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Testing the existence of an environmental Kuznets Curve for sulfur using panel data models

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Abstract

This paper uses a dynamic panel data for 73 (23 OECD and 50 non-OECD) countries for the time period 1960-1990 in order to estimate the relationship between Gross Domestic Product (GDP) and pollution in the form of sulphur emissions. For the purpose of performing our empirical estimate, fixed and random effects are used. This analysis shows significant differences between the most industrialized countries and the rest of the countries considered. This implies that a uniform policy to control pollution is not adequate. It is necessary to take into consideration the specific economic situation as well as the structure of the industrial and the business sectors in each country. Finally, in terms of policy implications, the study presents the main abatement options for sulphur reduction.

1. Introduction

The generation of electricity from conventional power stations is associated with a number of environmental problems. For example,

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generation using coal causes significant air pollution due to emissions of sulfur oxides, carbon dioxide, nitrogen oxides and particulates. In the UK a 2000 MW coal fired station operating at 60% load factor burns about 4.4 million tons of coal per year and each year emission into the atmosphere is about 10 million tons of carbon dioxide, 130,000 tons of sulfur dioxide, 40,000 tons of nitrogen oxides and between 4,000 and 40,000 tons of particulate matter depending on how well the stack emissions are cleared before they are released (Highton and Webb, 1980). Particular concern has been expressed about the emissions of sulfur dioxide because the use of tall stacks to disperse emissions can lead to problems of transnational pollution. Approximately 1 ton of sulfur burned produces 2 tons of sulfur dioxide (SO_2) and sulphur is present, in varying quantities, in both oil and coal.

Kuznets (1965, 1966) showed that during various economic development stages income disparities first rise and then begin to fall. The environmental Kuznets curve (hereafter EKC) hypothesis proposes that there is an inverted U-shape relation between environmental degradation and per-capita income. Environmental damage seems to be lower in the most developed countries compared to many middle-income countries and higher in many middle-income countries compared to less developed countries. It is worth mentioning that an alternative form of the EKC hypothesis suggests that environmental degradation as a function of income is not a stable relationship but may depend on the level of income. This is because in this alternative form, there may exist one relationship for poor and another for rich countries. On the aggregate this would give an inverted U-like curve.

Cropper and Griffiths (1994) and Selten and Song (1994) conclude that the majority of countries in their analyses are below their estimated peak levels for air pollutants and thus economic growth may not reduce air pollution or deforestation. This implies that estimating the left part of EKC is easier than estimating the right hand part.

A number of authors have estimated econometrically the EKC using OLS analysis. The use of OLS is not likely to yield accurate estimates of the peak levels. The EKC estimates for any dependent variable (e.g. SO_2, NO_X, deforestation, etc.) peak at income levels which are around the world's mean income per capita. Income as expected is not normally distributed but skewed (with a lot of countries below mean income per capita). Arrow *et al.* (1995), Ekins (1997) and Ansuategi *et al.* (1998) provide a number of reviews and critiques of the EKC studies. Stern et al. (1996) identified a number of problems with some of the main EKC estimators and their interpretation. They mention among other econometric problems, the mean-median income problems, the interpretation of particular EKCs in isolation from other environmental problems, the assumption of unidirectional causality from growth to environmental quality and the reversibility of environmental change and asymptotic behavior. Stern (1998) reviews these problems in details and shows where progress has been made in empirical studies.

In addition to the fact that the use of OLS is not an appropriate technique in modelling the EKC, most of the empirical studies do not present diagnostic statistics of the regression residuals. Due to this reason we cannot be certain that the peak levels provided –and the policy implications suggested– are accurate. Halkos and Tsionas, (2001) using cross-sectional data, obtained the following results:

$$\text{Deforestation} = \underset{(0.7824)}{-2.344} + \underset{(1.595)}{1.298} \log GNP \underset{(2.189)}{-0.243} [1/2(\log GNP)^2]$$

Harvey test for heteroskedasticity $x^2(2) = 9.213$,
RESET test for misspecification $F(3, 55) = 3.03$
BP test for heteroskedasticity $x^2(2) = 1.427$
Jarque-Bera Test for Normality: $x^2(1) = 4.67$

Where t-ratios are presented in parentheses. These results indicate the existence of an EKC. However, the diagnostics imply the specification is totally unreliable as we see heteroskedasticity, misspecification and non-normality problems.

In this paper, we examine the concept of an environmental Kuznets curve in a critical way with an eye towards proposing policies compatible with sustainable development. A dynamic panel data for 73 countries, for the time period 1960-1990, is used in order to estimate the relationship between Gross Domestic Product (GDP) and pollution in the form of sulphur emissions. Our empirical estimation is performed using fixed and random effects. To control for non-observable specific effects Two Stage Least Squares (2SLS) is applied.

