ZEF Bonn
Zentrum für Entwicklungsforschung
Center for Development Research
Universität Bonn

Renate Schubert, Simon Dietz

Environmental Kuznets Curve, Biodiversity and Sustainability

Number
40

ZEF – Discussion Papers on Development Policy
Bonn, October 2001

Renate Schubert, Simon Dietz: Environmental Kuznets Curve, Biodiversity and Sustainability, ZEF – Discussion Papers On Development Policy No. 40, Center for Development Research, Bonn, October 2001, pp. 30.

ISSN: 1436-9931

Published by:
Zentrum für Entwicklungsforschung (ZEF)
Center for Development Research
Walter-Flex-Strasse 3
D – 53113 Bonn
Germany
Phone: +49-228-73-1861
Fax: +49-228-73-1869
E-Mail: zef@uni-bonn.de
http://www.zef.de

The authors:
Renate Schubert, ETH Zürich, Switzerland
(contact: schubert@wif.gess.ethz.ch)
Simon Dietz, University of East Anglia, Norwich

Contents

List of Figures

Acknowledgements

A preliminary version of this paper had been presented at the ZEF Research Seminar. The authors thank all participants for the lively discussion and for their valuable comments. A special „merci" goes to Joachim von Braun for his invitation and for his challenging suggestions.

Abstract

This paper deals with the question of whether for biodiversity an Environmental Kuznets Curve (EKC) exists. In addition, we are interested in identifying the key determinants of the falling limb of such a curve. An Environmental Kuznets Curve here is understood to be a graphical representation of a function with the amount of environmental damages in a country as the dependent variable and with per capita income as the independent variable. The graph of this function is assumed to have the shape of an inverted U. As with the general case of environmental damages, the existence of an EKC for biodiversity cannot be proven empirically. On the contrary, an EKC for biodiversity seems rather not to exist. Given the rapid rate of depletion of species diversity, policy measures to protect or even increase the number of species play an important role. In particular, property rights regimes seem to matter with respect to the biodiversity issue.

Doubts over the existence of an EKC for biodiversity cast doubts over the corresponding sustainability implications. However, it seems reasonable to interpret losses in species numbers as a signal of danger for sustainability. Therefore, co-ordinated global conservation strategies seem to be the only way forward.

Kurzfassung

Die vorliegende Arbeit beschäftigt sich mit der Frage, ob es für den Bereich der Biodiversität eine Umwelt-Kuznetskurve (EKC) gibt und wovon die Existenz eines fallenden Asts einer solchen Kurve abhängt. Unter Umwelt-Kuznetskurve ist dabei eine Funktion zu verstehen, die das Ausmass der Umweltbelastungen in einem Land in Abhängigkeit vom Pro-Kopf-Einkommen abbildet und dabei von einem Graph in Form eines nach unten geöffneten U`s ausgeht. Ähnlich wie für den allgemeinen Fall, kann auch für den Fall der Biodiversität keine eindeutige empirische Evidenz zugunsten einer solchen Kuznetskurve gefunden werden. Im Gegenteil, die Existenz einer Umwelt-Kuznetskurve für Biodiversität ist eher zu verwerfen. Angesichts der sich rapide verringernden Biodiversität spielt Politik zur Bewahrung oder Vermehrung der Artenvielfalt eine wichtige Rolle. Insbesondere die Zuordnung durchsetzbarer Eigentumsrechte scheint dabei von Bedeutung zu sein.

Die Frage, ob die beobachtbare Verringerung von Biodiversität als Zeichen von weniger Nachhaltigkeit zu bewerten ist, kann nicht eindeutig beantwortet werden. Ein Gefahrenpotential ist aber nicht von der Hand zu weisen. Koordinierte globale Konservierungsstrategien scheinen sich daher zu empfehlen.

1 Introduction

The question of whether economic growth can be reconciled with environmental quality has generated contrasting views. At one extreme, economic activity is perceived to inevitably cause environmental degradation. At the other, environmental problems of significance are assumed to be more or less automatically cured as a consequence of economic growth. The "Environmental Kuznets Curve" (EKC) is central to the theoretical conception and empirical evaluation of the issue. The curve predicts an inverted U-shaped relationship between development, typically measured as income per capita, and various indicators of environmental quality, such that environmental quality first worsens and then improves with increasing income. The curve takes its name from Simon Kuznets, who hypothesized an inverted U-shaped curve for the relationship between income per capita and inequality of income distribution (Kuznets, 1955).

However, the evidence that an Environmental Kuznets Curve universally applies is ambiguous (Ekins, 1997; Bulte and van Soest, 2001). Various indicators do not yield an inverted-U relationship and even for those cases where one exists, any idea of quasi automatic improvement of environmental quality with increasing per capita income seems to be misleading.

Until now EKC tests have been mainly applied to pollution and deforestation indicators (Cropper and Griffiths, 1994). Biodiversity, an environmental indicator of great importance to the human race, has not yet been the subject of a global EKC study. This is surprising since biodiversity is currently being depleted at a rapid rate (Wilson, 1986; Ehrlich and Wilson, 1991). Therefore, this paper aims to investigate the existence of an Environmental Kuznets Curve for biodiversity. Due to the rapid depletion rate, irrespective of the functional form for the relationship between biodiversity and per capita income, the question of policy implications arises.

It seems relevant to know more about the question of whether with increasing per capita income a compensation of losses in biodiversity, arising at a stage of lower per capita income, takes place. If they can be compensated, it would of course be crucial to know more about the circumstances or conditions necessary for compensation. A decisive issue in this context would be to identify policy measures favorable to such compensation. If biodiversity losses cannot be compensated, i.e. if such a thing as an EKC for biodiversity does not exist, it would nevertheless be important to know more about the conditions under which additional losses can be cut down. This means that even in case of the non-existence of an EKC, knowledge from the EKC discussion would be helpful in order to mitigate an aggravation of the ongoing extinction of species. Therefore, whether the existence of an EKC for biodiversity can be shown or not, the background discussion seems to matter in order to conceive policies to cope with the rapid depletion rate. As we shall see, there are limits to the inferences that may be drawn from the EKC and a more focused consideration of specific policy responses to biodiversity loss may be more enlightening.

In addition it has to be noticed that the policy question is strongly linked to the question of impacts of the biodiversity-income-relationship on the sustainability of nations or regions. Therefore, data supporting or contradicting the existence of an EKC for biodiversity will also be used in order to assess changes in the degree of sustainability.

In order to be able to carry out the various analyses just proposed, we shall start with some definitions which are relevant to the rest of the paper. Hereby, the key definitions to look at are the definition of the EKC, the definition of biodiversity, and the definition of sustainability.

2 Some Definitions

In the following, the *Environmental Kuznets Curve* is defined as a function

(1) $E = f(y)$,

with E representing environmental damages and y income per capita. The relevant question with respect to the EKC discussion is whether f is an increasing or decreasing function and whether it is a linear, convex or concave function. This paper deals with the question whether f can be interpreted as an inverted U-shaped function. This interpretation is the one implied by a Kuznets-type function.

The second important definition in this paper is the definition of *biodiversity*. In accordance with the definition by the Convention of Biological Diversity (CBD) from 1992, we understand by biodiversity the "variability of living organisms from all sources... and the ecological complexes of which they form part; this includes diversity within species, between species and of ecosystems" (CBD 1992, art. 2). According to this definition there is no priority given to any particular form of biological diversity, such as species diversity, ecosystem diversity, or genetic diversity. In order to be able to understand the relative importance of this definition, it is important to know the principal objectives of the CBD. These are the conservation of biodiversity, the sustainable use of its components, and a fair and equitable sharing of the benefits arising out of the use of genetic resources (Ward, 2000).

Finally, the third definition tackles the field of *sustainability*. According to the Brundtland Report of 1987, sustainable development "meets the needs of the present without compromising the ability of future generations to meet their own needs". A very promising approach to make this very broad and very broadly acceptable definition a little more clear and hence more controversial comes from the World Bank (Serageldin 1995). According to this definition, development can be called sustainable if a country's or region's wealth is not decreasing over time. Hereby, a country's or region's wealth consists of four components, i.e. human capital, natural capital, man-made capital, and social capital. However, even this definition leaves several key questions unanswered. Among them is the question of whether substitution between the different types of capital is allowed and to what degree, whether comparisons over time are made with respect to quantities, values, or both, and whether the reference levels are chosen incidentally or deliberately fixed, for instance by means of political processes. This paper does not intend to answer all these questions. If necessary, they will be discussed in chapter 6.

