Explaining the Environmental Kuznets Curve: Structural Change and International Agreements in Reducing Sulphur Emissions

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ABSTRACT: Environmental Kuznets curves have been estimated using a simple reduced-form model that gives no information on the mechanisms underlying the estimated inverted U-shaped relationship between some pollutants and income. Various intuitive appealing explanations for the observed patterns have been offered, such as structural changes and environmental policy, but these have rarely been empirically investigated. Expanding the reduced-form model with explanatory variables may introduce serious multicollinearity problems, a reason why decomposition analysis is a preferable alternative for investigating the origins of change in emissions. Applying decomposition analysis fails to find evidence for structural changes as an important determinant of the impressive reductions in SO_2 emissions of developed economies during the 1980s. Environmental policy, fostered by international agreements, gives a better explanation why pollution curbs downward at high income levels. Besides the level of income, the present state of the environment seems an important, but often neglected, variable that explains the ambition of environmental policy.

1. Introduction
The single aspect in the environment-versus-the-economy debate that has received most attention in the 1990s has been the discovery of a so-called 'environmental Kuznets curve' (EKC) 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 exist between income inequality and income per capita.

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 World Bank (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.[1] One particular critique, that has united both allies and opponents of the EKC, is that the current set of investigations gives limited insight into the mechanisms that could explain the decline in pollutants after certain income levels. The EKC only describes the statistical relationship between income and certain types of pollutants as an inverted U, but does not explain why the inverted-U shape occurs. This lack of explanation for the EKC is an important omission in our knowledge about the relationship between economic growth and pollution.

The present article aims to expand upon previous work by empirically investigating the factors that could explain the reduction in sulphur dioxide emissions in developed economies. The focus is on SO_2 because many studies have found an EKC for sulphur emissions and concentrations. Besides, SO_2 concentrations have considerable human health impacts and are perceived as an important indicator of environmental quality. Section 2 reviews the models and arguments that have been used to show and explain why an EKC for SO_2 exists. Section 3 expands upon this current set of knowledge by introducing decomposition analysis as a useful technique to determine the underlying causes of the reduction in SO_2 emissions. Section 4 applies this methodology and concludes that structural change, elsewhere identified as an important mechanism for the reduction of pollutants, has not played an important role in the reduction in SO_2 emissions of most developed economies. Environmental policy is presumably the most important determinant and the international achievements for SO_2 emissions are described and analysed in Section 5. The implications of the findings for the future development of environmental quality in both developed and developing countries will be discussed in Section 6. Section 7 concludes.

2. Reduced forms, reduced interpretations?

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

$$E_{i,t} = \alpha_{i,t} + \beta_1 Y_{i,t} + \beta_2 Y^2_{i,t} + \beta_3 Y^3_{i,t} + \beta_4 Z_{i,t} + e_{i,t} \tag{1}$$

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 that are supposed to have an influence on environmental pressure. With $\beta_1 > 0$, $\beta_2 < 0$ and β_3 insignificant, a parabolic relationship is obtained that represents the EKC. For emissions and concentrations of SO_2, an EKC has been found by Shafik and Bandyopadhyay (1992), Panayatou (1993) and Selden and Song (1994). However, Grossman and Krueger (1995) and Torras and Boyce (1996) find evidence for a positive β_3, which assumes ambient

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[1] See also the subsequent discussions in special issues on EKCs of *Ecological Economics* (1995), *Environment and Development Economics* (1996) and *Ecological Applications* (1996).

sulphur concentrations to rise again at high income levels. These differences in estimation results are beyond the scope of this article, but have been discussed in Stern *et al.* (1996) and Ekins (1997).

Model (1) is a reduced-form model. The single equation (1) 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. In the structural model income relates thus only indirectly to environmental pressure. By the assumption of a direct link between income and environmental pressure and the omission of variables relating to technological innovation, composition of economic output and environmental policy, the model *reduces* to equation (1).

The advantages of working with a reduced-form model are the less extensive data requirements compared to the structural model and the direct estimation of the influence of income on environmental pressure. 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 equation (1). Because of the lack of explanatory power of model (1) itself, explanations for the coefficient estimates are given *ex-post*, i.e., they are forced upon the regression results but remain untested. The most discussed explanations for the EKC that have been given in the literature contain the following two arguments:

- positive income elasticities for environmental quality and more open political systems with rising incomes, which may result in effective environmental policies;
- changes in the composition of production and consumption associated 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, p. 372). 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. 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 SO_2 concentrations and find surprisingly that ambient air is worse in more democratic countries. But 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 SO_2 emissions. Many contingent valuation studies have found positive income elasticities for environmental quality but the effects on pollution are unclear beforehand, as elaborated by the theoretical model of McConnell (1997).