The paper is organised as follows: Section 2 discusses the existing theoretical and empirical work. Section 3 presents the data used while section 4 discusses the econometric models. The empirical evidence is presented in section 5. Section 6 describes briefly the abatement options for sulfur emissions reduction. The final section concludes the paper.

2. Previous work

The empirical analysis of the EKC has focused on whether a given index of environmental degradation shows an inverted-U relationship when it is related with income per capita. A number of possible explanations exists for the inverse U-shape relationship. Natural progression of economic development goes from clean agricultural to polluting industrial and to clean service economies. The argument here is that «scale effect», in the sense that more output results in more adverse effects for the environment, is (at least partly) offset by the «composition effect» due to the changes in the structure of the economy as well as the «technology effect» due to possible changes in the production methods. The improvement in environmental quality may be the result of the change in the technological mode of production (de Bruyn, 1997; Han and Chatterjee, 1997) or of the exportation of «dirty industry» to less developed or developing countries (Rock, 1996; Suri and Chapman, 1998; Heerink et al., 2001).

In the formalization of the transition to the low-pollution state there is a group of authors that provide significant analyses of the role of preferences and regulation on the emissions profile of polluters (Lopez, 1994; McConnell, 1997; Stokey, 1998). Dinda et al. (2000) claim that technological improvements, structural economic change and transition, increase in spending on environmental R & D accompanied with increasing per capital income are important in determining the nature of the relationship between economic growth and environmental quality.

Another explanation is that since air pollution is considered an externality, internalization of this externality requires relatively advanced institutions for collective decision making. This can be achieved only in developed economies. A better institutional set up in the form of credible property rights, regulations and good governance may create public awareness against environmental degradation (Dinda et al., 2000). Jones and Manuelli (1995) using an overlapping generations model and determining economic growth by pollution regulations and market interactions show that, depending on the decision making institution, the pollution-income relationship may have an inverted V shape, but it could also be monotonically increasing or a «sideways-mirrored S».

Another explanation relies on the fact that pollution will stop its increase and start to decrease with economic growth because some constraints will become non-binding. Stokey (1998) shows that pollution increases linearly with income until the threshold is passed and cleaner technologies can be used. The implied pollution-income path takes the form of an inverse-V with a sharp peak, taking place at the point where a continuum of cleaner technologies becomes available. Jaeger (1998), similarly to Stokey, finds that the pollution income relationship is an inversed-V. Jaeger relies on the assumption that at low levels of pollution consumers' taste for clean air is satisfied and marginal benefit of additional environmental quality is zero.

Finally, Andreoni and Levinson (2001) suggest another explanation due to the technological link between consumption of a desired good and abatement of its undesirable byproducts (pollution). Distribution issues may be considered as not has another explanation. Torras and Boyce (1998) argue that the greater equality of incomes results in lower level of environmental degradation. This claim is challenged by Scruggs (1998).

Shafik and Bandyopadhyay (1992) estimated EKC for ten different indicators of environmental degradation (lack of clean water, ambient sulfur oxides, annual rate of deforestation, etc.). The study uses three different functional forms (log-linear, log-quadratic in income, logarithmic cubic polynomial in GDP/c and a time trend). GDP was measured in PPP and other variables included were population density, trade, electricity prices, dummies for locations, etc. Deforestation was found to be insignificant in relation to income (R^2 adjusted $\cong$ 0).

Panayotou (1993, 1995) employed cross sectional data and GDP in nominal US \$ (1985). The equations for the pollutants considered were logarithmic quadratics in income per capita. Deforestation was estimated against a translog function in income/c and population density. All the curves estimated were inverted U's with turning point for deforestation at \$823 per capita. Panayotou used current exchange rates (instead of PPP) which lowers the income levels of developing countries compared to some developed ones.

Grossman and Krueger's (1991, 1995) and Shafik and Bandyopadhyay's (1992) suggest that at high-income levels, material use increases in a way that the EKC is N-shape. Pezzey (1989) presents arguments for an N-shape EKC and proposes that the optimal path of environmental degradation may be monotonically increasing with the level of development. However for our data this is not the case.

Cropper and Griffiths (1994) estimated three regional EKC for deforestation only. The regressions were for Africa, Latin America and Asia. They used pooled time series cross section data on a regional basis. The results for Latin America and Africa show an R^2-adjusted of 0.47 and 0.63 respectively. Both the population growth and time trend were insignificant in all areas. None of the coefficients in the Asian regression were significant and the R^2-adjusted was only 0.13. One of their main conclusions was that economic growth does not solve the problem of deforestation.

