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Explaining the environmental Kuznets Curve

The case of sulphur emissions

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Abstract

Environmental Kuznets Curves have been estimated using a simple econometric model that hampers interpretation of the various determinants underlying the inverted-U-shaped relationship between some pollutants and income. Explanations for the observed patterns have been offered ex-post without reference to theoretical or empirical investigations. The influence of environmental policy and structural change through sectoral shifts are frequently mentioned as important determinants of the achieved reductions of some pollutants in developed economies. Reviewing the literature on decomposition analysis and applying this method to sulphur emissions fails to find evidence for structural change to be an important determinant of the recorded reductions in sulphur emissions. Environmental policy, fostered by international agreements, has presumably been the main determinant of the reduction in emissions. A regression analysis on the determinants of the non-uniform reductions agreed under the Second Sulphur Protocol makes clear that higher income countries have a more ambitious environmental policy. This provides an explanation for the observed inverted-U curve between sulphur emissions and levels of income.

Keywords

Decomposition analysis, environmental policy, sulphur emissions, international agreements, structural change.

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1. Introduction

The single aspect in the environment versus the economy debate that received most attention in the 1990s has been the finding of a so called 'Environmental Kuznets Curve' (EKC hereafter) in the relationship between certain types of pollutants and levels of income. According to the EKC-hypothesis environmental quality declines during early stages of economic development but improves in later stages.' This visualizes to the inverted-u curve between pollutants and economic development, similar to the relationship Simon Kuznets (1955) suggested to possibly exist between income inequality and income per capita. Although improvements in environmental quality along economic development had already been hypothesized by certain 'optimists' in the 1970s (cf. Beckerman, 1972; Simon 1976, ch 9), it was not until the 1990s that enough data became available that allowed for empirical testing.

After the initiatory papers by Grossman and Krueger (1991), Shafik and Bandyopadhyay (1992) and Panayatou (1993), who found evidence that some pollutants follow an inverted-U curve with respect to income, the topic has been politicized by for example the Worldbank (1992;1995) and has since then raised a number of critiques of which the Science article by Arrow et *al.* (1995) has received most attention*. One of the elements that has been repeatedly brought to the attention is that even if pollutants decline after certain levels of income, this mere knowledge adds only limited insights to either the political or scientific debate since it is widely acknowledged that the process of reducing emissions is not endogenous. Shafik and Bandyopadhyay (1992), for example, state in their abstract that "it is possible to 'grow out of some environmental problems, but there is nothing automatic about doing so". Similar observations have been made by Grossman and Krueger (1995) and Panayatou (1993). It follows that the EKC-hypothesis can not give a freeway for unlimited economic growth because it may not be economic growth itself that causes emissions to decline. Arrow et a/. (1995) state this argument as follows: "Economic growth is not a panacea for environmental quality; indeed it is not even the main issue". This automatically

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[1] I prefer to label the EKC as a hypothesis given the yet poor understanding of the factors determining the phenomenon and the fact that for many substances no EKC could be detected.

[2] See also the subsequent discussions in special issues about the topic of EKC by Ecological Economics (1995), Environment and Development Economics (19%) and Ecological Applications (19%).

raises the question what can be a panacea for environmental quality.

While the benefits of economic growth can not be directly discerned from the EKC-hypothesis, the environmental costs of economic growth are far more distinct. Stem et a/. (1998) have pointed at the fact that the improvements in environmental quality according to the EKC-hypothesis are not attainable for the majority of world population that have standards of living still below the estimated turning points. Emissions world wide are therefore expected to continue to increase due to economic growth, even for pollutants of which inverted-U curves have been estimated (cf. Selden and Song, 1994; Stem et a/. 1998).

Interpreting the EKC-hypothesis as a sign that economic growth and environmental impacts are de-linked is therefore erroneous and distracts from the far more interesting research question: which factors have been successful in reducing emissions in developed economies? What matters for those living in less developed economies is not that environmental pressure may decrease after certain (high) income levels but how such reductions can be achieved against minimal social costs, preferably at lower levels of income. The current studies on EKCs have provided only limited insights in the underlying factors that shape the inverted-U relationship. Explanations for the observed patterns are offered ex-post, intuitively, and not based on empirical investigation or theoretical formalisation. The present article aims to fill in one of the blank spots in the EKC-hypothesis by empirically investigating the dominating factors behind the important decreases in sulphur dioxide emissions in European and Northern American countries in the 1980s. The focus is on sulphur emissions because many studies have found an EKC for sulphur emissions and concentrations (cf. Shafik and Bandyopadhyay, 1992; Worldbank, 1992; Panayatou, 1993; Selden and Song, 1994; Grossman and Krueger, 1995). Besides, sulphur concentrations are perceived as an important indicator for ambient air quality.

The organisation of the paper is as follows. In Section 2 an overview will be given of the current (ex-post) explanations that have been suggested in the literature on EKCs and highlights the importance of environmental policy and structural change for these explanations. Some recent empirical evidence for these factors will also be reviewed. Section 3 describes a methodology, decomposition analysis, that can be used to determine the factors other than income that are relevant for changes in environmental pressure. This methodology will in Section 4 be applied to the development of sulphur emissions in Western Germany and the Netherlands in order to test for the influence of structural change in the reduction of sulphur emissions. Section 5 investigates the role of environmental policy for the development of sulphur emissions and looks deeper into the question whether environmental policy is induced by higher incomes. The implications of these findings, both for developed and for developing economies, will be discussed in Section 6.