The second explanation for the EKC assumes a transition along economic development with respect to the structure of production. The shift from agricultural through industrial to services-oriented economies may

result in an inverted-U pattern of pollution, where the highest pressure is associated with the industrial stage. Although this is a very intuitive notion, empirical evidence again is scarce and not entirely convincing. The often-cited study by Hettige *et al.* (1992) claims to have found evidence for the importance of differences in the structure of production for toxic manufacturing emissions, but these authors calculated 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) and their outcomes may only reflect their assumptions. Suri and Chapman (1996) include in their regressions a variable $Z_{i,t}$ representing the share of manufacturing in GDP that is significantly positive on the levels of energy consumption. Kaufmann *et al.* (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 concentrations of SO_2.

The alleged emergence of compositional changes in the structure of production has been brought into connection with consumption and international trade by, among others, Arrow *et al.* (1995), Stern *et al.* (1996), Rothman (1996) and Ekins (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. Displacement can explain the inverted-U curve sufficiently: decreases of pollutants in developed countries and increases in developing countries. Empirical evidence is even more scarce owing to the lack of consumption-based indicators for environmental quality or the pollution intensity of international trade. Some authors (Shafik and Bandyopadhyay, 1992; Suri and Chapman, 1996) have investigated the role of international trade on the patterns of emissions by including in equation (1) a $Z_{i,t}$ trade variable, but the results are mixed.

The above-discussed empirical investigations into the factors that may explain the EKC share the common feature that the reduced-form model (1) is expanded by including some $Z_{i,t}$ variables representing 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. Therefore, empirical evidence on the various factors influencing environmental pressure may only be analysed 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. Stern (1993) has applied such a multivariate model to energy consumption, but his work shows that this method is very data intensive. Besides, the equations from the structural model have not been adequately

specified in theoretical contributions, which makes it unclear what kind of variables have to be included in the model. Another approach is the use of descriptive methods such as decomposition analysis that can be applied to determine the factors that shape the patterns of emissions over time. The data requirements to apply decomposition analysis are clearly determined and in some cases these data are available. That makes decomposition analysis an attractive tool for advancing insight in the mechanisms that could explain the EKC.

3. Decomposition analysis

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

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

where $j = 1, \ldots, n$ represents the various sectors in the economy, Y_t is GDP in year t, which is equivalent to the sum of the value added of all the n sectors ($Y_t = \Sigma Y_{j,t}$), $I_{j,t}$ 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 $S_{j,t} = Y_{j,t}/Y_t$. The Grossman decomposition can be found by differentiating equation (2) with respect to time, dividing the derivatives by E_t and rearranging the terms, which results in the following decomposition (see also Ekins, 1997):

$$\hat{E} = \hat{Y} + \sum_j e_j \hat{S}_j + \sum_j e_j \hat{I}_j \tag{3}$$

where e_j is the share of emissions of sector j in total emissions ($= E_j/E$) and

$$\hat{X} = \frac{dX/dt}{X_t}, \; X \in \{E, I, S, Y\} \tag{3a}$$

Changes in Y_t, the first term on the right-hand side (rhs) of equation (3) reflect the 'scale' effect of economic activity on emissions. Grossman (1995, p. 20) notes: '*all else equal*, an increase in output means an equiproportionate increase in pollution'. The 'all else equal' condition is, however, violated by changes in the composition of economic activities and changes in the technology of production. Changes in $S_{j,t}$ over time represent the influence on emissions of a change in the composition of economic activities. Such compositional changes, given by the second term on the rhs of equation (3), have been labelled alternatively as 'structural' or intersectoral changes and can be positive or negative. If sectors with low emission intensities grow faster than sectors with high emission intensities, structural change results in a downwards pressure on emissions so that total emissions will grow at a lower rate than the increase in income. The second argument why the 'all else equal' condition is violated relates to the changes in emission intensities within sectors ($I_{j,t}$). Such changes have been labelled as technological or intrasectoral changes and are given by the third term on the rhs of equation (3). Sectoral emission intensities may

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decline as a result of the use of more efficient production and end-of-pipe technologies, dematerialization of products and changes in the product mix within sectors, as well as changes in the material and fuel input mix. Hence, it is important to remember that the technological effect contains more than purely technological changes.

