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Working Paper

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Wirtschaftswissenschaftliche Diskussionspapiere // Ernst-Moritz-Arndt-Universität Greifswald, Rechts- und Staatswissenschaftliche Fakultät, No. 10/2001

Provided in cooperation with:
Ernst-Moritz-Arndt-Universität Greifswald

Suggested citation: Egli, Hannes (2001) : Are cross-country studies of the Environmental Kuznets Curve misleading? New evidence from time series data for Germany, Wirtschaftswissenschaftliche Diskussionspapiere // Ernst-Moritz-Arndt-Universität Greifswald, Rechts- und Staatswissenschaftliche Fakultät, No. 10/2001, http://hdl.handle.net/10419/48897

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

Discussion Paper 10/2001

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December 2001

ISSN 1437-6989

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 that includes all theoretical variations and different appropriate estimation procedures, 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.

JEL Classification: Q00, Q20, Q25

Keywords: Environmental Kuznets Curve, Time Series Data, Error Correction Model

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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. In principle, the disregard of this juxtaposition is a special case of parameter heterogeneity, which is a frequent problem in the 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 just one single country. For a brief treatise on parameter heterogeneity and other econometric problems in the growth context, see Temple (1999). More arguments for the use of time series data are provided by

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

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 of 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 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 finds 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 (see section 4), 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. They do not do so with respect to income but with respect to time. Further, 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[2], the estimation results of these studies are not very representative and, therefore, the conclusion cannot be generalised. 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 et al. (1996) or Borghesi (1999).[3]

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 semi-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. Beside the extensions of the traditional EKC equation, other model specifications are also tested: on the one hand, a specification that stems from resource economics and was introduced in the EKC literature by de Bruyn et al. (1998); on the other hand, a specification that can be regarded as a modified error correction model. Although these results come off better with regard to the estimation statistics and some evidence for a hump-shaped emissions pattern is found, the 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.

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

[3] Up to the present, there have been few theoretical EKC models. Exceptions are Andreoni/Levinson (1998), Bretschger/Smulders (2001), Bulte/van Soest (2001), de Groot (1999), Lieb (2001) or McConnell (1997).

2. Framework

The non-linear relationship between the indicators of environmental pollution and per capita income is usually specified in a semi-reduced form such as:[4]

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

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 form β_1 > 0, β_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 β_1> 0, β_2 < 0 and β_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. In appendix A, the different functional relationships between income and environmental pressure are illustrated.

While the incorporation of per capita income as an independent variable in single country studies seems undisputed,[6] 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

[4] Contrary to the literature, the term "semi-reduced" (and not just "reduced") is chosen, since income cannot be seen as an exogenous variable and thus this equation is not a reduced form model in its typical manner.
[5] This term should be small relative to mean per capita income, in order for the EKC to turn down at achievable income levels.
[6] To avoid the endogeneity problem of GDP, one could exclude GDP from the variable list and run regressions only with explanatory variables that are exogenous. However, income turning points could no longer be calculated.

exporting or former communist countries, literacy rate or political rights. All theses variables do not change, or at least not seriously, 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 semi-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 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 degradations tend to increase, whereas during the deindustrialisation phase (from industry to services), the reverse occurs. This argumentation is based on the assumption that industrial production is more polluting than the agricultural or the service sector. This second channel is usually called composition effect. Third, due to more research and development expenditure[7], 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,[8] only the composition effect is

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

[8] Nevertheless, this approximation is commonly used in empirical studies.

specified separately. Therefore, income 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 or pollution haven hypothesis refers 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 all in all, there is no world-wide emission reduction or, in other words, only an illusion of sustainability is created (Rees 1993). Therefore, a resulting EKC would not mean that with higher per capita income, environmental pressure would decrease or that with rising per capita income all environmental problems would be solved automatically, as 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, operates in the opposite direction. 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:

$$E_t = \beta_0 + \beta_1 Y_t + \beta_2 Y_t^2 + \beta_4 D_t + \beta_6 I_t + \varepsilon_t \qquad (4)$$

where I are the imports and exports of goods from pollution-intensive production relative to GDP. Taking into account all extensions mentioned so far, this leads to:

$$E_t = \beta_0 + \beta_1 Y_t + \beta_2 Y_t^2 + \beta_4 D_t + \beta_5 S_t + \beta_6 I_t + \varepsilon_t \qquad (5)$$

Not only the level of income but also the growth rate of income can have an influence on the environmental quality, because there could be a discrepancy between the rates of economic and social change (Panayotou 1997). With unhasty economic growth, individuals that are interested in an intact environment can better influence the institutional and legal conditions. In other words, faster economic growth would result in more environmental damage. In consideration of the income growth rate, equation (2) is modified to:

$$E_t = \beta_0 + \beta_1 Y_t + \beta_2 Y_t^2 + \beta_4 D_t + \beta_8 g\left(Y_t\right) + \varepsilon_t \qquad (6)$$

where $g\left(\cdot\right)$ stands for a variable's growth rate and. From the theoretical point of view, it cannot be determined whether the speed of economic development really matters. This question must be answered empirically.

If one uses time series data, two econometric problems - namely the assumption of no serial correlation[9] 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), however, controls for serial correlation and, therefore, is 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. Inasmuch as no other estimation technique is declared, all regressions in this paper are based on GLS.

