Are cross-country studies of the Environmental Kuznets Curve misleading? new evidence from time series data from Germany

Author(s):
Egli, Hannes

Publication Date:
2003

Permanent Link:
https://doi.org/10.3929/ethz-a-004588263 →

WIF - Institute of Economic Research

Are Cross-Country Studies of the Environmental Kuznets Curve Misleading? New Evidence from Time Series Data for Germany

Hannes Egli

Working Paper 03/28
September 2003

Economics Working Paper Series

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

September 2003

Are Cross-Country Studies of the Environmental Kuznets Curve Misleading? New Evidence from Time Series Data for Germany

Hannes Egli*
ETH Zurich

Abstract
In recent years, extensive literature on the Environmental Kuznets Curve leading to optimistic policy conclusions has attracted great attention. However, the underlying cross-section estimations are not very reliable. Accordingly, this contribution uses time series data for a single country with good data quality: Germany. With a specification in the tradition of error correction models, which are more appropriate in the presence of non-stationary time series, it is found that only for few pollutants can the typical EKC pattern be confirmed. For the major part, however, it is concluded that the doubts about the suitability of the EKC approach are well founded.

Keywords: Environmental Kuznets Curve, Error Correction Model, Time Series Data
JEL classification: Q00, Q20, Q25

* Institute of Economic Research, ETH Zurich, WET D4, CH-8092 Zurich, Switzerland. Phone +41 1 632 04 68, Fax +41 1 632 13 62, Email: egli@wif.gess.ethz.ch. The author thanks Lucas Bretschger, Peter Stalder, Thomas M. Steger and Urs von Arx for very valuable comments.

1. Introduction

Recently, a series of empirical studies about the so-called Environmental Kuznets Curve (hereafter EKC) has been published.[1] The EKC hypothesis postulates that environmental pollution follows an inverted U-shaped curve relative to income. Put differently, environmental quality first decreases with rising income but, after a certain income level has been reached, it begins to recover steadily. However, the reported empirical results and conclusions are ambiguous. Some authors find evidence for an EKC for different air and water pollutants and other measurements of environmental degradation (e.g. Grossman/Krueger 1995, Selden/Song 1994, Cole et al. 1997). Others, however, report either monotonically increasing or decreasing relationships between pollution and per capita income or even find no such relationship (e.g. Torras/Boyce 1998 and partly Shafik 1994).

Most empirical studies on the EKC hypothesis use cross-country or panel data for their empirical estimations. However, this is criticised fiercely. It is argued that only single-country studies could shed light on the question whether EKCs for different pollutants really exist (e.g. Roberts/Grimes 1997). The following arguments support this view. An EKC found by cross-country or panel data estimations could simply reflect the juxtaposition of a positive relationship between pollution and income in developing countries with a negative one in developed countries, and not a single relationship that applies to both categories of countries (Vincent 1997). Strictly speaking, this argument does not apply only to cross-country studies, but also to cross-regional studies (see e.g. Carson et al. 1997), because these studies implicitly assume that all regions considered follow the same development path as is assumed for the countries in cross-country or panel data studies. The heterogeneity of the considered regions is, therefore, a decisive point for cross-regional studies. In principle, the disregard of this juxtaposition is a special case of parameter heterogeneity, which is a frequent problem in the

[1] The EKC is named after Simon Kuznets (1955), who found a similar hump-shaped relationship between income and the inequality of income.

cross-section growth context. It is questionable if the homogeneity assumption that all estimated coefficients are country invariant is appropriate for a broad spectrum of countries, reaching from poor developing countries to rich and highly industrialised nations. Harberger (1987), for example, states: 'What do Thailand, the Dominican Republic, Zimbabwe, Greece, and Bolivia have in common that merits their being put in the same regression analysis?' Possibilities to avoid the parameter heterogeneity problem are the use of specifications, which allow varying coefficients, or – as in this paper – data limitation to one single country.[2] More arguments for the use of time series data are provided by List/Gallet (1999). Using data on sulphur dioxide and nitrogen oxide emissions between 1929 and 1994 for the US states, these authors find very different income turning points across the forty-eight considered states. In other words, the US states do not follow a uniform pollution path. Since US states are commonly and correctly assumed to be more homogenous than most samples of countries, this study backs up the advantage of time series estimations over cross-country studies. If the results of cross-section estimations are generalised, incorrect inferences about the further development of pollutant emissions or concentrations could be drawn and, therefore, misleading policies proposed. Similar conclusions are reported by Dijkgraaf/Vollebergh (1998) when comparing time series with panel estimations for carbon dioxide. Estimating the income-emission relation for OECD countries, they find that pooling countries in one panel, i.e. cross-country or panel studies, can bias the estimates and, therefore, the results may not be reliable. Again, the cause of this distortion is the juxtaposition of different income-emission relationships within the pooled countries.

So far, there are only few studies with time series data for a single country and, as in the case of cross-country studies, the results are mixed. Carson et al. (1997), using US states data between 1988 and 1994, find a negative relationship between seven types of air pollutant

---

[2] For a brief treatise on parameter heterogeneity and other econometric problems in the growth context, see Temple (1999).