The levels of several pollutants per unit of output in specific processes have declined in the developed countries over time with the use of strict environmental regulations. Stern et al. (1996) claim that the mix of effluent has shifted from sulfur and NO_X to CO_2 and solid waste, in a way that aggregate waste is still high and even if per unit output waste has declined, per capita waste may not have declined. Regressing per capita energy consumption on income and temperature gave them an inverted U-shape relationship between energy and income. Fitting a quadratic in income gave them a significant negative coefficient for the squared income term with an R^2-adjusted equal to 0.8081. Energy consumption peaked at $14600. The authors claim that the results depend on the income measure used. If income in PPP was used the coefficient on squared income was positive but small and insignificant. If in-come per capita was measured using official exchange rates, the fitted energy income relationship was an inverted U-shape with squared income coefficient negative, significant (with an R^2-adjusted = 0.6564). Energy use per capita peaked at income $23900. Table 1 presents the relevant EKC studies for sulfur.

3. Data

A large data set on sulfur emissions is used here (A.S.L. and Associates, 1997; Lefohn et al., 1999), which includes sulfur emissions from various fuels (hard coal, brown coal, and petroleum) as well as sulfur emissions from mining and smelting activities for most of the countries from 1850 to 1990. Emissions are based on the use of these fuels, their sulfur content, the level of smelting activity, and the sulfur retention factors. Stern and Common (2001) provide a comparison of the ASL's estimated emissions for some developed countries. Countries like Canada, West Germany, Japan and Sweden differ substantially from the better-known OECD estimates, while the data for countries like the UK and the USA are similar. GDP per capita (in real 1990 dollars) and population data are used from the Penn World Table (Summers and Heston, 1991).

Our sample consists of the 73 countries (23 OECD and 50 non-OECD member countries), which have a full set of sulfur and purchasing power parity GDP per capita information for the period 1960-1990. The database used has 2263 observations per variable. In terms of the raw data, it is observed that emissions increase with income, but there is some sign of a decrease at high-income levels. We have used emissions rather than concentrations as the latter depend on both emissions and geographic location and atmospheric conditions in the form of wind velocity etc. We may justify the use of emissions, as there is no reason to expect that developing countries differ in any systematic manner in the dispersion of pollutants.

4. Econometric methods

We have performed a Box-Cox test in order to test the linear against the logarithmic functional form of the relationship between air pollution and GDP/c. The model proposed here is a logarithmic quadratic estimated as:

$$\ln(S/c)_{it} = \alpha_i + \gamma_t + \beta_1 \ln(GDP/c)_{it} + \beta_2 (\ln(GDP/c))^2_{it} + \varepsilon_{it} \quad (1)$$

where the ·i's are country specific intercepts and the Ái's are time specific intercepts and the countries are indexed by i and time periods by t. S/c is sulfur emissions per capita in tons of sulfur and $\hat{A}_{it}$ is a disturbance term. Both dependent (emissions per capita) and independent (PPP GDP per capita) variables are in natural logarithms. The turning point (TP) level of income is calculated as:

$$TP = e^{\left(\frac{-\beta_1}{2\beta_2}\right)} \quad (2)$$

We have applied panel data methods to estimate the above equation. The first method employed imposes the same intercept and slope parameter for all countries and it is therefore equivalent to OLS estimation (omitted for simplicity in some cases). The second method is the fixed effects (hereafter FE) allowing each individual

Table 1
Sulfur EKC Studies

Authors	Turning Point 1990 USD	Additional Variables	Data Source for Sulfur	Time Period	Estimation Technique	Countries/ cities
Cole *et al.*, 1997	$8232	Country dummy, technology level	OECD	1970-92	RE, FE, OLS	11 OECD countries
Grossman and Krueger, 1991	$4772-5965	Locational dummies, population density, trend	GEMS	1977, '82, '88	RE	Up to 52 cities in up to 32 countries
Kaufmann *et al.*, 1998	$14730	GDP/Area, steel exports/GDP	UN	1974-89	RE, FE, OLS	13 developed and 10 developing countries
Panayotou, 1993, 1995	$3137	-	Own estimates from fuel use data	1987-88	OLS	55 developed and developing countries
Panayotou, 1997	$5965	Population density, policy variables	GEMS	1982-84	RE, FE	Cities in 30 developed and developing countries
Selden and Song, 1994	$10391-10620	Population density	WRI-primarily OECD source	1979-87	RE, FE, OLS	22 OECD and 8 developing countries
Shafik, 1994	$4379	Time trend, locational dummies	GEMS	1972-88	FE	47 Cities in 31 Countries
Stern and Common (2001)	$78703	Time and country effects	ASL	1960-90	RE, FE	74 developed and developing countries

Modified from Stern and Common (2001).

country to have a different intercept treating the α_i and γ_i as regression parameters. This practically means that the means of each variable for each country are subtracted from the data for that country and the mean for all countries in the sample in each individual time period is also deducted from the observations from that period. Then OLS is used to estimate the regression with the transformed data. The third model is the random-effects (hereafter RE) in which the individual effects are treated as random. In this model the α_i and γ_i are treated as components of the random di-sturbances. The residual from an OLS estimate of the model with a single intercept are used to construct variances utilized in a GLS estimates (for further details see Hsiao, 1986). If the effects α_i and γ_i are correlated with the explanatory variables then the random effects model cannot be estimated consistently (Hsiao, 1986, Mundlak, 1978). Only the fixed effects model can be estimated consistently.