Time series are often non-stationary;[10] this applies especially to GDP and, in our case, also to the pollutant emissions. If one regresses a non-stationary variable on another non-stationary one, the results may be spurious in the sense that conventional significance criteria indicate a

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

[10] A time series generating stochastic process is said to be stationary if its mean and variance are constant over time and the value of covariance between two time periods depends only on the distance or lag between the two time periods and not on the actual time at which the covariance is computed.

relationship between the two time series, although in reality there is no relationship between them. This problem, however, does not emerge if the two time series are cointegrated. Cointegration is given if both time series are non-stationary and a linear combination which is itself stationary exists between them. In other words, the non-stationary components of these variables neutralise each other. If this is not the case, the only possibility to avoid potentially spurious results would be to estimate with variables in their (first) difference. However, this would result in a loss of information about the long-term relationship embodied in the data. But since we are mainly interested in the long-term behaviour of the variables and not in the short-term disturbances, such estimations are no alternative.

In our case, none of the considered pollutants is a stationary time series and, unfortunately, nor are they cointegrated with GDP. Since we are not looking at a linear relationship between income and emissions but rather at a hump-shaped one, the question arises if the residuals of a regression with a linear and a quadratic income term are stationary. If they are, the two time series are quasi-cointegrated in the sense that the results are not spurious.[11] By regressing each pollutant on GDP (with a linear and quadratic term) and controlling for autocorrelation, the obtained residuals are indeed mostly stationary. In the following, two additional procedures are considered, where serial correlation and the non-stationarity of the variables are no longer of importance.

De Bruyn et al. (1998) propose a model specification which stems from resource economics. The authors argue that changes over time in emissions can be explained by changes in economic growth and changes in the emission intensity, whereas the emission intensity reflects the composition of economic activities, environmentally relevant technologies and substitution possibilities, etc. Changes in emission intensity can be either due to exogenous technological improvements or dependent upon the income level, since research and development efforts and the service sector share in total production increase with rising income. The former possibility is modelled by making the changes in emission intensity a function of time, the latter by making them a function of income. Together with the variable for the trade relations, this results in:[12]

$$g\left(E_t\right) = \alpha_0 + \alpha_1 g\left(Y_t\right) + \alpha_2 Y_{t-1} + \alpha_3 g\left(I_t\right) + \alpha_4 D_t + \alpha_5 g\left(E_{t-1}\right) + \varepsilon_t \qquad (7)$$

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

[12] Note that equation (7) is not exactly identical to the equation used in de Bruyn et al. (1998), since these authors control for energy price changes instead of the volume of trade.

If economic growth has a direct negative influence on environmental quality, then α_1 should be positive (scale effect). A negative α_1, however, would mean that economic growth directly fosters a stricter environmental policy. Time dependent, i.e. exogenous change in the emission intensity would result in a negative α_0, whereas income-dependent changes would result in a negative α_2. The one period lagged emissions growth rate is included to improve the overall fit of the model.

All these estimations 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 (short-term relationship) and the deviation of the dependent variable from its long-term value in the previous period. For our purposes, the specification of ECM equation must be modified, since the long-term relationship is assumed to be non-linear, i.e. to follow a hump-shaped pattern. This leads to the following equation:

$$\Delta E_t = \gamma_0 + \gamma_1 \Delta Y_t + \gamma_2 \left(E_{t-1} - \alpha_0 - \alpha_1 Y_{t-1} - \alpha_2 Y_{t-1}^2 - \alpha_3 D_{t-1} \right) + \gamma_3 D_t + \gamma_4 \Delta \left(E_{t-1} \right) + \varepsilon_t \qquad (8)$$

where Δ denotes a variable's first difference. The estimation of the long-term equilibrium value (i.e. $\alpha_0 + \alpha_1 Y_{t-1} + \alpha_2 Y_{t-1}^2 + \alpha_3 D_{t-1}$) corresponds to the above-mentioned traditional EKC specification (equation 2). The whole term in parenthesis is called error correction term and coincides with the residuals of equation (2). The one period lagged emission changes are again included to improve the estimation statistics. Together with the trade variable, equation (8) becomes:[13]

$$\Delta E_t = \gamma_0 + \gamma_1 \Delta Y_t + \gamma_2 \Delta T + \gamma_3 \left(E_{t-1} - \alpha_0 - \alpha_1 Y_{t-1} - \alpha_2 Y_{t-1}^2 - \alpha_3 I_{t-1} - \alpha_4 D_{t-1} \right)$$

$$+ \gamma_4 D_t + \gamma_5 \Delta \left(E_{t-1} \right) + \varepsilon_t \qquad (9)$$

All variables are defined as above and the long-term equilibrium value (i.e. $\alpha_0 + \alpha_1 Y_{t-1} + \alpha_2 Y_{t-1}^2 + \alpha_3 I_{t-1} + \alpha_4 D_{t-1}$) coincides with equation (4). To potentially obtain a hump-shaped pattern between environmental quality and income or an EKC, respectively, γ_2 must

[13] As will be shown in section 4, gross value added by the industry sector and the sum of imports and exports divided by GDP are highly correlated so that only one of them should be included in the regression at the same time. To keep the estimation results within a limit, only the displacement effect is considered.

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 the negative γ_2, operates towards a smaller or 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. Due to the scale effect, γ_1 is expected to be positive, if emissions are responsive to income changes in the short run.