Given the basic definitions for the key features of this paper, we can now turn to the first step in the main discussion, i.e. to the existence of an Environmental Kuznets Curve in general.

3 The Environmental Kuznets Curve in General

As already mentioned, in 1955 Kuznets introduced into the economic literature an inverted-U shaped curve by which he represented the inequality of income distribution (measured by the Gini coefficient G) as a function of per capita income (y). He used cross-sectional data stemming from various countries at different stages of development. Yet, the theoretical underpinning which was given to this curve subsequently was that with increasing per capita income the income distribution of one and the same country first becomes more unequal, then reaches a maximum of inequality, and finally becomes more equal again (see Figure 1).

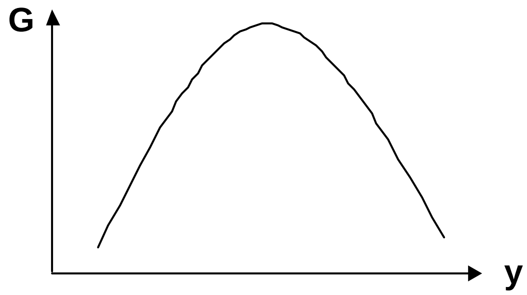

Figure 1

This interpretation seems to suggest some kind of automatism guaranteeing a reduction of distributional inequalities if only per capita income is increasing or if a country's development is proceeding. It turned out, however, that such automatism does not universally hold, i.e. that the so-called trickle-down could only be reached as a consequence of explicit policy measures. This implies that inferring predictions for single countries from the above mentioned cross-sectional data is rather dangerous. Nevertheless, the Kuznets Curve has been used since the 1950s for discussions on the influence of income growth on income distribution.

Since the beginning of the 1990s, several attempts have been undertaken in order to embed the Kuznets Curve into an environmental context. As a result, we see the discussion on the Environmental Kuznets Curve (EKC). As already mentioned, the basic idea of the EKC is that environmental damages E are a function of the status of development of a country or of its per capita income y, respectively, and that the f-function in (1) has the shape of an inverted U (see Figure 2).

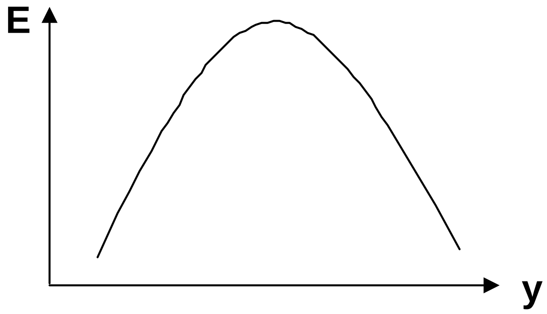

Figure 2

With respect to the EKC, empirical results as well as theoretical concepts have been discussed. In the following, both will be briefly presented (cf. Schubert et. al., 2000).

In order to obtain empirical results, it is of course first necessary to operationalize the E- and y-variables in (1). As could be expected, different authors suggest different ways of operationalization.

For the E variable, standing for environmental damages, either single indicators or indicator systems could be used. Single indicators may, firstly, take the form of *pressure* indicators, standing for the pressure on environmental quality which characterizes a country or region, such as GNP per capita, net investment per capita, or annual energy consumption. Single indicators may, secondly, be *state* indicators, characterizing the current threat to environmental quality. Such indicators are for instance the percentage of renewable energies with respect to total energy consumption, eco-GNP per capita, the GNP percentage of industrial activities, or the amount of natural reserves of non-renewable resources. Thirdly, single indicators may be *response* indicators, i.e. variables characterizing potential strategies to cope with deteriorations in environmental quality. Such an indicator would for example be government expenditure in the environmental field.

Indicator systems describing E can also have various forms. They can be constructed in analogy to the Human Development Indicator (HDI, see below), they can represent aggregate eco-points which say something about the relative environmental damages caused by specific substances or processes, they can represent the aggregate human exposure to ecological risks, etc. The type of E indicator most frequently used for the purpose of empirical studies is a single state indicator, measuring specific emissions, e.g. SO_2, CO_2 etc.

For the y variable, standing for per capita income or the development status of a country, respectively, there also exist different possibilities of operationalization. Total income as well as population size can be specified in different ways. This is not the place where to discuss at length the advantages and disadvantages of various income or population concepts. However, it should be emphasized that the income measurement by purely monetary variables such as the gross or net national or domestic product is just one line of measurement of the development status of a country. A broader concept would be for instance the HDI concept. According to this concept, a country's development can be characterized by three partial indicators, i.e. a country's relative position with respect to educational and literacy issues, with respect to health issues and with respect to income issues. By means of simple averaging, these three partial indicators can be amalgamated into just one indicator showing a country's average position taking into account different issues. There are, of course, a great number of other development indicators which should not be discussed here. The type of y indicator most frequently used by empirical investigations is a purely monetary indicator, notably gross national product per capita.

Given the aforementioned form of operationalizing E and y, four different types of functional forms f result from empirical studies. In these studies, f is estimated from cross-sectional data for a series of countries at a given point in time or from panel data where time series of cross sections are available. The advantage of panel data is of course that identical effects of income changes on the environment over different countries do not have to be assumed.

The four different functional forms that are identified in empirical studies are:

- Strictly increasing functions, occurring for instance for village waste per capita explained by per capita income (World Bank, 1992). For such a curve, it is important to point out a turning point may exist, but lies beyond the current maximum range of y values.

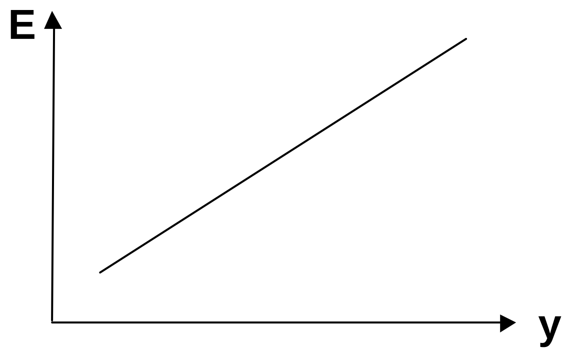

Figure 3

- Strictly decreasing functions, for example for the percentage of village inhabitants without access to safe water or sanitation explained by per capita income (World Bank, 1992).

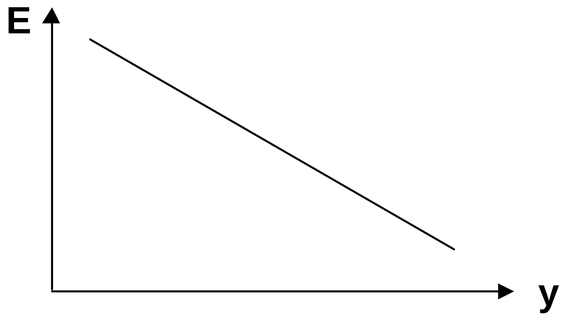

Figure 4

- Inverted-U shaped functions, for instance for the airborne concentration of SO_2 (Grossman and Krueger, 1995; Selden and Song, 1994; World Bank, 1992). It is interesting to see that the per capita income values yielding maximum emissions vary broadly between different studies (between 3700 and 8000 US-$). Similar curves have been found for NO_x, CO and VOC emissions.

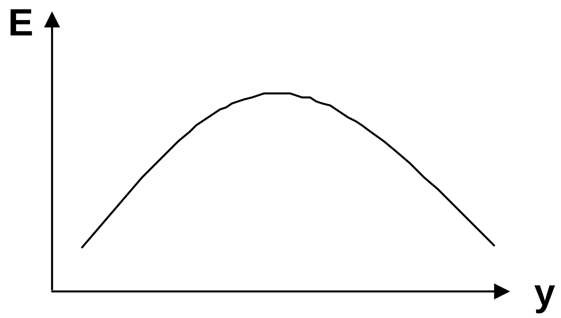

Figure 5

- N-shaped functions, for instance for CO_2 emissions per capita (Moomaw and Unruh, 1997).

Figure 6

One sees that from an empirical point of view, there is no striking evidence for an Environmental Kuznets Curve. It may occur, but one cannot be sure. The important point is that, for each of the above curves, the shape is predetermined by the functional form of the equation. More specifically, the monotonic increase and decrease represented by figures 3 and 4, respectively, is conditioned by the selection of a linear model beforehand. Similarly, figure 5 represents the best fit of a quadratic equation and figure 6 the best fit of a cubic equation.