The decomposition result (3) from Grossman holds for continuous, or indefinitely small, changes in all variables. Because of the discrete nature of the data over time, this is of limited value in empirical applications. There exists an extensive body of literature on how to transform equation (3) into a discrete equivalent, which is known as the decomposition technique (cf. Howarth *et al.*, 1991; Liu *et al.*, 1992; Rose and Casler, 1996). Decomposition analysis has been applied to determine the importance of technological and structural changes in, for example, employment (Skolka, 1989), energy consumption (Howarth *et al.*, 1991), CO_2 emissions (Torvanger, 1991) or atmospheric heavy metal emissions (Schucht and De Bruyn, 1997). The influence of technological and structural changes on the levels of emissions over time merits special interest, since these violate the 'all else equal' condition, as a result of which emissions can curve downwards despite economic growth. For that reason, it is more straightforward to consider the emission/output ratio (defined as $U_t = E_t/Y_t$, which is similar to the emission intensity of a given country). An absence of structural and technological changes will necessarily result in a stable emission/output ratio. A stable emission/output ratio implies that the 'all else condition' is not violated and that emissions grow at the same rate as GDP.[2]

Dividing every element in equation (2) by Y_t and differentiating with respect to time gives the following continuous decomposition of the emission/output ratio:

$$U_t' = \sum_j S_{j,t} I_{j,t}' + \sum_j I_{j,t} S_{j,t}' \tag{4}$$

The discrete approximation of this equation that is used in this paper is derived from Ang's Divisia index (Ang, 1994) and described in the Appendix. Using this decomposition, the change U in the emission/output ratio for a given country due to technological and structural changes between the years 0 and T can be defined as:

$$U_T - U_0 = \sum_j 0.5(S_{j,0} + S_{j,T})(I_{j,T} - I_{j,0}) + \sum_j 0.5(I_{j,0} + I_{j,T})(S_{j,T} - S_{j,0}) \tag{5}$$

The first term on the rhs defines the technological effect as the changes in the emission intensities of the individual sectors weighted by the *average* value of the production shares of each sector in years 0 and T. The second term defines the structural effect as the changes in the production shares weighted by the average value of the emissions intensities of each sector in years 0 and T. Both the technological and structural effects are equivalent to the total change in the emission/output ratio, so that this decomposition

[2] Another technical reason to decompose emission/output ratios instead of emissions is related to the reduction of the number of interaction terms (cf. Howarth *et al.*, 1991; Ang, 1994). See also the Appendix.

is not plagued by interaction terms that are difficult to explain. When all the terms in this equation are divided by U_0, the percentage change decomposition is obtained and this gives, for indefinite small changes in the variables, the same definition for the structural and technological effect as Grossman (see Appendix for proof).

Although decomposition analysis can be successfully applied in order to disentangle the structural and technological effects, it cannot provide an answer why these have occurred. The technique of decomposition is purely descriptive (Ang and Lee, 1994). The effects of environmental policy on emission levels are especially difficult to estimate using decomposition analysis and will have to be revealed with other methods (see Section 5). Nevertheless, decomposition analysis can be used in a meaningful manner to determine empirically the influence of structural change on emissions and the application can test the validity of one of the *ex-post* arguments that have been used to explain the EKC.

4. Empirical support for structural change?
Has structural change been an important determinant for the reduction of SO_2 emissions in developed economies? In order to apply decomposition analysis and test for the importance of structural change, disaggregated sectoral data on SO_2 emissions have to be available. In theory, these data should be available for all the years for which national SO_2 emissions are published, because the national estimates are obtained by using information on the fuel input of various economic sectors and by applying fuel- and sector-specific emission coefficients to the fuel input data. Emission coefficients are normally based on actual measurements at the end of the chimneys. In practice, however, few statistical offices publish these data. Notable exceptions are the statistical offices of the Netherlands and West Germany.

Despite the growth of incomes, emissions of SO_2 have fallen both in the Netherlands and in West Germany since the beginning of the 1970s, with the most profound reductions achieved during the 1980s. In terms of equation (3), this implies that the reductions due to structural and technological effects have dominated the effect of scale. In order to test for the relative contribution of each effect, a decomposition has been performed on the development of commercial SO_2 emissions between 1980 and 1990 using equation (5). The results are given in Table 1.

Table 1 shows that the emissions have declined considerably more in West Germany than in the Netherlands. Decomposition of the change in the emission/output ratio reveals that technological change explains the major part of the reductions in SO_2 emissions and that the reductions due to technological change are almost the same for both countries. The greater reductions in SO_2 emissions in West Germany can be explained with reference to the difference in structural change between the two countries. Whereas, during the 1980s, in West Germany structural change contributed to the decrease in emissions, the structure of the Dutch economy became more sulphur-intensive. The results for the two countries, however, are only partially comparable because of different sector classifications and the fact that the German statistics are more disaggregated (cf.