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 – 1998 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 DEM, while the imports and exports of goods from pollution-intensive production[14] 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 – 2000). Because of availability limitations, all data from 1966 to 1991 represent only the former West Germany, whereas the

[14] 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.

data from 1992 on incorporate all sixteen German Länder.[15] 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 very 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 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. The plots of the time profile for each pollutant are shown in appendix B.

3.3. Effects of the Pollutants

All the considered pollutants, with the exception of ammonia and particular matter, have direct greenhouse effects, especially carbon dioxide and methane. The third main greenhouse gas, chlorofluorocarbon, is not taken into account in this study because reliable data is hard to obtain. It is common knowledge that nowadays the anthropogenic greenhouse effect is one of the most serious environmental problems, although at present we do not know the exact - and especially not all – the consequences. On this account, it is even more important to gain information about the relation between economic growth and pollutant emissions or, more generally, environmental impact. Besides the global effect, these pollutants are also

[15] 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.

detrimental to health. For example, sulphur dioxide, a water-soluble irritant gas, leads to reddening, swelling and increased secretion of the mucous membranes of the nose, pharynx, bronchial system and of the eyes. Nitrogen dioxide, an irritant gas as well, affects the respiratory tract's mucous membranes, resulting in breathing difficulties and harm to the pulmonary function. Carbon monoxide, a respiratory poison, weakens the blood's oxygen transport capability and, with it, the heart circulation function and the central nervous system. In higher concentrations, carbon dioxide, despite being a component of exhaled air, leads to breathing difficulties, unconsciousness and, finally, to respiratory arrest. The effects of ammonia are irritations of the respiratory passages and the skin. Particular matter which measures less than ten micrometer in diameter deposits itself in the respiratory tract, resulting in various damaging effects, e.g. overstraining of the cleaning mechanism, irritation of the bronchial mucous membrane, chronic bronchitis or lung function disturbances. Larger particles, however, are not breathed in, but, through their toxic substance content, they have a detrimental effect on ground, water and foodstuffs. The effects of non-methane volatile organic compounds cannot be summarised briefly, since "non-methane volatile organic compounds" is a collective term for a number of chemical substances. This succinct enumeration of the pollutants' effects shows that the pollutants have large externalities.

4. Empirical Results and Discussion

In a first step, estimations for all pollutants of equations (2) to (6) were carried out. Because of serial correlation, generalised least squares (Cochrane-Orcutt procedure) as the estimation technique is required. 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. [16]

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

Table 1

Endogenous variable: per capita emissions of NO_x					
	(1)	(2)	(3)	(4)	(5)
const	-18.55 (0.66) (0.52)	-21.43 (0.71) (0.48)	-7.22 (0.25) (0.81)	-6.74 (0.22) (0.83)	-23.62 (0.72) (0.48)
Y	0.00*** (2.99) (0.01)	0.01** (2.45) (0.02)	0.00** (2.74) (0.01)	0.00** (2.16) (0.04)	0.01** (2.74) (0.01)
Y^2	-7.6e-8*** (3.70) (0.00)	-7.9e-8*** (2.97) (0.01)	-6.9e-8*** (3.35) (0.00)	-7.0e-8** (2.69) (0.01)	-7.9e-8*** (-3.41) (0.00)
S		0.09 (0.32) (0.75)		0.17 (0.57) (0.58)	
I			-12.60 (1.29) (0.21)	-15.97 (1.61) (0.12)	
g(Y)					-2.70 (0.25) (0.81)
D	-0.81 (0.74) (0.46)	-0.62 (0.51) (0.61)	-1.99 (1.41) (0.17)	-2.05 (1.36) (0.19)	-0.91 (0.77) (0.45)
adj. R^2	0.54	0.52	0.53	0.53	0.53
DW	1.83	1.79	1.67	1.67	1.83
Number of obs.	32	31	32	31	32
ρ	0.88	0.90	0.90	0.92	0.87
ITP in DEM 1991 prices	29,620	29,220	29,673	28,829	30,094
t-statistics and marginal significance levels in parenthesis *, **, *** for significance at the 10%, 5% and 1% level					

For the traditional semi-reduced form model (equation 2, column 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 DEM 29,620 (in 1991 prices). This level of per capita income was reached around 1977 and corresponds to roughly USD 14,700 (in 1985 prices).[17] The estimated run of the NO_x emissions curve is depicted in figure 1. 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

[17] 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).

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.[18]