Given the aforementioned problems with the empirical evidence, it seems worthwhile to investigate whether a theoretical analysis gives clear support to the EKC. Therefore, let us consider the relevant theoretical arguments.

The theoretical reasoning is based on equation (2):

$$E = \underbrace{P * y}_{F} * \sum_{i=1}^{N} e_i * s_i \tag{2}$$

with P standing for population size, F indicating the value of a country's economic activities, N the number of productive sectors, e_i the emissions per $ earned in sector i, and s_i the percentage of sector i's activities with respect to total gross national product (GNP).

Since one is interested in changes in E resulting from changes in y, it seems useful to express equation (2) by using the corresponding growth rates:

$$\hat{E} = \hat{P} + \hat{y} + \sum_i \frac{e_i * s_i}{\sum_j e_j * s_j} * \hat{e}_i + \sum_i \frac{e_i * s_i}{\sum_j e_j * s_j} * \hat{s}_i \tag{3}$$

with $\frac{e_i * s_i}{\sum_j e_j * s_j}$ as percentage of sector i's emissions with respect to total emissions.

Based on equation (3) one can identify four different effects by which changes in E can be explained and hence the shape of the f function can be predicted:

- The population effect: If the population size is increasing, the level of environmental damages will increase. Yet, two interesting questions arise. On the one hand one has to ask whether an increasing population causes increasing or decreasing per capita income, and on the other hand whether an increasing per capita income yields increasing or decreasing population size. Whereas with respect to the first question the empirical evidence is not clear, the situation is slightly better with respect to the second question. It seems as if increasing y delivers in the very long run decreasing populations so that in the very long run environmental damages might be reduced due to the population effect. With respect to forest cover, which is related to biodiversity, one can also question whether population growth has a deleterious effect on environmental quality at all. Some researchers conclude population is positively related to deforestation (Palo, 1994), yet other work shows that, in certain parts of the world, increasing population pressure actually increases environmental conservation (Mortimore and Tiffen, 1994).

- The scale effect: If, for given population size, per capita income is increasing, the level of environmental damages will also increase, at least if the third and fourth component in equation (3) are positive. If they are not positive, the second component still yields a positive effect on E.

- The technology effect: If the emission intensity of different sectors is decreasing, then the level E of environmental damages will also decrease. The open question is, however, whether or under which conditions the emission intensity will be decreasing. Importantly, a technological advancement that brings about a reduction in one kind of environmental burden may bring about an increase in another. For example, the introduction of flue-gas desulfurisation (FGD) at coal-fired power stations to reduce SO_2 emissions requires the quarrying and transport of limestone and reduces energy efficiency, thus increasing CO_2 emissions.

- The composition effect: If the production structure of an economy changes such that the proportion of low-emission sectors is growing, then the level E of environmental damages will decrease. Here, the open question is whether or under which conditions the proportion of low-emission sectors will increase. One condition under which this may occur is where a shift in production is not matched by a shift in consumption. In this case, consumption must be met through imports. This represents the idea of "exporting pollution", as polluting industries may relocate to developing countries where environmental regulations are more relaxed. If this is the case, then it has important future implications: those countries last to develop will not be able to export environmentally damaging production. However, evidence of pollution export is mixed and it is likely to play only a small role (Ekins, 1997).

Looking jointly at the four effects just mentioned, one can conclude that for a given population size of a country, f will be more likely to show a negative slope for high values of per capita income the more

- new technologies are increasingly environmentally friendly and
- the proportion of environmentally friendly sectors is increasing.

In spite of these insights, the likelihood of an EKC to occur is debatable. In the following, we therefore show under which conditions the likelihood of an EKC is high.

Negative technology and composition effects reducing environmental damages E with increasing per capita income y are more likely, the higher is the degree of internalization of negative externalities, i.e. the more scarce or the more expensive good environmental quality becomes. The degree of internalization, on the other hand, will be higher, the more strict the environmental policy is. Environmental policy will be more strict, the stronger populations' preferences for good environmental quality are. Populations' preferences for good environmental quality will, finally, be stronger the higher per capita income is. This is due to the fact that with increasing income per person more financial resources to take care of good environmental quality are available, negative effects of bad environmental quality on productivity and quality of life become more visible, and environmental protection becomes more estimated – last but not least because of the increasing level of education that comes along with increasing per capita income. In this sense, good environmental quality appears as luxury good, i.e. as a good which is asked for only in case of "sufficiently" high per capita income.

Wrapping up the theoretical arguments in favor of an Environmental Kuznets Curve, one can say that an EKC will prevail in the case of adequate environmental policy. It has been argued that such a policy is likely to occur with increasing y. However, political economy aspects have been omitted so far. This means that one cannot exclude that relevant and powerful political groups may produce societal structures such that with increasing y the environmental damages will even increase over a longer period of time. Looking at the other side of the coin this means that the existence of an EKC requires adequate policy measures and cannot be guaranteed. In other words: economic growth will not (quasi) automatically solve environmental problems. It may help to reduce environmental damages but only in the case of adequate environmental policy, i.e. if negative externalities are explicitly internalized.

Thus, one sees that not only the existence of the original Kuznets curve but also the existence of the Environmental Kuznets Curve is heavily policy dependent. Now, the interesting question is whether this result also holds for an EKC which is applied to the biodiversity context.

4 Biodiversity and the Environmental Kuznets Curve

As already mentioned, the EKC discussion has not been extended to the global biodiversity context until now. This is surprising as well as unacceptable since biodiversity is both of great importance to the human race and currently being depleted at a rapid rate.

Ehrlich and Wilson (1991) identify three basic reasons why biodiversity is important and should be protected. The first is ethical and aesthetic. In their view the human race has a moral obligation to protect the species with which it cohabits the earth. Similarly, many people gain aesthetic rewards from the existence of certain species. The second reason is the value of genetic diversity for agriculture and pharmaceuticals, which has been demonstrated in the past through, for example, the "green revolution" in agriculture. The third reason is the ecosystem services that biodiversity maintains, such as fertile soils and regulation of the earth's atmosphere. With the exception of moral obligation, these reasons represent economic value.

As indicated in chapter 2, biodiversity, as a general term, encompasses three different types of diversity: *ecosystem diversity*, which is the variety of different ecosystems in the world, *species diversity*, which is the number of different species, and *genetic diversity*, which is the genetic variation of individuals within and between populations of a species. Each type is related to the other, but it is species diversity that is most often taken as an expression of the magnitude of biodiversity loss. Therefore, and for simplicity's sake, we shall concentrate on species diversity in the following.

In order to analyze biodiversity in the light of the Environmental Kuznets Curve, first some theoretical considerations have to be made. The most important aspect is that the shape of an EKC for biodiversity should not be an inverted U but simply a U. The logic behind this is that, according to the EKC, with increasing per capita income the status of a specific context is first deteriorating and then improving. This means that if E stands for "something negative" such as undesired emissions, the EKC would have the form of an inverted U. However, if E stands for "something positive", for instance desired species diversity, the corresponding EKC would have the form of a U:

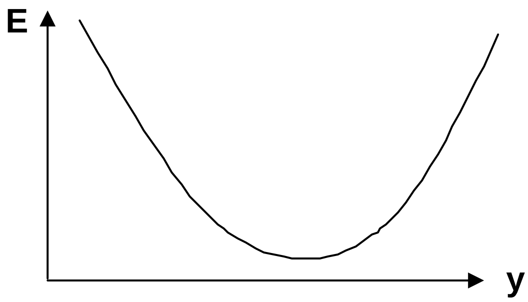

Figure 7

The corresponding functional form of such a U-shaped EKC is quadratic:

(4) $E = a - k_0 y + k_1 y^2$, where a, k_0, k_1 are positive constants

Theoretical considerations and empirical observations seem to suggest that there is evidence for the "falling limb" of a biodiversity EKC, i.e. for a decreasing number of species with increasing per capita income. However, replenishment of species diversity through "background speciation" at the same rate does not seem possible. In other words, one would not expect to see a "rising limb", i.e. an increase in species diversity of the same magnitude. It seems as if one could expect some "leveling off" with increasing y, i.e. a reduction in the rate of species depletion as opposed to a truly increasing number of species. If such a levelling off is relevant, the corresponding EKC would not be of a quadratic U-shape but we would instead have a hyperbolic curve:

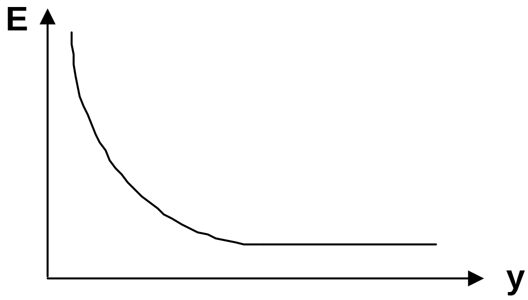

Figure 8

(5) $E = k_2 \frac{1}{y}$, where k_2 is a constant, $k_2 > 0$.

