On the use of headline indices to link environmental quality and income at the level of the nation state.

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ABSTRACT

This paper deconstructs the relationship between the Environmental Sustainability Index (ESI) and national income. The ESI attempts to provide a single figure which encapsulates 'environmental sustainability' for each country included in the analysis, and this allied with a 'league table' format so as to name and shame bad performers, has resulted in widespread reporting within the popular presses of a number of countries. In essence, the higher the value of the ESI then the more 'environmentally sustainable' a country is deemed to be. A logical progression beyond the use of the ESI to publicise environmental sustainability is its use within a more analytical context. Thus an index designed to simplify in order to have an impact on policy is used to try and understand causes of good and bad performance in environmental sustainability. For example the creators of the ESI claim that ESI is related to GDP/capita (adjusted for Purchasing Power Parity) such that the ESI increases linearly with wealth. While this may in a sense be a comforting picture, do the variables within the ESI allow for alternatives to the story, and if they do then what are the repercussions for those producing such indices for broad consumption amongst the policy makers, mangers, the press etc.? The latter point is especially important given the appetite for such indices amongst non-specialists, and for all their weaknesses the ESI and other such aggregated indices will not go away.

Keywords: Environmental Sustainability Index; environmental quality; Environmental Kuznets Curve

1. INTRODUCTION

With the turn of the 21st century there is an increasing popularity of indices of environmental sustainability promoted by powerful groups such as the World Economic Forum (WEF). The Environmental Sustainability Index (ESI), created in 1999 by Yale and Colombia Universities in the USA (the self-styled '*Global Leaders of Tomorrow'*), is one such index. The ESI combines a variety of diverse data sets including ambient pollution and emissions of pollutants to impacts on human health and being a signatory to international agreements. Values of the ESI for each country vary between 0 (most unsustainable) to 100 (most sustainable), and as with the Human Development Index of the United Nations Development Programme the results for individual countries are presented in a league table format with the aim of naming and shaming bad performance. As with many such aggregated indices the idea is straightforward – to condense complex data sets into a single value that can be easily interpreted and make the results as accessible as possible. Indeed the project has been successful at least in the sense that the ESI league tables have been widely reported in the popular press. The following are but a few examples:

"*Finland is the world leader in pursuing environmental friendly policies, according to a study of 146 countries for a global index that ranks North Korea, Iraq and Taiwan at the bottom.*"

The Economic Times (January 28th, 2005)

"*Britain has one of the worst environmental records in Europe………….It ranks 66th out of the 146 countries on the index, considerably behind most of northern Europe, the US (ranked 45th) and even most of the former Soviet Union………..Last night a spokesman for the*

Department for Environmental Food and Rural Affairs said 'The UK has a good record on sustainability. Drinking water quality, bathing waters, river water and air quality are all improving year by year and many endangered species are now recovering due to government action. We strongly dispute the methodology of the index which is flawed and potentially misleading. However, Norman Baker, environmental spokesman for the Liberal Democrats, said 'The government is always at pains to point out that the sustainability index isn't reliable. I'm sure if they came near the top they'd have an entirely different view of the matter' ……Belgium's abysmal ranking in 2002 triggered an outcry in that country."

Julian Borger and Ian Sample, The Guardian (January 25th 2005)

"*Out of 146 nations, the United States, the world's richest nation, ranked only 45th for protecting the environment………The average American has 54 times more money in GDP terms than the average person in Congo. Yet the Congolese exhibit better stewardship of the planet………..Five years ago, poor standings in a pilot version of the index sparked a cabinet-level review of environmental practices in Mexico. In 2002, bad rankings moved the governments of South Korea, the United Arab Emirates, the Philippines, and Belgium to also conduct policy reviews*."

Derrick Z. Jackson, Boston Globe (January 26th, 2005)

"*In the 2005 Yale/Colombia universities' global study, the Environmental Sustainability Index (ESI), this country has the worst scores of 146 nations for our percentage of negative land impacts and threats to biodiversity. Yale University contacted the Daily Express on Monday confirming 'your assessment corresponds to our findings for Trinidad & Tobago and we* *thank you for bringing the ESI and the environmental problems it highlights to the attention of the citizens and policymakers in your country*.'"

Mark Meredith, Trinidad & Tobago Express (May 30th, 2005)

"*The ESI is a third measure for the state of the world's nations, the others being the indices of human development and economic variables. It makes the vital point that sustainable economic growth actually requires the adoption of polices that aid its environment rather than destroy it. Several countries of the developing world, such as Gabon (ESI 61.7) and Uruguay (ESI 71.8) have done it. With some political commitment, so can we*."

G. Ananthakrishnan, The Hindu (21st February, 2005)

"*The price of Taiwan's economic juggernaut over the past 30 years was brought into stark focus last month at the Davos World Economic Forum when a highly regarded report on environmental sustainability placed the country at the very bottom of 146 surveyed nations, only slightly ahead of North Korea, but behind such countries as Iraq and Turkmenistan……………..When graphed to show its effectiveness in environmental sustainability relative to GDP/capita, Taiwan stands isolated in a very unfavourable zone on the chart, indicating that while national wealth can be a boost to environmental sustainability, Taiwan proves that it dos not guarantee it*."

Max Woodworth, Taipei Times (20th February, 2005)

Building upon this success, the creators of the ESI are understandably confident that it will continue to grow in popularity:

"*The ESI is still a work in progress, but it has reached the point where it provides a credible measure of relative government performance on many of the short- and medium-term actions necessary to achieve environmental sustainability. With continued improvement, it will grow in validity and impact – perhaps someday becoming as important a measure as GDP in assessing national progress*."

(Esty et al., 2005: page 41)

A logical step taken by the creators of the ESI, and indeed one that is echoed in much of the press reporting such as the examples provided above, is to link the ESI with national income. Esty (2001) claims the relationship to be highly significant and linear such that the ESI increases with GDP/capita (adjusted for Purchasing Power Parity). This relationship is presented in the ESI reports in the form of a graph such as that of Figure 1 along with associated commentary. Esty (2001: page 10611) has suggested that good economic performance is a result of good environmental performance rather than the reverse:

"*While the stronger hypothesis – that good environmental performance leads to good economic results – cannot be confirmed, the long-standing development theory, which argues that countries must get rich before they get clean, appears to be strongly disproved*".

Others have suggested that increasing economic returns can follow an abatement of pollution (Andreoni and Levinson, 2001), and the assertion for a positive linear relationship with GDP/capita is repeated in the ESI report of 2005 (Esty et al., 2005; page 26) where the R^2 is claimed to be 23%. Indeed Figure 1 has been constructed by this author from the ESI indices presented in the 2005 report, and the regression model is statistically significant at $P < 0.001$. The authors of the ESI report explain this link in straightforward terms as "*this result suggests that richer countries can – and do – invest in pollution control and other environmental amenities*" although it is also acknowledged that "*high-income countries put significantly more stress on their environments than low-income ones*" (Esty et al., 2005; page 26) and that there are 'outliers' – countries that perform better or worse than their income would predict. After all, an R^2 of 23% still leaves 77% of the variation unexplained by the 'best fit' regression model.

<Figure 1 near here>

Potentially this conclusion of an increase in wealth broadly leading to a better environment is of much interest, especially to those countries undergoing rapid economic development such as China but also globally. It certainly provides a comforting perspective even when allowing for some under and over-performance as predicted by income. However, is the ESI-based evidence conclusive?

This paper will deconstruct the simplistic linearity of the comforting linear ESI-income relationship, from here on referred to as the LEI, even if it is appealing. Do the variables within the ESI allow for alternatives to the story, and if they do then what are the repercussions for those producing such indices for broad consumption amongst the policy makers, mangers, the press etc.? The latter point is especially important given the appetite for such indices amongst non-specialists, and for all their weaknesses the ESI and other such aggregated indices will not go away. The paper will begin with a brief summary of the ESI and the research to date which has attempted to relate environmental sustainability to national income and then use this theory to deconstruct the ESI-income regression.

2. ENVIRONMETNAL SUSTAINABILITY INDEX (ESI)

The methodology to arrive at the ESI for a country is somewhat complex, and details can be found in the reports available at www.ciesin.columbia.edu/indicators/ESI/). Hence only a summary will be provided here for the ESI 2005. It should be noted that there was significant variation in methodology, including the selection of variables, across the three published versions of the ESI to date (2001, 2002 and 2005), but throughout these versions the underlying principle is the same – an aggregation of complexity into a single index.

The ESI 2005 process begins with raw data sets for 76 variables (Table 1) which are aggregated into 22 'indicators'. The choice of variables and the process of aggregation are made by the creators of the ESI. The variables all have very different units of measurement and need to be standardized for aggregation to take place. If the data within each variable has a highly skewed distribution then the original data are transformed by taking logarithms. Each variable is then 'capped' so as to remove extreme values, and for the most part this is achieved by employing the 97.5 and 2.5% percentiles. Once capped the variable data are standardised by subtracting the mean or subtracting from the mean and dividing by the standard deviation. The format of the standardisation depends upon whether higher values of the variable are deemed to be ‘good’ or ‘bad’ for sustainability. If higher values (e.g. biodiversity) are deemed to be good then the z-value is given by:

$$\text{z-value} = \frac{\text{country value - mean}}{\text{standard deviation}}$$

If high values are deemed to be bad for sustainability (e.g. emissions of pollutants) then the z value is given by:

$$\text{z-value} = \frac{\text{mean – country value}}{\text{standard deviation}}$$

The average z-value is then found for each indicator and these are in turn averaged to yield the ESI after conversion to a more intuitively meaningful statistic by calculating the ‘standardised normal percentile’. The result is a set of numbers with a theoretical minimum of 0 and a theoretical maximum of 100. The higher the ESI then the better the environmental sustainability for that country.

<Table 1 near here>

While there is no doubt of the high profile and popularity of the ESI reports as illustrated in the quotations above the nature of the index is not beyond reproach and has attracted criticism. To begin with it is a snapshot – a slice in time – and it would be far better to have a time-series dataset for individual countries. The ESI has only been published for three years (2001, 2002 and 2005) and the methodology does vary over those years making a time-series based analysis difficult. Secondly, the nation-state bounded nature of the ESI ignores the obvious fact that pollution can cross frontiers and indeed some countries will 'export' dirty and low wage production to developing countries thereby exacerbating the variation in the ESI (Lawn, 2007, pp 238-242). Thirdly, the ESI is a measure of 'environmental sustainability' and hence includes many variables that are not measures of environmental quality or degradation but instead assess what countries are 'doing' about such problems. Thus there are a number of components that measure institutional 'capacity', involvement in international collaborative efforts and investment in science and technology and this naturally favors the richer countries. Finally, the choice of variables that comprise the ESI is a subjective process and hence the index is largely reflecting what its creators at Yale and Colombia Universities feel is important (The Ecologist, 2001).

