Economy - environment relationship: The case of sulphur emissions

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Abstract
This paper explores the relationship between economic development (in the form of GDP/c) and environmental pollution (in the form of sulphur emissions) by using a dynamic panel data for 97 countries for the time period 1950-2003. Various panel data econometric techniques are applied to a sample including only European Union (EU) countries and to a full sample including both the EU countries of the EU-countries sample, as well as, certain non-EU countries. The empirical results indicate significant differences between the two samples. For the case of the full sample, cross-country variation in the estimated slopes is observed, and parameters are extremely heterogeneous across countries making aggregate summarization not to be useful at all. However, the previous findings do not hold for the sample of the EU country members, resulting to the conclusion that policies to control pollution have to take into consideration both the specific economic situation and the structure of the industrial and the business sectors of each region. The last argument is even more important if someone takes into consideration transboundary pollution problems. Finally, in terms of policy implications, the study discusses the main options for sulphur emissions abatement.

Keywords: Panel data analysis; sulphur emissions; economic development.

JEL Classifications: C23, O10, O20, Q50, Q56.

1. Introduction

During the various economic development stages, income inequalities first increase and then start to fall as shown by Kuznets (1955). The environmental Kuznets curve (hereafter EKC) hypothesis relies on this idea and proposes that there is an inverted U-shaped relationship between environmental degradation and per-capita income. The EKC estimates for any environmental degradation dependent variable (like SO_2, NO_X etc.) peak at income levels around the world's mean income per capita. At the same time, income is not normally distributed but skewed (with a lot of countries below mean income per capita) and environmental damage seems to be lower in the most developed countries compared to middle-income countries and higher in many middle-income countries compared to less developed countries.

Among others, 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) point out the problems associated with some of the main EKC estimators and their interpretation. Specifically, they refer to the mean-median income problems, to the interpretation of particular EKCs in isolation from other environmental problems and the possible synergistic effects, the asymptotic behaviour and the assumption of unidirectional causality from growth to environmental quality and the reversibility of environmental change. They also refer to econometric problems claiming that many empirical studies do not provide any diagnostic tests for heteroskedasticity (due to large variations in income levels and environmental degradation variables) and autocorrelation.

The existence of spatial relationships in the data may affect the properties of the econometric methods used and lead to biases, inconsistencies, invalid inferences etc (Anselin and Griffiths, 1988). Dijkgraaf and Vollebergh (2005) claim that across countries the homogeneity of income is not proved by the data set used and turning points in higher income levels may be found even when cross-country heterogeneity is permitted.

At the same time an important issue is the choice between homogeneous and heterogeneous estimators. Due to potential heterogeneity bias associated with the use of pooled estimators, some researchers propose the employment of heterogeneous estimators that permit individual slopes (Pesaran and Smith, 1995; Hsiao et al. 1999). This situation is possible to occur when the range of independent variables (like GDP/c) differs across cross-sections. Other researchers propose in-between estimators like Bayesian shrinkage estimators (Maddala et al. 1997) or Pooled Mean Group (PMG) estimators (Pesaran et al., 1999). Finally, Mazzanti and Musolesior (2011) use "heterogeneous estimators" like Swamy's (1970) random coefficients GLS estimator, the Mean Group (MG) estimator (Pesaran and Smith, 1995) for dynamic models, the hierarchical Bayes approach (Hsiao et al. 1999) and the Empirical and the Iterative Empirical Bayes estimators (Maddala et al. 1997).

In this paper we use a panel data set of 97 countries for the time-span 1960-2003 for sulphur dioxide emissions as an index of environmental degradation and GDP/c as index of economic development. We use both "homogeneous and heterogeneous estimators". Specifically, a number of panel data models are used like fixed (within) effects, between effects, random effects with GLS and MLE, fixed and random effects with AR(1) errors and a "heterogeneous estimator" like Swamy's random coefficient estimator. Our findings and results are given separately, first for sample including European Union (EU) and non European Union countries, and then for the sample including only the EU countries, exploring for both samples the issues of cross-section dependence and the associated policy implications.