The levelling off may even be doubted in favour of a simple (linear) decrease of species diversity with increasing per capita income. In this case, the relevant functional form of an EKC would be a linear one:

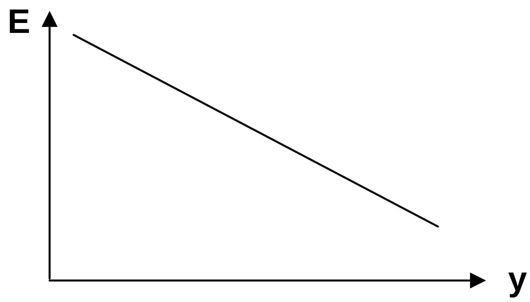

Figure 9

(6) $E = -k_3 y$, where k_3 is a constant, $k_3 > 0$.

Given the various possibilities of shapes for the f-function, empirical testing seems helpful in order to find out whether (5), (6) or (7) has higher relevance. The problem, however, with such testing is that panel data on species diversity is needed, yet panel data hardly exists. The only data available are present day numbers for some species (see for example the World Conservation Monitoring Centre, 2000, and the World Resources Institute 1999). An additional problem is that the total number of species is not even known to the nearest order of magnitude. It is estimated to range from 5 to 100 million species (Wilson, 1986). If the total number is not known, then species losses cannot be quantified either.

However, there is a pragmatic way out which most studies dealing with biodiversity rely on. This pragmatic solution proposes to work with species-area relationships, relating the number of species in a given area to the size of the area:

(7) $$S = c * A^z$$

with S the number of species in a given area A and c and z constants.

Species-area relationships are, like the EKC, purely empirical and any biological significance is inferred. To discuss the various theoretical underpinnings is beyond the scope of this paper, suffice to say c and z are technically meaningless constants (Connor and McCoy, 1979). Z, which defines the slope of the curve, has been relatively extensively researched in the literature and most authors agree it lies somewhere between 0.15 and 0.35 (MacArthur and Wilson, 1967). The variation in these values is generated when one moves across region, taxa and between island and (subsets of) continental flora and fauna. In this paper, the median value 0.25 is taken. However, Reid (1992) shows that results are sensitive to the z value taken. For example, estimates of the percentage loss of tropical closed forest species up to the year 2040 range from between 9% for a z value of 0.15 and 19% for a z value of 0.35.

Little, on the other hand, is known about c, with the result that studies using the species-area relationship tend to eliminate it through the following reworking of the equation

(8) $$\frac{S^t}{S_0} = \frac{A_t^z}{A_0^z}$$

where t stands for the current time period and 0 for a reference time period.

If (8) is used in order to estimate the change in number of species in a given region over time, several problems occur. The most important problems are:

- The destruction of area in the sense of habitat is assumed to eliminate the species reliant on it. Yet the partial depletion of a specific area must not necessarily destroy the species completely. Therefore, species loss would be overestimated (Lugo et. al., 1993).
- Habitats are often fragmented and hence support low numbers of species. Under this aspect, an underestimation of species loss seems likely if area destruction is used as the main explanatory variable for species destruction (Simberloff, 1992).

- Habitat lost is assumed to have constant species diversity, whereas impingement might preferentially take place in areas of high species diversity (underestimation of losses) or low species diversity (overestimation of losses), as would be the case if species-rich areas were protected. In this case, the direction of bias is not immediately apparent.
- As mentioned, variation in z creates broad confidence bands.

Nevertheless, until now the species-area relationship appears to be the only alternative available in order to have at least some estimate of the E indicator as far as biodiversity is concerned. A promising new area of research is investigating the application of phylogenies (family tree-like structures showing the evolution of species from a common ancestor) to measure species diversity (Weitzman, 1992; Solow et. al., 1993). However, this methodology is still at an early stage.

Practical steps in order to estimate (8) are:

- Define A. Here it is prudent to concentrate on just one region with a constant z. The example looked at in the following is primary tropical rainforest, since species diversity is recognized to be highest in these areas (Myers, 1980; Wilson, 1986). However, such data is in short supply. The only set which satisfies our need for a time series comes from the FAO's Production Yearbook (FAO, various years). Unfortunately, this source adopts a broad definition of forests as "all woody vegetations" (Koop and Tole, 1999). Thus we cannot confine ourselves to *primary* tropical forests. It has also to be taken into consideration that between different countries and their national statistics various inconsistencies exist, for instance with respect to the definition of what constitutes tropical rainforests, deforestation, or how to measure it (Pearce and Brown, 1994). The final data set comprises 36 countries, with a time series beginning in 1970 and running up to 1990.

- Fix z, according to expert opinion.
- Estimate S_t / S_0 from A_t / A_0 and z and indicate the corresponding confidence bands. Use this estimation as E indicator.

By the procedure just described, panel data on E can be artificially generated based on area panel data.

Let us assume now that estimates of the E indicator have been made available by means of the procedure just described. Let us further assume that data on y is available. The next task is then to test the potential EKC types (4) – (6) against each other. In order to do so, one needs models by which to estimate E values out of a set of explanatory variables including y. When using panel data, simple ordinary least squares (OLS), fixed effects, random effects or random coefficients models can be applied to estimate the coefficients in

(9) $$E_{it} = \alpha + \beta_j * X_{ijt} + \varepsilon_{it}$$ (simple OLS)

with X representing j independent variables to explain E, y being amongst them, i standing for different countries, and t standing for different points in time.

The other three estimation models can be described as follows:

(9a) $E_{it} = \alpha_i + \beta_j * X_{ijt} + \varepsilon_{it}$
(fixed effects)

(9b) $E_{it} = \alpha + \beta_j * X_{ijt} + \varepsilon_{it} + \mu_i$
(random effects)

(9c) $E_{it} = \beta_i * X_{it} + \varepsilon_{it}$, with $\beta_i = \beta + \nu_i$
(random coefficients)

Hereby, the idea of the fixed effects model is that international differences in E are generated by country-specific factors not covered by the regressors. We would not, for instance, expect an income variation of fixed magnitude to generate the same change in E in Brazil and Indonesia. The random effects model argues that national peculiarities are unimportant to explain differences in E and that differences should be assumed random. This is a responsible approach if the sample is part of a much larger population (Greene, 1997). The random coefficients model finally assumes that each country possesses its own function (9) drawn from a random distribution.

With respect to the data available, it turns out that the random coefficients model is not applicable since the data implies a heavily distorted Covariance Matrix. Fixed effects and random effects can be tested against simple OLS using LM statistics: a Lagrange multiplier test which analyses whether the variance of μ_i is equal to zero, i.e. whether fixed/random effects are constant, in which case simple OLS is valid. Fixed effects can be tested against random effects using the Hausman test, which assesses whether individual effects are correlated with the regressors. If so, random effects are inconsistent. If not, both random and fixed effects are consistent but random effects are more efficient.

Bringing together the models (4) – (6) and the model (9), one receives the following testable models:

(10a) $E_{it} = \alpha + \beta_1 * y_{it} + \beta_2 * y_{it}^2 + \beta_3 * P_{it} + \beta_4 * D_{it} + \beta_5 * F_{it} + \beta_6 * T_t + \varepsilon_{it}$

(10b) $E_{it} = \alpha + \beta_1 * \frac{1}{y_{it}} + \beta_2 * P_{it} + \beta_3 * D_{it} + \beta_4 * F_{it} + \beta_5 * T_t + \varepsilon_{it}$

(10c) $$E_{it} = a + b_1 * y_{it} + b_2 * P_{it} + b_3 * D_{it} + b_4 * F_{it} + b_5 * T_t + e_{it}$$

Hereby, the list of independent variables can be indicated as follows:

y_{it} GNP per capita, log form[1]
P_{it} Population change with respect to previous year
D_{it} Population density, people per hectar
F_{it} Forest area, hectares
T_t Linear time trend

Population is, as mentioned, likely to have an effect on E. In addition, forest area is included to control for the fact that the relative impact of deforestation in any country depends on absolute forest area and feeds back into future trends. A simple linear time trend captures the positive time dependency of both income and biodiversity (current levels depend on previous levels).