3. LINKING NATIONAL WEALTH AND ENVIRONMENTAL DEGRADATION

Linking environmental degradation to economic performance at nation-state levels does have something of a long and complex pedigree that predates the ESI reports. Perhaps the best known theory of such a relationship is expressed in terms of the Environmental Kuznets Curve (EKC). The EKC is perhaps one of the iconic visual images of sustainable development (Nahman and Antrobus, 2005). The theory behind it is simple (Figure 2a), but does deviate somewhat from the LEI. In essence the EKC implies that as income of a geographical region (e.g. a country) increases then so does environmental degradation (a decline in environmental ‘quality’) but at a certain point the relationship reverses – degradation declines as income increases further (Jha and Bhanu Murthy, 2003a; Stern, 2004). It is theorized that at some level of income the population begins to value the environment and this leads to responses such as pressure being placed (legal, moral or otherwise) on the polluters to reduce the damage which they are inflicting (Dasgupta et al., 2002; Jha and Bhanu Murthy, 2003a; Di Vita, 2004; Stern, 2004; Dinda, 2005). As a result damaging processes are replaced by less damaging ones or perhaps closed altogether. Thus whereas the LEI relationship suggests that environmental sustainability improves more of less continuously with national wealth the EKC provides a more complex and less comforting theory that environmental degradation actually worsens with wealth before improving. As already discussed environmental sustainability (as envisioned in the ESI) is admittedly not the same as environmental degradation but one would expect them to be inversely related – degradation should, by definition, imply unsustainability.

<Figure 2 near here>

In contrast to the ‘bullish’ expression of the LEI regression in the ESI reports proof for the EKC has been less forthcoming and indeed has been somewhat contentious. Given the extent of the EKC literature this paper can only aspire to touch upon the topic rather than provide an exhaustive review. Theory suggests that the EKC should have a quadratic form (Torras and Boyce, 1998; Dasgupta et al., 2002; Cole, 2003) and there have been various studies since 1991, largely reported in the applied economics literature, to test whether the EKC exists. The relationship can be explored within a region, country or group of countries (List and Gallet, 1999) by looking at change in 'degradation' as a geographical entity (population) become wealthier over time and some recent examples are He (2005) and De Groot et al. (2004) for China, Paudel at al. (2005)and Rupasingha et al. (2004) in the US and Kristrom and Lundgren (2005) for CO_2 emission in Sweden. The problem with this approach is typically the availability of good quality time-series data. A second approach is to take a cross-section of countries spanning a range of income and check for the existence of the EKC using various means of gauging 'degradation'. Using this cross-sectional approach, often allied with time-series data, some studies have indeed provided evidence for a 'quadratic' EKC based on pollution (Roberts and Grimes, 1997; Lindmark, 2004; Hartman and Kwon, 2005; Chimeli and Braden, 2005), deforestation (Mather et al., 1999; Koop and Tole, 1999) and threatened species (McPherson and Nieswiadomy, 2005). However, one problem with the cross-sectional approach is that there may be cross-country interactions at play in environmental degradation that could generate an EKC but by a different set of mechanisms than originally postulated. Pollution, of course, does not respect borders, and indeed some richer countries may 'export' their polluting industries to poorer ones; the so-called Pollution Haven Hypothesis (Cole, 2004).

In a further development that provides some methodological resonance with the LEI graphs Jha and Bhanu Murthy (2003a) have created what they refer to as an Environmental Degradation Index (EDI) comprising:

- Annual per capita fresh water withdrawals
- Annual fresh water withdrawals as a percentage as a percentage of water resources
- Printing and writing paper consumed per capita

- CO_2 emissions per capita
- Share of world CO_2 emissions
- Average annual rate of deforestation

The data for these were obtained from the Human Development Report publications of the United Nations Development Programme. Jha and Bhanu Murthy (2003a) use the EDI as a measure of degradation and go on to show how it can be employed in the development of an 'inverted U' EKC using the widely publicized Human Development Index (HDI) rather than just income as the vertical axis.

Nonetheless given that the meaning of 'degradation' and 'quality' can be rather subjective, and given that environmental data can be 'noisy', it is perhaps no surprise that conclusive evidence for a quadratic form of EKC has been elusive (Stern et al., 1996; Ekins, 1997; Perman and Stern, 2003; Stern, 2004; Galeotti and Lanza, 2005; Nahman and Antrobus, 2005). Indeed it has been postulated that an *a priori* assumption of a quadratic type curve and the economic theory upon which it is based may be deceptive (Galeotti and Lanza, 2005). After all as with the LEI any attempt to generate an EKC from a complex set of empirical data inevitably involves a reduction of complexity and thus is arbitrary (Harbaugh et al. 2002). For example, Sobhee (2004) suggests a logistic type model where there is a flattening of degradation at some level of income but not an eventual decline (Figure 2b), and there is also the possibility that the relationship is logarithmic where degradation continues to increase with income, albeit at a slower rate (Figure 2c). There are even more exotic suggestions based on empirical studies such as a 'two-hump' (cubic) polynomial curve (Figure 1d; Rupasingha et al., 2004; Bousquet and Favard, 2005). Much can depend upon how environmental degradation is measured, the quality of the data, what countries and years are included etc. (Harbaugh et al., 2002).

Given that environmental sustainability and environmental degradation are related – degradation would by definition suggest unsustainability – then can the ESI datasets be used to generate an EKC or does the story continuously point towards a linear, simple and comforting improvement in sustainability with income? The ESI is an aggregate index combining many variables, and it may be that while the variables could suggest an EKC the result of aggregation may be to lose that detail and leave the tempting mirage of the LEI.

3. METHODOLOGY

For the purposes of this study it was decided to employ the z-values of the variables as provided in the ESI report of 2005 (Esty et al., 2005) rather than the raw data, indicators or the final ESI. It should be noted that the z-values would have passed through the process of capping of extreme values and possibly also logarithmic transformation. For various reasons the ESI values of 2001 and 2002 are not directly comparable to those of 2005, although comments are frequently made in the media regarding an 'improvement' or 'worsening' of a country's position in the ESI league table. Hence a time-series analysis was not possible.

The ESI variables can be placed into four categories based on the Pressure-State-Impact-Response (PSIR) framework as shown in Table 1:

- Pressure (18 variables) e.g. rate of release of pollutants
- State (19 variables) e.g. concentration of pollutants
- Impact (6 variables) e.g. rate of respiratory disease arising from air pollution
- Response (33 variables) e.g. policy responses to limit the release of pollutants

It has to be acknowledged that the classification of variables in this way is a subjective process, as indeed is the selection of variables for the ESI. The z-values for ‘state’ and ‘pressure’ categories of variables were employed as measures of environmental degradation, while ‘response’ variables were also included in the analysis to test whether this category does improve with income. The assumption is that the ‘pressure’ and ‘state’ variables provide a two-dimensional measure of environmental degradation – state being a function of pressure.

A Principal Component Analysis (PCA) was employed in order to extract out a first and second principal component from the z-values classified as ‘state’, ‘pressure’ and ‘response’. The use of PCA for ESI datasets has formed the basis for some published studies, and Jha and Murthy (2003b) argue that PCA provides a much better alternative to the averaging inherent within the ESI. In the analysis presented here it is the 1st and 2nd principal components that act as proxy measures of environmental quality. The pressure and state PCAs were based on 17 and 18 variables respectively. WQ_SS (state) and SO2EXP (pressure) were not included in the PCA as the numbers of z-values published for ESI 2005 were low. The response PCA was based on all 33 variables included in that category.

For the national income, the values for GDP/capita (adjusted for purchasing power parity, PPP) published in the 2002 Human Development Report (UNDP, 2002) were employed. The real GDP/capita values were for 2000 (base year is 1996) and the intention was allow for a 5 year time-lag between income and impact on the state, pressure and response variables. For the most part the analysis of the linkage between the state and pressure principal components and income was via regression. Gaps in the availability of GDP/capita (PPP) data for 2002 meant that the analysis could only be based on 141 countries of the 146 included in the ESI 2005 report.

4. RESULTS

The matrix of correlation coefficients between the ESI variables classified as 'pressure' and those as 'state' is shown as Table 2. It is these matrices which formed the basis of the PCA, and the results are shown as Table 3. For the pressure variables the first principal component accounted for some 70% of the variation which the second accounted for some 9%. For the state variables the respective figures were 40% and 19%.

<Tables 2 and 3 near here>

As would be expected, the state 1st PC (dependent variable) can be significantly ($P < 0.001$) correlated to pressure 1st PC (independent variable) as shown in Figure 3. This suggests that the state and pressure 1st principal components are related in a way which seems logical as cause-effect. As pressure worsens (i.e. becomes greater on the environment) then the state of the environment (degradation) also worsens. Note that high values of the state 1st PC correspond to 'better' environments.

<Figure 3 near here>

So how do these measures of ‘state’ and ‘pressure’ relate to GDP/capita? Is the LEI regression upheld? Starting with an *a priori* assumption of a quadratic EKC then the 1st and 2nd principal components of the pressure variables can be shown to be significantly related to GDP/capita ($0000, PPP) as shown in Figure 4. As income increases then so do the pressure PCs (pressure on the environment increases) until a point is reached where the pressure begins to decline. The R^2 for both these components are 76% and 21% respectively, and hence are at least comparable to the 23% R^2 of the LEI in Figure 1. Similarly, the state 1st and 2nd principal components can also be significantly regressed using a quadratic model onto GDP/capita (Figure 5). Again, as income increases then the state of the environment worsens (the principal components decline) before improving once a certain income is reached. Although the R^2 for the ‘state’ regressions are lower than for ‘pressure’ the respective values of 37% and 32% are still reasonable and well above the 23% of Figure 1. In each of the four cases the quadratic models provides a significantly better fit than simple linear models. Thus a separation of the state and pressure components of the ESI shows a quite different trend with national income than does the aggregated index.

<Figures 4 and 5 near here>

The assumption behind the quadratic form of the EKC is that as income increases then a host of mitigating factors come into play such as a switching to less polluting industries as a consequence of better regulation/ enforcement and investment in cleaner technologies. Do the ESI ‘response’ variables support such an assertion that ‘response’ gets better with income? The correlation coefficients and PCA for the response variables are presented in Tables 2 and 3 respectively, and a plot of the response 1st and 2nd principal components against GAP/capita is presented as Figure 6. The results for the 1st PC suggest that ‘response’ does improve linearly with income (note that lower values of the response 1st PC equate to ‘better’ response). But note that these findings imply that for lower levels of income an increasing ‘response’ does not necessarily lead to better environmental quality (‘state’ and ‘pressure’ worsen) but there is nonetheless a point where better ‘response’ flips the state and pressure trends into a curve.

<Figure 6 near here>

But is the quadratic (EKC) form of the relationships between state, pressure and income the most appropriate in the first place? After all, there have been various suggestions as to which form of reduced model best encapsulates the trend in complex data sets such as these. Only one alternative will be explored here, the logarithmic model, largely because it provides a significant contrast to a simple assumption that environmental quality improves with income. The versions of the relationship between pressure and state principal components and GDP/capita based upon the logarithmic hypothesis (i.e. that pressure and state always ‘worsen’ with income) are shown as Figures 7 and 8. In each case the log (base e) of the GDP/capita values have been taken and the hypothesis tested by looking for a linear trend.

<Figures 7 and 8 near here>

A significant ($P<0.001$) linear relationship can be found for 3 out of the 4 figures, with the only exception being for the 2nd PC of pressure. If anything the values of the R^2 are just as high – if not slightly higher – than for the quadratic model. Thus it would appear that while a quadratic fit can be made to the principal components then so can a logarithmic one, although in each case the hypothesis behind the model is quite different. The quadratic reduced form implies that the environment will eventually get ‘better’ as income increases while the logarithmic model implies that it will not, although the rate of decline in environmental quality does fall. In either case a separation of state and pressure components from the ESI does provide for a more complex argument than a simple ‘more income equals better sustainability’ implied by the LEI in Figure 1.