emissions and income. Since, for the period under consideration, the per capita income levels of the United States are clearly above the EKC turning points usually calculated by cross-country studies, these results are consistent with the EKC hypothesis. No support for the EKC supposition, however, is given by Vincent (1997). This author reports that the emission profiles that are actually observed in Malaysia do not coincide with those that are predicted by cross-country studies for a country with a per capita GDP like Malaysia. Mostly, the concentration path of pollutants is incorrectly predicted and the pollutant emissions changes are vastly overstated by cross-country estimations. Applying a somewhat more sophisticated model specification, de Bruyn et al. (1998) find that economic growth has a negative effect on environmental quality, but, despite the increase in emissions due to economic growth, emissions are likely to decline over time, given sufficient technological progress or structural change. On this account, the authors reason 'the presumption that economic growth results in improvements in environmental quality is unsupported by evidence […]'. Unruh/Moomaw (1998) and Moomaw/Unruh (1997) find evidence that the carbon dioxide emission trajectories of sixteen OECD countries follow an inverted U-shaped curve; however not with respect to income, but with respect to time. Furthermore, the income levels corresponding to the turning points are not identical. The change from an increasing to a decreasing relationship, however, occurred in all countries around 1973 – the time of the world-wide oil price shock. Unruh/Moomaw (1998, page 227) conclude that 'emissions trajectories would be expected to follow a regular, incremental path until subjected to a shock that leads to the establishment of a new trajectory or attractor.' However, since the included countries were selected on the basis that their EKC shows evidence of a structural break around 1973[3], the estimation results of these studies are not very representative and, therefore, the conclusion cannot be generalised. A historical perspective about the carbon dioxide emissions in Sweden from 1870 – 1997 (Lindmark 2002) shows that emission fluctuations can be explained mostly

[3] This can be regarded as a form of sample selection bias.

by technological and structural change, by economic growth and by changing prices. More comprehensive surveys of the empirical EKC literature, i.e. with time series as well as cross-country data, are provided by e.g. Ekins (1997), Stern (1998), Stern et al. (1996) or Borghesi (1999).[4]

This paper, using time series data for Germany, aims at investigating the relationship between several pollutants and income within a single, developed country. First, the traditional reduced form model with only one independent variable, namely gross domestic product (GDP), is estimated. The estimation results of this simple specification, which was first introduced by Grossman/Krueger (1995), give rise to the supposition that the development of environmental pressure is more complex and that the different stages of environmental degradation cannot be explained by per capita income alone. Therefore, other variables must yield at least as much influence on the environment as income. Different possibilities, such as the incorporation of trade variables or gross value added by the industry sector, which are commonly proposed by theory, are evaluated.

Second, this paper contributes to the EKC literature by introducing a model specification that can be regarded as a modified error correction model. The advantages of this specification are the distinction between two different influence channels and the more favourable estimation characteristics in the presence of serial correlation and non-stationarity. Although these results come off better with regard to the estimation statistics and some evidence for a hump-shaped emissions pattern is found, the empirical validity of the EKC hypothesis is not conclusively determined.

The remainder of this paper is organised as follows. In section 2, the theoretical framework is set forth. Some explanatory notes to the data are provided in section 3. In section 4, the empirical results are presented and discussed. Finally, section 5 concludes**.**

---

[4] Up to the present, there have been few theoretical EKC models. Exceptions are Andreoni/Levinson (2001), Bretschger/Smulders (2000), Bulte/van Soest (2001), de Groot (1999), Kelly (2003), Lieb (2002) or McConnell (1997).

2. Framework

The non-linear relationship between the indicators of environmental pollution and per capita income is usually specified in a reduced form such as:

$$E_t = \beta_0 + \beta_1 Y_t + \beta_2 Y_t^2 + \beta_3 Y_t^3 + \beta_4 Z_t + \varepsilon_t \qquad (1)$$

where E stands for the pollution indicator, Y for income and Z for other variables that are supposed to influence pollution; t denotes a time index and ε is the normally distributed error term. An EKC results from $\beta_1 > 0$, $\beta_2 < 0$, and $\beta_3 = 0$. The income level at which environmental degradation begins to decline is called income turning point (ITP). The ITP of an EKC is obtained by setting the first derivation (with respect to income) of equation (1) equal to zero and solved for income; this yields $-\beta_1/2\beta_2$.[5] Whereas with $\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 > 0$, an N-shaped pattern is obtained. This means that a second turning point exists, after which the environmental degradation rises again with increasing income. However, investigating the relationship between carbon dioxide (CO_2) and GDP for a subset of OECD countries, Moomaw/Unruh (1997) conclude that an N-shaped curve is more the result of polynomial curve fitting than a reflection of any underlying structural relation. In addition, if a N-shaped pattern is obtained, the second turning point usually occurs at relatively high per capita income levels reached only by very few countries; thus, these results should be viewed with caution. Accordingly, this possible curve pattern is not taken into further account in this study. An either monotonically increasing or decreasing relationship between income and environmental quality is achieved if only β_1 is significant (negative or positive sign, respectively), whereas the other estimators of the income variables, i.e. β_2 and β_3, remain insignificant.

---

[5] Under the assumption $\beta_3 = 0$. This term should be small relative to mean per capita income, in order for the EKC to turn down at achievable income levels. Moreover, dependent on the scaling of y, $|\beta_1| > |\beta_2|$ in order to get a rising curve segment at the beginning.

While the incorporation of per capita income as an independent variable in single country studies seems undisputed, the choice of the other explanatory variables is not clear, since, contrary to cross-country studies, country specific but over time constant differences do not matter in time-series. For example, it is unnecessary to control for population density, oil exporting or former communist countries, literacy rate or political rights. All theses variables do not change, or at least not relevantly, over the time period under consideration. Kaufmann et al. (1998) propose to control for the density of economic activity. This appears appropriate for their cross-country study. In this paper, however, the variable would be nothing else than a linear transformation of GDP, since the country's area is constant.

But the reunification of the former East German states with the West German states calls for a dummy variable, if one would also like to use more recent data. From 1992 on, the statistical data about pollutant emissions is only published for the reunified Germany and not separately for the two former German republics. Without any other independent variables than per capita GDP and omitting the cubic per capita income term, equation (1) becomes:

$$E_t = \beta_0 + \beta_1 Y_t + \beta_2 Y_t^2 + \beta_4 D_t + \varepsilon_t \qquad (2)$$

where D_t is the reunification dummy and all other variables are defined as above.