If an environmental Kuznets curve exists for biodiversity, we would expect equation (10a) to be statistically significant at the 1% level, both overall and with income and income squared. The significance of other variables is less important, although we expect each to be significant at the 1% level according to theory. To produce the necessary U-shape, the coefficient of income should be negative and of income squared positive (cf. equation (4)). Equation (10a) should fit the data significantly better than its rivals, so we might in turn expect (10b) and (10c) to be less significant. However, we postulate a hyperbolic equation, so we would expect (10b) to be a better fit than (10a) or (10c). The income coefficient should be positive in this case.

The results for equations (10a) – (10c) are outlined in TABLES 1-5 in the Appendix. ** indicates statistical significance at the 1% level. *shows statistical significance at the 5% level. Standard errors are in parenthesis.

TABLE 1 shows summary statistics for this stage of the analysis. The important point to note here is the low variability in $E = S_t / S_0$, species number, and y, income. This will emerge as an important influence on the quality of results.

TABLE 2 displays the outcome of tests between OLS, fixed and random effects for each equation. LM statistics return high values, favouring fixed/random effects over simple OLS. The results of the Hausman test further favor fixed effects over random effects in all cases. Thus we can conclude that national environmental and socio-economic characteristics play a significant role in biodiversity levels and that group differences in E are not randomly distributed.

TABLE 3, 4 and 5 report coefficients for equations (10a) – (10c). All three equations are significant at the 1% level (F-statistics) and have income coefficients significant at the 1% level. In

[1] The log form is chosen in accordance with most other EKC studies. This form appears appropriate as long as the relationship between E and y is not linear.

fact, all coefficients are significant at this level, except population change and population density, which are only significant at the 5% level. These two variables were confirmed to be jointly insignificant by a post-analysis Wald test and in general, the suspected role of population in biodiversity levels is not corroborated here. With regards to the paper's main hypothesis, all of the equations significantly fit the data – no one equation can be distinguished as most suitable. Furthermore, looking at the signs of the income and income squared coefficients for equation (10a), the curve is the opposite of that anticipated. Equations (10b) and (10c) display positive trends with rising y.

To confirm this positive relationship and to test the earlier hypothesis that the data can be separated into two distinct limbs, a Chow test was carried out. The income distribution is split around the median and the significance of the two halves analyzed by performing separate regressions and comparing their residual errors with those of the whole data set. TABLE 6 returns for the lower and upper halves of the income distribution. F-statistics for the test is 14.99, significant at the 1% level. Thus two distinct limbs can be confirmed. However, the income coefficient is positive, confirming the unsuspected positive relationship between income and species. Note that income per capita is only significant at the 5% level for higher incomes. This cannot readily be explained.

Wrapping up, it turns out that the shape of f is precisely the opposite of what one would expect. This means that obviously an EKC for species diversity does not exist. All three functional forms for f fit the data significantly. The quadratic form which would be in line with the EKC presumption has no better fit than the other two functional forms. There does not seem to be a "falling limb" for increasing y. The positive relationship between y and E can be explained by the low variation in both the species diversity and income data. Any increase or decrease is a procentually slight one and may not be considered meaningful.

The following conclusions can be drawn from the above results:

- The possibilities of generating accurate data to test the EKC hypothesis for biodiversity are quite limited at present. Direct time series would be needed to improve the quality of the results, yet there are none available presently. Deriving E values indirectly by means of the species-area approach causes problems with respect to the achievable results. The ex-ante fixation of z is just one example for these problems.
- The presumption that the EKC applies universally to "environmental quality" including for instance biodiversity is further challenged.
- Fixed effects estimations are statistically favored over random effects estimations. This implies that national environmental and socio-economic conditions not covered by the regressors significantly influence the level of species diversity.
- "Trend"(or time) seems to play an important role in the sense that with increasing time E, i.e. species diversity, is deteriorating.

5 Policy Intervention in Biodiversity Conservation

We shall now discuss the role of policy. As outlined in chapter 3, policy theoretically plays an important role in the EKC transition. However, because the EKC is a purely empirical entity, one must refocus attention directly on policy measures in order to draw firm conclusions. In the context of biodiversity, two globally important conservation measures are (i) the state protection of land and (ii) the international regulation of trade in endangered species. In the following, some empirical testing of the hypothesis that with increasing per capita income the intensity of biodiversity protection measures will increase is presented. This hypothesis is very much in line with the general argumentation given in chapter 3.

(i) State protected land represents a form of property rights regime where the single state owner prevents or reduces resource-take in order to protect valuable species or a valuable natural environment. This can take different forms: nature reserves protected for scientific interest, natural monuments protecting natural features or national parks that have some emphasis on recreation, for example.

This study uses the updated 1993 United Nations List of National Parks and Protected Areas (IUCN, 1994), which uses the general term "wildland management area" to embrace a range of protected area categories with different management objectives. Broadly, the UN list only includes those areas "especially dedicated to the protection and maintenance of biological diversity" (World Conservation Monitoring Centre, 2000); yet the extent to which species diversity is prioritised varies between categories. All categories are included and the sum of protected area for each country is normalised as a percentage of national land territory. This is the dependent variable PA in the regression analysis which is reported in the following. Development is measured through per capita income only. Population density is included to account for the likelihood that in densely populated countries, significant tracts of ecosystem may have been lost prior to the advent of protection. In other words, there is little land protectable. A linear time trend (as before) is meant to account for the positive time dependency of income and percentage of protected area. Population change is further present. The basic regression model is then

$$(11)\quad PA_{it} = \alpha + \beta_1 y_{it} + \beta_2 P_{it} + \beta_3 D_{it} + \beta_4 T_{it} + \varepsilon_{it}$$

Ordinary least squares, fixed effects and random effects are tested as before. Again, theory in this case would suggest socioeconomic and natural factors varying by country and not captured by the regressors in (11) should exert a significant influence. Therefore fixed effects should be favoured. An inverted-U shape should not be produced, as countries are expected to supplement the area of protection incrementally as development proceeds. Thus only a linear model is tested.

(ii) The regulation of trade in endangered species is designed to prevent certain species, valued for their products, from being driven to extinction. The Convention on International Trade in Endangered Species (CITES) was first signed in 1973 by 21 states. 127 states are now members. During this time, CITES has been viewed as the "flagship of the flora and fauna preservation treaties" (Lanchberry, 1998, p.69). Species covered by the convention are listed in one of three appendices, I, II and III. Trade in Appendix I species is essentially banned. Trade in Appendix II and III species is permitted but regulated through a system of permits. In principle, trade restrictions help to drive prices up and quantities down, thus reducing the threat of extinction. However, much depends on how effectively illegal trade is controlled. Furthermore, controlling trade can cut off valuable sources of revenue for many societies. Pearce and Moran (1997) identify the same problems for those cut off from the resources they depend on by state protected land. For them, these two strategies represent a "moral view", which disinvests value in biodiversity, taking away its economic value.

CITES is reviewed through a reporting process. Importantly, almost all parties are required to report on trade in species listed in Appendices I and II annually and there are strict deadlines for their submission. In the latest edition of World Resources (World Resources Institute, 2001), the percentage of reports submitted relative to those expected is listed for all parties. Reporting does not necessarily reflect actual implementation but it does reflect the only systematic means the convention has of monitoring how strictly trade is regulated (Lanchberry, 1998). Furthermore, failure to meet deadlines is identified as a particular problem among developing countries (Ong, 1998), where resources and expertise may be lacking.

On this premise, this study tests the relationship between development, as measured by per capita GNP for 1999 (World Bank, 2000), and the percentage of expected reports actually submitted in 1999. GNP does not represent a direct causal factor, but it is correlated with the quality of national bureaucracy (Rausch and Evans, 2000). The number of reports required is also included, as the dependent variable is sensitive to changes in this factor. For example, a country that fails to submit its one report meets 0% of its requirement, whereas a country failing to submit one of its 20 reports meets 95% of its requirement.