Table 2

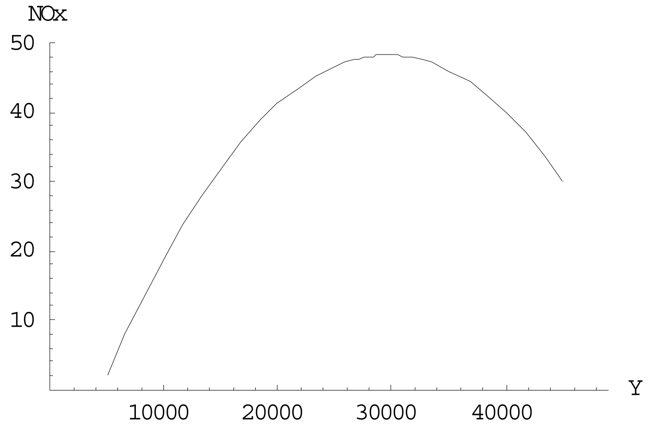
Endogenous variable: per capita emissions of NH_3					
	(1)	(2)	(3)	(4)	(5)
const	3.82 (0.48) (0.64)	-11.7** (2.47) (0.03)	-11.40*** (4.13) (0.00)	-9.64** (3.44) (0.01)	3.92 (0.41) (0.69)
Y	0.00 (1.06) (0.30)	0.00*** (6.39) (0.00)	0.00*** (7.67) (0.00)	0.00*** (6.39) (0.00)	0.00 (0.89) (0.39)
Y^2	-7.7e-9 (1.49) (0.15)	-2.2e-8*** (6.93) (0.00)	-1.8e-8*** (8.69) (0.00)	-1.8e-8*** (7.36) (0.00)	-7.7e-9 (-1.26) (0.22)
S		-0.08** (2.59) (0.02)		-0.02 (0.66) (0.52)	
I			4.17*** (5.72) (0.00)	4.03*** (3.94) (0.00)	
g(Y)					0.04 (0.02) (0.98)
D	-0.34** (2.70) (0.01)	-0.56*** (3.10) (0.01)	0.14 (1.09) (0.29)	0.06 (0.30) (0.77)	-0.34** (2.36) (0.03)
adj. R^2	0.73	0.94	0.97	0.97	0.72
DW	2.26	1.93	1.70	1.79	2.26
Number of obs.	23	22	23	22	23
ρ	0.80	0.16	0.18	0.12	0.80
ITP in DEM 1991 prices		33,629	32,563	32,064	
t-statistics and marginal significance levels in parenthesis *, **, *** for significance at the 10%, 5% and 1% level					

When incorporating the gross value added of the industry sector (equation 3, column 2) the estimation results of NO_x do not change notably. The income coefficients are stable in size and the ITP is only slightly lower than before. However, the industry share shows no significant influence. 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

[18] The income turning point of NH_3 is not calculated in column (1) and (5), since the income coefficients are not significant.

sectors is plausible and not at all controversial in literature. The ITP for ammonia (about DEM 33,500 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.

Figure 1: Estimated EKC for NO_x



The estimation results of equation (4) (column 3) reveal ambiguous information about both the force ratio 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 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.

The estimations with both the GDP share of the industry sector as well as the trade openness do not give many new insights (column 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.

As reasoned in section 2, the question whether the income growth rate should be ingested to the explanatory variables must be answered empirically. The results of the corresponding specification (equation 6) are reported in column (5). Concerning the linear and quadratic income term, one can refer to the discussion above. The coefficients of the income growth rate are not significant and neither the Durbin-Watson test nor the adjusted R^2 improves. In summary, it must be said that the income growth rate does not seem to be important here, and no evidence of a discrepancy between the rate of economic growth and social change, as propagated by Panayotou (1997), can be found.

As in de Bruyn et al. (1998), equation (7) was estimated in three variations. First, the changes in emission intensities were assumed to be time-dependent (parameter restriction $\alpha_2 = 0$). Second, these changes were modelled as income-dependent (parameter restriction $\alpha_0 = 0$). Finally, both possibilities were taken into account simultaneously. From these three regressions, the best fit was selected for each pollutant. The results are shown in Table 3. Since, in this specification, the variables are growth rates rather than levels, one can use OLS as the estimation technique.

Contrary to de Bruyn et al. (1998), who find for Germany[19] significant positive coefficients for the income growth rate and negative ones for either the time-dependent or income-dependent changes in emission intensity (or both), the results here are less clear-cut. In six out of eight cases, the income growth rate has a negative sign, although one would expect a positive one. The result that increased output leads to reduced emissions holding environmentally relevant technology constant is not very plausible and has never been found so far. However, the income growth rate coefficients are not significant at any usual significance level (except for non-methane volatile organic compounds).

Table 3

Endogenous variable: emissions growth rate								
	SO_2	NO_x	CO_2	PM	CO	NH_3	CH_4	NMVOC
const	0.60** (2.32) (0.03)	0.18*** (2.98) (0.01)	-0.04* (1.74) (0.10)		0.18*** (2.93) (0.01)			0.12*** (6.18) (0.00)
g(Y)	-0.40 (0.20) 0.84	-0.05 (0.16) (0.87)	0.12 (0.88) (0.39)	-0.25 (0.43) (0.67)	0.49 (1.26) (0.22)	-0.16 (0.51) (0.62)	-0.09 (0.35) (0.73)	-0.36** (2.41) (0.02)
Y_{t-1}	-1.8e-5** (2.31) (0.03)	-5.5e-6*** (3.09) (0.01)	1.0e-6 (1.54) (0.14)	-7.4e-7 (1.37) (0.18)	-7.3e-6*** (3.79) (0.00)	-1.6e-7 (0.61) (0.55)	-1.7e-7 (0.79) (0.44)	-3.9e-6*** (6.59) (0.00)
g(I)	-1.61*** (3.60) (0.00)	-0.07 (1.26) (0.22)	0.02 (0.89) (0.38)	-0.10 (0.96) (0.34)	-0.03 (0.32) (0.75)	0.12** (2.14) (0.05)	0.02 (0.38) (0.71)	0.06* (1.92) (0.07)
D	0.17 (1.42) (0.17)	0.02 (1.28) (0.21)	-0.02* (1.98) (0.06)	-0.03 (1.11) (0.28)	0.04 (1.58) (0.13)	0.00 (0.14) (0.89)	-0.01 (1.17) (0.26)	-0.02** (2.58) (0.02)
$g(E)_{t-1}$		0.04 (0.19) (0.85)	0.20 (1.02) (0.32)	0.34 (1.39) (0.18)	-0.35 (1.66) (0.11)	0.25 (1.10) (0.29)	0.38 (1.62) (0.12)	
adj. R^2	0.29	0.54	0.11	0.63	0.42	0.31	0.66	0.84
DW test	1.89	1.87	1.79	2.06	1.95	1.93	1.94	2.00
Number of obs	32	31	27	31	31	22	22	32
t-statistics and marginal significance levels in parenthesis *, **, *** for significance at the 10%, 5% and 1% level								

[19] Also for the Netherlands, the United Kingdom and the USA.