5. DISCUSSION

The ESI is, by design not accident, a simplified measure of environmental sustainability, and includes a substantial proportion of ‘response’ variables that are positively related to income. The simplification was for a purpose – to generate a single value representing ‘environmental sustainability’ which can be used to rank countries and thereby put peer pressure on politicians, policy makers and mangers to make decisions that enhance sustainability. The ESI is not meant to help us understand environmental sustainability. However, despite the limitations it is easy to appreciate the temptation to use the ESI to explore cause-effects in environmental sustainability, and one of them is the link with national income. Indeed this is a relationship that does receive some prominence within the ESI reports. Taking the index as a whole there is a very comforting ‘linear’ improvement in environmental sustainability with income. Countries having a low income also have low values for the ESI and vice versa. In fairness to its creators, they do stress the reverse cause-effect (better sustainability gives better economic performance) but it is more likely that the message implied by graphs such as Figure 1 will reinforce the notion that ‘richer is environmentally better’. Given the ‘headline’ power of the ESI in the popular media and hence to influence policy then the potential for such a reduction to be established as 'truth' is strong. Statements such as the following are arguably almost inevitable (this one is based on the ESI 2002):

"*there is a connection between a country's wealth, economic freedom and environmental sustainability. This suggests that the best strategy for sustainable development is free markets and liberal democracy*."

Daily Policy Digest, National Centre for Policy Analysis (2002; www.ncpa.org)

Thus the implication of LEI for the NCPA is that countries should strive for economic growth (via free markets and democracy) and environmental sustainability will follow.

But what do the results of the research reported here say about the relationship between the ESI and income? Unpacking the ESI leads to more complex conclusions that despite the limitations of the evidence are more in tune with existing knowledge on the form of the relationship between environmental quality and wealth. With both the pressure and state principal components (proxies for environmental quality) there were significant quadratic relationships with GDP/capita – the indicator of income employed here. If it is assumed that the pressure and state principal components derived from the z-values of the ESI variables are related to some notion of 'environmental quality', and admittedly this is a major assumption, then the results provide evidence for an *a priori* hypothesis that environmental quality initially worsens with increasing income before improving. The improvement in 'response' variables with income provides some support for this inverted ‘U’ EKC hypothesis. Admittedly the inverted ‘U’ is but one reduced form of many possibilities (Dasgupta et al., 2002), and only one, the logarithmic model (Sobhee, 2004), has been employed here as an alternative where environmental quality continues to degrade with increasing income, albeit at a diminishing rate. For these ESI component data the logarithmic model provides an equally valid explanation of the relationship between the pressure and state PCs and GDP/capita as the quadratic model. Thus it would appear that the data can support at least two quite different visions of the link between income and environmental degradation, a dilemma noted by many others (Stern et al., 1996; Ekins, 1997; Perman and Stern, 2003; Stern, 2004; Galeotti and Lanza, 2005; Nahman and Antrobus, 2005). It could be argued, of course, that the quadratic form of the EKC is ‘real’ and that there are simply not enough rich countries to pull the curve down in a way which limits the explanatory power of other models. In other words, the more or less linear part of the EKC which operates at lower levels of national income is dominating the analysis, and what is needed is for more countries to get richer. This is a similar argument, albeit on a larger scale, to that employed by Khanna and Plassmann (2004) for their study of the demands for better environmental quality in US households.

Some points of caution do need to be mentioned. The impact on environmental quality of the pressure and state variables employed in the analysis could be far more complex and indeed there could be thresholds beyond which the impact could be far greater (multiplier effects). Thus while both models imply that the rate of change of degradation with income slows down as income increases the impact could continue to increase at a much higher rate and ‘flip’ the environment from a desired state to one which is distinctly undesirable. There are also socio-cultural aspects to consider. Even if the degradation of the environment with increasing income is deemed to be an acceptable ‘trade off’ and does not damage critical natural capital to the extent that recovery is impossible, are the changes acceptable in a socio-cultural sense? Having made that point it has to be said that recent evidence suggests that many developing countries are already putting in place standards within short time scales that could lead them to performing much better than their ranking along the horizontal axis of the EKC would suggest (Dasgupta et al., 2002; Stern, 2004).

Nonetheless the main point is both of these alternative analyses – quadratic and logarithmic – provide quite different perspectives upon the link between national income and environmental degradation (sustainability) to that of Figure 1, even if it is the latter which receives the greater publicity. Environmental sustainability is, of course, not the same thing as environmental quality or degradation, and clearly much depends on exactly what is being measured, when and how. In order to encapsulate a dynamic sense of sustainability the ESI includes 'impact' and 'response' components alongside measures of environmental quality rather than supply four separate indices of pressure, state, impact and response. Given that the 'response' variables are positively related to income then this component swamps the 'state' and 'pressure' components and generates the positive association between ESI and income. Somewhat perversely it is possible for environmental degradation to worsen while environmental sustainability as encapsulated by the ESI improves! Irrespective as to whether the environmental quality-income relationship is quadratic, cubic or logarithmic the danger is that many of those reporting or indeed 'using' the ESI to formulate policy will not look further than the LEI of Figure 1 presented in the report and make an assumption that that the environment will broadly get 'better' with increasing income, even if the existence of 'outliers' is acknowledged.

Therefore, those generating such aggregated indices clearly have much responsibility. Indices such as the ESI were not created in order to help understand cause-effect relationships as their prime purpose. Instead they were created to highlight the importance of an issue – such as environmental sustainability - and help provide pressure for positive change. While it is readily acknowledged that indices such as the ESI are human constructs and thus have a strong element of subjectivity inherent within them, they do nonetheless have a role to play. As shown in this paper, problems can occur if they are taken too literally as objective measures and thereby used to understand complex processes and relationships within a broad cause-effect context. The creators of the ESI encourage that 'use' of the index by presenting such analyses within their reports, but care needs to be taken to think through the repercussions that can arise from such simplistic cause-effect conclusions.

5. CONCLUSIONS

Those creating and promoting indices such as the ESI do have substantial responsibility. After all, by design and not accident it is their voice that has the best chance of being heard. The ESI is a powerful tool that has been successful in terms of its reporting by the popular media and through that vehicle it has undoubtedly influenced policy. Given the prominence of economic development amongst politicians and indeed the general public it is a natural extension to link environmental performance as measured with the ESI to income. But the ESI is a broad-based index of environmental sustainability that has elements which attempt to gauge environmental quality packaged with others that do not. This can generate misleading conclusions with regard to a linkage with income, and place into shadow much of the extensive literature based on the EKC and other such models which show that environmental quality has a far more complex relationship to income.

In fairness it has to be stressed that the creators of the ESI have been very diligent in terms of their presentation of the index in the reports. All methods and datasets used in the construction of the index are readily accessible, and there is an effort to listen to and address criticism. The problems related in this paper are more to do with interpretation of the ESI once placed into the public domain, especially a tendency to relate it to highly sensitive variables such as income. The ESI makes a valuable contribution in that it does help to raise the importance of environmental sustainability amongst groups who have the power to do something, and the inclusion of variables that gauge response is a novel and positive step. Clearly there is a tension between the need to simplify for busy policy makers, managers, journalists etc. to absorb a broad trend while there is also a necessity to avoid dangerous over-simplification. Getting this balance right is admittedly not easy, and adds a further level of complication beyond issues of choice of variable, data quality etc. It is all too easy to become fixated on the technicalities of such indices, but the evidence from this paper suggests that an appreciation as to how the index may be applied cannot be avoided. This is an area of research that has not received anything like the attention as the more technical aspects of index creation, and the ESI does provide something of a unique example given that elements of pressure-state-impact-response are rolled into one index and the fact that it has the high level of exposure that follows in part from its promotion by a powerful body - the WEF. Even so the following quotation encapsulates the need to go beyond technical concerns of index construction:

"*You are not only responsible for what you say, but also for what you do not say*"

Martin Luther

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REFERENCES

Andreoni, J. and Levinson, A. (2001). The simple analytics of the environmental Kuznets curve. *Journal of Public Economics* **80**(2), 269-286.

Bousquet, A. and Favard, P. (2005). Does S. Kuznets's belief question the Environmental Kuznets Curves? *Canadian Journal of Economics* **38**(2), 604-614.

Chimeli, A. B. and Braden, J. B. (2005). Total factor productivity and the environmental Kuznets curve. *Journal of Environmental Economics and Management* **49** (2), 366-380.

Cole, M. A. (2003). Development, trade and the environment: How robust is the Environmental Kuznets Curve? *Environment and Development Economics* **8** (4), 557-580.

Cole, M. A. (2004). Trade, the pollution haven hypothesis and the environmental Kuznets curve: examining the linkages. *Ecological Economics* **48** (1), 71-81.

Dasgupta, S., Laplante, B., Wang, H. and Wheeler, D. (2002). Confronting the Environmental Kuznets Curve. *Journal of Economic Perspectives* **16** (1), 147-168.

De Groot, H. L. F., Withagen, C. A. and Zhou, M. L. (2004). Dynamics of China's regional development and pollution: an investigation into the Environmental Kuznets Curve. *Environment and Development Economics* **9**, 507-537.

Dinda, S. (2005). A theoretical basis for the environmental Kuznets curve. *Ecological Economics* **53**(3), 403-413.

Di Vita, G. (2004). Another explanation of pollution-income patterns. International *Journal of Environment and Pollution* **21** (6), 588-592.

Ekins, P. (1997). The Kuznets curve for the environment and economic growth: Examining the evidence. *Environment and Planning A* **29** (5), 805-830.

Esty, D. C. (2001). Towards data-driven environmentalism: The Environmental Sustainability Index. *Environmental Law Reporter* **31**(5), 10603-10613

Esty, D. C., Levy, M. A., Srebotnjak, T., and de Sherbinin, A. (2005) *Environmental Sustainability Index: Benchmarking National Environmental Stewardship.* New Haven, Conn.: Yale Center for Environmental Law & Policy.

Galeotti, M. and Lanza, A. (2005). Desperately seeking environmental Kuznets. *Environmental Modelling and Software* **20** (11), 1379-1388.

Harbaugh, W. T., Levinsom, A. and Wilson, D. M. (2002). Re-examining the empirical evidence for an Environmental Kuznets Curve. *The Review of Economics and Statistics* **84**(3), 541-551.

Hartman, R. and Kwon, O. S. (2005). Sustainable growth and the environmental Kuznets curve. *Journal of Economic Dynamics & Control* **29** (10), 1701-1736.

He, J. (2005). Estimating the economic cost of China's new desulfur policy during her gradual accession to WTO: The case of industrial S02 emission. *China Economic Review* **16** (4), 364-402.

Jha, R. and Bhanu Murthy, K V. (2003a). An inverse global environmental Kuznets curve. *Journal of Comparative Economics* **31**, 352-368.

Jha, R. and Bhanu Murthy, K. V. (2003b). *A critique of the Environmental Sustainability Index*. Technical Report Working papers in Trade and Development no.2003/08, Economics, RSPAS, ANU. Available at rspas.anu.edu.au/economics/publish/papers/wp2003/wp-econ-2003-08.pdf

Khanna, N. and Plassmann, F. (2004). The demand for environmental quality and the environmental Kuznets Curve hypothesis. *Ecological Economics* **51** (3-4), 225-236.

Koop, G. and Tole, L. (1999). Is there an Environmental Kuznets Curve for deforestation? *Journal of Development Economics* **58** (1), 231-244.