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Table 1. *Decomposition of the emission/output ratio of commercial SO$_2$ emissions in West Germany and the Netherlands, 1990 compared to 1980*

	West Germany	Netherlands	West Germany[1]
Emissions	−73.6%	−58.7%	−73.6%
GDP	26.1%	28.2%	26.1%
Emission/output ratio	−79.0%	−67.7%	−79.0%
technological change	−74.5%	−73.5%	−74.9%
structural change	−4.5%	+5.7%	−4.1%
Number of sectors	59	19	19

Note: Author's own calculations based on data from Dutch Statistical Office (CBS), German Statistical Office (SBA). Commercial sulphur emissions equal total emissions minus the emissions from households.
[1] An estimation where the data have been classified according to Dutch sectoral classification.

Ang (1993) for the importance of sector classification in decomposition analysis). A decomposition of West 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 show evidence of structural change as an important determinant for the reduction in SO$_2$ emissions of these two countries during the 1980s. Can these results be generalized to other developed countries and a longer time span? To a certain extent this is possible, since these results are consistent with a set of studies that have decomposed the determinants of energy consumption since the 1970s. Howarth *et al.* (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 a decreasing amount of energy over the period considered, despite the growth in incomes. This reduction was not the result of a decrease in manufacturing share of total GDP, since that share remained almost constant over the period considered (cf. Torvanger, 1991). A decomposition of the reduction in industrial energy intensities into structural and technological effects has revealed that, with the exception of the United States, structural change played only a minor role in the reduction in industrial energy intensities (and in Norway the structure of industry became even more energy intensive). Instead, technological changes, probably triggered by the rapid energy price increases after 1973, resulted in a decrease of energy consumption. Binder (1993) has decomposed industrial energy use in ten other OECD countries and comes to similar conclusions. The absence of structural change in energy consumption is indicative of the absence of structural change in SO$_2$ emissions, since these emissions are mostly energy related. Therefore, it can be expected that the conclusions of Table 1 hold both for a wider set of countries and for a longer time span.

The importance of technological changes for the reduction in SO$_2$ emissions may relate to a variety of different causes: changes in the fuel mix (substitution of coal for gas and renewables); the use of more efficient energy production technologies; and the instalment of end-of-pipe

technology. The latter has probably been the most important determinant. The share of coal in total energy consumption fell only slightly in West Germany and rose in the Netherlands during the 1980s. The energy efficiency in the various sectors improved in both countries during the 1980s, but not more than an estimated 15–25 per cent.[3] The largest part of the reductions in SO_2 emissions due to technological change could hence be attributed to the instalment of end-of-pipe technology. This suggests that environmental policy may have been quite successful in reducing SO_2 emissions in the two countries involved. Since both West Germany and the Netherlands are highly developed economies, the importance of environmental policy for reducing SO_2 emissions may be in line with the EKC hypothesis if richer countries are assumed to prefer stricter environmental policies. Evidence that the level of income influences national environmental programs for SO_2 emissions will be presented in the next section.

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

Sulphur emissions can travel through the atmosphere for a relatively long time and may cause damage in other regions or countries through wet and dry deposition. For these reasons, SO_2 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 for taking appropriate steps. The focus of the LRTAP has primarily been on emissions causing acid rain. Within the framework of the LRTAP, various protocols have been negotiated that set binding reductions on SO_2, NO_x and VOC pollutants.

Binding reductions for SO_2 emissions were reached in the First and Second Sulphur Protocols. The First Sulphur Protocol was signed in Helsinki in 1985 by a group of 20 countries that agreed to reduce annual SO_2 emissions in 1993 by 30 per cent compared to 1980. The Protocol has been criticized for the arbitrariness of the 30 per cent target, which was not related to either cost-effectiveness or environmental impacts; this was one reason why the United Kingdom refused to sign (Klaassen, 1995). Such criticisms were taken into account in formulating the Second Sulphur Protocol that was signed by 27 parties in Oslo in 1994. This protocol specifies, among other things, non-uniform reduction percentages for the signatory countries. The non-uniform reduction percentages reflect the principal agreement to reduce the gap between sulphur deposition in 1990 and the 5 percentile critical load by 60 per cent in 2010 at the latest.[4]

[3] De Bruyn *et al.* (1996) estimate the total industrial energy efficiency improvements due to technological change in the Netherlands between 1980 and 1992 as about 28 per cent. Binder (1993) derives a figure of 18 per cent for West Germany between 1973 and 1987.