Whether changes in emissions are time- or income- dependent cannot be unambiguously concluded, since the results are mixed. In four cases, the constant term, which stands for time-dependent changes in the intensity of use, has a positive and significant coefficient. This is contradictory to the undisputed assumption that, due to exogenous technological improvements, the pollutant emissions can be reduced. In five cases, however, the income-dependent intensity changes have the expected negative sign and are significantly different from zero. As before, the trade variable almost always fails to be significant. Therefore, no information about the relative forces of the factor endowment hypothesis and the displacement effect is obtained. In all estimations, where the one-period lagged growth rate of the considered pollutant is included in the estimation, no significant coefficients are obtained, but the Durbin-Watson statistics are remarkably improved. Thus, serial correlation seems to be no longer a problem here. In summary, this specification does not considerably improve the insights about the relationship between income and environmental degradation.

Table 4

Endogenous variable: emissions first difference								
	SO_2	NO_x	CO_2	PM	CO	NH_3	CH_4	NMVOC
const	-1.65 (0.69) (0.50)	-0.30 (0.76) (0.46)	-19.87 (0.46) (0.65)	-0.06 (0.33) (0.74)	-3.80** (2.01) (0.05)	-0.05 (0.72) (0.48)	76.22 (0.94) (0.36)	0.00 (0.00) (0.99)
ΔY	-3.13e-6 (0.00) (0.99)	-0.00 (0.34) (0.73)	0.03 (0.72) (0.48)	-0.00 (0.14) (0.89)	0.00 (0.58) (0.57)	-0.00 (1.19) (0.25)	-0.00 (0.70) (0.49)	-0.00*** (4.10) (0.00)
ECT_{t-1}[20]	0.21 (0.61) (0.55)	-0.18*** (3.02) (0.01)	-0.39*** (2.96) (0.01)	-0.13*** (8.67) (0.00)	-0.12* (-1.86) (0.07)	-0.26*** (2.90) (0.01)	-0.05 (0.95) (0.36)	-0.21*** (5.61) (0.00)
D	1.63 (0.56) (0.58)	-0.53 (0.97) (0.34)	-83.38 (1.60) (0.13)	-0.26 (1.24) (0.23)	0.47 (0.23) (0.82)	-0.02 (0.22) (0.83)	-1.83 (1.58) (0.13)	-1.26*** (4.13) (0.00)
ΔE_{t-1}[21]	0.07 (0.31) (0.76)	0.31* (1.91) (0.07)	0.22 (1.35) (0.19)	0.14 (0.91) (0.37)	0.55*** (3.98) (0.00)	0.34* (1.79) (0.09)	0.45* (1.90) (0.08)	0.24* (1.84) (0.08)
adj. R^2	0.0	0.49	0.33	0.74	0.40	0.46	0.29	0.88
DW test	1.78	2.11	1.95	1.79	2.29	2.08	1.99	2.21
Number of obs	31	31	27	32	31	22	22	31
t-statistics and marginal significance levels in parenthesis *, **, *** for significance at the 10%, 5% and 1% level								

[20] ECT stands for "error correction term" and corresponds to the term in square brackets of equation (8) or the residuals of equation (2)

[21] E stands for the respective pollutant.

Table 5

Endogenous variable: emissions first difference								
	SO_2	NO_x	CO_2	PM	CO	NH_3	CH_4	NMVOC
const	0.89 (0.53) (0.60)	-0.38 (0.92) (0.36)	-20.79 (0.44) (0.67)	-0.04 (0.24) (0.81)	-3.73** (2.22) (0.04)	0.05 (0.84) (0.41)	57.62 (0.69) (0.50)	0.05 (0.32) (0.75)
ΔY	-8.8e-4 (0.51) (0.62)	-8.7e-5 (0.21) (0.83)	0.03 (0.73) (0.47)	-6.8e-5 (0.45) (0.66)	3.8e-4 (0.24) (0.81)	-1.4e-4* (2.05) (0.06)	-3.7e-4 (0.63) (0.54)	-6.2e-4*** (4.15) (0.00)
ECT_{t-1}[22]	-0.18 (0.73) (0.47)	-0.14*** (2.97) (0.01)	-0.40** (2.64) (0.02)	-0.13*** (9.02) (0.00)	-0.25*** (3.19) (0.00)	-0.80* (2.07) (0.06)	-0.04 (0.70) (0.50)	-0.22*** (5.39) (0.00)
ΔI	-149.92*** (4.30) (0.00)	-11.33 (1.57) (0.13)	-78.64 (0.09) (0.93)	-0.94 (0.31) (0.76)	-22.48 (0.79) (0.44)	2.10* (1.93) (0.07)	1.08 (0.13) (0.90)	1.89 (0.66) (0.52)
D	-0.43 (0.20) (0.85)	-0.60 (1.09) (0.29)	-88.88 (1.58) (0.13)	-0.27 (1.23) (0.23)	-0.54 (0.28) (0.78)	-0.04 (0.58) (0.57)	-1.60 (1.27) (0.22)	-1.26*** (4.08) (0.00)
ΔE_{t-1}[23]		0.30* (1.76) (0.09)	0.23 (1.29) (0.21)		0.45*** (3.45) (0.00)	0.53** (2.44) (0.03)	0.44* (1.79) (0.09)	0.24* (1.85) (0.08)
adj. R^2	0.35	0.50	0.29	0.73	0.50	0.43	0.24	0.88
DW test	1.72	1.97	1.96	1.79	2.16	1.83	1.98	2.36
Number of obs	32	31	27	32	31	22	22	31
t-statistics and marginal significance levels in parenthesis *, **, *** for significance at the 10%, 5% and 1% level								