As will be shown in section 4 below, per capita income fails to satisfactorily explain the environmental degradation with regard to economic development. Therefore, the traditional reduced form equation must be extended. Income can either be included directly in the model as a variable that summarises all effects associated with income or it can be disaggregated into different channels through which income affects pollution (Grossman 1995). First, there is a scale effect. Ceteris paribus, more economic activity leads to increased environmental damage, since increasing output requires ceteris paribus more natural resources as inputs and causes more emissions and waste as a by-product. Second, structural changes in the economy lead to altered environmental pressure. During industrialisation (from agricultural to industrial production), environmental degradation tends to increase, whereas during the deindustrialisation phase (from industry to services), the reverse occurs. This argumentation is based on the legitimate assumption that industrial production is more polluting than both the agricultural and the service sector. This second channel is usually called composition effect. Third, due to more research and development expenditure[6], economic growth is usually accompanied by technological progress. Therefore, a replacement of obsolete machineries and technologies with more environmentally friendly ones can be observed. This is labelled the technique effect. Since it is quite difficult to measure environment-related technology levels and the approximation with a time trend is not very satisfactory,[7] only the composition effect is specified separately. Therefore, income now indicates the net effect of the scale and technology effect. This leads to:

$$E_t = \beta_0 + \beta_1 Y_t + \beta_2 Y_t^2 + \beta_4 D_t + \beta_5 S_t + \varepsilon_t \qquad (3)$$

where Y stands for income and indicates the net income effect and S is the industry share of GDP and represents the composition effect.

Besides these income-related variables, which do not differ from cross-country studies, other variables influencing pollution come to the fore in studies with time series data. The displacement effect (also referred to as pollution haven hypothesis) relates to the possibility that developed countries may shift pollution-intensive production to developing countries with laxer environmental regulations and import those products. By doing so, developed countries cut back their domestic emissions without having to alter their consumption habits. But overall, there is no world-wide emission reduction or, in other words, only an illusion of sustainability is created (Rees 1994). Therefore, a resulting EKC would not mean that with higher per capita income, environmental pressure would decrease or that with rising per capita

[6] The positive correlation between income and R&D expenditure can be traced back to rising preferences for environmental quality.

[7] Nevertheless, this approximation is sometimes used in empirical studies.

income all environmental problems would be solved automatically, as it is sometimes suggested. Beckerman (1992, page 491), for example, concludes that 'in the longer run, the surest way to improve your environment is to become rich'. The factor endowment hypothesis, however, counteracts the pollution heaven hypothesis. It suggests that dirty production, which is usually capital intensive, is located where capital is more abundant, i.e. in developed countries. Antweiler et al. (2001) investigate the consequences of free trade on the environment and find empirical evidence that capital abundance is more important than lax environmental policy. However, Suri/Chapman (1998) incorporate the amount of imported manufactured goods as an additional explanatory variable and find that this leads to significantly higher income turning points than estimations without trade variables. The existence and importance of the displacement effect is also supported by a meta-analysis of twenty-five EKC studies by Cavlovic et al. (2000). If one controls for the countries' trade relations, higher EKC turning points are obtained. As mentioned above, it is not the quantity of goods produced that is decisive for the pollution a country is responsible for, but rather the amount consumed. Investigating consumption habits relative to income, Rothman (1998) finds that only one out of eight consumer good categories, namely 'food, beverages and tobacco', shows a declining trend after a certain income level is reached. Moreover, the decline in this category is mainly caused by a large decrease in the amount of grains and starches consumed, neither of which products is very environmentally destructive. Regarding the volume of trade, equation (2) becomes:

$$E_t = \beta_0 + \beta_1 Y_t + \beta_2 Y_t^2 + \beta_4 D_t + \beta_6 I_t + \varepsilon_t \tag{4}$$

where I is the sum of imports and exports of goods from pollution-intensive production relative to GDP. Taking into account all extensions mentioned so far yields:

$$E_t = \beta_0 + \beta_1 Y_t + \beta_2 Y_t^2 + \beta_4 D_t + \beta_5 S_t + \beta_6 I_t + \varepsilon_t \tag{5}$$

If one uses time series data, two econometric problems - namely the assumption of no serial correlation[8] and of stationarity - must not be neglected. In time series studies, the assumption that errors corresponding to different observations are uncorrelated often fails to prove true. Therefore, one cannot use ordinary least squares as the estimation technique. The generalised least squares procedure (GLS), controls for serial correlation and is, therefore, widely applied in time series studies. Besides the favourable characteristics with regard to autocorrelation, the GLS method also produces best linear unbiased estimators if the assumption of homoscedasticity, i.e. equal variances of the error term, is not fulfilled. Therefore, all estimations of the equations (2) – (5) are based on GLS.

Time series are often non-stationary. Non-stationary time-series can only be regressed on each other, if they are cointegrated. Otherwise, the results may be spurious. Cointegration is given if both time series are non-stationary and a linear combination that is itself stationary exists between them. In other words, the non-stationary components of these variables neutralise each other. In our case, none of the considered pollutant is a stationary variable nor are they cointegrated with GDP in the usual sense[9]. However, since we are not looking at a linear relationship between income and emissions but rather at a hump-shaped one, income squared should be added as an additional variable while testing for cointegration. If the resulting residuals are stationary, the two time series can be viewed as quasi-cointegrated in the sense that the non-stationary components of the considered time series neutralise each other and that, therefore, the estimation results are not spurious. By regressing each pollutant on GDP (with a linear and a quadratic term) and controlling for autocorrelation, the obtained residuals are indeed mostly stationary. In the following, an estimation procedure is considered

---

[8] Unless otherwise stated, correlation stands for correlation of first order.