The structure of the paper is the following. Section 2 reviews the existing relative literature. Section 3 discusses the data and the econometric models used in this study. The empirical evidence is presented in section 4 while section 5 discusses the findings of this paper in terms of justifying the inverted U-shape extracted curves and the available abatement techniques for sulphur emissions control. The last section concludes the paper.

2. Literature review

Empirical formulations of the environment-income relationship and the exploration of the EKC hypothesis rely on econometric specifications that consist of an environmental damage indicator served as dependent variable and an economic variable representing economic development, like GDP/c in level, square and cubic values, being used as independent variable. Different variables have been used so far in empirical modelling to approximate environmental damage like air pollutants (SO_X, NO_X, CO_2, PM10, CO, etc.), water pollutants (e.g. toxic chemicals discharged in water, etc.) and other environmental indicators (e.g. deforestation, municipal waste, energy use, urban sanitation and access to safe drinking water).

Grossman and Krueger's (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. Specifically, Grossman and Krueger (1991), using the Global Environmental Monitoring System (GEMS) for 52 cities in 32 countries in the time span 1977-88, found N-shape curves in the cases of SO_2, dark matters and suspended particles with turning points between $4000-$5000. But as income approached the $10000-$15000 all the pollutants started to rise again. Shafik and Bandyopadhyay's (1992) examined 10 different indexes of environmental damage like among others sulphur oxides, xabon emissions, deforestation, etc for 149 countries for the time span 1960-1990. On contrary to other indexes, air pollutants presented an EKC behaviour with turning points between \$300-\$4000. At the same time Panayotou (1993) using cross sectional data found turning points for air pollutants between \$3000 and \$5000. Selden and Song (1998) found EKC for sulphur and NO_X among others in the case of developed countries with turning points at \$8700 for SO_2, \$11200 for NO_X and \$5600 for CO.

Stern and Common (2001) find that sulfur emissions per capita are a monotonic function of income per capita, when they use a global sample and an inverted U-shape function of income when they use a sample of high-income countries only. They calculate a much larger in size turning point (\$908178) compared with the total sample, again implying a monotonic EKC. Halkos (2003a), using the same database but proposing a dynamic model formulation finds much lower turning points in the range of \$2805-\$6230 and inverted U-shape curves. The differences in the extracted relationships as well as in the estimated turning points may be attributed to the econometric models' functional form used and the adoption of static or dynamic analysis.

Ansuategi (2003) used emission density as a dependent variable for a sample of 21 Western and Eastern European countries taking into account the spatial dispersion of pollutants in the growth–pollution relationship. De Bruyn (1997) examined mainly the 1994 Oslo Sulfur Protocol environmental policy and the agreed reduction targets in sulfur emissions of the 27 signatories for the year 2000. One of the main findings was that reductions of emissions at high levels of income are justified by environmental policy and not by any structural change. Panayotou (1997) used income per capita to capture the ''quantitative'' aspects of policy (e.g., environmental expenditures by the government) as well as an index of the enforcement of contracts.

The empirical results indicated that effective institutions and policies may reduce environmental damage at low income levels. At the same time they may speed up progresses at higher income levels. In this way, the EKC starts to become flatter while the environmental cost of growth decreases.

Markandya et al. (2006) examined the EKC hypothesis using sulphur dioxide emissions in Europe, like Ansuategi (2003) but with attention to countries of the Western European region. Similarly to De Bruyn (1997) and Panayotou (1997) they also paid attention to the effect of policy variables, like EU Directives and other national and international agreements.

At the same time the inclusion of other independent variables in the model formulation, affects significantly the estimated relationship. Roca et al. (2001) claim that estimated EKC is weaker when more explanatory variables are used together with income. Empirical evidence is not clear and mixed results have been found (Galeotti et al., 2006; He and Richard, 2010; Chuku, 2011). Shafik and Bandyopadhyay (1992) estimated an 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. Finally, Akbostanci et al. (2009) examined the income–environment relationship in the case of Turkey and found an *N*-shaped relationship in the case of SO_2 using time series and provincial panel data for the periods 1968-2003.

