further, as already emphasized, economic growth (even accompanied by export of pollution-intensive industries), does not by itself produce the EKC. Other factors are important. Corruption is often rife in developing countries, democracy often shaky or absent, income inequality great, conflict sometimes common (think of sub-Saharan Africa!). All these factors will militate against the EKC relationship developing in LDCs. And as far as corruption is concerned, recall what Lopez and Mitra (2000) said with special reference to large developing countries such as China, India and Indonesia, countries that are "experiencing explosive economic growth":
"Unless this growth process brings about a rapid reduction of corruption (an unlikely event given that institutions and cultural norms typically show extraordinary resilience), pollution will remain much higher in these countries than the levels reached in currently developed countries when their per capita incomes were comparable".

On top of all these considerations, we have the effects of human population growth which were dealt with in the previous section. With many developing countries at least, the population growth effect on environmental degradation for some indicators is likely to override, to swamp, the beneficial effects of any reduction of per capita environmental degradation for these indicators occurring as average incomes rise.

However, the general picture is not entirely one of gloom and doom. In the first place, some industrial nations have achieved strong de-linking at least for a while, despite usually modest continued population growth. Also, bearing in mind that achieving the EKC relationship seems to require the introduction of strong regulations, some have feared that the resultant increases in business costs could reduce a country's competitiveness. Yet we saw that Esty and Porter (2005) found a strong positive correlation between regulatory regime and competitiveness. They concluded that the evidence supports the view that environmental progress can be made without sacrificing competitiveness.

REFERENCES

Arrow, K. et al. (1995). Economic growth, carrying capacity and the environment. Ecological Economics 15: 91-95.

Ayres, R.U. (1995). Economic growth; politically necessary but not environmentally friendly. Ecological Economics 15: 97-99.

Barbier, E.B. (1997). Environmental Kuznets Curve special issue. Environment and Development Economics 2: 369-381.

Beckerman, W. (1992). Economic growth and the environment: Whose growth? Whose environment? World Development 20, 4: 481-496.

Bhaskar, V. & Glyn, A. Eds. (1995). The North, the South and the Environment. Ecological Constraints and the Economy. Earthscan, London

Bhattarai, M. & Hammig, M. (2004). Governance, economic policy, and the environmental Kuznets curve for natural tropical forests. Environment and Development Economics 9: 367-382.

Birdsall, N. et al. (2001). Population matters. Demographic change, economic growth, and poverty in the developing world. Oxford University Press.

Bruvoll, A. & Medin, H. (2003). Factors behind the Environmental Kuznets Curve. Environmental and Resource Economics 24: 27-48.

Canas, A. (2003). A new environmental Kuznets curve? Relationship between direct material input and income per capita: evidence from industrialised countries. Ecological Economics 46, 2: 217-229.

Cole, M.A. et al. (1997). The environmental Kuznets curve: an empirical analysis. Environment and Development Economics 2: 401-416.

Cole, M.A. (2003). Development, trade, and the environment: how robust is the Environmental Kuznets curve? Environment and Development Economics 8: 557-580.

Cole, M.A. & Neumayer, E. (2004). Examining the impact of demographic factors on air pollution. Population and Environment 26, 1: 5-21.

Cole, M.A. & Neumayer, E. (2005). Environmental policy and the environmental Kuznets curve: can developing countries escape the detrimental consequences of economic growth?. In “Handbook of global environmental politics” (ed. P. Dauvergne). Edward Elgar.

Cramer, J.C. (1998). Population growth and air quality in California. Demography 35, 1: 45-56.

Cropper, M. & Griffiths, C. (1994). The interaction of population growth and environmental quality. The American Economic Review 84, 2: 250-254.

Dietz, T. & Rosa, E.A. (1997). Effects of population and affluence on CO2 emissions. Proceedings of the National Academy of Sciences of the USA 94: 175-179

Dinda, S. (2004). Environmental Kuznets Curve hypothesis; a survey. Ecological Economics 49, 4: 431-455.