[9] If they were cointegrated in the usual sense, the relation between the two variables would be linear and, therefore, there would be no income turning point.

which deals with serial correlation and the non-stationarity of the time series in an appropriate way.[10]

All estimation specifications considered so far do not distinguish between a long-term income-emission relationship and short-term disturbances from the long-term equilibrium path. A model specification that differentiates between these two effects is the so-called error correction model (ECM), which was popularised by Davidson et al. (1978) in estimating a consumption function for the UK. In the ECM specifications, the relationship between the endogenous variable and the explanatory variable is modelled as follows. The changes in the dependent variable are influenced by changes in the exogenous variable (channel one) and the deviation of the dependent variable from its long-term value in the previous period (channel two). For our purposes, the specification of ECM equation must be modified, since the hypothesised relationship is not linear, but follows a hump-shaped pattern. Considering this for both influence channels, the modified ECM-equation is:

$$\Delta E_t = \gamma_0 + \gamma_1(\alpha_1 + 2\alpha_2 Y_t)\Delta Y_t + \gamma_2\left(E_{t-1} - \alpha_0 - \alpha_1 Y_{t-1} - \alpha_2 Y_{t-1}^2 - \alpha_3 D_{t-1}\right) + \gamma_3 D_t + \varepsilon_t \qquad (6)$$

where Δ denotes a variable's first difference. The whole term in the second parenthesis, i.e. the deviation from the long-term relation $\left(E_{t-1} - \alpha_0 - \alpha_1 Y_{t-1} - \alpha_2 Y_{t-1}^2 - \alpha_3 D_{t-1}\right)$, is called error correction term and coincides with the one-period lagged residuals of the above-mentioned traditional EKC equation (equation 2).

To potentially obtain a hump-shaped pattern between environmental degradation and income or an EKC, respectively, the coefficient of the error correction term, γ_2, must be negative. This can be interpreted in the following way. If, in the previous period, the actual emissions were greater than the optimal long-term emissions, the error correction term becomes positive and, together with its negative coefficient, operates towards a smaller or

---

[10] The use of error correction models leads to optimal estimation properties with cointegrated time series. With quasi-cointegrated time series, the properties are still optimal.

even negative emission growth rate. If, however, the actual emissions were less than the optimal emissions, the error correction term becomes negative and, together with the negative sign of its coefficient, the reverse effect occurs. This means that, due to socially optimal activities, individuals put up with an increasing emission growth rate and not that individuals intend to reduce environmental quality unnecessarily. For example, it may be optimal to invest in infrastructure equipment, although this causes higher emissions. In this case, income rises with investments but emissions temporarily fall below the long-term equilibrium because pollution does not start immediately when the infrastructure is ready to use. γ_1 is expected to be positive. This means that changes in GDP can lead either to increasing or decreasing environmental degradation, depending upon the sign of the term in parenthesis $(\alpha_1 + 2\alpha_2 Y_t)$.[11] As before, α_1 and α_2 are expected to be positive and negative, respectively.

3. Data

3.1. Data Source

Since in this study environmental damage is the object of concern, aggregate emissions and not urban concentration are to be preferred, because they are more likely to relate to environmental damage than to harm human health (Ekins 1997). Therefore, per capita emission data for eight pollutants for the years 1966 – 1999 are used, namely sulphur dioxide (SO_2), nitrogen oxide (NO_x, as usually measured by nitrogen dioxide NO_2), carbon dioxide (CO_2), carbon monoxide (CO), ammonia (NH_3), methane (CH_4), particular matter (PM) and non-methane volatile organic compounds (NMVOC). All pollutants are measured in kilograms. Per capita GDP is measured in Euros at 1991 prices, while the imports and exports

---

[11] From the regressions in section 4 it can be calculated, that this term is positive for low income levels and negative for high income levels.

of goods from pollution-intensive production[12] are set in relation to GDP. Gross value added by sector is gauged by percent of total value added. All data, i.e. emissions data, GDP, population data, gross value added by sectors as well as import and export data, are taken from the Statistical Yearbooks for the Federal Republic of Germany (1966 – 2002). Because of availability limitations, all data from 1966 to 1991 represent only the former West Germany, whereas the data from 1992 on incorporate all sixteen German Länder.[13] Since empirical work with time series data requires observations over a longer period, one has to accept this data break. To restrict the sample to West Germany and/or up to 1991 is no real alternative and observations for the years before 1966 are not available.

3.2. Descriptive Statistics

If one looks at the time profile of the emissions, several points stand out. Without exception, all pollutants declined in the last few years; however, the rate of the decrease is not at all equal among the pollutants or over time. While the decrease of methane emissions intensifies, particular matter shows a decline in the rate of reduction. Carbon monoxide and the non-methane volatile organic compounds, however, show nearly constant negative growth rates. The drop in ammonia emissions, on the other hand, remains limited. In all these cases, the transition from former West Germany to the reunified Germany does not cause many problems since the amount of the per capita emissions of West and East Germany were similar. A different situation is observed for carbon dioxide and sulphur dioxide. The emission levels of both pollutants make a great leap in the first year of reunification. These emission paths can possibly be explained by the fact that the heavily polluting power stations

[12] The following product categories are assumed to be pollution-intensive in production and are, therefore, taken into account: raw materials (apart from foodstuffs), mineral fuels, lubricants, chemicals, manufactured goods, machine and vehicle construction and various finished products.

[13] Notice that, due to data availability, the value of the dummy variable does not change in the year of German reunification, but only in 1992.

of former East Germany stayed in operation for some years, whereas the replacement of vehicles, which were largely responsible for carbon monoxide and nitrogen oxide emissions, was carried out more quickly.

4. Empirical Results and Discussion

In a first step, estimations for all pollutants of equations (2) to (5) were carried out. Because of serial correlation, generalised least squares (Cochrane-Orcutt procedure) is required as the estimation technique. Nevertheless, in most estimations the problem of serial correlation cannot be solved by GLS, meaning that the equations are mis-specified and an interpretation of the estimated coefficients is not possible. Problems arise for SO_2, CO, CO_2, CH_4 and NMVOC. In addition, the coefficients for particular matter are not significant at the usual significance levels, i.e. up to the 10% significance level. Thus, in the following, only the successful examples of these estimations, i.e. the estimations for NO_x and NH_3, are reported. The results of these pollutants are shown in tables 1 and 2, respectively. [14]

Table 1 about here

For the traditional reduced form model (equation 2, columns 1), positive linear and negative quadratic income coefficients are obtained. This results in a hump-shaped emissions profile, but only in the case of NO_x are the coefficients significant. The calculated turning point of the NO_x-EKC occurs at a per capita income of € 15,169 (in 1991 prices). This level of per capita income was reached around 1977 and corresponds to roughly USD 14,700 (in 1985 prices).[15] The estimated run of the NO_x emissions curve is depicted in figure 1.