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

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Because of the diversity in current emission levels and climatic conditions and the 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 were used as a baseline on which the negotiations took place. The final agreed non-uniform reductions do not differ substantially from national environmental policy plans that had already been 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 had already planned to do and two countries do less than they planned to do (Klaassen, 1995, p. 217).

Table 2 gives an overview of the 1980 and 1990 levels of emissions and the planned reductions for the year 2000. 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 have already reduced their national emissions over the 1980s. The USA is not part of the LRTAP or the 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 in SO_2 emission by fossil fuel power plants to 50 per cent in the year 2000 compared to 1980.

One interesting question 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 SO_2 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. To test the influence of income on environmental policy the following log-linear model has been constructed:

$$TAR_i = \beta_0 + \beta_1 \ln (Y_i) + \sum_{k=2}^{n} \beta_k Z_{i,k} + e_i \qquad (6)$$

where i is a country index, TAR are the agreed reduction targets in SO_2 emissions recalculated with the base year of 1990, Y is income measured in 1993 US\$ with market exchange rates[5] and the Z_k's are $n-1$ specific variables that were assumed to have an influence on the negotiated results because of the characteristics they possess for each individual country. The Z_k variables that were tested include:

- population density, to test the assumption that more heavily populated areas require stricter environmental policies (cf. Selden and Song, 1994);
- emissions per capita, to test the assumption that countries with higher emissions per capita may want to reduce their emissions faster;
- emissions per unit of area as a proxy for overall ambient air

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[5] Because the sample contains a cross section of countries, income measured in purchasing power parities would have better expressed the ability of countries to pay for environmental policy. Unfortunately such figures were not available for all countries and that is why market exchange rates were used as a proxy.

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

Countries[1]	Emissions in ktons		Targets under the Second Sulphur Protocol	
	1980	1990	2000	2000/1980
Austria[2]	397	90	79	−80%
Belgium[2]	828	443	248	−70%
Bulgaria[2]	2050	2020	1374	−33%
Canada[2]	4643	3323	3250	−30%
Czech Republic[2]	2257	1876	1129	−50%
Denmark[2]	451	180	90	−80%
Finland[2]	584	260	117	−80%
France[2]	3338	1202	868	−74%
Germany (unified)[2]	7494	5803	1274	−83%
Greece	400	500	596	+49%
Hungary[2]	1632	1010	898	−45%
Ireland	222	168	155	−30%
Italy[2]	3800	1988	1330	−65%
Luxembourg[2]	24	10	10	−58%
Netherlands[2]	466	207	107	−77%
Norway[2]	142	54	34	−76%
Poland	4100	3210	2583	−37%
Portugal	266	211	303	+14%
Russia[2]	7161	4460	4440	−38%
Slovakia[2]	700	539	280	−60%
Slovenia	235	195	129	−45%
Spain	3319	2316	2157	−35%
Sweden[2]	126	62	60	−52%
Switzerland[2]	503	130	101	−80%
Ukraine[2]	3850	2782	2310	−40%
United Kingdom	4898	3780	2449	−50%
USA[3]	23780	21060	NA	−33%

Notes: Sources: OECD, Environmental Data Compendium (1995), Klaassen (1995), *World Resources* (1994–1995).
[1] Croatia and Liechtenstein[2] have signed the Second Sulphur Protocol, but are not included in this table because no data were available.
[2] These countries (or their jurisdictional predecessors) also signed the First Sulphur Protocol.
[3] The USA is not part of the LRTAP. The target for national power plants (−50 per cent in 2000 compared to 1980) has been translated to a national emission target by multiplying the target by the share of power plants emissions in total SO_2 emissions.

concentrations within a country, to test the assumption that countries with worse ambient air will agree upon higher reductions;
• dummies for former communist countries, to test the assumption that the fall in economic output and emissions during the early 1990s allowed them to agree upon additional reductions;
• 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 (6) contains all the 27 countries listed in Table 2. All of the Z_k variables were first 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.[6] The AIC selected the model that includes for Z_k two parameters: the dummy for former communist countries and the emissions per unit of surface area. Other Z_k variables were not significant at the 10 per cent critical level. The results of this regression are given in Table 3.