Kristrom, B. and Lundgren, T. (2005). Swedish CO2 emissions 1900-2010: an exploratory note. *Energy Policy* **33** (9), 1223-1230.

Lawn, P. (2007). *Frontier issues in ecological economics*. Edward Elgar, UK.

Lindmark, M. (2004). Patterns of historical CO_2 intensity transitions among high and low-income countries. *Explorations in Economic History* **41** (4), 426-447.

List, J. A. and Gallet, C. A. (1999). The Environmental Kuznets Curve: Does one size fit all? *Ecological Economics* **31** (3), 409-423.

Mather, A. S., Needle, C. L. and Fairbairn, J. (1999). Environmental Kuznets Curves and forest trends. *Geography* **84** (362), 55-65.

McPherson, M. A. and Nieswiadomy, M. L. (2005). Environmental Kuznets curves: Threatened species and spatial effects. *Ecological Economics* **55** (3), 395-407.

Nahman, A. and Antrobus, G. (2005). The environmental Kuznets curve: A literature review. *South African Journal of Economics* **73** (1), 105-120.

Paudel, K. P., Zapata, H. and Susanto, D. (2005). An empirical test of Environmental Kuznets Curve for water pollution. *Environmental and Resource Economics* **31** (3), 325-348.

Perman, R. and Stern, D. I. (2003). Evidence from panel unit root and cointegration tests that the Environmental Kuznets Curve does not exist. *Australian Journal of Agricultural and Resource Economics* **47** (3), 325-347.

Roberts, J. T. and Grimes, P. E. (1997). Carbon intensity and economic development 1962-91: A brief exploration of the Environmental Kuznets Curve. *World Development* **25** (2), 191-198.

Rupasingha, A., Goetz, S. J., Debertin, D. L. and Pagoulatos, A. (2004). The environmental Kuznets curve for US counties: A spatial econometric analysis with extensions. *Papers in Regional Science* **83** (2), 407-424.

Sobhee, S. K. (2004). The environmental Kuznets curve (EKC): a logistic curve? *Applied Economics Letters* **11** (7), 449-452.

Stern, D. I., Common, M. S. and Barbier, E. B. (1996). Economic growth and environmental degradation: The Environmental Kuznets Curve and sustainable development. *World Development* **24** (7), 1151-1160.

Stern, D I. (2004). The rise and fall of the environmental Kuznets curve. *World Development* **32** (8), 1419-1439.

The Ecologist (2001) Keeping score The Ecologist April 44-47 or for on line edition see http://www.findarticles.com

Torras, M. and Boyce, J. K. (1998). Income, inequality and pollution: A reassessment of the Environmental Kuznets Curve. *Ecological Economics* **25** (2), 147-160.

UNDP (2002). *Human Development Report*. Human Development Report Office, UNDP, New York.

Table 1. Variables included in the Environmental Sustainability Index (ESI) of 2005 categorised as pressure, state, impact and response.

(a) Pressure

Variable Code	Variable
ACEXC	Acidification exceedance from anthropogenic sulphur deposition
BODWAT	Industrial organic water pollutant (BOD) emissions per available freshwater
CARSKM	Vehicles in use per populated land area
CO2GDP	Carbon emissions per million US dollars GDP
CO2PC	Carbon emissions per capita
COALKM	Coal consumption per populated land area
EFPC	Ecological Footprint per capita
FERTHA	Fertilizer consumption per hectare of arable land
GR2050	Percentage change in projected population 2004-2050
HAZWST	Generation of hazardous waste
NOXKM	Anthropogenic NOx emissions per populated land area
OVRFSH	Productivity overfishing
PESTHA	Pesticide consumption per hectare of arable land
POLEXP	Import of polluting goods and raw materials as percentage of total imports of goods and services
SO2EXP	SO2 Exports
SO2KM	Anthropogenic SO2 emissions per populated land area
TFR	Total Fertility Rate
VOCKM	Anthropogenic VOC emissions per populated land area

(b) State

Variable Code	Variable
ANTH10	Percentage of total land area (including inland waters) having very low anthropogenic impact
ANTH40	Percentage of total land area (including inland waters) having very high anthropogenic impact
ECORISK	Percentage of country's territory in threatened eco-regions
FOREST	Annual average forest cover change rate from 1990 to 2000
GRDAVL	Internal groundwater availability per capita
INDOOR	Indoor air pollution from solid fuel use
NBI	National Biodiversity Index
NO2	Urban population weighted NO2 concentration
PRTAMPH	Threatened amphibian species as percentage of known amphibian species in each country
PRTBRD	Threatened bird species as percentage of known breeding bird species in each country
PRTMAM	Threatened mammal species as percentage of known mammal species in each country
SO2	Urban population weighted SO2 concentration
TSP	Urban population weighted TSP concentration
WATAVL	Freshwater availability per capita
WATSTR	Percentage of country under severe water stress
WQ_DO	Dissolved oxygen concentration
WQ_EC	Electrical conductivity
WQ_PH	Phosphorus concentration
WQ_SS	Suspended solids

(c) Impact

Variable Code	Variable
DISCAS	Average number of deaths per million inhabitants from floods, tropical cyclones, and droughts
DISINT	Death rate from intestinal infectious diseases
DISRES	Child death rate from respiratory diseases
U5MORT	Children under five mortality rate per 1,000 live births
UND_NO	Percentage of undernourished in total population
WATSUP	Percentage of population with access to improved drinking water source

(d) Response

Variable Code	Variable
AGENDA21	Local Agenda 21 initiatives per million people
AGSUB	Agricultural subsidies
CIVLIB	Civil and Political Liberties
CSDMIS	Percentage of variables missing from the CGSDI "Rio to Joburg Dashboard"
DAI	Digital Access Index
DISEXP	Environmental Hazard Exposure Index
DJSGI	Dow Jones Sustainability Group Index (DJSGI)
ECOVAL	Average Innovest EcoValue rating of firms headquarted in a country
EIONUM	Number of memberships in environmental intergovernmental organizations
ENEFF	Energy efficiency
ENROL	Gross tertiary enrollment rate
FORCERT	Percentage of total forest area that is certified for sustainable management
FUNDING	Contribution to international and bilateral funding of environmental projects and development aid
GASPR	Ratio of gasoline price to world average
GOVEFF	Government effectiveness
GRAFT	Corruption measure
INNOV	Innovation Index
IRRSAL	Salinized area due to irrigation as percentage of total arable land
ISO14	Number of ISO 14001 certified companies per billion dollars GDP (PPP)
IUCN	IUCN member organizations per million population
KNWLDG	Knowledge creation in environmental science, technology, and policy
LAW	Rule of law
PARTICIP	Participation in international environmental agreements
PECR	Female primary education completion rate
POLITY	Democracy measure
PRAREA	Percentage of total land area under protected status

(d) Response (continued)

Variable Code	Variable
RECYCLE	Waste recycling rates
RENPC	Hydropower and renewable energy production as a percentage of total energy consumption
RESCARE	Participation in the Responsible Care Program of the Chemical Manufacturer's Association
RESEARCH	Number of researchers per million inhabitants
WEFGOV	World Economic Forum Survey on environmental governance
WEFPRI	World Economic Forum Survey on private sector environmental innovation
WEFSUB	World Economic Forum Survey on subsidies

Table 2. Correlation coefficients for the pressure, state and response variables (z-values) of the ESI 2005.

(a) Pressure

	NOXKM	SO2KM	VOCKM	COALKM	CARSKM	ACEXC	GR2050	TFR	EFPC	HAZWST	BODWAT	FERTHA	PESTHA	OVRFSH	CO2GDP	CO2PC	POLEXP
NOXKM	1	0.5	0.499	0.563	0.655	0.39	-0.393	-0.455	0.498	0.124	0.456	0.509	0.515	0.146	-0.155	0.499	0.186
SO2KM	0.5	1	0.584	0.552	0.646	0.275	-0.595	-0.632	0.424	0.268	0.497	0.505	0.472	0.16	0.27	0.663	0.245
VOCKM	0.499	0.584	1	0.346	0.454	0.213	-0.261	-0.262	0.375	0.042	0.328	0.354	0.187	0.1	-0.07	0.353	0.193
COALKM	0.563	0.552	0.346	1	0.613	0.538	-0.483	-0.534	0.488	0.308	0.529	0.455	0.485	0.277	0.053	0.548	0.233
CARSKM	0.655	0.646	0.454	0.613	1	0.438	-0.647	-0.755	0.637	0.227	0.502	0.664	0.713	0.144	0.065	0.824	0.338
ACEXC	0.39	0.275	0.213	0.538	0.438	1	-0.357	-0.398	0.321	0.212	0.321	0.373	0.315	0.192	-0.187	0.365	0.188
GR2050	-0.393	-0.595	-0.261	-0.483	-0.647	-0.357	1	0.916	-0.421	-0.283	-0.338	-0.443	-0.49	-0.23	-0.21	-0.694	-0.282
TFR	-0.455	-0.632	-0.262	-0.534	-0.755	-0.398	0.916	1	-0.527	-0.32	-0.385	-0.564	-0.621	-0.218	-0.233	-0.799	-0.264
EFPC	0.498	0.424	0.375	0.488	0.637	0.321	-0.421	-0.527	1	0.199	0.231	0.461	0.373	0.04	-0.097	0.733	0.401
HAZWST	0.124	0.268	0.042	0.308	0.227	0.212	-0.283	-0.32	0.199	1	0.1	0.103	0.176	0.017	-0.126	0.285	0.215
BODWAT	0.456	0.497	0.328	0.529	0.502	0.321	-0.338	-0.385	0.231	0.1	1	0.371	0.362	0.171	0.142	0.422	0.128
FERTHA	0.509	0.505	0.354	0.455	0.664	0.373	-0.443	-0.564	0.461	0.103	0.371	1	0.685	0.33	-0.081	0.591	0.23
PESTHA	0.515	0.472	0.187	0.485	0.713	0.315	-0.49	-0.621	0.373	0.176	0.362	0.685	1	0.104	0.052	0.62	0.272
OVRFSH	0.146	0.16	0.1	0.277	0.144	0.192	-0.23	-0.218	0.04	0.017	0.171	0.33	0.104	1	-0.098	0.075	-0.112
CO2GDP	-0.155	0.27	-0.07	0.053	0.065	-0.187	-0.21	-0.233	-0.097	-0.126	0.142	-0.081	0.052	-0.098	1	0.339	0.082
CO2PC	0.499	0.663	0.353	0.548	0.824	0.365	-0.694	-0.799	0.733	0.285	0.422	0.591	0.62	0.075	0.339	1	0.451
POLEXP	0.186	0.245	0.193	0.233	0.338	0.188	-0.282	-0.264	0.401	0.215	0.128	0.23	0.272	-0.112	0.082	0.451	1