[14] The complete estimation results are available on request from the author.

[15] The amounts are first converted into USD using the annual mean exchange rate of 1991 (source: http://www.oanda.com) and than deflated using the implicit price deflator for GDP (source: Bureau of Economic Analysis, U.S. Department of Commerce).

Figure 1 about here

In comparison with cross-country studies, the turning point of nitrogen oxide matches those of others estimations; in Selden/Song (1994), the curve turns down at about USD 11,000, in Cole et al. (1997) between 14,700 and USD 17,600 and, finally, Grossman (1995) reports a turning point of USD 18,453. Although Carson et al. (1997) report a monotonically decreasing relationship between NO_x emissions and GDP for the US, this result is not inconsistent with the EKC pattern found here, since they use only data from 1988 to 1994. In this period, the NO_x emissions in Germany decreased as well. This follows directly from the calculated income turning point, which was reached not later than 1977.[16]

Table 2 about here

When incorporating the gross value added of the industry sector (equation 3, columns 2) the estimation results of NO_x do not change notably; the industry share shows no significant influence. However, the income coefficients are stable in size and the ITP is only slightly higher than before. All coefficients of ammonia are significant. Still, the GDP share of the industry sector does not have the predicted positive sign. This result is difficult to explain, since the assumption that the industry sector is more polluting than the agriculture and service sectors is plausible and not at all controversial in literature. The ITP for ammonia (about € 17,000 or USD 16,700) is somewhat higher than the one for nitrogen oxide, but since to my knowledge ammonia is not considered in any other EKC study, comparisons with other estimations are impossible.

The estimation results of equation (4) (columns 3) reveal ambiguous information about the relative strength of the displacement effect and the factor endowment hypothesis. For NO_x, no significant result is obtained. This could be interpreted in the sense that the two effects offset

---

[16] The income turning point of NH_3 is not calculated in column (1), since the income coefficients are not significant.

each other. For ammonia, however, a positive sign results. This means that with increasing trade openness emissions also rise. Therefore, the factor abundance hypothesis is supported. The calculated income turning points for this specification match those of equations (2) and (3), respectively.[17]

The estimations with both the GDP share of the industry sector as well as the trade openness do not give many new insights (columns 4). One reason may be that the two variables are highly correlated (about 0.9). Apart from that, the same remarks as for the previous estimations apply here.

Table 3 about here

The results of equations (6), which follows the error correction model tradition, are set forth in table 3. Two things strike the observer's eye. First, the coefficients for the direct channel, γ_1, i.e. the income changes, are all not significant and have mostly not the predicted positive sign. Therefore, the first channel exerts no influence on pollutant emissions. Second, the coefficients of the error correction term, γ_2, are significant and - as expected - negative for NO_x, CO, CH_4 and NMVOC.[18] The income coefficients, α_1 and α_2, respectively, are significant with the predicted signs for NO_x, CH_4 and NMVOC. Taking together, only for the pollutants NO_x, CH_4 and NMVOC significant coefficients for the important explanatory variables can be observed. These three cases can be interpreted in the sense that changes in income have only an influences through the second channel. Deviations from the long-term relationship, which is specified to be hump-shaped, are corrected in the next period. Therefore, for these three pollutants an EKC pattern can be observed.[19] However, there is one reason why this interpretation is debatable. If environmental degradation indeed follows a

[17] The graphical illustration of the estimations of equations (3) and (4) are shown in appendix A.

[18] The other coefficients for the error correction term are also negative but not significant.

[19] The hump-shaped pattern is traced back to the non-linear specification of the two influence channels in equation (6).

hump-shaped curve, this result should already have been found in equation (2). But there, the EKC hypothesis could only be verified for NO_x and NH_3. One can argue that if the distinction between the two different channels, i.e. income changes and deviations form the optimal long-term relation, is important, specifications where this differentiation is not made could lead to distorted results and that, therefore, estimation specification with different channels should be preferred.[20]

5. Summary and Conclusions

Using time series data for Germany instead of cross-country or panel data and testing different specifications to gain new insights into the EKC hypothesis for different pollutants, the estimation results remain ambiguous. First, the traditional reduced form model and some extensions with additional explanatory variables, namely the trade relations and the GDP share of the industry sector, are estimated. For nitrogen oxide and mostly for ammonia, an EKC pattern is found, with income turning points around € 15,200 and 16,500, respectively. Thus, for these two pollutants, the results of most cross-country studies can be confirmed. However, and more importantly, the other six pollutants do not show clear results. Either the t-statistics are unsatisfactory or the Durbin-Watson tests give rise to a rejection of these simple model specifications. Astonishingly, this is valid not only with respect to a possible EKC pattern, i.e. a positive linear income term together with a negative quadratic one, but also with respect to monotonically increasing or decreasing development paths of the considered harmful chemical emissions[21]. These results indicate clearly that cross-country studies provide unreliable estimations. Second, and because of the variables' non-stationarity and motivated by error correction models, equations are estimated that distinguish between

[20] Because of the limited observations, estimations auf the modified ECM equation with additional explanatory variable, i.e. GDP share of the industry sector and/or trade openness of the country, are not possible.

[21] At least if one does not impose the parameter restriction $\beta_2 = 0$. If one does, mostly implausible signs result.

two different influence channels. But contrary to the well-known error correction models (e.g. for a consumption function), the long-term relationship is specified as a non-linear, i.e. hump-shaped function. The estimations show that only the deviations from the long-term optimal value have a significant influence on pollutant emissions. Income changes, however, do not have a direct impact. But since this is not true for all pollutants and all in all the estimation results are not very robust, the question if EKCs really exist for a single country is not conclusively answered. Therefore, general policy recommendations with regard to the environment should only be based on the EKC approach with caution.