2. Reduced forms, reduced interpretations?

The relationship between some indicator of environmental pressure E and income Y has been estimated by various authors using a fairly similar reduced form model, which can be formulated as:

$$E_{i,t} = \alpha_{i,t} + \beta_1 Y_{i,t} + \beta_2 Y_{i,t}^2 + \beta_3 Y_{i,t}^3 + \beta_4 Z_{i,t} + e_{i,t} \qquad (1)$$

where the subscript i stands for a country index, t is a time index, e is the normally distributed error term and $Z_{i,t}$ relates to other variables of influence on environmental degradation (see below). With $\beta_1 > 0$, $\beta_2 < 0$ and β_3 insignificant, a parabolic relationship is obtained that represents the EKC. In the case of sulphur dioxide emissions and concentrations, such a relationship has been found by Shafik and Bandyopadhyay (1992), Panayatou (1993) and Selden and Song (1 994).[3] Grossman and Krueger (1995) find evidence for a positive β_3 which assumes ambient sulphur concentrations to rise again at high income levels.

Model (1) is a reduced form model since the single equation is supposed to capture the structural model in which income influences technology, the composition of economic output and environmental policy and changes in these factors in turn influence environmental pressure. The advantage of working with a reduced form model is that the influence of income on environmental pressure is estimated directly. A disadvantage of this approach, as pointed out by Grossman and Krueger (1995), is that it is not clear why the estimated relationship exists and especially what kind of interpretation should be given to the estimated coefficients of the polynomial in (1). Because of the lack of explanatory power of model (1)

[3] All these authors use the basic model (1) albeit with some modifications which are beyond the scope of the present paper (but see Ekins, 1996, Stem et al., 1996 and De Bruyn et al., 1996a for details).

itself, explanations for the coefficient estimates are given ex-post. Panayatou (1993), Selden and Song (1994, p147), Grossman and Krueger (1995, p372) and others present several arguments that may explain the inverted-U curve for air pollutants. The most discussed are:

(i) positive income elasticities for environmental quality and more open political systems with rising incomes which may result in effective environmental policies;

(ii) changes in the composition of production and consumption going along with rising incomes;

Behind the first argument is a simple notion of induced policy response: as citizens grow richer they demand more environmental quality and governments start to internalize external effects by appropriate legislation (cf. Grossman and Krueger 1995, p372). If this argument is valid, it assumes a relatively smooth transition from citizen demands for public goods to the provision thereof by governments. Such a process is only likely to occur in democratic countries. At present no studies have gathered empirical evidence for the importance of environmental policy in explaining the EKC. Empirical evidence for the influence of democracy on pollutants exists but is scarce and contradictory. Shafik and Bandyopadhyay (1992) test for the influence of political and civil rights on, among others, ambient sulphur concentrations and find that these are higher, not lower, in more democratic countries. However, Torras and Boyce (1996), focusing on various aspects of power equality, find evidence that less 'power-equal' countries (both with respect to democracy as income equality) have higher sulphur dioxide emissions.

The second argument assumes a transition along economic development with respect to the structure of production. The transition from agricultural through industrial to services-oriented economies may result in an inverted-U pattern of pollution where the highest pressure is to be associated with the industrial stage. Although this is a very intuitive notion, empirical evidence again is scarce and not entirely convincing. Lucas et a/., (1992) found evidence for the importance of differences in the structure of production for toxic manufacturing emissions. However, this study calculates emissions for the developing countries using emission coefficients of the United States. Hence the only difference in emissions can be explained by differences in the production structure (since the technology of production is similar over their sample). Suri and Chapman (1996) include in their regressions a variable $Z_{i,t}$ representing the share of manufacturing in GDP and find this to be significantly positive on the levels of energy consumption. Kaufmann ef a/.

(1996) include a variable representing steel exports to GDP and interpret this as an indicator for the structure of the economy. Higher steel exports are associated with higher ambient air concentrations of sulphur.

The alleged emergence of such structural change in production has been brought into connection with consumption and international trade by, among others, Arrow et a/. (1995), Stem *et* al. (1996), Ekins (1996), Rothman (1996) and de Bruyn and Opschoor (1997). If changes in the structure of production in developed economies are not accompanied by equivalent changes in the structure of consumption, the EKC simply records displacement of dirty industries to less developed economies. Such a displacement can explain the inverted-u curve quite satisfactorily: decreases of pollutants in developed countries and increases in developing countries. Empirical evidence on displacement is even more scarce, mainly because of the lack of consumption based indicators for environmental quality and the lack of information on the pollution intensity of international trade. Some authors have, however, investigated the role of international trade on the on the patterns of emissions. Shafik and Bandyopadhyay (1992) found mixed evidence for the effects of trade on the various indicators they have used. In the case of sulphur dioxide emissions more trade seems to result in less emissions which may reflect efficiency improvements in resource use due to increasing competition. Suri and Chapman (1996), however, found opposite results for energy consumption when taking into consideration the composition of international trade. Countries that export more manufactured goods tend to have a higher energy consumption.