To control for non-observable specific effects Two Stage Least Squares (2SLS) was applied but the results were insignificant. Due to exogeneity strict requirement for the efficiency of these methods we also control for endogeneity of GDP using the GDP variable lagged two periods as the instrumental variable (IV) and in order to achieve completeness.

The orthogonality test for the RE and the independent variables is also examined. For this reason, a Hausman test is used in order to test for inconsistency in the RE estimate. This test compares the slope parameters estimated for FE and RE models. A significant difference indicates that the RE model is estimated inconsistently due to correlation between the independent variables and the error components. If there are no other statistical problems the FE model can be estimated consistently although the estimated parameters are conditional on the country and time effects in the selected sample of data (Hsiao, 1986).

We also test for serial correlation in the regression residuals, regressing the residuals on one lag of the residual and calculating the t-statistic for the autocorrelation coefficient. The Chow F tests whether pooling the data in the EU level instead of estimating separate regressions for poor and rich countries significantly reduces the goodness of fit.

We tried separating the countries according to their geographical position into Southern and Northern countries as well as according to their income level. According to the latter distinction, we have defined the first group as above average income countries and the second as below average income countries. The turning points in this case were \$8203, \$8671 and \$7529 and \$9221 for the FE and RE and for the above- and below-average income countries.

5. Empirical evidence

We first present the results for the whole of the database and for the non-OECD countries as shown in Table 2 (modified and re-estimated from Stern and Common, 2001). Both the fixed and random effects models indicate the presence of a Kuznets curve and, parameter estimates as well as t-statistics are quite similar. As we observe the implied turning points are extremely high for both the fixed and random effects for the whole dataset (n=2263) and they are equal to \$123571/c and \$91991/c respectively. Thus using the ASL database and fixed and random effect models produces a monotonic EKC for the total sample. The turning points for non-OECD countries and for the fixed and random effects models are much higher (\$501936 and \$361942 respectively).

Similarly, and from Table 3, the turning points for the OECD countries are inside the sample. Specifically for the fixed and random effects models they are equal to \$9152 and \$9166 respectively. Confirming the results derived in Stern and Common (2001), sulfur emissions per capita are a monotonic function of income per capita, when they use a global sample, and an inverted U-shaped function of income when they use a sample of high-income countries only.

The Hausman test shows that country intercepts and income are correlated in the global model. The test shows that the random effects formulation cannot be consistently estimated. This suggests that there are omitted variables which are correlated with GDP. The Chow test shows that there are differences in the estimated parameters between high- and low-income countries. The reported tests for serial correlation show that there is significant residual serial correlation in the individual countries even after common time effects have been removed[1].

The F test performed in order to test for the significance of the FE shows that the null hypothesis (of non significance) is always rejected implying that the assumption of constant intercept may not always be valid for the different countries. That is, although the above-average (and the below-average) income countries exhibit identical patterns in terms of the relationship between GDP increases and sulfur emissions, there are differences in levels as they start from different levels of sulfur emissions.

A high level of predictability is observed in both cases of FE and RE model formulation. At an income level of \$4135 (the lowest in the sample considered and for Portugal) the elasticity of emissions with respect to income was found to be 1.11. For an income level of \$5819 (Ireland) the elasticity of emissions with respect to income was found to be 0.6329, for an income of \$8838 (Austria) the elasticity is 0.049, for an income of \$9366 (Belgium) the elasticity is -0.0325 and for an income of \$11426 (Sweden) the elasticity is -0.31042[2].

6. Abatement options for sulfur emission's reduction

Desulfurization processes exist to reduce the sulfur content of the fuel in use. The extent of removal is dependent on the physical and chemical characteristics of the sulfur in the fuel. Control technologies can be classified into three categories: 1. pre-combustion (physical coal washing and oil desulfurization); 2. during-combustion (sorbent injection and fluidized bed combustion); and 3. post-combustion (flue gas desulfurization, FGD). The choice of the technology will depend upon the characteristics of the fuel being burned and the standards for emissions, which must be met. Ease of disposition or ability to reuse waste products was found to be a secondary but important determinant of the technology used, especially as it affects the economics of certain processes.