In conclusion, two points must be addressed. First, the quality and, for the most part, quantity of the data available is limited. It would be helpful for empirical researchers if they could access a more widespread data pool. Second, it is likely that imported explanatory variables are still omitted in the model specifications. Future research and especially theoretical work on the EKC hypothesis for a single country may lead to more adequate model specifications. Further empirical studies should maybe adhere less to the traditional reduced form model and rather enlarge the well-known specifications by additional structural variables or use completely different approaches, e.g. non-linear estimation equations[22].

[22] Meaning non-linear in parameters.

References

Antweiler, Werner, Brian R. Copland and M. Scott Taylor (2001), 'Is Free Trade Good for the Environment?', American Economic Review 91: 877-908.

Andreoni, James and Arik Levinson (2001), 'The Simple Analytics of the Environmental Kuznets Curve', Journal of Public Economics, 80: 269 – 286.

Beckerman, Wilfred (1992), 'Economic Growth and the Environment: Whose Growth? Whose Environment?', World Development 20: 481-496.

Borghesi, Simone (1999), 'The Environmental Kuznets Curve: a Survey of the Literature', Nota Di Lavoro 85.1999, Fondazione Eni Encrico Mattei.

Bretschger, Lucas and Sjak Smulders (2000), 'Explaining Environmental Kuznets Curves: How Pollution Induces Policy and New Technologies', Working Paper 12/2000, Ernst-Moritz-Arndt University of Greifswald.

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

Carson, Richard T., Yongil Jeon and Donald R. McCubbin (1997), 'The relationship between air pollution emissions and income: US Data', Environment and Development Economics 2: 433-450.

Cavlovic, Therese A., Kenneth H. Baker, Robert P. Berrens and Kishore Gawande (2000), 'A Meta-Analysis of Environmental Kuznets Curve Studies', Agriculture and Resource Economics Review 29: 32-42.

Cole, Matthew A., Anthony J. Rayner and John M. Bates (1997), 'The environmental Kuznets curve: an empirical analysis', Environment and Development Economics 2: 401-416.

Davidson, James E. H., David F. Hendry, Frank Srba and Stephen Yeo (1978), 'Econometric modelling of the aggregate time series relationship between consumer expenditure and income in the United Kingdom', The Economic Journal 88: 661-692.

de Bruyn, Sander M., Jeroen C. J. M. van den Bergh and Johannes B. Opschoor (1998), 'Economic growth and emissions: reconsidering the empirical basis of environmental Kuznets curves', Ecological Economics 25: 161-175.

de Groot, Henri L. F. (1999), 'Structural Change, Economic Growth and the Environmental Kuznets Curve, A Theoretical Perspective', OCFEB Research Memorandum 9911, Erasmus University Rotterdam.

Dijkgraaf, Elbert and Herman R. J. Vollebergh (1998), 'Environmental Kuznets revisited, Time-series versus panel estimation: The CO_2 case', OCFEB Research Memorandum 9806, Erasmus University Rotterdam.

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

Federal Statistical Office, Wiesbaden, Germany (1966-1989), Statistical Yearbook for the Federal Republic of Germany, Stuttgart and Mainz: W. Kohlhammer GmbH.

Federal Statistical Office, Wiesbaden, Germany (1989-2002), Statistical Yearbook for the Federal Republic of Germany, Stuttgart: Metzler-Poeschel.

Grossman, Gene M. (1995), 'Pollution and growth: What do we know?' in: Ian Goldin and Alan L. Winters, eds., The economics of sustainable development, Cambridge: Cambridge University Press.

Grossman, Gene M. and Alan B. Krueger (1995), 'Economic Growth and the Environment', Quarterly Journal of Economics 110: 353-377.

Harberger, Arnold C. (1987), 'The Macroeconomics of Successful Development: What Are the Lessons? Comment' in: Fischer, Stanley, ed., NBER Macroeconomic Annual, London and Cambridge: MIT Press, 255 – 258.

Kaufmann, Robert K., Brynhildur Davidsdottir, Sophie Garnham and Peter Pauly (1998), 'The determinants of atmospheric SO_2 concentrations: reconsidering the environmental Kuznets curve', Ecological Economics 25: 209-220.

Kuznets, Simon S. (1955), 'Economic Growth and Income Inequality', American Economic Review 45: 1-28.

Kelly, David L. (2003), 'On environmental Kuznets Curves Arising from Stock Externalities', Journal of Economic Dynamics & Control, 27: 1367 – 1390.

Lieb, Christoph M. (2002), 'The Environmental Kuznets Curve and Satiation: a simple static model', Environment and Development Economics 7: 429 - 448.

Lindmark, Magnus (2002), 'An EKC-pattern in historical perspective: carbon dioxide emissions, technology, fuel prices and growth in Swede 1870 - 1997', Ecological Economics 42, 333 - 347.

List, John A. and Craig A. Gallet (1999), 'The environmental Kuznets Curve: does one size fit all?', Ecological Economics 31: 409-423.

McConnell, Kenneth E. (1997), 'Income and the demand for environmental quality', Environment and Development Economics 2: 383-399.

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

Rees, William E. (1994), 'Pressing Global Limits: Trade as the Appropriation of Carrying Capacity', in Schrecker, T. and Dalgleish, J., eds., Growth, trade, and environmental values, London, Ontario: Westminster Institute for Ethics and Human Values.

Roberts, J. Timmons and Peter E. Grimes (1997), 'Carbon Intensity and Economic Development 1962-91: A Brief Exploration of the Environmental Kuznets Curve' World Development 25: 191-98.

Rothman, Dale S. (1998), 'Environmental Kuznets curves – real progress or passing the buck? A case for consumption-based approaches', Ecological Economics 25: 177-197.

Selden, Thomas M. and Daqing Song (1994), 'Environmental Quality and Development: Is there a Kuznets Curve for Air Pollution Emissions?', Journal of Environmental Economics and Management 27: 147-162.