From Table 3 it can be concluded that the overall fit of the model is reasonable. About 56 per cent of the variation in reduction targets can be related to the variables in the model. All selected variables are significant at the 1 per cent level. The conducted White test shows that the estimation is not plagued by heteroscedasticity and that the t-statistics are efficient.[7] The negative value of β_1 implies that the negotiated targets tend to be higher if income is higher. Hence, the aim of environmental policy depends on the level of income, as was postulated by the *ex-post* explanations for the EKC. The partial coefficient of determination of income, however, is 13.3 per cent, which indicates that income only explains a meagre 13 per cent of the negotiated targets. Other variables of influence are the dummy for the former communist countries and the emissions per km^2. The negative value for the emissions per km^2 indicates that countries with worse ambient air concentrations in 1990 have set higher targets, which is intuitively very appealing. The negative value for the dummy of the former communist countries indicates that these countries will reduce their

Table 3. *Results from regressions on the additional SO_2 emission reductions to be achieved during the 1990s given the targets for the year 2000*

Variable	Coefficient (t-statistics)	Mean (standard deviation)
Dependent: targets		−0.1360 (0.1863)
β_0 Constant	0.406 (3.211)	
β_1 Income (logs)	−0.142 (−3.455)	2.379 (1.057)
β_2 Former communist	−0.315 (−3.197)	0.333 (0.480)
β_3 Emissions (kg/km²)	−15.096 (−3.269)	0.0066 (0.0064)
Adjusted R^2	55.6%	
White F-test	0.64	

Note: Incomes for 1993 in 1000 US$ are based on market exchange rates.
Data sources: Income from World Bank, World Tables (1995); Emissions, see Table 2. Surface area from United Nations, Demographic Statistics (1994). Critical t-statistics for $n = 27$ at 10, 5 and 1 per cent two-tail confidence levels: 1.703, 2.052, 2.771 respectively.

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

[7] 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 table) showed that the errors are not auto-correlated.

emissions by an additional 31 per cent over the reduction expected from their relative income position and ambient air conditions. This figure is higher than the fall in industrial output that countries like Poland and the Czech Republic experienced from 1991 to 1993 and it may be indicative of the additional expected gains in improving the energy efficiency of their industries, which currently is relatively low when compared to western European standards.

This regression analysis deals with environmental policy targets and not with past environmental policy achievements. However, if the targets are assumed to be representative of environmental policy efforts, these results provide empirical evidence that richer countries do have a more ambitious environmental policy. This is in line with the EKC hypothesis and may provide an explanation why the EKC turns downwards above certain levels of income. Of equal importance, however, is the notion that income is only a minor determinant of the aim of environmental policy. In particular, the current state of the environment, expressed as the emissions per km^2, can be perceived as an important determinant of the reduction in SO_2 emissions. Dirty countries have a more urgent need to clean up their environments, which is not surprising but is ignored in present EKC studies.[8]

The emissions per unit of area are only a proxy for the overall ambient air conditions because of atmospheric transport of sulphur. Hence, this variable can be decomposed in the emissions that fall within the borders of a country and emissions that are 'exported'. These two elements have been investigated in recent empirical work by Murdoch *et al.* (1997). They show that emission reductions during the 1980s were less impressive in countries that 'export' a large share of their total sulphur emissions. They claim that such free-rider behaviour is an important determinant in international agreements, but do not test the importance of strategic behaviour for the emission reductions agreed under the Second Sulphur Protocol, presumably because of data limitations. Part of the unexplained variation in emission targets in the present study could hence be due to strategic behaviour. It should be noted, however, that the majority of the emissions of the countries under investigation in this study do fall within the borders of that country, so that there can be some confidence that the results will remain unchanged when strategic behaviour is considered in the regressions.

6. Perspectives for other countries
The EKC hypothesis has suggested that structural change and an induced policy response have been the main mechanisms through which pollution is reduced above certain income levels. The turning points that have been discovered in various empirical studies range between US$3,000 and US$10,000 per capita income (1985), which is relatively high when compared to the median world-wide income level. Stern *et al.*

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[8] The partial correlation coefficient between the emissions per km^2 and the logarithm of income is -0.437, which implies that this variable is not adequately captured by the income variable if it is omitted.

(1996) have pointed out that the improvements in environmental quality according to the EKC hypothesis are not attainable for the majority of world population, who have standards of living that are still below the estimated turning points. Emissions world wide are therefore expected to continue to increase as a result of economic growth, even for pollutants of which inverted-U curves have been estimated (cf. Selden and Song, 1994; Stern *et al.* 1996). Do the results from this study shed a new light on these world-wide developments and especially on the prospects for economic growth without environmental deterioration in developing countries?