The above discussed empirical investigations into the importance of some factors for the shape of the EKC share the common feature that the reduced form model (1) is expanded by including some variables $Z_{i,t}$, representing for example democracy, international trade or structural change. Hence the reduced form model is being expanded by including some factors from the structural model. This approach is not without problems, however. If $Z_{i,t}$ is used to represent democracy or the share of manufacturing in total GDP, and if this variable is also related to income (as is suggested by the ex-post explanations for the EKC), a serious multicollinearity problem can be expected between $Z_{i,t}$ and the various orders of $Y_{i,t}$. Such intercorrelation among the explanatory variables makes the regression estimates difficult to interpret since the individual effects of the variables cannot be disentangled. For these reasons empirical evidence on the various factors influencing environmental pressure may only be analyzed appropriately along different research lines. One of the possibilities is the estimation of the structural model with more equations and two-way impacts between environmental pressure and income, using for example structural VARs (cf. Stern (1993) for an application to energy consumption). This method is very data intensive and because the equations from the structural model have not yet been adequately specified in theoretical contributions it is unclear which relationships are to be estimated. Another approach is to use descriptive methods such as decomposition analysis that can be used to determine the factors that shape the patterns of emissions over time. The next section discusses this technique and outlines how it can be related to the EKC-hypothesis.

3. Decomposition analysis

Decomposition analysis is a descriptive technique that can be used for analyzing determinants of change of an aggregated variable. Decomposition analysis has mainly been occupied with disentangling the effects of sectoral shifts on e.g. employment (Skolka 1989), economic growth (Wyckoff, 1992) or CO, emissions (Torvanger, 1991). Emissions can be perceived as aggregated variables because they are emitted through a number of different production processes in various economic sectors. Changes in the composition of economic activities through sectoral shifts, or structural changes, may have an important impact on the total emissions.

Grossman (1995) has mentioned decomposition analysis in combination with the EKC as offering an explanation for the shape of the inverted-U curve. Following Grossman emissions E in a given country can be described by the following identity:

$$E_t = \sum_{j=1}^{n} Y_t I_{j,t} S_{j,t} \qquad (2)$$

where $j=1 \ldots n$ represent the various sectors in the economy and Y_t is overall income (GDP), $I_{j,t}$ is the emission intensity of sector j and $S_{j,t}$ is the share of sector j in GDP, or the 'production share'. Equation (2) is an identity since $I_{j,t} = E_{j,t}/Y_{j,t}$ and $S_{j,t} = Y_{j,t}/Y_t$.

Changes in $S_{j,t}$ over time may represent the influence on emissions of a change in the structure of the economy. Changes in $I_{j,t}$ are perceived as primarily technological of nature (declining emissions within sectors), or intrasectoral changes[4]. Changes in Y_t reflects the 'scale' effect of economic activity on emissions. Grossman (1995, p20) notes: "*all* else equal, an increase in output means an equiporportionate increase in pollution". Emissions may decline actually if the growth in output is appropriately compensated by intrasectoral and structural changes.

There exists an extensive body of recent literature, especially in energy economics, that deals with the question how to transform (2) into an equation that can disentangle and specify the scale, structural and intrasectoral effects (cf. Howarth et al., 1991; Liu et al., 1992; Ang and Lee, 1994; Ang, 1994).[5] Following Howarth et al. (1991) we can first transform (2) into an identity describing the emission intensity of a specific country by dividing it by Y_t:[6]

$$I_t = \sum_{j=1}^{n} I_{j,t} S_{j,t} \tag{3}$$

$$I_T - I_0 = \int_0^T \sum_j \dot{I}_{j,t} S_{j,t}\, dt + \int_0^T \sum_j \dot{S}_{j,t} I_{j,t}\, dt \tag{4}$$

where I_t are the aggregated emissions per unit GDP (= E_t/Y_t). The effects of changes in the structure of the economy and intrasectoral changes can be disentangled by differentiating (3) with respect to time and then integrating over a time interval (O,T), where 0 and T can be characterized as the only points in the interval about which data are available. This gives (Ang, 1994):

where variables with a dot indicate derivatives with respect to time.

The first integral in (4) defines the 'intrasectoral effect' as the sum of changes in each sector's emission intensity holding the production share constant. The second integral defines the 'structural effect' as the sum of changes in each sector's production share holding the emission intensity constant. In order to apply this decomposition in empirical analysis we need to find discrete approximations of

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[4] Changes in the emission intensities within sectors may also be due to a change in the product mix within sectors and therefore the term intrasectoral change is more appropriate than 'technological change'. Intrasectoral change denotes the combination of technological change and shifts in the product mix within sectors.

[5] Grossman (1995) seems not to be aware of this literature.

[6] Howarth et al. (1991) prove that the scale effect is simply equal to the growth in GDP. If the emphasis is on the underlying factors of changes in energy consumption (or emissions) it is better to work with energy (emission) intensities because the number of interaction terms will be reduced.

the two continuous integrals on the right hand side of (4). This is known as the integral path problem in the theory of index numbers, or the Divisia Index problem (Liu et a/., 1992), similar to the well-known difficulties encountered in national income statistics to disentangle the changes in prices from changes in volume. In short, it is not decided whether the changes in the structure of the economy should be weighted by the emission intensities of year 0 or year T or some average of these (cf. Ang and Lee (1994). For these reasons the integrals in (4) have to be approximated. In the Annex to this paper the proposed approximations to this integral path problem by Ang (1994) are described which form the technique of decomposition.