Shafik, Nemat (1994), 'Economic Development and Environmental Quality: An Econometric Analysis', Oxford Economic Papers 46: 757-773.

Stern, David I. (1998), 'Progress on the environmental Kuznets curve?', Environment and Development Economics, 3: 173 – 196.

Stern, David, I., Michael S. Common and Edward B. Barbier (1996), 'Economic Growth and Environmental Degradation: The Environmental Kuznets Curve and Sustainable Development', World Development 24: 1151-1160.

Suri, Vivek and Duane Chapman (1998), 'Economic growth, trade and energy: implications for the environmental Kuznets curve', Ecological Economics 25: 195-208.

Temple, Jonathan R. W. (1999), 'The New Growth Evidence', Journal of Economic Literature 37: 112-156.

Torras, Mariano and James K. Boyce (1998), 'Income, inequality, and pollution: a reassessment of the environmental Kuznets Curve', Ecological Economics 25: 147-160.

Unruh, Gregory C. and William R. Moomaw (1998), 'An alternative analysis of apparent EKC-type transitions', Ecological Economics 25: 221-229.

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

Table 1

Endogenous variable: per capita emissions of NO_x				
	(1)	(2)	(3)	(4)
const	-20.74 (0.76) (0.46)	-24.54 (0.88) (0.39)	11.05 (0.39) (0.70)	-13.91 (0.47) (0.65)
Y	4.7e-3*** (3.20) (0.00)	5.1e-3*** (2.90) (0.01)	4.3e-3*** (3.00) (0.01)	4.6e-3** (2.55) (0.02)
Y^2	-7.8e-8*** (4.00) (0.00)	-8.4e-8*** (3.41) (0.00)	-7.3e-8*** (3.71) (0.00)	-7.7e-8*** (3.03) (0.01)
S		-0.08 (0.34) (0.73)		-0.07 (0.27) (0.79)
I			-11.57 (1.21) (0.24)	-11.50 (1.18) (0.25)
D	-0.81 (0.75) (0.46)	-0.98 (0.82) (0.42)	-1.89 (1.36) (0.19)	-2.00 (1.31) (0.20)
adj. R^2	0.59	0.59	0.57	0.56
DW	1.93	1.90	1.83	1.82
Number of obs.	33	33	33	33
ρ	0.88	0.87	0.90	0.90
ITP in € at '91 prices	15,169	15,347	15,190	15,354
t-statistics and marginal significance levels in parenthesis *, **, *** for significance at the 10%, 5% and 1% level				

Table 2

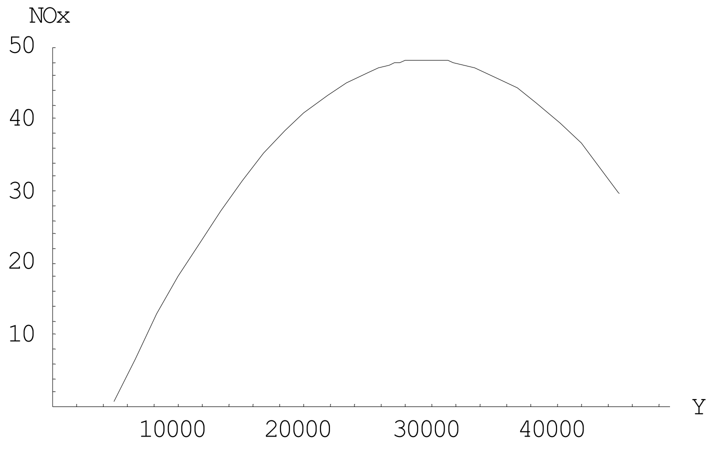
Endogenous variable: per capita emissions of NH_3				
	(1)	(2)	(3)	(4)
const	6.31 (0.81) (0.43)	-8.61*** (2.95) (0.01)	-8.66*** (3.40) (0.00)	-8.52*0* (3.72) (0.00)
Y	3.0e-4 (0.75) (0.46)	1.3e-3*** (8.62) (0.00)	1.0e-3*** (7.25) (0.00)	1.1e-3*** (8.11) (0.00)
Y^2	-5.9e-9 (1.18) (0.25)	-2.0e-8*** (9.17) (0.00)	-1.6e-8*** (8.35) (0.00)	-1.7e-8*** (9.17) (0.00)
S		-0.10** (4.55) (0.00)		-0.03 (1.09) (0.29)
I			4.56*** (6.00) (0.00)	3.81*** (3.60) (0.00)
D	-0.35** (2.74) (0.01)	-0.67*** (4.75) (0.00)	0.14 (1.00) (0.33)	0.01 (0.06) (0.96)
adj. R^2	0.73	0.97	0.97	0.98
DW	2.29	2.03	1.70	1.84
Number of obs.	24	24	24	24
ρ	0.80	-0.00	0.13	0.00
ITP in € at '91 prices		16,975	16,327	16,391
t-statistics and marginal significance levels in parenthesis *, **, *** for significance at the 10%, 5% and 1% level				