The regression model is then a simple cross-section of the form

(12) $$R_i = \alpha + \beta_1 y_1 + \beta_2 TR_i + \varepsilon_{it}$$

where R is the percentage of reports submitted for country i, y is per capita income and TR is the total number of reports expected. The model is estimated by ordinary least squares.

TABLES 7 and 8 in the appendix display results for equations (11) and (12). Equation (11) was estimated by simple OLS, fixed and random effects. An LM statistics value of 16,871.46 and a Hausman test result of 85.33 are sufficient to select fixed effects as most suitable. TABLE 7 shows that equation (11) is significant at the 1% level (F-statistics) as is income. However, R^2 for fixed effects is only 0.36. Thus the relationship is not strong.

TABLE 8 shows that equation (12) is significant at the 1% level but, again, the relationship is not strong. R^2 is only 0.26.

From this second set of results, we can conclude that, although neither relationship is strong (cf. R^2 values), economic development does appear to be related to the level of effort national governments invest in conservation, confirming the theory outlined in chapter 3.

However, biodiversity is still being lost at a rapid rate, in spite of policy responses such as the above. Therefore, one can conclude that more must be done in order to safeguard global biodiversity. Developing countries may be less capable of increasing and effectively managing protected lands, but a significant proportion of global biodiversity, and in particular threatened biodiversity, is located there. This is recognised by Myers et. al (2000), who identify 25 "hotspots" of biodiversity based on species endemism and the degree of threat to it. 16 of the 25 hotspots are in the tropics and are largely made up of developing countries. 62% of the total area of hotspots is not afforded any protection and much of the remaining 38% is thought to be weakly safeguarded. Thus Myers et. al provide an ecology-based framework for focused and intensified global biodiversity conservation, what they call a "silver bullet" strategy. Implicit in this is the recognition that the number of species threatened with extinction far outstrips the available funding.

Moran et. al. (1997) and Drechsler and Wätzold (2001) extend this analysis to explicitly consider economic factors. Moran et al. calculate a cost-effectiveness index to rank global biodiversity investments by country. Benefit is measured as species richness and cost as international investment. Threat to biodiversity, measured as the rate of deforestation, and the probability of success, measured as the area of protectable land actually protected, are also included. The authors emphasise that the index is no more than a suggestion of how to prioritise biodiversity conservation, and identify severe data limitations. However, economic considerations are important and, as such, the index represents a step forward. Drechsler and Wätzold (2001) examine the issue in greater theoretical detail by looking at how different benefit and cost functions interact to generate a complex set of outcomes. Benefit functions are either defined in terms of species richness, using the species-area relationship, or in terms of individual keystone species. Cost functions are defined in terms of marginal costs of conservation with area. Again, the importance of interdisciplinarity between ecology and economics is clear.

How this targeted global conservation should be implemented is open to debate. As Myers et. al (2000) point out, those biodiversity hotspots currently protected by national governments are still vulnerable, since enforcement is often weak. Therefore, although increased state land protection is an important option, alternative property rights regimes should be considered.

6 Sustainability Implications

Having looked at various results concerning the existence of an EKC for biodiversity, one can now consider the sustainability implications. What do the doubts over the existence of the EKC imply for sustainability?

Obviously, there is no quasi-automatic recovery of the number of species along with increasing per capita income. On the other hand, there is empirical evidence for current species losses, for instance as a result of global deforestation. Estimates indicate a loss of 1 – 10% of species per decade. This means that the quantity component of the natural capital of countries or regions is decreasing. Ceteris paribus, the value of natural capital would also be decreasing if the extinct species were meaningful to present or future generations.

Yet, in this context several problems arise. Firstly, it is not clear how the values given to species by present or future generations could be found out and by whom. Secondly, if a decrease in species quantities is assumed, will it not be overcompensated by an increase in the price component caused by the increasing scarcity of species? And how could one differentiate between the quantity and price component? Thirdly, if – due to the species extinction - a decrease in the value of natural capital is assumed, can this be compensated by value increases of other components of the total wealth of nations or regions? This brings up the question of the admissibility of substitution in general or of specific types of substitution. This question of substitution has been broadly discussed in the literature but there is no clear "objective" answer. Instead, the degree of admissible substitution depends on the value judgments of the involved persons or societies.

Therefore, it seems reasonable to conclude that the observable loss in species numbers is a signal of danger for sustainability. Clear results reflecting a loss or gain in sustainability are not obtainable.

However, remember the above argument that good environmental quality is a luxury good and that this characteristic is the basis for successful policies which yield improvements in environmental quality. If one tries to make an analogy to the case of biodiversity, one of the most important steps in fighting the rapid depletion rate would be to concentrate on the perception of biodiversity in the public. The more the public is convinced that with increasing per capita income increasing income can and should be invested in the field of species preservation, the basis for policy measures in favor of such preservation would be created. Amongst such policy measures one would expect on the one hand direct governmental investment in biodiversity preservation and on the other hand incentives yielding changes in individuals' behavior implying consequences for species preservation or extinction.

Especially the direct investment aspect emphasizes that improvements with respect to biodiversity are competing with other expenditures in a society. This raises the question of whether biodiversity improvements have to be seen – from the perspective of society as a whole – as consumption or investment expenditure. If they were to be seen as consumption expenditure, they would compete with other projects at low discount or interest rates (2-3 %). If, however, biodiversity measures were interpreted as competing with other investment projects, they would have to yield much higher interest rates (10-15%). Yet, it is not possible to decide on the interpretation of biodiversity measures from a purely scientific point of view. Even this decision should be societal, i. e. a value judgment. An important puzzle stone in this judgment is the definition of "investment" or of "capital" respectively. The more one restricts "capital" to man-made capital the higher the threshold interest rate with which the returns to biodiversity improvements have to be compared will be. The more comprehensive the notion of "capital" is (cf. the World Bank definition given above), the lower the reference interest rate will be. Yet, even the choice of an adequate notion of capital can be seen as a decision for which there are no objective grounds. Given the immense uncertainty involved due to the value aspects, it is important to be aware of the importance of the consumption-versus-investment decision when framing measures concerning the perception of biodiversity issues in a society.

7 Summary and Concluding Discussion

The main result of this paper is that the existence of an EKC for biodiversity cannot be proven empirically. On the contrary, an EKC for biodiversity seems rather not to exist. We have no *a priori* expectation of an EKC in this case and the results appear to confirm our suspicion. Yet we are in no better position to identify the real relationship, since low variation in both biodiversity and income data delivers a spurious positive relationship. More expansive, accurate and direct measurement of biodiversity is needed before the results of such an environmental Kuznets curve analysis can be relied upon. If this is forthcoming, then it is our hypothesis that a falling limb will become clear, yet with no recovery trend. In other words, we expect the relationship to follow a hyperbolic path as in equation (10b).

Given an EKC seems not to exist, the decisive question is whether and how we could bring an EKC for biodiversity into existence, i.e. whether and how we could at least stop species extinction. It is obvious that we cannot answer this question in our paper. Yet, we can give some hints on policy and research implications which would bring us closer to an answer.

Among the policy implications to be drawn from Chapter 5, the most important one is that, with respect to biodiversity, economic growth on its own will not solve the problem. Government interventions are needed in order to cope with species losses. However, in order to be efficient, these interventions should be based on knowledge about society's present and future preferences for numbers and types of species. As long as such preferences are not known, smooth measures towards a lower rate of species losses seem appropriate. In this context, property regimes which encourage conservation of biodiversity resulting for instance from sensible land use are significant. Examples of measures and property regimes pointing in this direction are state protection of land, regulation of trade in endangered species, "corporate citizenship", "rights that come with responsibilities", "no rights without responsibilities", financing pro-biodiversity business, pro-conservation tourism etc. Finally, it should be mentioned that, given the fact that global biodiversity continues to be rapidly depleted, that the world's most biodiverse areas are in developing countries and that financial resources are limited, co-ordinated global conservation strategies seem to be the only way forward.

With respect to further research implications, the following seem of special importance:

- The need for accurate biodiversity panel data.
- The need for an identification of more significant explanatory variables for the E variable, such as literacy, political and civil rights, income distribution etc.
- The need for the determination of social costs or negative externalities of species extinction in order to cause political pressure which will generate a biodiversity EKC.
- The need for efficient national and international policies to encourage conservation of biodiversity.