The extent of removal is dependent on the physical and chemical characteristics of the sulfur in the fuel. Fuel cleaning techniques are relatively simple and well established but their effectiveness depends on the physical characteristics of the specific coals and crude oils, which, are subject to treatment. Fluidized Bed Combustion (FBC) can only be used for new installations and could only have an effect on total emissions over a long period. It is not possible to define abatement costs precisely since air pollution control is an integral part of the FBC boiler design. Sorbent injection could be a low cost retrofit option in cases where only moderate SO_2 emission reductions are required. Flue Gas Desulfurisation (FGD) is the most

Table 2
Fixed and Random Effects results for the World and non-OECD countries

Region	World n=2263		Non-OECD n=1550	
Model	Fixed Effects	Random Effects	Fixed Effects	Random Effects
Constant		-24.661		-19.3753
		(-14.029)		(-7.724)
ln GDP/P	4.1036	4.1146	2.6725	2.684
	(6.141)	(9.4749)	(4.1386)	(4.191)
(ln GDP/P)^2	-0.175	-0.18	-0.1018	-0.10485
	(-4.999)	(-7.706)	(-2.762)	(-2.784)
Adjusted R^2	0.144	0.155	0.143	0.151
ρ	0,873	0,882	0,852	0,86
AR(1)	88,3	89,7	71,59	73,71
Turning Point	123571	91991	501936	361942
Chow F Test	10.681	4.026		
	(0.016)	(0.04)		
Hausman Test		10.8		13.54
		(P=0.0045)		(P=0.0011)

Figures in parentheses are t statistics. AR(1) is a t-test on the residual autocorrelation coefficient ρ.[3]

Table 3
Fixed and Random Effects Results for the OECD countries

Regressors	OLS	FE	RE	TSLS
Constant	-69,711		-59.59	
	(-11,582)		(-18.4671)	
Ln GDP	14,261	12.245	12.2196	-1,636
	(10,524)	(16.1613)	(16.7735)	(-1,382)
Ln GDP^2	-0,7716	-0.6712	-0.6697	0,1318
	(-10,12)	(-16.26)	(-16.282)	(1,89)
R^2 Adjusted	0,2998	0.311	0.332	
SE	0,565	0,29011	0,29122	0,3745
Sign. FE		2095,9		
ρ	0,99	0,911	0,908	
AR(1)	98,91	56,4	54,94	
Turning Point	10313	9152	9166	
Hausman test			0.25	

commercially developed technology and the only one available for achieving very high removal efficiency at all types of installation, new or retrofit. The general trend is for Sorbent Injection (SI) to have the lowest capital costs among pre-combustion technologies, FBC and spray-dry scrubbers next, followed by wet scrubbers with regenerable processes having the highest capital costs.

Cost estimates for each technology are influenced by fuel type, plant size, sulfur content of the fuel, new or retrofit application, labor, construction and electricity cost factors. The slopes of the total abatement cost curves differ from country to country and if, for any given abatement level, the slope of the total abatement cost curve for one country is steeper than for another, then the abatement cost in the first country is higher than in the second. Given projections of uncontrolled emissions, estimates can be made of the potential for their reduction using available abatement technologies and of the likely cost. Table 4 presents information on the cost-effectiveness of the available technologies as well as the applicability, the capital, operating and maintenance costs.

The selection of appropriate strategies to reach and implement pollution control objectives is of crucial importance to planners. Because of the existing differences between countries in energy-use patterns, emissions, source locations and other economic factors, it is unlikely that a single uniform program of secondary abatement will be appropriate in all countries. To reduce sulfur emissions, the national decision maker may set a maximum allow-able rate of pollution output for each generic type of source (electricity generating, industry, petroleum refineries and transport) by type of pollutant. Furthermore, fuel quality regulations can be structured around the types of fuels in use (e.g. coal, oil etc) and can be limited by the technical possibilities and the costs of cleaning process for the different fuels.

Reducing energy consumption through either conservation or energy improvements can also reduce sulfur emissions. The latter can be achieved for instance by reducing energy consumption through more efficient generation, use of combined heat and power, etc. Denmark, Norway and Sweden are the only OECD countries that continue to increase energy taxation since the 1980s aiming to encourage energy conservation. On the other hand, IEA claims that inconsistency of taxation and energy policy is evident in the UK, which actually discourages efficiency by charging VAT on home-insulation products. IEA suggests that the potential for demand reductions for the UK, the Netherlands, Austria, the EEC and Western Europe in the industrial sector in 2000 can be as high as 25%, 21%, 10%, 25% and 30% respectively. At the same time Sweden can achieve demand reductions of 50% in its residential sector and 40% in its commercial sector. The EEC countries and the Netherlands can achieve an average of approximately 30% and 21% savings through cost-effective means in the residential and commercial sectors respectively. A 30% increase in energy efficiency can reduce energy requirements by 25%, which is equivalent to more than 1200 million tons of oil equivalent per year in 2000 (IEA, 1987).