The results of equations (8) and (9), which follow the error correction model tradition, are set forth in tables 4 and 5. Two things strike the observer's eye. First, the income changes, i.e. the short-term dynamic, are mostly non-significant and in some cases do not have the predicted positive sign. The long-term dynamic, represented by the error correction term, however, has significant negative coefficients for NO_x, CO_2, PM, CO, NMVOC and NH_3[24]. This can be interpreted in the sense that changes in income have no immediate influence on emissions but in the long run, the emissions follow an inverted U-shaped curve relative to income. The hump-shaped pattern is traced back to the non-linear specification of the error correction term. However, there is one reason why this interpretation is debatable. If environmental degradation indeed follows a hump-shaped curve, this result should already have been found in equations (2) and (4), respectively. But there, the EKC hypothesis could only be verified for NO_x and NH_3. Having said that, one can argue that if the distinction between long- and short-term changes is important, specifications where this differentiation is not made could

[22] ECT stands for "error correction term" and corresponds to the term in square brackets of equation (9) or the residuals of equation (4)
[23] See footnote (21)
[24] The coefficients of SO_2 and CH_4 are also negative but not significant.

lead to distorted results and that, therefore, equations with explicit short- and long-term dynamics should be preferred. As can be seen in Table 5, the trade variable, i.e. changes in the trade volume, exerts no decisive influence on emission changes. This endorses the previous results with regard to the displacement effect and the factor endowment hypothesis, respectively.

11. 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 semi-reduced form model and some extensions with additional explanatory variables, namely the trade relations, the GDP share of the industry sector and the income growth rate, are estimated. For nitrogen oxide and mostly for ammonia, an EKC pattern is found, with income turning points around 30,000 and DEM 33,000, 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[25]. These results indicate clearly that cross-country studies provide unreliable estimations. Second, and because of the variables' non-stationarity, an imitation of the model specification of de Bruyn et al. (1998) is empirically explored. Here, pollution and the exogenous variables are measured in growth rates rather than in levels, and the environmentally relevant technological progress is assumed to be either income- dependent or time-dependent (i.e. exogenous technological improvements). In contrast to their specification, the additional independent variable incorporated is not an energy price index but, following the modification of the semi-reduced model, a variable measuring the volume of foreign trade. However, de Bruyn et al. (1998)'s significant results for Germany, which also confirm predictions, cannot be endorsed in this study. Finally, motivated by error correction models, equations are estimated that distinguish between short- and long-term dynamics. But, contrary to the well-known error correction models (e.g. for a consumption function), the error correction term, i.e. the long-term

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

influence, is specified as a hump-shaped function. The estimations show that in the short run, income changes do not have an influence on the pollutant emission. In the long run, however, some pollutant emissions seem to follow a U-shaped curve relative to income. 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 semi-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[26].

[26] Meaning non-linear in parameters.

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Appendix A

Figure 2: Environmental Kuznets Curve; $\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 = 0$

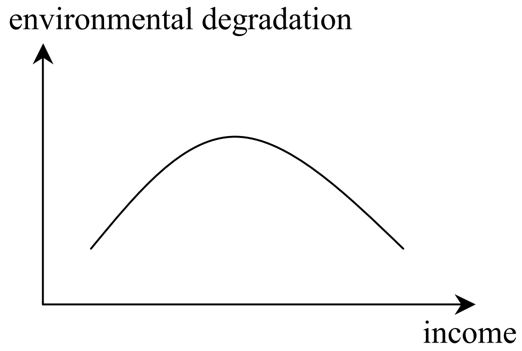


Figure 3: N-shaped curve; $\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 > 0$

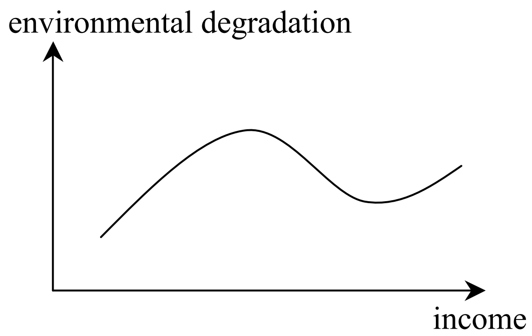


Figure 4: Monotonically increasing: $\beta_1 > 0$, $\beta_2 = 0$ and $\beta_3 = 0$