References

Bulte, E. H. and D. P. van Soest (2001): Environmental Degradation in Developing Countries: Households and the (Reverse) Environmental Kuznets Curve. *Journal of Development Economics*, **65**, pp. 225-235.

CBD (Convention on Biological Diversity) (1992): In: International Legal Materials (ILM) **31**, pp. 848.

Connor, E.F. and E.D. McCoy (1979): The statistics and biology of the species-area relationship. *The American Naturalist*, **113(6)**, pp. 791-833.

Cropper, M. and Griffiths, C. (1994): The Interaction of Population Growth and Environmental Quality. *American Economic Review*, **84 (2.**), pp. 250-254.

Drechsler, M. and F. Wätzold (2001): The importance of economic costs in the development of guidelines for spatial conservation management. *Biological Conservation*, **97**, pp. 51-59.

Ehrlich, P.R. and E.O. Wilson (1991): Biodiversity studies: science and policy. *Science*, **253**, pp. 758-761.

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

FAO (various years): *Production Yearbook*. FAO, Rome.

Greene, W.H. (1997): *Econometric Analysis.* 3rd Int. edn., Prentice Hall, Englewood Cliffs, NJ.

Grossman, G. and Krueger, A. (1995): Econometric growth and the environment. *Quarterly Journal of Economics*, ***60***, pp. 353-377.

IUCN (1994): *1993 United Nations List of National Parks and Protected Areas*. IUCN, Gland, Switzerland and Cambridge.

Koop, G. and L. Tole (1999): Is there an environmental Kuznets curve for deforestation? *Journal of Development Economics*, **58**, pp. 231-244.

Kuznets, S. (1955): Economic growth and income equality. *American Economic Review*, **49**, pp. 1-28.

Lanchberry, J. (1998): Long-term trends in systems for implementation review in international agreements on fauna and flora. In: D.G. Victor, K. Raustalia and E.B. Skolnikoff, eds.: *The Implementation and Effectiveness of International Environmental Commitments: Theory and Practice.* MIT Press, Cambridge, Mass. and London, pp. 57-89.

Lugo, A.E., J.A. Parotta and S. Brown (1993): Loss in species caused by tropical deforestation and their recovery through management. *Ambio*, **22(2-3)**, pp. 106-109.

MacArthur, R.H. and E.O. Wilson (1967): *The Theory of Island Biogeography*. Princeton University Press, Princeton, NJ.

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

Moran, D., D.W. Pearce and A. Wendelaar (1997): Investing in biodiversity: an economic perspective on global priority setting. *Biodiversity and Conservation*, **6**, pp. 1219-1243.

Mortimore, M. and M. Tiffen (1994): Population Growth and the Environment: The Machakos Story. *Environment*, **36 (8)**, pp. 10-32.

Myers, N. (1980): *Conservation of Tropical Moist Forests.* National Academy Press, Washington, DC.

Myers, N., R.A. Mittermeier, C.G. Mittermeier, G.A.B. da Fonseca and J. Kent (2000): Biodiversity hotspots for conservation priorities. *Nature*, **403**, pp. 853-858.

Ong, D.M. (1998): The convention on international trade in endangered species (CITES, 1973): implications of recent developments in international and EC environmental law. *Journal of Environmental Law*, **10(2)**, pp. 291-314.

Palo, M. (1994): Population and Deforestation. In: D.W. Pearce and K. Brown (eds.*): The Causes of Tropical Deforestation*. UCL Press, London, pp. 42-56.

Pearce, D.W. and K. Brown (1994): Saving the world's tropical forests. In: D.W. Pearce and K. Brown (eds.): *The Causes of Tropical Deforestation*. UCL Press, London, pp. 2-26.

Pearce, D.W. and D. Moran (1997): The economics of biodiversity. In: H. Folmer and T. Tietenberg, eds.: *The Yearbook of Environmental and Resource Economics 1997/1998.* Edward Elgar, Cheltenham, pp. 82-114.

Rausch, J.E., and P.B. Evans (2000): Bureaucratic structure and bureaucratic performance in less developed countries. *Journal of Public Economics*, **75**, pp. 49-71.

Reid, W.V. (1992): How many species will there be? In: T.C. Whitmore and J.A. Sayer, eds.: *Tropical Deforestation and Species Extinction*. Chapman and Hall, London, pp. 55-74.

Schubert, R., Saladin, S., Spitze, K. (2000): Wirtschaftliche Entwicklung und Umwelt – Zur Relevanz der Umwelt-Kuznetskurve. In: E. Scholing: Währung und wirtschaftliche Entwicklung. Volkswirtschaftliche Schriften Heft 505, pp. 275-300.

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

Serageldin, I. (1995): Monitoring Environmental Progress – A Report on Work in Progress, Washington.

Shafik, N. and Bandyopadhyay, S. (1992): Economic Growth and Environmental Quality: Time Series and Cross-Country Evidence. *Policy Research Working Paper* No. WPS 904, Washington D.C.: The World Bank.

Simberloff, D. (1992): Do species-area curves predict extinction in fragmented forest? In: T.C. Whitmore and J.A. Sayer, eds.: *Tropical Deforestation and Species Extinction*. Chapman and Hall, London, pp. 75-89.

Solow, A., S. Polasky and J. Broadus (1993): On the measurement of biological diversity. *Journal of Environmental Economics and Management*, **24**, pp. 60-68.

Ward, H. (2000): Special Biodiversity Issue - Introduction and Overview. *International Affairs*, **76 (2)**, pp. 213 – 222.

Weitzman, M. (1992): On diversity. *Quarterly Journal of Economics*, **107**, pp. 363-405.

Wilson, E.O. (1986): The current state of biological diversity. In: E.O. Wilson, ed.: *Biodiversity*. National Academy Press, Washington, DC, pp. 3-18.

World Bank (1992): *World Development Report 1992*. World Bank, Washington, DC.

World Bank (2000): *World Development Indicators*. World Bank, Washington, DC.

World Conservation Monitoring Centre (WCMC), www.wcmc.org.uk, viewed at 15/10/2000.

World Resources Institute (1999): *World Resources 1998-9*. Oxford University Press, Oxford.

World Resources Institute (2001): *World Resources 2000-1*. Stationery Office, London.

Appendix

Table 1. Summary statistics for selected variables in the species diversity analysis.

	Mean	*Standard deviation*
Species number ((S_t/S_0)*1000)	975.1	31.6
GDP (PPP$)	2116.5	1484.9
Time trend (year)	1980.7	6.5
Forest area (*1000ha)	40468.7	87325.0
Percentage change in population	0.03	0.01
People per hectare of land	0.7	1.2

(sample size N = 828)

Table 2. Comparing OLS, fixed and random effects for each equation linking species diversity with income.

	Quadratic equation	*Hyperbolic equation*	*Linear equation*
LM statistics	3201.7**	3389.1**	3491.4**
Hausman statistics	39.2**	29.0**	29.0**

(sample size N = 828)

Table 3. Estimates of the quadratic equation linking species diversity with income.

	Result for fixed effects
lnGDP	136.2 (41.6)**
$(\ln GDP)^2$	-8.2 (2.8)**
Time trend	-2.0 (0.1)**
Forest area	9E-04 (2E-04)**
Population change	77.5 (41.7)*
Population density	-7.2 (3.2)*
F-statistics	59.6**

(sample size N = 828)

Table 4. Estimates of the hyperbolic equation linking species diversity with income.

	Result for fixed effects
1/lnGDP	-15871.6 (3927.6)**
Time trend	-2.2 (0.1)**
Forest area	0.8 (2E-04)**
Population change	73.8 (41.8)*
Population density	-6.1 (3.1)*
F-statistics	63.0**

(sample size N = 828)

Table 5. Estimates of the linear equation linking species diversity with income.

	Result for fixed effects
lnGDP	12.3 (3.1)**
Time trend	-2.2 (0.1)**
Forest area	9E-04 (2E-03)**
Population change	69.1 (41.8)*
Population density	-5.2 (3.1)*
F-statistics	63.0**

(sample size N = 828)

Table 6. Linear equations, for the lower and upper halves of the income distribution, linking species diversity with income.

	Lower income	*Higher income*
lnGDP	18.3 (4.0)**	8.4 (5.0)*
Time trend	-1.4 (0.1)**	-1.7 (0.2)**
Forest area	4E-03 (3E-04)**	-2E-04 (2E-04)
Population density	-7.1 (2.5)**	-124.8 (11.0)**
Population change	33.0 (3.9)	98.7 (76.9)
F-statistic	74.8	96.9

(sample size N = 828)

Table 7. The linear relationship between percentage protected area and income, based on panel data for 141 countries between 1950 and 1991.