Low sulfur coal may be a good way to reduce emissions where emission standards are met by using coal within a specific range of sulfur content. For instance, a standard of 2000 mg/m^3 is equivalent to approximately 1% sulfur content of coal, as the cut-off level above which sulfur abatement technologies would be used. Emission standards between 1000 and 2000 mg/m^3 are equivalent to coal sulfur content of 0.5-1% and there is no percentage removal requirement. Plants facing these standards can use either low sulfur content coal alone, or in conjunction with a limited-efficiency abatement technique (Vernon, 1989).

The use of low sulfur coal is a function of its availability and its cost relative to other control methods. Obviously, if the demand for low sulfur coal increases then both price and availability will change. Technical barriers exist to using low sulfur coal because it has a low calorific value and different ash characteristics which affect the operation of electrostatic precipitators. There are political barriers when no local supplies exist and government energy policies restrict, through import quotas, the import of supplies from elsewhere (Germany, Spain).

Substitution of fossil fuels by nuclear power and natural gas is also possible. But nuclear and hydropower have seen opposition on environmental grounds while other non-fossil fuel sources have been under-developed. Public pressure may increase the demand for gas fired power plants. High capital cost and costs of decommissioning mean that the nuclear plants have no advantage over coal-fired plants with secondary emissions control. The costs of NO_X and SO_2 controls on coal-fired plants are similar to those of gas firing plants. A range of $36-$50 m per kWh (US $1987) for coal-fired plants with full environmental control compares with $44-$48 m per kWh for a natural gas plant meeting similar standards (assuming a coal price of $40-60 per ton and a relative gas price of $160 per ton

Table 4
Sulfur emission abatement options and costs (in $ million 1985). Costs are based on a new 500 MW power plant, using hard coal with 2% sulfur content, 70% load factor and 5% retention factor

Abatement Method	Applicability	Sulfur removal efficiency (%)	Capital Cost	Operating and Maintenance cost FIXED VAR	Cost-Effectiveness $/t SR
Fuel switching (e.g. oil to gas)	All Users	Up to 99	-	—	(1)
Physical coal cleaning	All users	25	-	—	635-1625
Heavy fuel oil desulfurisation	All users	80	7.775	6.32 12.28	2100-2930
Sorbent injection	All users	50	0.344	0.22 2.59	485-750
Atmospheric Fluidised Bed Combustion	Power plants, industrial boilers	80	3.259	0.16 2.71	238-446
Circulating Fluidized Bed Combustion	New plants only	85	7.061	0.35 4.77	529-835
Flue Gas Desulfurization	Power plants, industrial boilers and process emissions	90	29.462	1.67 4.02	650-1200
Gas Oil Desulphurization	All users	90	1.918	1.93 2.2	2900-3740

(1) Depends on relative price and sulfur content
Source: Halkos (1995)

coal equivalent) (IEA, 1988). Newbery (1993) cites that if FGD investment is coordinated with gas, then capital costs of a gas burning Combined Cycle Gas Turbine (CCGT) will be £360-£500/kW compared with FGD capital costs of £150-£175/kW capacity. According to the same source, at the 1993 import parity price of coal, FGD was cheaper than new CCGT stations. This implies that FGD can be competitive with CCGT.

Table 5
Technologies applied by fuel used

Existing plants	HARD COAL Hard Coal Washing (HCW) Sorbent Injection (SI) Flue Gas Desulfurization (FGD) Combination of HCW and SI Combination of HCW and FGD
New plant (less or equal to 500 MWe)	All the above technologies and additionally: Atmospheric Fluidized Bed Combustion (AFBC) Circulating Fluidized Bed Combustion (CFBC) Combination of HCW and AFBC Combination of HCW and CFBC
Existing plants	BROWN COAL Sorbent Injection (SI) Flue Gas Desulphurization (FGD)
New plants	All the above technologies and additionally: Atmospheric Fluidized Bed Combustion (AFBC) Circulating Fluidized Bed Combustion (CFBC)
	HEAVY FUEL OIL Heavy Fuel Oil Desulfurization (HFOD) Flue Gas Desulfurization (FGD) Combination of HFOD and FGD
	GAS DIESEL OIL Gas Diesel Oil Desulfurization (GDOD) Flue Gas Desulfurization (FGD) Combination of GDOD and FGD
	PEAT AND BROWN COAL BRIQUETTES Sorbent Injection (SI) Flue Gas Desulfurization (FGD)

Source: Halkos (1995)

But would a massive program of sulfur control have a large effect on the prices which consumers pay for electricity? Highton and Webb (1984) showed that the increased price for the consumer would be about 4% in electricity costs with a 50% reduction in Central Electricity Generating Board of England and Wales (CEGB) emissions of sulfur. For large industrial consumers the effect would be an increase of slightly over 5%. Of course, this percentage increase in the electricity cost will vary from country to country due to different domestic unrestricted tariffs or different industrial tariffs.