(b) State

	NO2	SO2	TSP	INDOOR	ECORISK	PRTBRD	PRTMAM	PRTAMPH	NBI	ANTH10	ANTH40	WQ_DO	WQ_EC	WQ_PH	WATAVL	GRDAVL	FOREST	WATSTR
NO2	1	0.388	-0.011	-0.203	-0.27	-0.047	0.024	0.094	-0.122	-0.208	0.164	-0.261	-0.11	0.124	-0.055	-0.158	-0.023	0.043
SO2	0.388	1	0.293	0.028	-0.033	0.018	0.152	0.264	-0.431	-0.05	-0.033	-0.056	-0.064	0.213	-0.142	-0.218	0.247	-0.197
TSP	-0.011	0.293	1	0.627	0.032	0.126	-0.074	0.29	-0.461	0.145	-0.368	0.495	-0.063	0.342	0.041	-0.011	0.425	-0.073
INDOOR	-0.203	0.028	0.627	1	0.038	-0.075	-0.254	0.029	-0.353	-0.033	-0.51	0.57	-0.22	0.095	-0.141	-0.107	0.533	-0.243
ECORISK	-0.27	-0.033	0.032	0.038	1	-0.057	0.078	-0.006	-0.068	0.625	0.204	0.082	0.101	0.204	0.224	0.085	0.119	-0.146
PRTBRD	-0.047	0.018	0.126	-0.075	-0.057	1	0.503	0.52	-0.122	0.077	0.037	-0.004	0.007	0.069	0.161	0.186	-0.143	0.184
PRTMAM	0.024	0.152	-0.074	-0.254	0.078	0.503	1	0.271	0.027	0.003	0.151	-0.094	0.075	0.073	0.11	0.138	-0.275	0.157
PRTAMPH	0.094	0.264	0.29	0.029	-0.006	0.52	0.271	1	-0.529	0.148	0.044	0.062	0.057	0.012	0.053	-0.134	0.254	-0.092
NBI	-0.122	-0.431	-0.461	-0.353	-0.068	-0.122	0.027	-0.529	1	-0.102	0.154	-0.279	0.109	-0.11	0.225	0.345	-0.41	0.248
ANTH10	-0.208	-0.05	0.145	-0.033	0.625	0.077	0.003	0.148	-0.102	1	0.435	0.08	0.208	0.198	0.435	0.235	0.073	-0.022
ANTH40	0.164	-0.033	-0.368	-0.51	0.204	0.037	0.151	0.044	0.154	0.435	1	-0.349	0.196	0.094	0.354	0.286	-0.216	0.199
WQ_DO	-0.261	-0.056	0.495	0.57	0.082	-0.004	-0.094	0.062	-0.279	0.08	-0.349	1	0.135	0.251	0.033	0.091	0.397	-0.03
WQ_EC	-0.11	-0.064	-0.063	-0.22	0.101	0.007	0.075	0.057	0.109	0.208	0.196	0.135	1	0.249	0.491	0.41	-0.144	0.455
WQ_PH	0.124	0.213	0.342	0.095	0.204	0.069	0.073	0.012	-0.11	0.198	0.094	0.251	0.249	1	0.391	0.335	0.162	0.333
WATAVL	-0.055	-0.142	0.041	-0.141	0.224	0.161	0.11	0.053	0.225	0.435	0.354	0.033	0.491	0.391	1	0.791	-0.007	0.466
GRDAVL	-0.158	-0.218	-0.011	-0.107	0.085	0.186	0.138	-0.134	0.345	0.235	0.286	0.091	0.41	0.335	0.791	1	-0.104	0.471
FOREST	-0.023	0.247	0.425	0.533	0.119	-0.143	-0.275	0.254	-0.41	0.073	-0.216	0.397	-0.144	0.162	-0.007	-0.104	1	-0.345
WATSTR	0.043	-0.197	-0.073	-0.243	-0.146	0.184	0.157	-0.092	0.248	-0.022	0.199	-0.03	0.455	0.333	0.466	0.471	-0.345	1

(c) Response

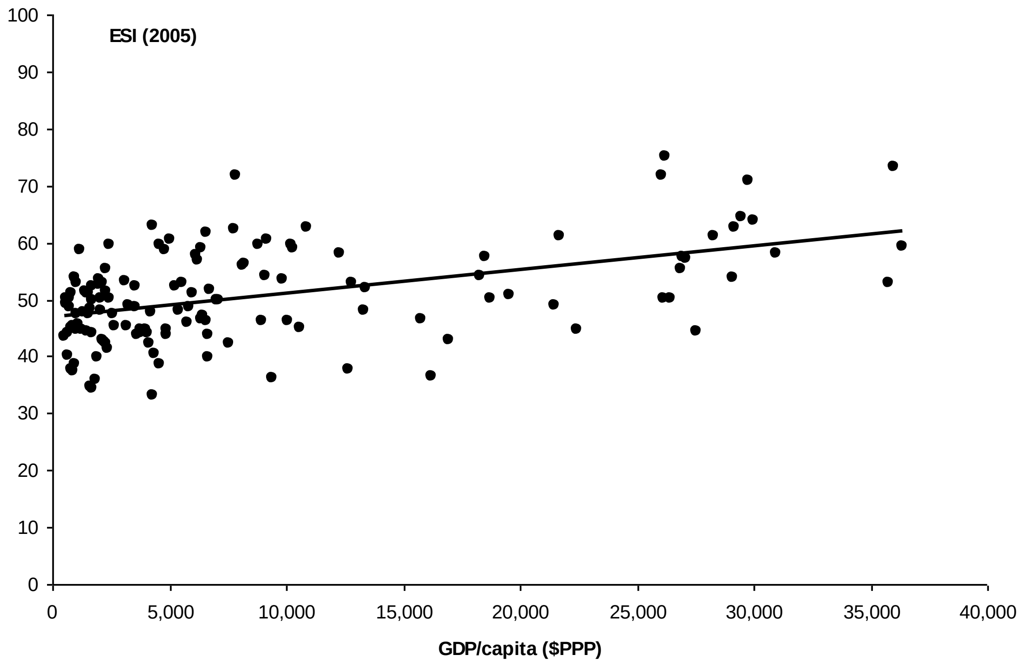
	AGENDA21	AGSUB	CIVLIB	CSDMIS	DAI	DISEXP	DJSGI	ECOVAL	EIONUM	ENEFF	ENROL	FORCERT	FUNDING	GASPR	GOVEFF	GRAFT	INNOV	IRRSAL	ISO14	IUCN	KNWLDG	LAW	PARTICIP	PECR	POLITY	PRAREA	RECYCLE	RENPC	RESCARE	RESEARCH	WEFGOV	WEFPRI	WEFSUB
AGENDA21	1	-0.586	0.654	0.335	0.685	0.165	0.609	0.419	0.109	-0.131	0.606	0.592	0.141	0.576	0.692	0.697	0.618	0.287	0.563	0.604	0.139	0.194	0.298	0.268	0.499	0.148	0.62	0.027	0.372	0.687	0.679	0.519	-0.615
AGSUB	-0.586	1	-0.578	-0.574	-0.689	0	-0.499	-0.362	-0.562	-0.065	-0.609	-0.494	-0.003	-0.624	-0.73	-0.717	-0.686	-0.213	-0.666	-0.324	-0.105	-0.171	-0.544	-0.227	-0.48	-0.082	-0.823	0.047	-0.684	-0.685	-0.736	-0.593	0.659
CIVLIB	0.654	-0.578	1	0.612	0.664	-0.003	0.472	0.384	0.375	0.144	0.546	0.53	0.215	0.523	0.704	0.662	0.597	0.486	0.618	0.462	-0.068	0.166	0.578	0.332	0.893	0.176	0.558	0.043	0.614	0.487	0.648	0.454	-0.598
CSDMIS	0.335	-0.574	0.612	1	0.522	-0.28	0.563	0.446	0.638	0.205	0.434	0.414	0.178	0.344	0.617	0.525	0.503	0.293	0.556	0.338	-0.153	0.15	0.732	0.344	0.591	0.2	0.643	-0.007	0.655	0.377	0.575	0.431	-0.49
DAI	0.685	-0.689	0.664	0.522	1	-0.038	0.518	0.557	0.398	-0.261	0.866	0.552	0	0.36	0.836	0.794	0.895	0.122	0.786	0.391	0.034	0.213	0.469	0.503	0.559	0.064	0.698	-0.175	0.677	0.749	0.826	0.642	-0.756
DISEXP	0.165	0	-0.003	-0.28	-0.038	1	0.25	-0.321	-0.157	-0.283	0.016	0.055	-0.191	0.049	-0.025	0.041	-0.065	-0.225	-0.015	-0.028	0.084	-0.039	-0.079	-0.168	-0.137	-0.112	-0.005	-0.013	-0.162	0.14	0.007	-0.009	0.029
DJSGI	0.609	-0.499	0.472	0.563	0.518	0.25	1	0.773	0.531	0.124	0.286	0.656	0.236	0.585	0.586	0.587	0.498	0.326	0.728	0.531	-0.01	0.017	0.379	-0.089	0.399	0.068	0.55	0.103	0.268	0.633	0.684	0.647	-0.577
ECOVAL	0.419	-0.362	0.384	0.446	0.557	-0.321	0.773	1	0.41	0.116	0.288	0.4	0.445	0.455	0.525	0.541	0.662	0.155	0.547	0.323	-0.019	-0.005	0.281	-0.076	0.295	0.063	0.625	0.25	0.343	0.655	0.682	0.71	-0.638
EIONUM	0.109	-0.562	0.375	0.638	0.398	-0.157	0.531	0.41	1	0.315	0.314	0.294	-0.001	0.314	0.475	0.463	0.452	0.157	0.435	0.152	-0.224	0.133	0.596	0.195	0.344	0.098	0.579	-0.138	0.595	0.312	0.48	0.442	-0.413
ENEFF	-0.131	-0.065	0.144	0.205	-0.261	-0.283	0.124	0.116	0.315	1	-0.311	0.038	0.232	0.339	0.021	0.013	-0.191	0.511	0.001	0.007	-0.107	0.023	0.221	-0.276	0.155	0.16	-0.075	0.102	0.131	-0.265	-0.006	0.027	-0.005
ENROL	0.606	-0.609	0.546	0.434	0.866	0.016	0.286	0.288	0.314	-0.311	1	0.502	-0.062	0.318	0.689	0.654	0.864	0.081	0.658	0.269	0.071	0.158	0.396	0.423	0.48	-0.019	0.591	-0.171	0.582	0.749	0.702	0.49	-0.603
FORCERT	0.592	-0.494	0.53	0.414	0.552	0.055	0.656	0.4	0.294	0.038	0.502	1	0.063	0.443	0.587	0.558	0.533	0.249	0.591	0.28	0.133	0.08	0.443	0.211	0.427	0.158	0.526	-0.041	0.471	0.507	0.593	0.429	-0.495
FUNDING	0.141	-0.003	0.215	0.178	0	-0.191	0.236	0.445	-0.001	0.232	-0.062	0.063	1	0.222	0.187	0.14	0.02	0.18	0.112	0.189	-0.095	0.049	0.268	0.066	0.187	0.169	0.022	0.229	0.069	0.1	0.161	0.188	-0.191
GASPR	0.576	-0.624	0.523	0.344	0.36	0.049	0.585	0.455	0.314	0.339	0.318	0.443	0.222	1	0.466	0.477	0.383	0.461	0.427	0.228	0.091	0.101	0.456	-0.014	0.445	0.073	0.575	0.093	0.423	0.419	0.463	0.35	-0.468
GOVEFF	0.692	-0.73	0.704	0.617	0.836	-0.025	0.586	0.525	0.475	0.021	0.689	0.587	0.187	0.466	1	0.951	0.822	0.258	0.76	0.451	-0.03	0.286	0.571	0.32	0.544	0.166	0.749	-0.068	0.682	0.719	0.919	0.789	-0.866
GRAFT	0.697	-0.717	0.662	0.525	0.794	0.041	0.587	0.541	0.463	0.013	0.654	0.558	0.14	0.477	0.951	1	0.805	0.171	0.708	0.494	-0.088	0.272	0.525	0.221	0.488	0.158	0.744	-0.065	0.645	0.716	0.889	0.758	-0.833
INNOV	0.618	-0.686	0.597	0.503	0.895	-0.065	0.498	0.662	0.452	-0.191	0.864	0.533	0.02	0.383	0.822	0.805	1	0.11	0.756	0.295	-0.007	0.16	0.422	0.374	0.481	0.08	0.745	-0.157	0.647	0.835	0.851	0.73	-0.749
IRRSAL	0.287	-0.213	0.486	0.293	0.122	-0.225	0.326	0.155	0.157	0.511	0.081	0.249	0.18	0.461	0.258	0.171	0.11	1	0.192	0.18	0.008	0.043	0.205	-0.054	0.538	0.319	0.241	0.215	0.199	0.124	0.201	0.169	-0.198
ISO14	0.563	-0.666	0.618	0.556	0.786	-0.015	0.728	0.547	0.435	0.001	0.658	0.591	0.112	0.427	0.76	0.708	0.756	0.192	1	0.308	0.016	0.179	0.576	0.339	0.509	0.128	0.658	-0.117	0.666	0.635	0.793	0.651	-0.723
IUCN	0.604	-0.324	0.462	0.338	0.391	-0.028	0.531	0.323	0.152	0.007	0.269	0.28	0.189	0.228	0.451	0.494	0.295	0.18	0.308	1	-0.096	0.195	0.345	0.187	0.373	0.209	0.273	0.113	0.154	0.353	0.424	0.299	-0.455
KNWLDG	0.139	-0.105	-0.068	-0.153	0.034	0.084	-0.01	-0.019	-0.224	-0.107	0.071	0.133	-0.095	0.091	-0.03	-0.088	-0.007	0.008	0.016	-0.096	1	-0.009	-0.311	0.004	-0.097	-0.088	-0.006	-0.297	-0.238	0.047	-0.047	-0.038	0.091
LAW	0.194	-0.171	0.166	0.15	0.213	-0.039	0.017	-0.005	0.133	0.023	0.158	0.08	0.049	0.101	0.286	0.272	0.16	0.043	0.179	0.195	-0.009	1	0.094	0.165	0.136	0.07	0.23	0.028	0.126	0.157	0.22	0.148	-0.245
PARTICIP	0.298	-0.544	0.578	0.732	0.469	-0.079	0.379	0.281	0.596	0.221	0.396	0.443	0.268	0.456	0.571	0.525	0.422	0.205	0.576	0.345	-0.311	0.094	1	0.253	0.567	0.188	0.542	-0.034	0.595	0.364	0.544	0.388	-0.506
PECR	0.268	-0.227	0.332	0.344	0.503	-0.168	-0.089	-0.076	0.195	-0.276	0.423	0.211	0.066	-0.014	0.32	0.221	0.374	-0.054	0.339	0.187	0.004	0.165	0.253	1	0.316	-0.064	0.238	-0.101	0.291	0.288	0.323	0.25	-0.35
POLITY	0.499	-0.48	0.893	0.591	0.559	-0.137	0.399	0.295	0.344	0.155	0.48	0.427	0.187	0.445	0.544	0.488	0.481	0.538	0.509	0.373	-0.097	0.136	0.567	0.316	1	0.201	0.512	-0.006	0.566	0.381	0.488	0.279	-0.462
PRAREA	0.148	-0.082	0.176	0.2	0.064	-0.112	0.068	0.063	0.098	0.16	-0.019	0.158	0.169	0.073	0.166	0.158	0.08	0.319	0.128	0.209	-0.088	0.07	0.188	-0.064	0.201	1	0.245	0.177	0.143	-0.007	0.192	0.192	-0.104
RECYCLE	0.62	-0.823	0.558	0.643	0.698	-0.005	0.55	0.625	0.579	-0.075	0.591	0.526	0.022	0.575	0.749	0.744	0.745	0.241	0.658	0.273	-0.006	0.23	0.542	0.238	0.512	0.245	1	-0.068	0.662	0.789	0.781	0.652	-0.67
RENPC	0.027	0.047	0.043	-0.007	-0.175	-0.013	0.103	0.25	-0.138	0.102	-0.171	-0.041	0.229	0.093	-0.068	-0.065	-0.157	0.215	-0.117	0.113	-0.297	0.028	-0.034	-0.101	-0.006	0.177	-0.068	1	-0.096	-0.045	-0.085	-0.034	-0.04
RESCARE	0.372	-0.684	0.614	0.655	0.677	-0.162	0.268	0.343	0.595	0.131	0.582	0.471	0.069	0.423	0.682	0.645	0.647	0.199	0.666	0.154	-0.238	0.126	0.595	0.291	0.566	0.143	0.662	-0.096	1	0.462	0.688	0.542	-0.608
RESEARCH	0.687	-0.685	0.487	0.377	0.749	0.14	0.633	0.655	0.312	-0.265	0.749	0.507	0.1	0.419	0.719	0.716	0.835	0.124	0.635	0.353	0.047	0.157	0.364	0.288	0.381	-0.007	0.789	-0.045	0.462	1	0.788	0.667	-0.682
WEFGOV	0.679	-0.736	0.648	0.575	0.826	0.007	0.684	0.682	0.48	-0.006	0.702	0.593	0.161	0.463	0.919	0.889	0.851	0.201	0.793	0.424	-0.047	0.22	0.544	0.323	0.488	0.192	0.781	-0.085	0.688	0.788	1	0.884	-0.899
WEFPRI	0.519	-0.593	0.454	0.431	0.642	-0.009	0.647	0.71	0.442	0.027	0.49	0.429	0.188	0.35	0.789	0.758	0.73	0.169	0.651	0.299	-0.038	0.148	0.388	0.25	0.279	0.192	0.652	-0.034	0.542	0.667	0.884	1	-0.818
WEFSUB	-0.615	0.659	-0.598	-0.49	-0.756	0.029	-0.577	-0.638	-0.413	-0.005	-0.603	-0.495	-0.191	-0.468	-0.866	-0.833	-0.749	-0.198	-0.723	-0.455	0.091	-0.245	-0.506	-0.35	-0.462	-0.104	-0.67	-0.04	-0.608	-0.682	-0.899	-0.818	1