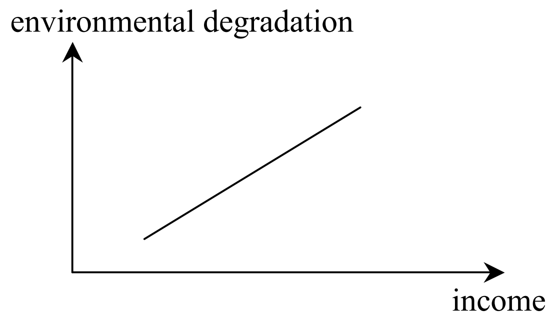
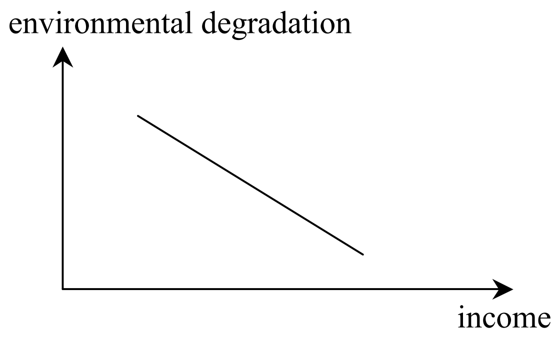


Figure 5: Monotonically decreasing: $\beta_1 < 0$, $\beta_2 = 0$ and $\beta_3 = 0$