Table 3

Endogenous variable: emissions first difference								
	SO_2	NO_x	CO_2	PM	CO	NH_3	CH_4	NMVOC
γ_0	16.48 (0.72) (0.48)	-17.71 (1.34) (0.19)	2832.7 (1.17) (0.25)	-7.24 (0.78) (0.44)	93.89*** (3.58) (0.00)	-1.07 (0.29) (0.78)	9.20 (0.57) (0.58)	-17.77*** (4.34) (0.00)
γ_1	-0.02 (0.13) (0.90)	0.32 (1.05) (0.30)	-0.33 (0.18) (0.86)	-0.07 (0.40) (0.69)	-0.13 (1.28) (0.21)	0.09 (0.36) (0.72)	0.18 (0.88) (0.39)	-0.21 (1.61) (0.12)
γ_2	-0.08 (0.54) (0.60)	-0.23* (1.78) (0.09)	-0.26 (1.52) (0.14)	-0.09 (1.15) (0.26)	-0.12** (2.30) (0.03)	-0.14 (0.78) (0.45)	-0.39*** (5.15) (0.00)	-0.40*** (6.14) (0.00)
γ_3	31.70*** (7.59) (0.00)	0.68 (0.44) (0.67)	-178.4 (0.73) (0.48)	0.38 (0.64) (0.53)	7.00 (1.10) (0.28)	-0.02 (0.08) (0.94)	1.40 (1.02) (0.32)	-0.46 (0.68) (0.50)
α_0	0.57 (·)	0.11 (·)	-0.87 (·)	0.15 (·)	1.75 (·)	0.00 (·)	0.06 (·)	0.12 (·)
α_1	-6.0e-3 (0.15) (0.88)	8.0e-3*** (4.16) (0.00)	7.2e-2 (0.18) (0.86)	5.2e-3 (0.55) (0.59)	-2.8e-2 (1.02) (0.32)	1.3e-3 (1.06) (0.30)	5.1e-3* (2.03) (0.06)	6.0e-3*** (12.58) (0.00)
α_2	-9.9e-9 (0.02) (0.99)	-1.3e-7*** (3.88) (0.00)	-1.4e-6 (0.22) (0.83)	-7.8e-8 (0.59) (0.56)	2.2e-7 (0.54) (0.60)	-2.3e-8 (1.19) (0.25)	-9.6e-8** (2.58) (0.02)	-1.0e-7*** (12.33) (0.00)
α_3	22.38 (0.46) (0.65)	0.13 (0.02) (0.98)	-962.6 (1.01) (0.33)	0.29 (0.05) (0.96)	21.72 (0.53) (0.60)	1.96 (0.51) (0.62)	-7.19** (2.18) (0.04)	-4.87*** (3.49) (0.00)
adj. R^2	0.85	0.56	0.16	0.73	0.62	0.52	0.72	0.87
DW	1.70	1.88	1.45	1.84	2.03	2.50	2.22	1.48
N. of obs.	33	33	29	33	33	24	24	33

t-statistics and marginal significance levels in parenthesis
*, **, *** for significance at the 10%, 5% and 1% level
estimation technique: non linear least squares
Parameter α_0 taken as constant term in model.

Figure 1: Estimated EKC for NO_x



Appendix A

In the following, the estimations of equations (3) and (4) are illustrated. Although these three-dimensional illustrations may be somewhat unfamiliar, these graphs are nothing but the fitted regression surface.

Figure 2: Estimated three-dimensional EKC for NO_x from equation (3), i.e. with gross value added by the industry sector

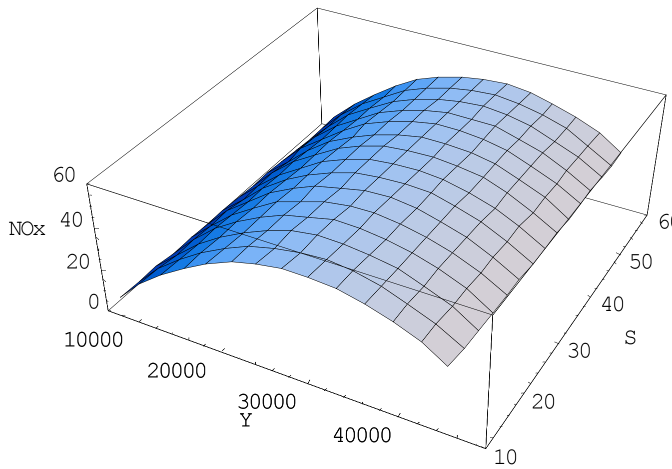


Figure 3: Estimated three-dimensional EKC for NH_3 from equation (3), i.e. with gross value added by the industry sector

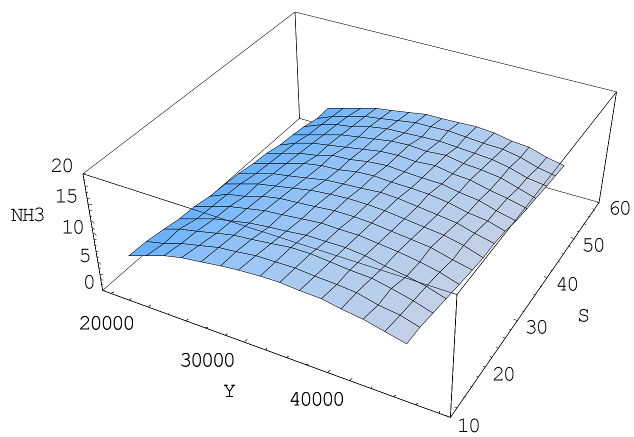


Figure 4: Estimated three-dimensional EKC for NO_x from equation (4), i.e. with the sum of imports and exports of goods from pollution-intensive production relative to GDP

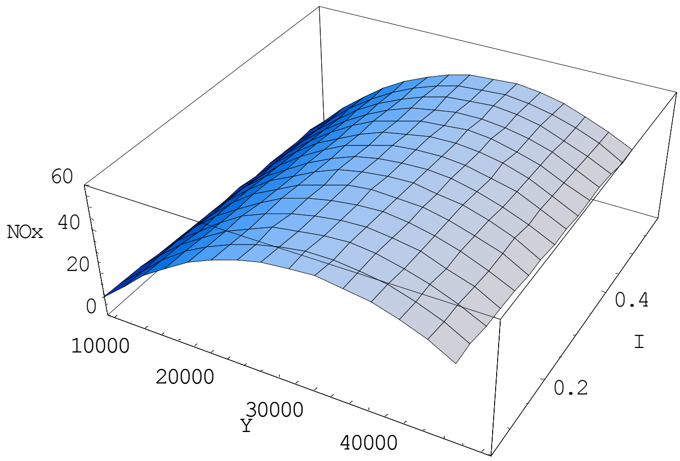


Figure 5: Estimated three-dimensional EKC for NH_3 from equation (4), i.e. with the sum of imports and exports of goods from pollution-intensive production relative to GDP