Decomposition analysis then can be used to empirically determine the influence on emissions of structural change, which has been suggested as an important determinant of the EKC. Although decomposition analysis can successfully be applied in order to disentangle the structural and intrasectoral effects from each other, it cannot provide an answer why these have occurred. The technique of decomposition is purely descriptive (Ang and Lee, 1994). In the light of the EKC-hypothesis this implies that decomposition analysis cannot provide the answer whether intrasectoral change has been the result of endogenous improvements in the efficiency of technology or the result of environmental policies. As in the case of the reduced form models, such explanations for the observed patterns can be expressed ex-post only, or through some hypothesis. Actual observation of environmental policy in various countries by Jänicke et al. (1993), however, result in the notion that the structure of the economy is not subject to environmental policy considerations in most countries at present[7]. Hence structural change seems to be largely the result of endogenous changes. Environmental policy then in turn may largely effect the intrasectoral change through the implementation of standards for various production processes.

4. Empirical support for structural change?

Empirical applications using decomposition analysis show only limited evidence for structural change to be an important determinant of changes in energy

[7] Notice also that the assumption of the possibility of governmental regulation concerning the structure of the economy implies central planning, an allocation scheme which has almost everywhere been abandoned.

consumption and some pollutants. Howarth et a/. (1991) performed decomposition of the factors underlying the developments in energy consumption for eight OECD countries between 1973 and 1987. All countries in their sample consumed less energy over the period considered, despite the growth in output. This reduction has not been the result of a decrease in manufacturing share of total GDP, since this share has remained almost constant over the period considered (cf. Torvanger, 1991). A decomposition of the reduction in industrial energy intensities into structural and intrasectoral effects has revealed that, on average, structural change played only a minor role in the reduction of industrial energy intensities. In Norway the structure of industry became even more energy intensive. Because of the importance of energy consumption for most of the pollutants of which EKCs have been found, these findings should be of relevance for the discussion on EKCs too.

Decomposition analysis applied to emissions directly are scarce at present. Torvanger (1991) has investigated the determinants of change in CO_2 emissions in nine OECD countries over the same time span as Howarth et al. (1991). He also fails to find strong evidence of structural change. In Schucht and De Bruyn (1997) the reductions in atmospheric heavy metals emissions in Northrhine-Westfalia, a German federal state, have been analyzed using decomposition analysis over a much longer time span. It was found that between 1955 and 1988 structural change provided no explanation for the decreases in the emissions of cadmium, zinc and lead. Instead, federal and national environmental policies seemed to be the major determinants of the impressive reductions (in the order of magnitude of 90%) of heavy metal emissions over this time period.

It is expected that similar conclusions will hold for sulphur emissions as well, indicating that the downward sloping part of the EKC could not be attributed to structural change but to intrasectoral change instead. In order to test for the importance of structural change on the emissions of sulphur, sectoral data on sulphur emissions have to be gathered. The statistical offices of the Netherlands and Western Germany have published such data for a decent number of sectors. Both in the Netherlands and Western Germany emissions of sulphur have fallen considerably, especially during the 1980s, despite the growth in incomes. Hence the reductions due to structural and intrasectoral effects have dominated the scale-effect. In order to test for the relative contribution of each effect, a decomposition has been performed on the development of commercial sulphur emission intensities between 1980 and 1990 using the method described in Annex 1.[8] The results are given in Table1.

Table 1: Rates of change in commercial SO_2 emissions, GDP, emission intensities and the factors thereof, 1990 compared to 1980:

	Western-Germany	Netherlands	Western Germany'
Emissions	-73.6%	-58.7%	-73.6%
GDP	26.1%	28.2%	26.1%
Emission intensities	-79.0%	-67.7%	-79.0%
of which			
intrasectoral change	-74.5%	-73.5%	-74.9%
structural change	-4.5%	+5.7%	-4.1%
Number of sectors	59	19	19

Note: Own calculations using PDM2 with α=ß=0.5 (see Annex 1) based on data from Dutch Statistical Office (CBS), German Statistical Office (SBA). * implies a classification according to Dutch standards.

Table 1 shows that the emissions have declined more considerably in Western Germany than in the Netherlands. Decomposition of the change in emission intensities shows that intrasectoral changes explain the largest part of the reductions in SO_2 emissions. The reductions due to-intrasectoral change are almost similar in both countries. Hence the more profound reductions in sulphur emissions in Western Germany can largely be explained with reference to the difference in structural change between both countries, In the Netherlands during the 1980s the structure of the economy became even more sulphur intensive. It should be noted that the results between the two countries are only partially comparable because of different sector classifications and the fact that the German statistics are more disaggregated.[9] An attempted decomposition of Western German SO_2 emissions according to the Dutch sectoral classification in the fourth column of Table 1 shows only slight differences with the more fully disaggregated decomposition.

When these findings are linked to the EKC-hypothesis they fail to find evidence of sectoral shifts to be an important determinant for the reduction in

[8] Commercial sulphur emissions are total sulphur emissions minus the emissions from households. The share of household emissions for 1980 and 1990 are for Western Germany 6.7% and 11.6 % respectively and for the Netherlands (estimation) 2.4% and 3.9% respectively.