The cost of an emission abatement option is given by the total annualized cost (TAC) of an abatement option, including capital and operating cost components:

$$TAC = [(TCC) * (r / (1-(1+r)^{-n})] VOMC + FOMC$$

Where TCC is the total capital cost ($), VOMC and FOMC are the variable and fixed operating and maintenance costs ($) respectively and $(r/(1-(1+r)^{-n})$ is the capital recovery factor at real discount rate r, which converts a capital cost to an equivalent stream of equal annual future payments, considering the time value of money (represented by the discount rate, r); n represents the economic life of asset (in years). The estimation of the annual operating and maintenance costs requires a great deal of information (for example, the sulfur content of fuel used, the annual operating hours, removal efficiencies of the control methods, etc). It consists of a fixed portion that is dependent on the use of the plant (e.g. maintenance and labor costs) and a variable portion dependent on the prices for electricity, labor, sorbents and waste disposal and the specific demand for energy due to the abatement process. Table 5 presents the control technologies applied to each fuel type while table 6 presents the fuels used by each sector and to which we apply the available abatement technologies.

7. Conclusions and policy implications

Like inequality, pollution tends to become worse before it becomes better along a country's development path. Our results indicate the existence of an inverted U-shaped relationship between economic development and pollution in the form of sulfur emissions as shown in Figure 1. The turning point occurs at $9152 for the OECD countries, at $501936 for the non-OECD countries and at $123571 for the world in general.

Specifically, using this panel database and fixed and random effect models produces a monotonic EKC for global and non OECD samples with extremely high turning points and an inverted U-shaped curve within the sample turning points for the case of OECD countries. Estimating an EKC using data for only the OECD countries leads to estimates where the turning point is not biased downwards relative to those estimated using data for the World as a whole.

Table 6
Fuels in which control technologies are applied in each sector

Fuels / Sectors	Hard Coal	Brown Coal	Brown Coal Briquettes	Heavy Fuel Oil	Gas Diesel Oil	Peat	Refinery Fuel Oil
Electricity Generating	*	*	*	*	*	*	
Industry	*	*	*	*	*	*	
Energy							*
Transport	*			*	*		
Others	*			*	*		

Source: Halkos (1995)

The acceptance of an EKC hypothesis means that there is an inevitable level of environmental damage that follows a country's development at the earlier stage but with a significant improvement at a later stage of this country's economic growth. Thus, an EKC is the result of structural change that follows economic growth. However, this may not be optimal if environmental critical loads are crossed irreversibly. The positively sloped part of an EKC where growth is worse may take a long time to cross. This implies a present value of higher future growth and cleaner future environment may be offset by high current rates of environmental damage. At the same time it may be cheaper to abate today than in the future.

The decomposition of the EKC into its main determinants shows that economic growth increases pollution levels due to scale and industrialization but ignores the abatement effect of richer countries (Panayotou, 1997).

Acceptance of an EKC may seem as a temporary phenomenon and we may seek ways to stimulate growth like trade liberalization, price reform, economic restructuring, etc. Some of the steepness of an inverted U-shaped relationship between environmental damage in the form of pollution and economic growth is caused by various policy distortions such as protection of industry, energy subsidies, etc. Developing countries can flatten out their EKCs by defining and applying property rights over natural resources, eliminating any policy distortions and internalizing environmental costs to the sources that generate them (Panayotou, 1993). Additionally, the improper allocation of property rights may lead to market failure.

Figure 1
A global EKC between S/c and GDP/c

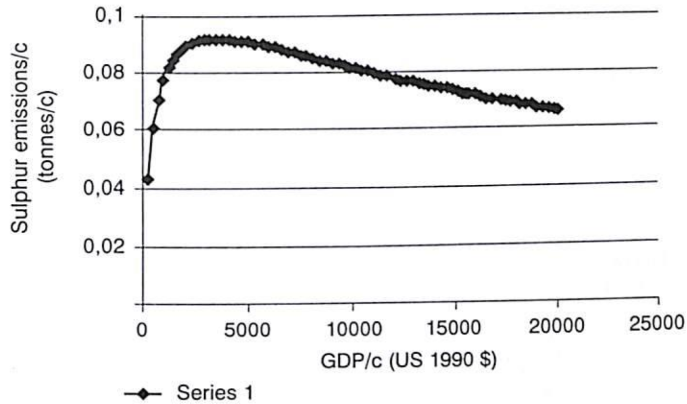
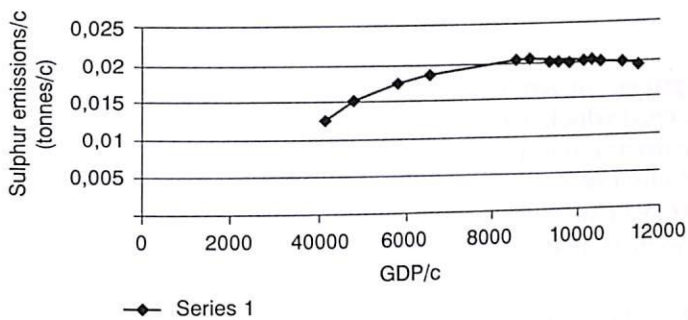