Table 3. Results of a principal component analysis on the z-values of the pressure, state and response variables of the ESI 2005.

	Pressure			State			Response	
	1st PC	2nd PC		1st PC	2nd PC		1st PC	2nd PC
Eigenvalue	11.81	1.51		7.2	3.45		21.64	3.771
Percentage	69.5	8.9		40.0	19.2		65.6	11.4
NOXKM	-0.266	0.17	NO2	-0.036	0.385	AGENDA21	-0.197	-0.083
SO2KM	-0.275	-0.105	SO2	-0.234	0.248	AGSUB	0.209	0.031
VOCKM	-0.219	0.106	TSP	-0.316	-0.163	CIVLIB	-0.203	0.063
COALKM	-0.276	0.096	INDOOR	-0.316	-0.238	CSDMIS	-0.196	0.119
CARSKM	-0.288	-0.027	ECORISK	0.035	-0.298	DAI	-0.207	-0.119
ACEXC	-0.235	0.263	PRTBRD	0.044	0.244	DISEXP	0.031	-0.301
GR2050	0.283	0.092	PRTMAM	0.14	0.316	DJSGI	-0.187	0.047
TFR	0.285	0.089	PRTAMPH	-0.178	0.212	ECOVAL	-0.182	0.09
EFPC	-0.263	-0.036	NBI	0.317	-0.031	EIONUM	-0.181	0.101
HAZWST	-0.166	-0.028	ANTH10	0.099	-0.281	ENEFF	0.022	0.444
BODWAT	-0.243	0.035	ANTH40	0.293	0.088	ENROL	-0.198	-0.17
FERTHA	-0.269	0.133	WQ_DO	-0.236	-0.331	FORCERT	-0.199	-0.04
PESTHA	-0.27	-0.026	WQ_EC	0.262	-0.172	FUNDING	-0.0141	0.337
OVRFSH	-0.116	0.502	WQ_PH	0.015	-0.236	GASPR	-0.18	0.124
CO2GDP	-0.05	-0.65	WATAVL	0.294	-0.227	GOVEFF	-0.213	-0.03
CO2PC	-0.28	-0.189	GRDAVL	0.3	-0.217	GRAFT	-0.212	-0.038
POLEXP	-0.187	-0.348	FOREST	-0.323	-0.181	INNOV	-0.207	-0.104
			WATSTR	0.299	-0.021	IRRSAL	-0.086	0.364
						ISO14	-0.211	-0.045
						IUCN	-0.169	0.057
						KNWLDG	0.036	-0.277
						LAW	-0.096	-0.053
						PARTICIP	-0.191	0.126
						PECR	-0.14	-0.173
						POLITY	-0.189	0.112
						PRAREA	-0.045	0.299
						RECYCLE	-0.21	-0.028
						RENPC	0.059	0.308
						RESCARE	-0.203	0.029
						RESEARCH	-0.202	-0.127
						WEFGOV	-0.212	-0.039
						WEFPRI	-0.204	-0.023
						WEFSUB	0.211	0.018

All countries reported in the ESI 2005 were included in the analysis.

Figure 1. ESI 2005 as a function of GDP/capita for 2002 ($ PPP): the Linear ESI-Income (LEI) relationship.

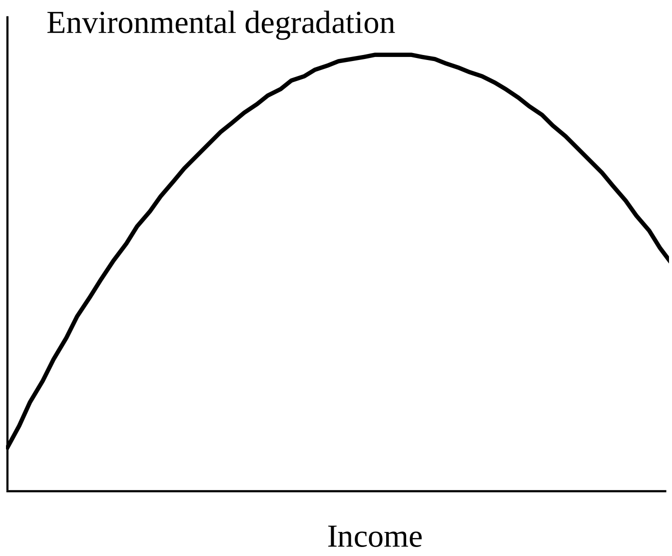


	Coefficient	SE	t-value	Significance
Intercept	46.75	0.8194	57.06	P < 0.001
GDP	0.000418	0.0000645	6.48	P < 0.001

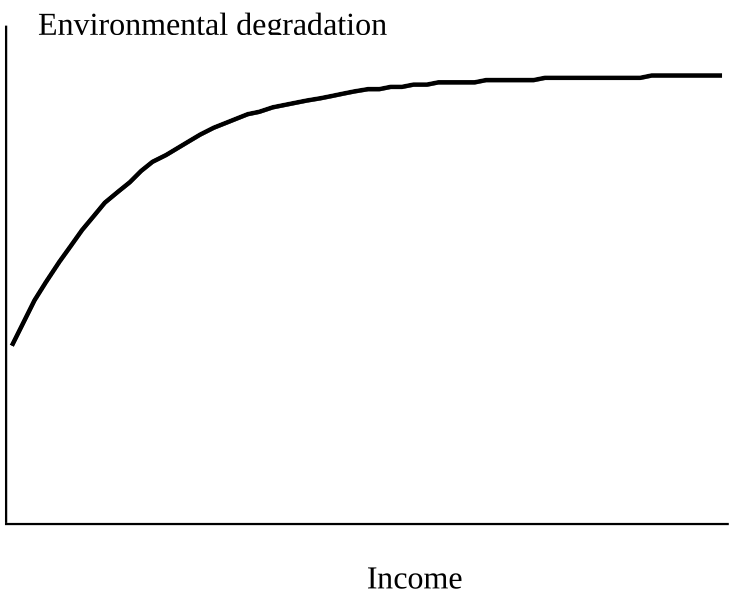
$F = 41.95$ ($P < 0.001$) df = 1, 139
$R^2 = 23.2\%$

Figure 2. Four theoretical reduced models of the relationship between income and environmental degradation.