[9] Ang (1993) has elaborated the importance of sector classification for decomposition outcomes.

sulphur emissions and hence invalidating one of the frequently mentioned explanations for the EKC-hypothesis. It can, however, be safely argued that 10 years is a too short period of time to conclude anything fundamental about structural changes and therefore these results are only an outline. But they are also not contradicted by other empirical studies using decomposition analysis. The importance of intrasectoral change suggests that environmental policy may have been quite successful in reducing sulphur dioxide emissions in the two countries involved, although this cannot be discerned from decomposition analysis alone. In Germany sector specific emission limits for exhaust gasses at the national level have been subsequently sharpened in the TA-Luft legislation. In the Netherlands environmental legislation in the 1980s was basically enforced by local administrators, often through voluntary (or sometimes binding) agreements with industries. Since both Western Germany and the Netherlands are highly developed economies, the importance of environmental policy in reducing sulphur dioxide emissions may be in line with the EKC-hypothesis if richer countries would prefer stricter environmental policies. Evidence that the level of income influences national environmental programs for sulphur emissions will be presented in the next section.

5. Do higher incomes result in more ambitious environmental policies?

One of the explanations that has been suggested for the EKC-hypothesis is that richer countries request (or require) a stricter environmental policy. The previous section has hinted at the importance of investigations into environmental policy to describe the patterns of sulphur emissions. This section will discuss the development of environmental policy for sulphur emissions during the 1980s and 1990s and test the hypothesis that citizens from richer countries request a more ambitious environmental policy.

Sulphur emissions can travel a relatively long time through the atmosphere and may cause damage in other regions or countries through wet deposition (acid rain). For these reasons, sulphur emissions are recognized as a typical transboundary air pollution problem, which has induced various countries to cooperate through supranational institutions. The Convention on Long Range Transboundary Air Pollution (LRTAP), signed by 35 countries and put into force in March 1983, constitutes an international institutional framework within which contracting countries identify the problems posed by transboundary air pollution and accept the responsibility of taking appropriate steps, albeit without making any commitments for future reductions. The focus of the LRTAP has primarily been on emissions causing acid rain. Under the framework of the LRTAP various protocols have been negotiated that set binding reductions on SO_2, NOx and VOC pollutants.

Binding reductions for sulphur emissions have been reached in the First and Second Sulphur Protocols. The First Sulphur Protocol was signed in Helsinki in 1985 by a group of 20 countries which agreed to reduce annual sulphur emissions by 30% compared to 1980, by 1993 at the latest." One of the critiques to this protocol has been that the reduction goal of 30% was set rather arbitrarily and is not related to deposition and environmental impacts or to cost-effectiveness, a reason why for example the United Kingdom refused to sign (Klaassen, 1995). Such critiques have been taken into account in formulating the Second Sulphur Protocol, which has been signed by 27 parties in Oslo in 1994.[11] This protocol

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[10] The protocol has been signed by: Austria, Belarus, Belgium, Bulgaria, Canada, Czechoslovakia, Denmark, Finland, France, Hungary, Italy, Liechtenstein, Luxembourg, the Netherlands, Norway, the Soviet Union, Sweden, Switzerland and Western Germany.

[11] All countries from the First Sulphur Protocol except Belarus and Czechoslovakia singed the Second Sulphur Protocol. In addition also Croatia, Czech Republic, Greece, Ireland, Poland, Portugal, Slovakia, Slovenia, Ukraine and the United Kingdom signed the Second Sulphur Protocol.

specifies, among other things, non-uniform reduction percentages for the various countries. The non-uniform reduction percentages reflect the principal agreement to reduce the gap between sulphur deposition in 1990 and the 5 percentile critical loads by 60% in 2010 at latest'*. Because of the diversity in current emission levels, climatic conditions and sensitivity of various ecosystems to acid rain, different emission targets were defined using the RAINS model (Alcamo et *al.*, 1990). The optimal outcomes from the RAINS model have been used as a baseline along which the negotiations took place. The final agreed non-uniform reductions do not differ substantially from the national environmental policy plans that were already established. Compared to the various national policy initiatives, the Second Sulphur Protocol implies that nine countries have to tighten their national environmental policy, ten countries carry out what they planned to do, and two countries agreed to do less than they planned to do (Klaassen 1995, p217).

Table 2 gives an overview of the 1980 and 1990 levels of emissions and the planned reductions aimed at the year 2000. As we can see from Table 2, the reductions that have been agreed upon differ considerably among the various countries. All countries, except Greece and Portugal, aim to reduce their emissions compared to 1980. Moreover, most countries already reduced their national emissions over the 1980s. The US is not part of the LRTAP or Second Sulphur Protocol but has been included in this table because of the national programme under Title IV of the 1990 Clean Air Act Amendments for reduction of sulphur emission of fossil fuel power plants to 50% in the year 2000 compared to 1980.

[12] The 5 percentile critical load is the maximum level of deposition below which, according to current scientific knowledge, 95% of the ecosystems will be undamaged.

Table 2: Development of emissions 1980, 1990 and agreed targets for the year 2000 from the Second Sulphur Protocol.