The decomposition results described in Section 4 suggest that structural change is not an important mechanism for the reduction of pollutants in developed economies. This does not imply that the structure of production is irrelevant to environmental quality, but it indicates the rather stable production structures of developed economies. For developing economies, however, the situation is less obvious. Ang (1987) has reviewed the developments in industrial energy consumption in Taiwan during the 1970s and concluded that, contrary to usual belief, structural changes had a slight downwards influence on the industrial consumption of energy, despite the very rapid expansion of heavy industry. The reason is that the growth in heavy industry was accompanied by an even bigger growth in the light consumer industries. Similar results for China during the 1980s are provided in Huang (1993) and for Singapore in Ang and Lee (1994). These results show in general that rapid economic growth need not to be accompanied by a more pollution-intensive structure for developing countries. With a reference to the poor economic growth rates of former communist countries during the 1980s and the falling prices of raw materials, it can even be argued that rapid economic growth is no longer possible with only the heavy industrial sectors expanding.

While the structure of the economy may not impede economic growth from an environmental perspective, the scale effect of economic growth does result in more environmental pressure when not corrected with appropriate environmental policies. The outcomes of this study imply that a correction may be undertaken, even before the turning points have been reached, in those countries and places that suffer from poor ambient air concentrations, as indicated by the significant influence of the variable representing the emissions per unit of surface area. Democratic governments and open political systems may certainly enhance such corrections through the election of green political parties and the influence of environmental pressure groups. More importantly, however, do the results of this study imply that international cooperation in the field of environmental problems can be an effective way to reduce emissions in those countries that have not reached the turning points estimated according to the EKC. One of the main achievements of the Second Sulphur Protocol has been the inclusion of former communist countries that have per capita income levels well below the turning points, but nevertheless have agreed upon emission ceilings for their SO_2 emissions. While the agreed targets for former communist countries are not particularly ambitious when the fall in industrial output is taken into account, they may have reinforced the

position of the national ministries that deal with environmental issues in those countries. In Poland and the Czech Republic, relatively strict standards have been imposed upon production processes and a system of environmental fees and fines relating to emissions to air and water has been put into operation; this system raises funds for environmental clean-up of past pollution (Slezynski, 1996). As a consequence, emissions have declined considerably during the last few years.

Although the average per capita income of US$2,800 (1993) for the eight former communist countries in the sample is comparable to the income levels in many developing countries, these economies possess many particularities that mean that they do not provide a valid blueprint for all developing economies. Nevertheless, their inclusion in the Second Sulphur Protocol may serve as an example for international cooperation on those environmental problems that exhibit transboundary externalities. Given the fact that the aim of the Second Sulphur Protocol was 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 cleaning up for the 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. Such a strategy, where richer countries make room for developing countries to expand or stabilize their pollution-intensive activities, could form an important model for international cooperation in the field of climate change.

7. Conclusions

This article has investigated the roles of structural change and environmental policy as mechanisms that could explain the EKC hypothesis, from both a methodological and an empirical perspective. It has been argued that the expansion of the commonly used reduced-form models with variables from the structural model introduces multicollinearity problems that make this a less preferred option when seeking explanations for the EKC. A number of alternatives are available and decomposition analysis seems promising with respect to the ease of use and data availability.

When the empirical findings in this paper are interpreted in the light of the EKC hypothesis, they suggest that the downward sloping part of the EKC can be better explained by reference to environmental policy than to structural change. This is in line with studies that have found a monotonic increase with income for emissions of pollutants such as CO_2 emissions or solid wastes, for which environmental policy is still in its infancy (Shafik and Bandyopadhyay, 1992). Hence, the existence of an EKC could be solely the effect of environmental policy, which indeed may be more ambitious in countries with higher incomes. International cooperation may provide 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 for richer countries to take responsibility for a greater part of the reductions in a geographically bounded ecosystem.

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APPENDIX

Approximations to the integral path problem
The continuous decomposition of the emission output ratio into structural and technological effects has been given by equation (4) in the main text. For discrete data available in years 0 and T, the decomposition can be found by integrating equation (4) over the time interval $\langle 0, T\rangle$:

$$\int_0^T U_t dt = \int_0^T \sum_j S_{j,t} I'_{j,t} dt + \int_0^T \sum_j S'_{j,t} I_{j,t} dt \approx \Delta U_{tec} + \Delta U_{str} \tag{A.1}$$