	Result for fixed effects
lnGDP	12.3 (1.9)**
Time trend	0.2 (2E-02)**
Population density	1.8 (0.2)**
Population change	2.7 (1.2)*
F-statistic	18.8**

(sample size N = 4620)

Table 8. The relationship between percentage reports for CITES expected in 1999 actually submitted and income.

	Results for OLS
GNP	1E-03 (3E-04)**
Reports expected	1.3 (0.3)**
Constant	43.3 (5.6)**
F-statistics	20.3**
Adjusted R^2	0.3

(sample size N = 109)

The following papers have been published so far:

No. 1	Ulrike Grote, Arnab Basu, Diana Weinhold	Child Labor and the International Policy Debate Zentrum für Entwicklungsforschung (ZEF), Bonn, September 1998, pp. 47.
No. 2	Patrick Webb, Maria Iskandarani	Water Insecurity and the Poor: Issues and Research Needs Zentrum für Entwicklungsforschung (ZEF), Bonn, Oktober 1998, pp. 66.
No. 3	Matin Qaim, Joachim von Braun	Crop Biotechnology in Developing Countries: A Conceptual Framework for Ex Ante Economic Analyses Zentrum für Entwicklungsforschung (ZEF), Bonn, November 1998, pp. 24.
No. 4	Sabine Seibel, Romeo Bertolini, Dietrich Müller-Falcke	Informations- und Kommunikationstechnologien in Entwicklungsländern Zentrum für Entwicklungsforschung (ZEF), Bonn, January 1999, pp. 50.
No. 5	Jean-Jacques Dethier	Governance and Economic Performance: A Survey Zentrum für Entwicklungsforschung (ZEF), Bonn, April 1999, pp. 62.
No. 6	Mingzhi Sheng	Lebensmittelhandel und Kosumtrends in China Zentrum für Entwicklungsforschung (ZEF), Bonn, May 1999, pp. 57.
No. 7	Arjun Bedi	The Role of Information and Communication Technologies in Economic Development – A Partial Survey Zentrum für Entwicklungsforschung (ZEF), Bonn, May 1999, pp. 42.
No. 8	Abdul Bayes, Joachim von Braun, Rasheda Akhter	Village Pay Phones and Poverty Reduction: Insights from a Grameen Bank Initiative in Bangladesh Zentrum für Entwicklungsforschung (ZEF), Bonn, June 1999, pp. 47.
No. 9	Johannes Jütting	Strengthening Social Security Systems in Rural Areas of Developing Countries Zentrum für Entwicklungsforschung (ZEF), Bonn, June 1999, pp. 44.
No. 10	Mamdouh Nasr	Assessing Desertification and Water Harvesting in the Middle East and North Africa: Policy Implications Zentrum für Entwicklungsforschung (ZEF), Bonn, July 1999, pp. 59.
No. 11	Oded Stark, Yong Wang	Externalities, Human Capital Formation and Corrective Migration Policy Zentrum für Entwicklungsforschung (ZEF), Bonn, August 1999, pp. 17.

No. 12	John Msuya	Nutrition Improvement Projects in Tanzania: Appropriate Choice of Institutions Matters Zentrum für Entwicklungsforschung (ZEF), Bonn, August 1999, pp. 36.
No. 13	Liu Junhai	Legal Reforms in China Zentrum für Entwicklungsforschung (ZEF), Bonn, August 1999, pp. 90.
No. 14	Lukas Menkhoff	Bad Banking in Thailand? An Empirical Analysis of Macro Indicators Zentrum für Entwicklungsforschung (ZEF), Bonn, August 1999, pp. 38.
No. 15	Kaushalesh Lal	Information Technology and Exports: A Case Study of Indian Garments Manufacturing Enterprises Zentrum für Entwicklungsforschung (ZEF), Bonn, August 1999, pp. 24.
No. 16	Detlef Virchow	Spending on Conservation of Plant Genetic Resources for Food and Agriculture: How much and how efficient? Zentrum für Entwicklungsforschung (ZEF), Bonn, September 1999, pp. 37.
No. 17	Arnulf Heuermann	Die Bedeutung von Telekommunikationsdiensten für wirtschaftliches Wachstum Zentrum für Entwicklungsforschung (ZEF), Bonn, September 1999, pp. 33.
No. 18	Ulrike Grote, Arnab Basu, Nancy Chau	The International Debate and Economic Consequences of Eco-Labeling Zentrum für Entwicklungsforschung (ZEF), Bonn, September 1999, pp. 37.
No. 19	Manfred Zeller	Towards Enhancing the Role of Microfinance for Safety Nets of the Poor Zentrum für Entwicklungsforschung (ZEF), Bonn, October 1999, pp. 30.
No. 20	Ajay Mahal, Vivek Srivastava, Deepak Sanan	Decentralization and Public Sector Delivery of Health and Education Services: The Indian Experience Zentrum für Entwicklungsforschung (ZEF), Bonn, January 2000, pp. 77.
No. 21	M. Andreini, N. van de Giesen, A. van Edig, M. Fosu, W. Andah	Volta Basin Water Balance Zentrum für Entwicklungsforschung (ZEF), Bonn, March 2000, pp. 29.
No. 22	Susanna Wolf, Dominik Spoden	Allocation of EU Aid towards ACP-Countries Zentrum für Entwicklungsforschung (ZEF), Bonn, March 2000, pp. 59.

No. 23	Uta Schultze	Insights from Physics into Development Processes: Are Fat Tails Interesting for Development Research? Zentrum für Entwicklungsforschung (ZEF), Bonn, March 2000, pp. 21.
No. 24	Joachim von Braun, Ulrike Grote, Johannes Jütting	Zukunft der Entwicklungszusammenarbeit Zentrum für Entwicklungsforschung (ZEF), Bonn, March 2000, pp. 25.
No. 25	Oded Stark, You Qiang Wang	A Theory of Migration as a Response to Relative Deprivation Zentrum für Entwicklungsforschung (ZEF), Bonn, March 2000, pp. 16.
No. 26	Doris Wiesmann, Joachim von Braun, Torsten Feldbrügge	An International Nutrition Index – Successes and Failures in Addressing Hunger and Malnutrition Zentrum für Entwicklungsforschung (ZEF), Bonn, April 2000, pp. 56.
No. 27	Maximo Torero	The Access and Welfare Impacts of Telecommunications Technology in Peru Zentrum für Entwicklungsforschung (ZEF), Bonn, June 2000, pp. 30.
No. 28	Thomas Hartmann-Wendels Lukas Menkhoff	Could Tighter Prudential Regulation Have Saved Thailand's Banks? Zentrum für Entwicklungsforschung (ZEF), Bonn, July 2000, pp. 40.
No. 29	Mahendra Dev	Economic Liberalisation and Employment in South Asia Zentrum für Entwicklungsforschung (ZEF), Bonn, August 2000, pp. 82.
No. 30	Noha El-Mikawy, Amr Hashem, Maye Kassem, Ali El-Sawi, Abdel Hafez El-Sawy, Mohamed Showman	Institutional Reform of Economic Legislation in Egypt Zentrum für Entwicklungsforschung (ZEF), Bonn, August 2000, pp. 72.
No. 31	Kakoli Roy, Susanne Ziemek	On the Economics of Volunteering Zentrum für Entwicklungsforschung (ZEF), Bonn, August 2000, pp. 47.
No. 32	Assefa Admassie	The Incidence of Child Labour in Africa with Empirical Evidence from Rural Ethiopia Zentrum für Entwicklungsforschung (ZEF), Bonn, October 2000, pp. 61.
No. 33	Jagdish C. Katyal, Paul L.G. Vlek	Desertification - Concept, Causes and Amelioration Zentrum für Entwicklungsforschung (ZEF), Bonn, October 2000, pp. 65.

ISSN: 1436-9931

The papers can be ordered free of charge from:

Zentrum für Entwicklungsforschung (ZEF)
Center for Development Research
Walter-Flex-Str. 3
D – 53113 Bonn, Germany

Phone: +49-228-73-1861
Fax: +49-228-73-1869
E-Mail: zef@uni-bonn.de
http://www.zef.de