	Emissions			Targets
	1980	1990	2000	2000/1980
Austria	397	90	79	-80%
Belgium	828	443	248	-70%
Bulgaria	2050	2020	1374	-33%
Canada	4643	3323	3250	-30%
Czech Republic	2257	1876	1129	-50%
Denmark	451	180	90	-80%
Finland	584	260	117	-80%
France	3338	1202	868	-74%
Germany (unified)	7494	5803	1274	-83%
Greece	400	500	596	+49%
Hungary	1632	1010	898	-45%
Ireland	222	168	155	-30%
Italy	3800	1988	1330	-65%
Luxembourg	24	10	10	-58%
Netherlands	466	207	107	-77%
Norway	142	54	34	-76%
Poland	4100	3210	2583	-37%
Portugal	266	211	303	+14%
Russia	7161	4460	4440	-38%
Slovakia	700	539	280	-60%
Slovenia	235	195	129	-45%
Spain	3319	2316	2157	-35%
Sweden	126	62	60	-52%
Switzerland	503	130	101	-80%
Ukraine	3850	2782	2310	-40%
United Kingdom	4898	3780	2449	-50%
USA	23780	21060	NA	-50%'

Note: * targets relate to emissions from power plants only.
Croatia and Liechtenstein have signed the Second Sulphur Protocol but are not included in this Table because no data were available. Sources: OECD, Environmental Data Compendium, 1993, Klaassen 1995, World Resources, 1994-95.

One interesting question in the light of the discussion surrounding EKCs is to what extent income differences explain the variation in emission targets. Do countries with higher incomes have a more ambitious environmental policy expressed through a higher reduction target for sulphur emissions? As discussed in Section 2, stricter environmental policy induced by higher incomes has been offered as one of the explanations for the shape of the EKC. This ex-post explanation can simply be tested by regressing the agreed targets under the Second Sulphur Protocol on the levels of income of 1993, which represents the relative wealth of nations during the tie the negotiations took place. To test the influence of income on environmental policy the following log-linear model has been constructed:

$$TAR_i = \beta_0 + \beta_1 \ln(Y_i) + \sum_{k-2}^{n} \beta_k Z_{i,k} + e \qquad (5)$$

where i is a country index, TAR are the agreed percentage reduction targets in sulphur emissions for the year 2000 with the base year 1980 as given in Table 2 (but with the sign reversed), Y is income measured in 1993 US$ with market exchange rates[13] and the Z_k's are n-l specific variables that were supposed to have an influence on the negotiated results because of the characteristics they posses for each individual country. The Z_k variables that have been tested include: (i) population density, to test the assumption that more heavily populated areas require tougher environmental policies (cf. Selden and Song, 1994); (ii) emissions per capita, to test the assumption that countries with higher emissions per capita may need to reduce their emissions faster; (iii) emissions per unit of area, as a proxy for overall ambient air concentrations within a country, to test the assumption that countries with worse ambient air will agree upon higher reductions; (iv) dummies for former communist countries to test the assumption that the resource intensiveness of these countries allows for higher reductions in the future (Jänicke et al., 1989); (v) dummies for countries with an eastern coast line, to test the assumption that dominant westward winds allow these countries to set lower national targets.

The cross-country sample used to test model (5) contains all the 27 countries listed in Table 2. For the US, the target for national power plants has been translated to a national emission target by multiplying the 50% goal by the share of power plants emissions in total sulphur emissions (=67%). All of the Z_k variables have first been included in a test-regression and in successive rounds excluded if not significant, using the Aikaike Information Criterion (AIC) as a guiding principle for obtaining the maximum degrees of freedom[14]. The AIC selected the model that includes for Z_k only one parameter: the dummy for former communist countries. Other Z_k variables were not significant at the 10% critical level. The results of this regression are given in Table 3.

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[13] Because the sample is a cross-section of countries, income measured in purchasing power parities may better express the ability of countries to pay for environmental policy. Unfortunately such figures were not available for all countries in the Penn World Tables (Summer and Heston, 199 1).

[14] The AIC places a penalty on the inclusion of non-significant parameters. The regression that minimizes the AIC is the preferred.

Table 3: Results from regressions on the national environmental policy targets for the year 2000 for SO, emissions.

Variable	Coefficient (t-statistics)	Mean (standard deviation)
Dependent: Targets		0.4956 (0.3001)
β_0 Constant	-0.422 (-1.688)	
β_1 Income (logs)	0.310 (3.808)	2.379 (1.057)
β_2 Former communist	0.539 (3.010)	0.333 (0.480)
Adjusted R^2	32.6%	
White F-test	2.02	

Note: Incomes for 1993 in US$ using market exchange rates. Data: Income from Worldbank, Worldtables 1995; Emissions from OECD, Environmental Data Compendium, 1993, Klaassen 1995, World Resources, 1994-1995. Surface area from United Nations, Demographic Statistics, 1994. Critical t-stats for n=27 at 10,5 and 1 percent two tail confidence levels: 1.703, 2.052, 2.771 respectively.