Appendix B

Figure 6: SO_2 per capita emissions, 1966 - 1998

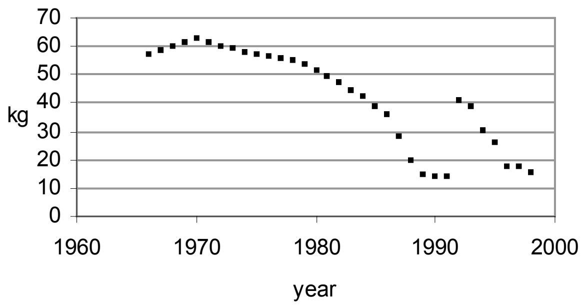


Figure 7: NO_x per capita emissions, 1966 – 1998

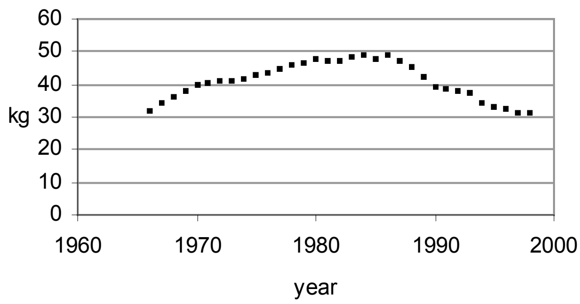


Figure 8: CO_2 per capita emissions, 1970 – 1998

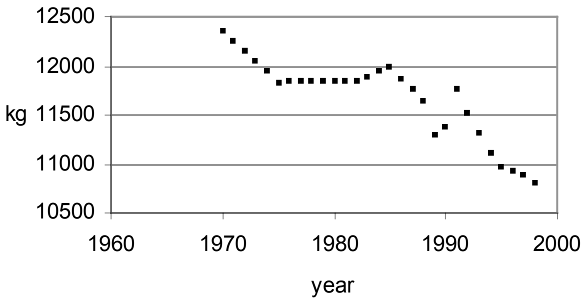


Figure 9: PM per capita emissions, 1966 - 1998

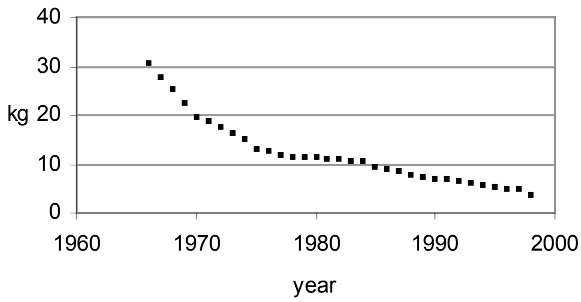


Figure 10: CO per capita emissions, 1966 - 1998

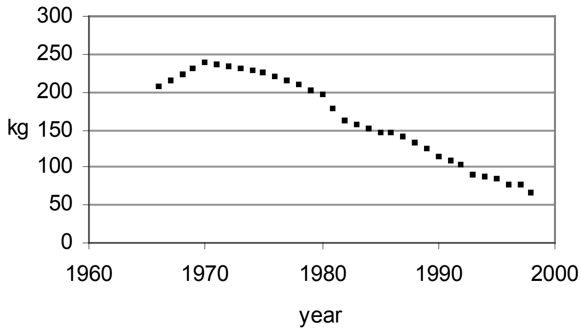


Figure 11: NH_3 per capita emission, 1975 – 1998

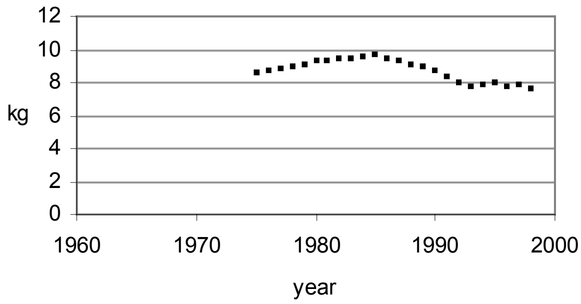


Figure 12: CH_4 per capita emissions, 1975 – 199

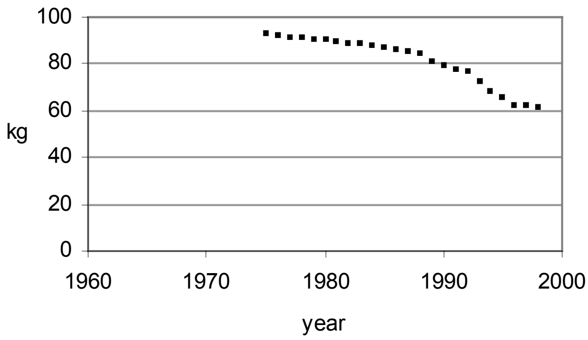
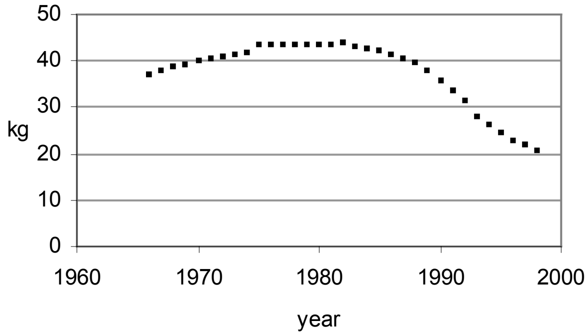


Figure 13: NMVOC per capita emissions, 1966 - 1998



Appendix C

In the following, the significant 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 14: Estimated three-dimensional EKC for NO_x from equation (3), i.e. with gross value added by the industry sector

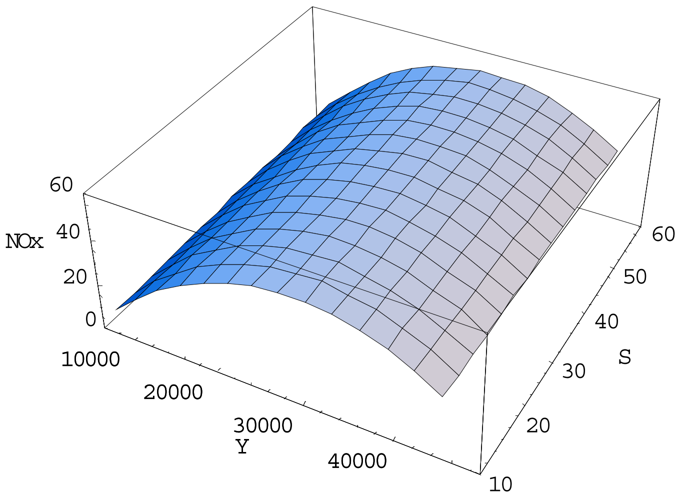


Figure 15: Estimated three-dimensional EKC for NH_3 from equation (3), i.e. with gross value added by the industry sector

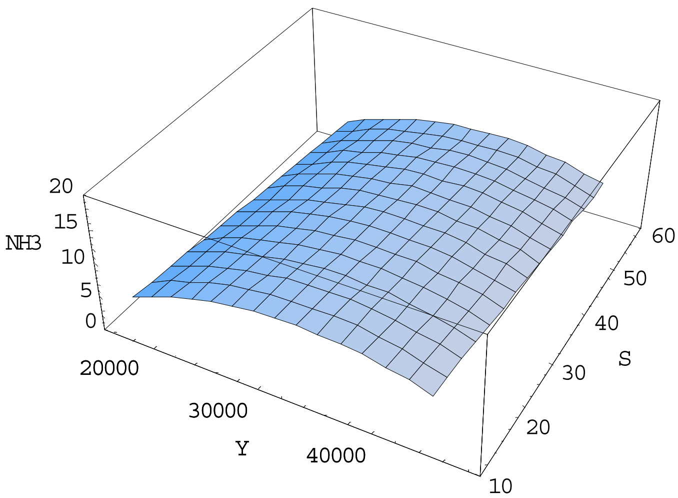


Figure 16: Estimated three-dimensional EKC for NO_x from equation (4), i.e. with the sum of imports and exports of goods from pollution-intensive production relative to GDP

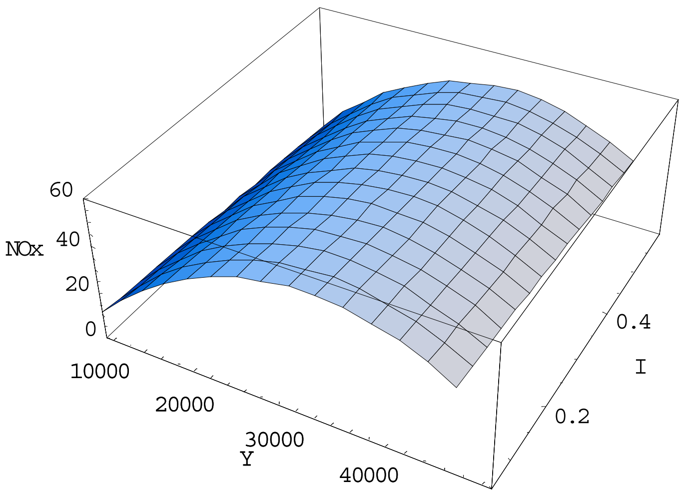


Figure 17: Estimated three-dimensional EKC for NH_3 from equation (4), i.e. with the sum of imports and exports of goods from pollution-intensive production relative to GDP