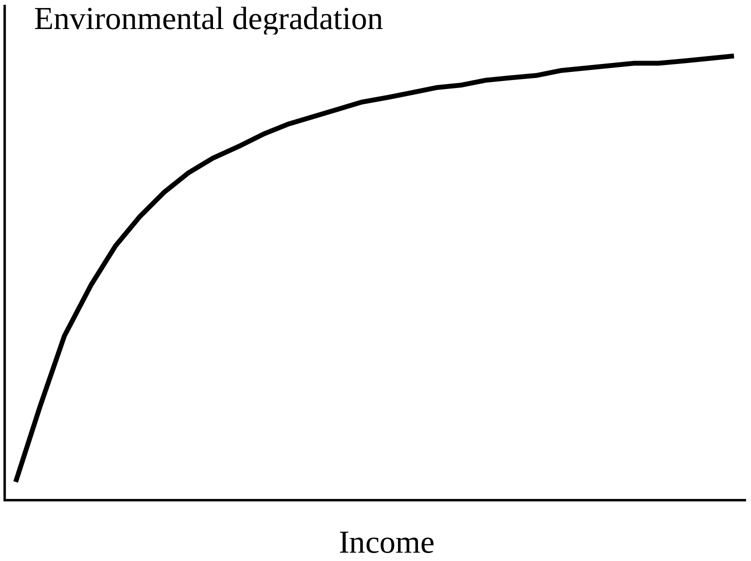
(a) Environmental Kuznets Curve (EKC): quadratic.



(b) Logistic



(c) Logarithmic



(d) Cubic

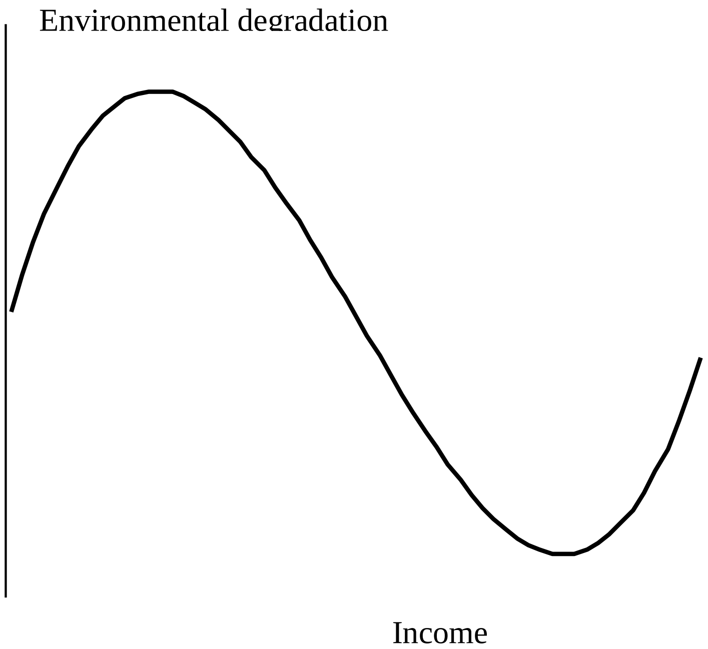
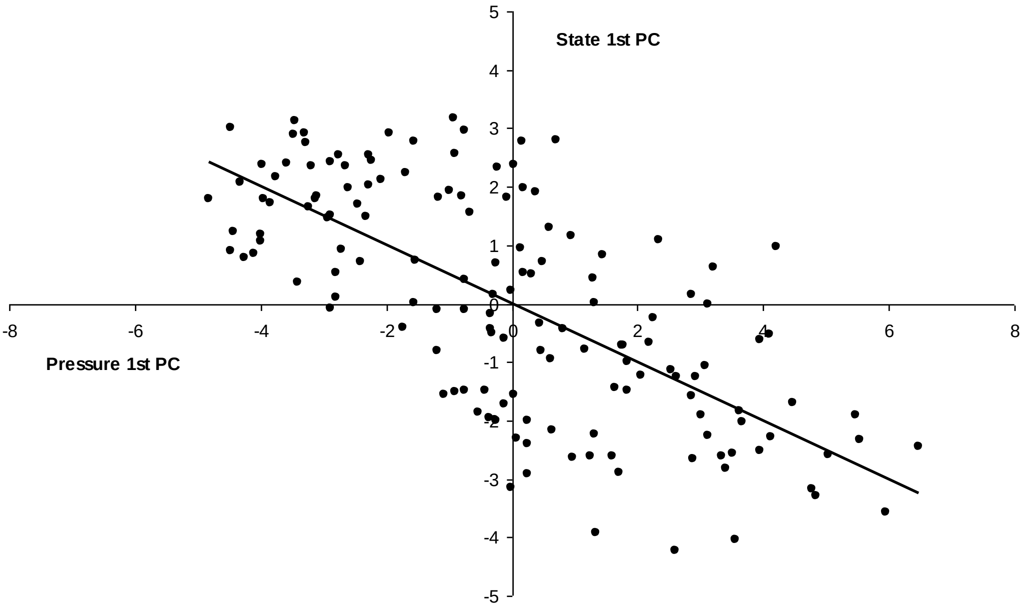
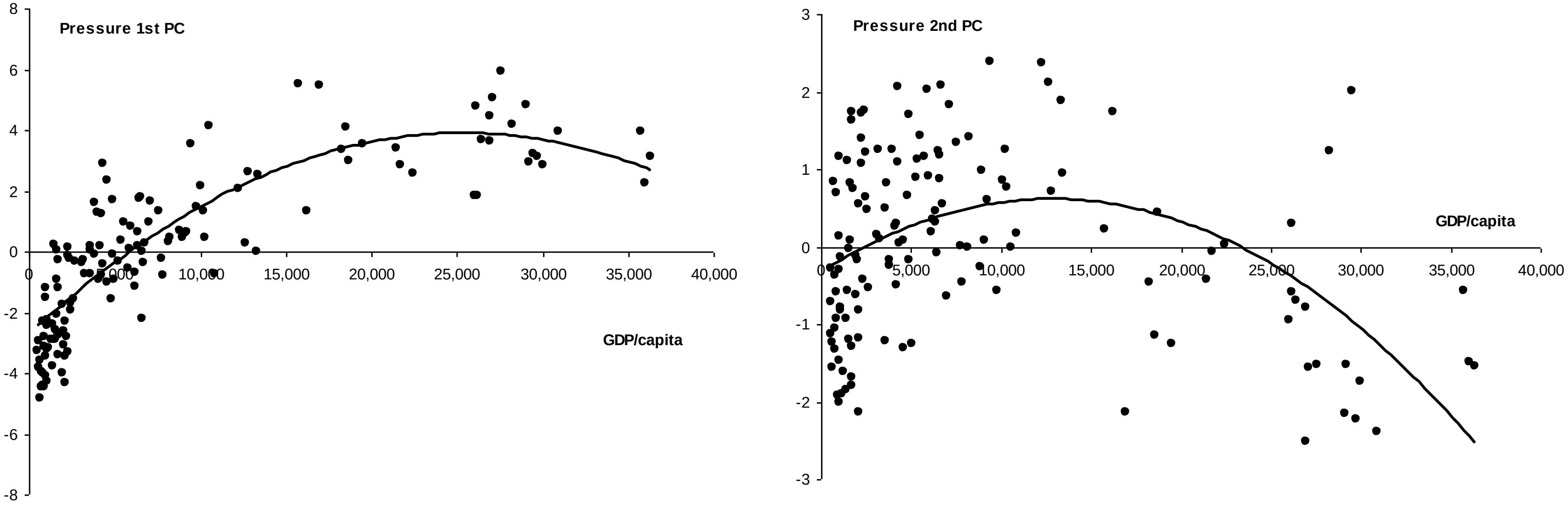


Figure 3. State 1st PC as a function of pressure 1st PC.



	Coefficient	SE	t-value	Significance
Intercept	0.00	0.1153	0.00	ns
Pressure 1st PC	-0.50147	0.0434	-11.56	$P < 0.001$
$F = 133.52$ ($P < 0.001$) df = 1, 144				
$R^2 = 48\%$				

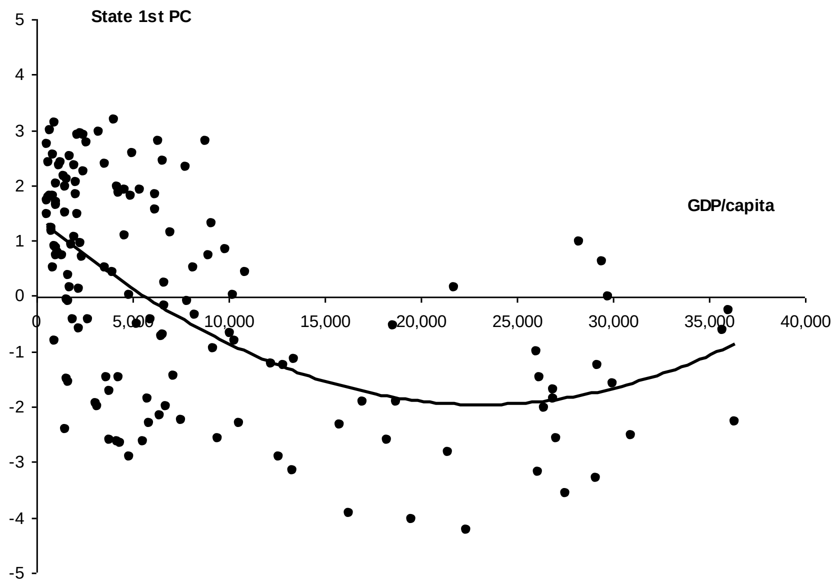
Figure 4. The two pressure principal components as a function of GDP/capita: the quadratic EKC model.