From Table 3 it can be concluded first that the overall fit of the model is not very satisfactory. Only 33% of the variation in reduction targets can be related to the variables in the model. The income and dummy variables are significant at the 1% critical level while the constant is almost significant at the 10% level. The positive value of β_1 implies that the negotiated targets tend to be higher if income is higher. Hence the ambition of environmental policy depends on the level of income, as was postulated by the ex-post explanations for the EKC. The value of 0.310 implies that a doubling of income results in emissions decreasing by 21.5% in the year 2000, if environmental policy is implemented successfully. The partial coefficient of determination of income, however, is 13.7% which indicates that income alone explains not even 14% of the negotiated targets. Another variable that is highly significant is the dummy for the former communist countries. Regardless of their income position these countries agreed to cut down emissions by almost 12% ($=\beta_2-\beta_0$). This justifies the assumption that the communist countries are able to achieve additional reductions due to the resource intensiveness of their economies under central planning regimes. On average the emissions from all the countries in the sample will be reduced by almost 50% compared to 1980. The White test shows that the estimation is not plagued by heteroscedasticity and that hence the t-statistics are efficient.[15]

[15] The White tests have been conducted without cross-terms because of the limited number of observations in the sample. As expected from cross-section analysis, DW-statistics (not given in the

The negotiators of the countries that have signed the Second Sulphur Protocol set 1980 as the baseline but were of course well aware of the reductions that had been achieved meanwhile. Hence part of the negotiated reductions may reflect actual improvements in emission levels that took place during the 1980s. In order to test for the level of ambition of the negotiated targets a second regression has been conducted that calculates the necessary reductions that have to be achieved in the year 2000 compared to 1990 (the latest year for which of all the countries in the sample data are available). This reflects the reductions that have to be achieved during the 1990s. The results of this regression, with the same variables and procedure as described above, are given in Table 4.

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table) showed that the errors are not autocorrelated.

Table 4: Results from regressions on the additional reductions to be achieved during the 1990s given the targets for the year 2000 for SO, emissions.

Variable	Coefficient (t-statistics)	Mean (standard deviation)
Dependent: Reductions		0.1360 (0.1863)
$ß_0$ Constant	-0.406 (-3.211)	
$ß_1$ Income (logs)	0.142 (3.455)	2.379 (1.057)
$ß_2$ Former communist	0.315 (3.197)	0.333 (0.480)
$ß_3$ Emissions (kg/km')	15.096 (3.269)	0.0066 (0.0064)
Adjusted R^2	55.6%	
White F-test	0.64	

Note: For data and confidence levels, see Table 3.

Relating the targets in 2000 to 1990 as base year considerably improves the overall fit of the model. All the estimated parameters are significant at the 1% critical level including the emissions per unit of surface area. The results show that the influence of income decreases compared to the targets with 1980 as base year. For every doubling of income, the reductions are now only 11% higher. The partial coefficient of determination of the income variable remains roughly the same at 13.3%. The positive value for the emissions per km^2 indicates that countries with worse ambient air concentrations in 1990 have set higher targets. Relating the targets to the base year of 1990 has reduced the mean of the reductions required from 50 to less than **14%,** indicating that, on average, the major part of the negotiated reduction targets have already been achieved during the 1980s.

When these results are linked to the EKC-hypothesis they provide evidence that richer countries do have a more ambitious environmental policy. This is in line with the EKC-hypothesis and provides an explanation why the EKC bends downwards after certain levels of income. But the results also show that income is not the only determinant of the negotiated reductions in sulphur emissions. High ambient air concentrations also seem to influence the reduction targets considerably. Special dummies for the former communist countries seem to improve the overall fit of the estimations here considerably and their position as potential outliers in any sample should be recognized more firmly in other EKC-studies. Per capita emissions of sulphur were in these countries during the late 1980s about IO-20 times higher than in Western European economies. For these reasons it is not surprising that many of the studies that found EKCs for sulphur emissions peak nearby the per capita income levels of the former communist countries (about 3000 US$ in market exchange rates and about 7000 US$ in purchasingpowerparities).

The fact that the ambition of environmental policy depends on the level of income can be interpreted in three different ways. The first interpretation is that citizens from richer countries may have a higher elasticity of demand for environmental quality and are willing to finance a more ambitious environmental policy. This argument has frequently been offered in the literature on EKCs (see Section 2). A complete different interpretation refers to the critical loads concept. Richer countries may have a more pressing urgency to clean up their environments because of accumulated past pollution. In that case higher incomes only reflect higher damages to ecosystems which are perceived as unacceptable due to the growing information on the state of the environment. The third interpretation refers to the transboundary environmental problems associated with sulphur emissions. Given the fact that the aim of the Second Sulphur Protocol is the protection of the ecosystems in Europe, it is appealing to notions of fairness if richer countries take a larger share of the costs in the cleaning up of a common good. Hence for any transnational or global environmental problem the EKC may form a blueprint for the design of a fair international environmental policy. Which of these arguments provides the correct explanation for the fact that richer countries have settled more ambitious targets cannot be discerned from this analysis, but all of them should be kept in mind when interpreting the results presented above.

Finally, when these results are linked to the decomposition analysis from Section 4, they show that in the Nehterlands environmental policy may be more ambitious than the agreed reduction of 77%. Given the unfavourable structural change in the Netherlands during the 1980s standards for individual production processes will have to aim at reductions higher than the agreed 77%. The absence of structural change in the Dutch economy implies that the costs of environmental policy for the Netherlands may be higher than for other countries. A reconsideration of the structure of the economy in the light of environmental pressure in the Netherlands has been proposed in the DEOS-study (Verbruggen, 1996), but was received negatively by various public and governmental organisations. The costs that are associated with this neglect of unfavourable structural change are normally notrecognized.