where ΔU_{tec} reflects the technological effect and ΔU_{str} the structural effect. Unfortunately there exist no unique solutions to the integrals on the rhs of equation (A.1), which is known in the literature as the integral path problem (Liu *et al.*, 1992). For the technological effect, for example, it is not determined whether the changes in sectoral emission intensities should be weighted by the production shares in year 0 or in year T or some weighted average of these. From equation (A.1) Ang (1994) derives for both effects two specific discrete approximations, called parametric Divisia methods (PDM1 and PDM2). The PDM2 that has been used in this study reads as:

$$\Delta U_{tec} = \sum_j (S_{j,0} + \alpha_j(S_{j,T} - S_{j,0}))(I_{j,T} - I_{j,0}) \tag{A.2}$$

$$\Delta U_{str} = \sum_j (I_{j,0} + \beta_j(I_{j,T} - I_{j,0}))(S_{j,T} - S_{j,0}). \tag{A.3}$$

The parameters α_j and β_j can be regarded as determining the weights put on the changes in energy intensities and production shares, respectively, and are being determined *ex-ante* under the condition $0 \le \alpha_j, \beta_j \le 1$. 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 shares respectively, which is equivalent to using Laspeyres index numbers (Allen, 1975). Choosing $\alpha_j = \beta_j = 1$ implies end-year weighting, equivalent to Paasche index numbers.

The structural and technological effects relate to equation (A.1) in the following general framework:

$$\int_0^T U_t \, dt = U_T - U_0 = \Delta U_{tec} + \Delta U_{str} + R \tag{A.4}$$

where R is the residual term that results from the discrete approximation of the continuous integrals on the rhs of equation (A.1). Solving R from equation (A.4), using equations (A.2) and (A.3), proves that the residual can be rewritten as a simple interaction term between the changes in intensities and production shares depending on the relative values of the parameters (De Bruyn *et al.*, 1996):

$$R = \sum_j (1 - \alpha_j - \beta_j)(I_{j,T} - I_{j,0})(S_{j,T} - S_{j,0}). \tag{A.5}$$

From equation (A.5) it follows that any combination that fulfils $\alpha_j + \beta_j = 1$ for all j will give a decomposition result without a residual. The empirical

application in Section 4 has used PDM2 with $\alpha_j = \beta_j = 0.5$, similar to Marshall–Edgeworth index numbers. An alternative decomposition without residual has been proposed in De Bruyn *et al.* (1996).

Proof that the Ang decomposition is a general case of the Grossman decomposition

Notice that emissions E_t of a given country can be rewritten as the product of the income Y_t and the emission/output ratio U_t $(= E_t/Y_t)$ of that country:

$$E_t = Y_t \cdot U_t \tag{A.6}$$

Differentiating equation (A.6) with respect to time and dividing by E_t results in:

$$\hat{E} = \hat{Y} + \hat{U} \tag{A.7}$$

where the variables with a 'hat' are defined according to equation (3a) in the main text.

An expression for U can be found by using equation (A.4), with the expression for the technological effect taken from equation (A.2), that for the structural effect from equation (A.3) and that for the residual effect from equation (A.5), with every element divided by U_0. Since $U = e_j S_j I_j$, equation (A.4) can then be rewritten as the percentage change decomposition:

$$\tilde{U} = \sum_j e_{j,0}(1 + \alpha_j \tilde{S}_j)\tilde{I}_j + \sum_j e_{j,0}(1 + \beta_j \tilde{I}_j)\tilde{S}_j + \sum_j (1 - \alpha_j - \beta_j)\tilde{I}_j\tilde{S}_j \tag{A.8}$$

where for all variables

$$\tilde{X} = \frac{X_T - X_0}{X_0} . \tag{A.9}$$

For indefinite small changes and $\alpha_j = \beta_j = 0$, equation (A.8) reduces to:

$$\hat{U} = \sum_j e_{j,0}\hat{I}_j + \sum_j e_{j,0}\hat{S}_j \tag{A.10}$$

Substituting this expression in equation (A.7) gives the Grossman decomposition, as given in equation (3), which is hence a special case of the more general Ang decomposition. In discrete applications, this may result in a large residual term R because the number of interaction terms due to decomposition with three explanatory variables increases from 1 to 4 as a result of simultaneous changes in scale, structure and technology over the time period of interest (Park, 1992). An application of this decomposition with the data of Section 4 gave for the scale, technological, structural and residual effects for West Germany 26.1, -75.9, -6.0 and -23.2 per cent respectively and for the Netherlands 28.2, -70.0, 9.3 and -26.2 per cent respectively. While the size of the structural and technological effects is not significantly altered, the large interaction term prevents a clear interpretation of these effects.