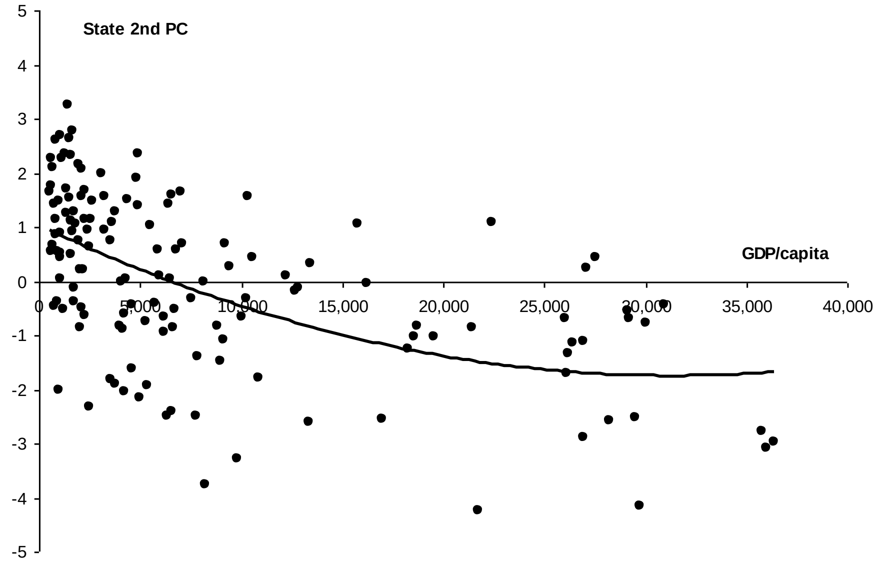


	Coefficient	SE	t-value	Significance	Coefficient	SE	t-value	Significance
Intercept	-3.1139	0.1993	-15.62	P<0.001	-0.3869	0.1648	-2.35	P<0.05
GDP	5.8416	0.4276	13.86	P<0.001	1.5617	0.3536	4.42	P<0.001
GDP^2	-1.1934	0.1348	-8.85	P<0.001	-0.5951	0.1115	-5.34	P<0.001
F = 219.85 (P<0.001) df = 2, 138					F = 17.79 (P<0.001) df = 2, 138			
R^2 (adjusted) = 75.8%					R^2 (adjusted) = 19.3%			

Note: GDP regression coefficients are in $0,000

Figure 5. The two state principal components as a function of GDP/capita: the quadratic EKC model.

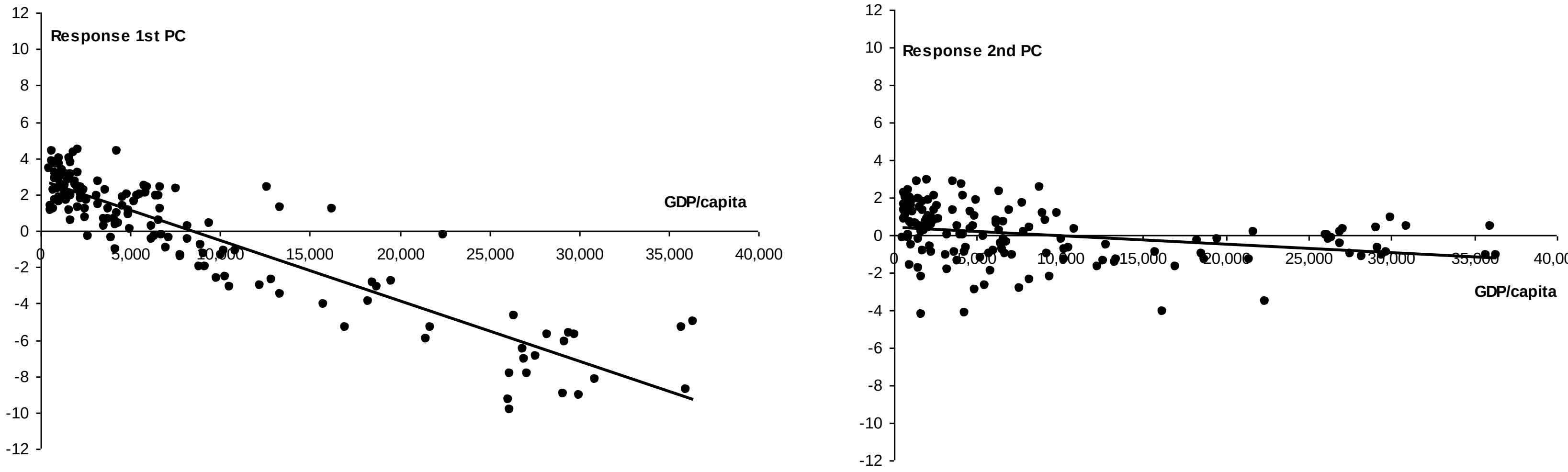




	Coefficient	SE	t-value	Significance	Coefficient	SE	t-value	Significance
Intercept	1.6686	0.2396	6.96	P<0.001	1.0462	0.2048	5.11	P<0.001
GDP	-3.2925	0.5139	-6.41	P<0.001	-1.8023	0.4393	-4.1	P<0.001
GDP^2	0.7275	0.1621	4.49	P<0.001	0.2909	0.1385	2.1	P<0.05
F = 39.8 (P<0.001) df = 2, 138					F = 31.81 (P<0.001) df = 2, 138			
R^2 (adjusted) = 35.7%					R^2 (adjusted) = 30.6%			

Note: GDP regression coefficients are in $0,000

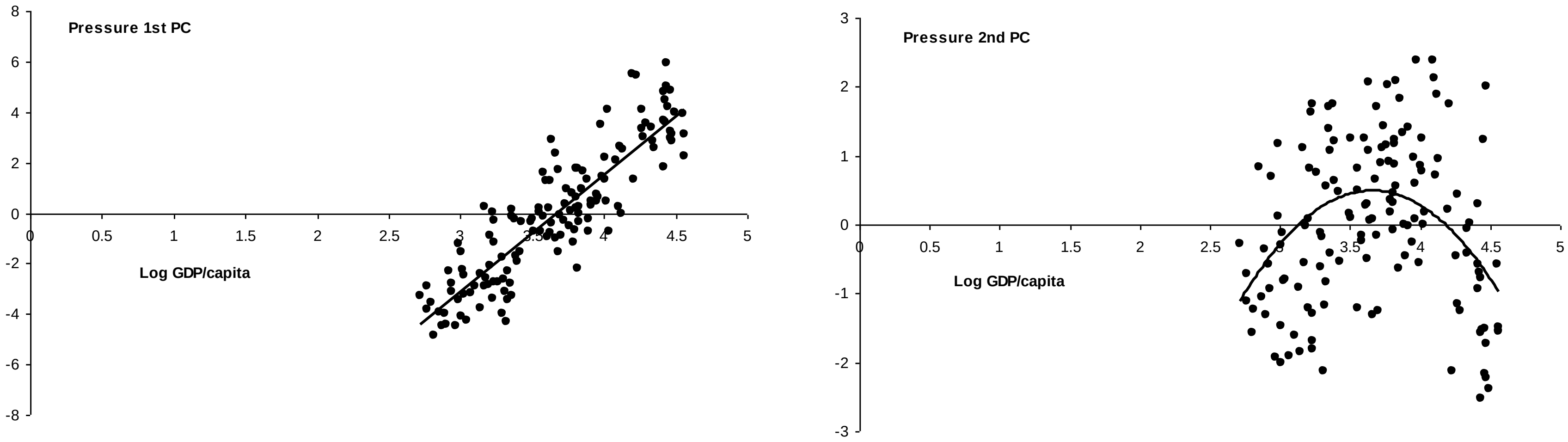
Figure 6. The two response principal components as a function of GDP/capita



	Coefficient	SE	t-value	Significance	Coefficient	SE	t-value	Significance
Intercept	2.7673	0.1667	16.6	P<0.001	0.4419	0.1611	2.74	P<0.01
GDP	-3.3286	0.1312	-25.37	P<0.001	-0.4583	0.1268	-3.62	P<0.001
F = 643.59 df = 1, 139					F = 13.07 df = 1, 139			
R^2 = 82.2%					R^2 = 8.6%			

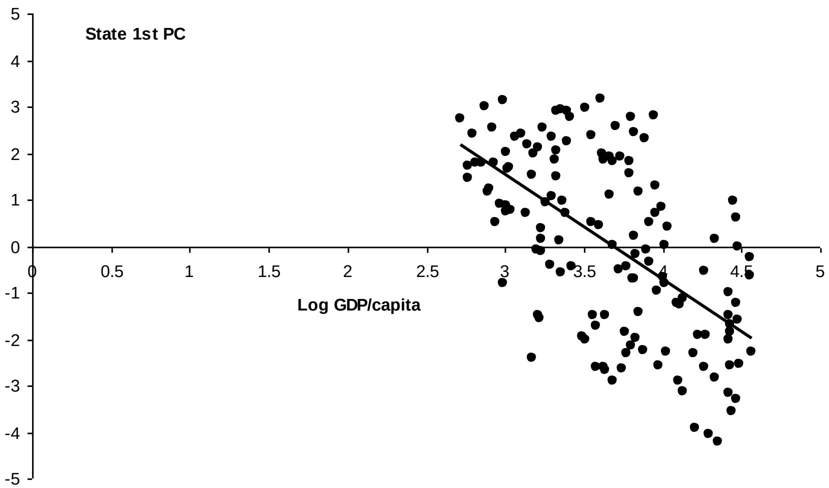
Note: GDP regression coefficients are in $0,000

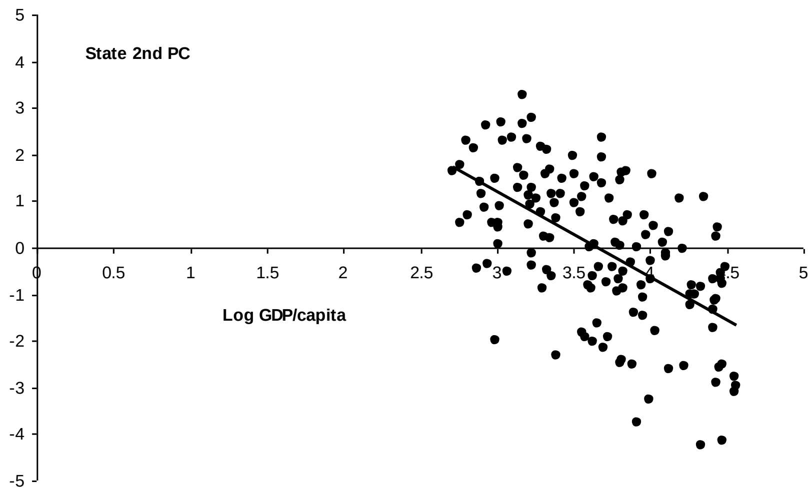
Figure 7. The two pressure principal components as a function of log GDP/capita: the logarithmic model.



	Coefficient	SE	t-value	Significance	Coefficient	SE	t-value	Significance
Intercept	-16.9287	0.7577	-22,34	P<0.001	-31.526	4.708	-6.7	P<0.001
Log GDP	4.6062	0.2048	22.5	P<0.001	17.343	2.59	6.7	P<0.001
Log GDP^2					-2.342	0.3514	-6.67	P<0.001
F = 506.05 df = 1, 139					F = 22.44 df = 2, 138			
R^2 = 78.5%					R^2 (adjusted) = 23.4%			

Figure 8. The two state principal components as a function of log GDP/capita: the logarithmic model.





	Coefficient	SE	t-value	Significance	Coefficient	SE	t-value	Significance
Intercept	8.2945	0.974	8.52	P<0.001	6.6964	0.8064	8.3	P<0.001
Log GDP	-2.2556	0.2632	-8.57	P<0.001	-1.8337	0.2179	-8.41	P<0.001
F = 73.45 df = 1, 139					F = 70.81 df = 1. 139			
R^2 = 34.1%					R^2 = 33.8%			