6. Discussion and conclusions

Various empirical investigations have shown that some pollutants follow an inverted-U curve along economic development. The reduced form models that have been used in these studies fail to make clear why this is the case. In recent empirical work some of the ex-post explanations have been included in the reduced form model but this mixture of reduced form and structural models is not free from econometric problems (multicollinearity). A different approach is decomposition analysis that decomposes the change in emissions into scale, technological and structural effects. Emissions may decline despite the growth in output if the technological and structural effects outweigh the scale effect.

A decomposition of sulphur emissions in the Netherlands and Western Germany during the 1980s fails to find evidence for structural change to be an important determinant of the distinct reduction in emissions. It appears that the combination of scale and intrasectoral effects explains the patterns of emissions satisfactorily where the potential increases due to the scale effect have been more than compensated by intrasectoral effects. This is in line with other studies that found little evidence of structural change in energy consumption or some pollutants.

Intrasectoral change may be the result of technological improvements as well as changes in the product mix within sectors. Technological change, and especially the instalment of sulphur abating end-of-pipe technology, may have been enforced by environmental policy in the form of combustion standards (European countries), environmental fees and fines (former communist countries) or marketable permits (US). An impetus to structure and tighten national environmental policy in the less developed economies of Europa has been the negotiations on transboundary air pollutants through the First and Second Sulphur Protocols. The non-uniform reductions that have been agreed upon in the Second Sulphur Protocol have been tested for their relation to income. This provides the insight that countries with higher incomes have agreed upon tougher targets, although other factors are also important.

When the partial findings in this paper are interpreted in the lights of the EKC-hypothesis they suggest that the downward sloping part of the inverted-U curve for some pollutants can be better explained by reference to environmental policy than to endogenous structural change. This is in line with studies that found along income monotonically increasing emissions for pollutants such as CO_2 emissions or solid wastes for which environmental policy is still in its infancy (cf. Holtz-Eaking and

Selden, 1992; Shafik and Bandyopadhyay, 1992). Hence the existence of an EKC could be solely the effect of environmental policy that indeed may be more ambitious in countries with higher incomes. However, the low partial coefficients of determination for income levels suggest that low income levels may not impede the instalment of an effective environmental policy. International cooperation may form an encouragement for those countries that have not yet reached their turning points on the hypothesized EKC and that would otherwise experience increasing emissions. Within an international policy framework it may then be appealing to notions of fairness if richer countries would take account for a greater part of the reductions in a geographical bounded ecosystem.

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ANNEX 1: Approximations to the integral path problem

$$I_T - I_0 = \int_0^T \sum_j \dot{I}_{j,t} S_{j,t}\, dt + \int_0^T \sum_j \dot{S}_{j,t} I_{j,t}\, dt \approx \Delta I_{int} + \Delta I_{str} \qquad (6)$$

The continuous decomposition into structural and intrasectoral effects can be given by (cf. equation (4) in the main text).
where ΔI_{int} reflects the intrasectoral effect and Al,, reflects the structural effect. From the continuous integrals in (6) Ang (1994) derives for both effects two specific discrete approximations, called parametric Divisia methods (PDM1 and PDM2). These can be given as:
for PDM1:

$$\Delta I_{int} = \sum_j (V_{j,0} + \alpha_j (V_{j,T} - V_{j,0}))(\ln I_{j,T} - \ln I_{j,0}) \qquad (7)$$

$$\Delta I_{str} = \sum_j (V_{j,0} + \beta_j (V_{j,T} - V_{j,0}))(\ln S_{j,T} - \ln S_{j,0}) \qquad (8)$$

(where $V_{j,t} = E_{j,t}/Y_t$)
for PDM2:

$$\Delta I_{int} = \sum_j (S_{j,0} + \alpha_j (S_{j,T} - S_{j,0}))(I_{j,T} - I_{j,0}) \qquad (9)$$

$$\Delta I_{str} = \sum_j (I_{j,0} + \beta_j (I_{j,T} - I_{j,0}))(S_{j,T} - S_{j,0}) \qquad (10)$$

$$AI = \Delta I_{int} + \Delta I_{str} + R \qquad (11)$$

Both methods fit in the general framework:
R is the residual term that results from the discrete approximation of the continuous integrals on the right hand side of (4). The parameters α_j and β_j can be regarded as determining the weights attached to the change in energy intensity and production share, respectively, and are being determined ex-ante by the researcher under the condition:

$$0 \leq \alpha_j, \beta_j \leq 1 \qquad (12)$$

Choosing $\alpha_j = \beta_j = 0$ for every j means that the production share and the emission intensity of the base year 0 is being used to weight the changes in intensities and production share respectively, equivalent to Laspeyres indexnumbers. Choosing $\alpha_j = 1$ implies end-year weighting, equivalent to Paasche indexnumbers.

Using PDM2 the residual can be perceived as a simple interaction term between the changes in intensities and production share, depending on the relative values of the parameters (cf. De Bruyn et a/., 1996):

$$\sum_j R_j = \sum_j (1-\alpha_j-\beta_j)(U_{j,T}-U_{j,0})(S_{j,T}-S_{j,0}) \qquad (13)$$

From this expression follows immediately that any combination that fulfils $\alpha_j + ß_j = 1$ for all j will give a decomposition result without a residual. The empirical application in Section 3 has used PDM2 with $\alpha_j = ß_j = 0.5$. A test using **PDM1** gave almost the same results. An alternative decomposition without residual has been proposed in De Bruyn *et* a/. (1996b).