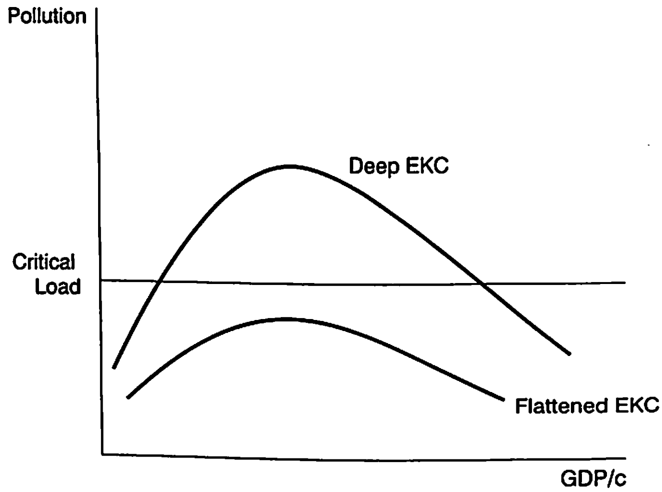
Figure 2
An EU EKC between S/c and GDP/c



A kind of development assistance can be organized in order to flatten out developing countries' EKC by making environmental protection an integral part of the OECD's financial policy. In the case that ecological thresholds, in the form of critical loads that might be crossed irreversibly, then a deep EKC implying high rates of pollution per unit of GDP/c increase is not optimal economically and environmentally as more of both can be attained with a better managed used of the same resources.

A part of the steepness of the inverted U-shaped relationship between economic growth and pollution is due to policy distortions

Figure 3
EKC and critical loads



Source: Modified from Panayotou (1993)

(under-pricing of natural resources, subsidies of energy and agrochemicals, etc), which are at the same time environmentally and economically destructive. Governments can flatten out their EKC by reducing or eliminating policy distortions, defining and applying property rights over natural resources and internalizing environmental costs to the sources that generate them.

The need for technology transfer to help developing countries to achieve sustainability emerges. The main idea is that abatement technologies in developed countries are cleaner and more advanced. As developing countries have no financial resources to import and use these technologies at commercial cost, this implies that developed countries should transfer or facilitate the transfer of these technologies to less developed or developing countries. The impact of this technology transfer depends on the type of industrial activity. That is, in the energy sector these transfers will be more beneficial for the environment compared to other industries such as textiles, etc. It should be emphasized that transfer of information must accompany these technology transfers on know-how and skills to enable countries to design or modify their own technologies.

Notes

1. A model estimated in first differences reduces statistical problems but results in a monotonic EKC when estimated on both high and low income samples. Stern and Common (2001) provide the results in first differences where the turning points again differ substantially. They equal \$53590, \$586965 and \$21545 for the global, OECD and non-OECD samples respectively.

2. GDP may be an integrated variable at least in the case of the Western European countries (Stern, 1998; Perman and Stern, 1999). The Hausman tests reported in Table 2 show that there may be omitted variables correlated with GDP. If the EKC regressions do not co-integrate the estimates may be spurious and non-co-integration is very possible. The very high reported autocorrelation coefficients in Stern and Common (2001) imply this conclusion. Thus the regression results reported above may be spurious. Differencing the data will eliminate potential stochastic trends in the series.

3. Data are for the following countries:

OECD: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Greece, Ireland, Italy, Japan, Luxembourg, Netherlands, Norway, New Zealand, Portugal, Spain, Sweden, Switzerland, Turkey, UK, USA, West. Germany.

Non-OECD: Algeria, Argentina, Barbados, Bolivia, Brazil, Chile, China, Colombia, Cyprus, Czechoslovakia, Egypt, Ghana, Guatemala, Honduras, Hong Kong, India, Indonesia, Iran, Israel, Kenya, Korea, Madagascar, Malaysia, Mexico, Morocco, Mozambique, Myanmar, Namibia, Nicaragua, Nigeria, Peru, Philippines, Romania, South Africa, Saudi Arabia, Singapore, Sri Lanka, Syria, Taiwan, Tanzania, Thailand, Trinidad & Tobago, Tunisia, Uruguay, U.S.S.R., Venezuela, Yugoslavia, Zaire, Zambia, Zimbabwe.

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