Dinda, S. (2005). A theoretical basis for the Environmental Kuznets Curve. Ecological Economics 53, 3: 403-413.

Ekins, P. (1997). The Kuznets curve for the environment and economic growth; examining the evidence. Environment and Planning A 29: 805-830.

Esty, D.C. & Porter, M.E. (2005). National environmental performance: an empirical analysis of policy results and determinants. Environment and Development Economics 10: 391-434.

Fischer-Kowalski, M. & Amann, C. (2001). Beyond IPAT and Kuznets Curves: Globalization as a vital factor in analysing the environmental impact of socio-economic metabolism. Population and Environment 23, 1: 7-47.

Grossman, G.M. & Krueger, A.B. (1991). Environmental impact of a North American free trade agreement. Working paper 3914, National Bureau of Economic Research, Cambridge, MA.

Herman, R. et al. (1990). Dematerialization. Technological Forecasting and Social Change 38: 333-347.

Kuznets, S. (1955). Economic growth and income inequality. The American Economic Review 45, 1: 1-28.

Kuznets, S. (1967). Population and economic growth. Proceedings of the American Philosophical Society 111, 3: 170-193.

Lantz, V. & Feng, Q. (2005). Assessing income, population, and technology impacts on CO_2 emissions in Canada: Where's the EKC? Ecological Economics. In Press, available online 13 June 2005.

Lopez, R. & Mitra, S. (2000). Corruption, pollution and the Kuznets environment curve. Journal of Environmental Economics and Management 40:137-150.

Moomaw, W.R. & Unruh, G.C. (1997). Are environmental Kuznets curves misleading us? The case of CO_2 emissions. Environment and Development Economics 2: 451-463.

O'Neill, R.V. et al. (1996). Economic growth and sustainability: a new challenge. Ecological Applications 6, 1: 23-24.

Patel, S.H. et al. (1995). Smallholder wood production and population pressure in East Africa: evidence of an environmental Kuznets curve? Land Economics 71, 4: 516-530.

Pender, J. (2001). Rural Population growth, agricultural change, and natural resource management in developing countries: a review of hypotheses and some evidence from Honduras. In: Population Matters. demographic change, economic growth, and poverty in the developing world. Birdsall, N. et al (Eds.) Oxford University Press.

Qiguo, Z. (1994). Land degradation and improvement. In: Population - the complex reality. The Royal Society.

Schindler, D.W. (1996). The environment, carrying capacity and economic growth. Ecological applications 6, 1: 17-19.

Selden, T.M. & Song, D. (1994). Environmental quality and development: Is there a Kuznets curve for air pollution emissions? Journal of Environmental Economics and Management 27: 147-162.

Shi, A. (2003). The impact of population pressure on global carbon dioxide emissions, 1975-1996: evidence from pooled cross-country data. Ecological Economics 44: 29-42.

Taylor, M.S. (2005). Unbundling the pollution haven hypothesis. University of Calgary Department of Economics Discussion Paper 2005-15.

Tiffen, M. et al. (1994). More people, less erosion: environmental recovery in Kenya. J.Wiley, Chichester, New York.

Torras, M. & Boyce, J.K. (1998). Income, inequality, and pollution: a reassessment of the environmental Kuznets curve. Ecological Economics 25: 147-160.

Vehmas, J. et al. (2003). Material flows and economic growth. Linking analyses and environmental Kuznets curves for the EU-15 member countries in 1980-2000. Tutu publications 8/2003, Turku School of Economics and Business Administration, Finland.

Vincent, J.R. (1997). Testing for environmental Kuznets curves within a developing country. Environment and Development Economics 2: 417-431.

Yandle, B. et al. (2004). Environmental Kuznets Curves: A review of findings, methods, and policy implications. Research study 02-1 update April 2004, The Property and Environment Research Centre.

York, R. et al. (2003a). STIRPAT, IPAT and ImPACT: analytic tools for unpacking the driving forces of environmental impacts. Ecological Economics 46: 351- 365.

York, R. et al. (2003b). Footprints on the earth: the environmental consequences of modernity. American Sociological Review 68: 279-300.