3. Data used and proposed econometric methods

3.1 Data

Our sample consists of the 97 countries[1] which have a full set of sulphur and GDP per capita information for the period 1950-03[2]. The database used has 4947 observations per variable. In terms of 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 depends upon emissions and geographic location, as well as atmospheric conditions in the form of wind velocity. 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.

3.2 Proposed econometric methods

We analyze the sulphur emissions in the European Union framework as well as for the full sample of countries. To establish the relationship between air pollution and GDP/c, Box-Cox tests have been performed to test linearity against logarithmic functional forms. Findings of the tests lead us to propose the following model:

$$(SO_2/c)_{it} = \beta_0 + \alpha_i + \gamma_t + \beta_1 (GDP/c)_{it} + \beta_2 (GDP/c)^2_{it} + \beta_3 (GDP/c)^3_{it} + \varepsilon_{it}$$

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[1] The countries considered in our analysis are the ones with full record on the data used. These are:
Full sample: Afghanistan, Albania, Algeria, Angola, Argentina, Australia, Austria. Bahrain. Belgium, Bolivia, Brazil, Bulgaria, Canada, Cape Verde, Chile, China, Colombia, Costa Rica, Cuba, Denmark, Djibouti, Dominican Rep, Ecuador, Egypt, El Salvador, Ethiopia, Finland, France, Germany, Ghana, Greece, Guateala, Guinea, Guinea Bissau, Haiti, Honduras, Hong Kong, Hungary, India, Indonesia, Iran, Iraq, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kenya, Lebanon, Liberia, Libya, Madagascar, Mauritius, Mexico, Mongolia, Morocco, Mozambique, Nepal, Netherlands, New Zealand, Nicaragua, Nigeria, North Korea, Norway, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Puerto Rico, Qatar, Romania, Sierra Leone, South Africa, South Korea, Spain, Sri Lanka, Sudan, Sweden, Switzerland, Syria, Taiwan, Thailand, Togo, Trinidad, Tunisia, Turkey, Uganda, United Kingdom, United States, Uruguay, USSR, Venezuela, Yugoslavia, Zaire.
EU: Austria. Belgium, Bulgaria, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Ireland, Netherlands, Poland, Portugal, Romania, Spain, Sweden, United Kingdom.

[2] The source for the sulphur dioxide emissions is:
http://www.sterndavidi.com/datasite.html'GlobalSulfurEmissionsbyCountry covering the time period 1850-2003 (although for the majority of countries the data refer to the period 1950-2000); while for the Gross Domestic Product the source is http://www.ggdc.net/MADDISON/oriindex.htm.

where SO_2/c is sulphur dioxide emissions per capita (in tons of sulphur) and GDP/c is Gross Domestic Product per capita (in 1990 Int$). Indexing countries by i and time by t, α_i's represent country specific intercepts, while γ_t's time specific intercepts. Finally, ε_{it} is the stochastic error term.

We have applied panel data methods to estimate the above equation. The first method employed is the fixed effects (hereafter FE) allowing each individual country to have a different intercept treating the α_i and γ_t 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 second model is the random effects (hereafter RE) in which the individual effects are treated as random. In this model the α_i and γ_t are treated as components of the random disturbances. The residuals 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_t are correlated with the explanatory variables then the random effects model cannot be estimated consistently (Hsiao, 1986, Mundlak, 1978).

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 test for cross-sectional dependence using the Pesaran's (2004) cross-section dependence (CD) test to evaluate if the time series in the panel are cross-sectional independent. If not, OLS Dummy estimator (FEM) allowing for individual fixed effects with Driscoll-Kraay standard errors, correcting the variance-covariance matrix in cases of serial and spatial correlation after testing for cross-sectional dependence, is used. Pesaran's CD test is valid for N and T tending to ∞ in any order and the test is robust to structural breaks (Camarero et al, 2011). According to Pesaran (2004) the need for unit root tests that take into account cross-section dependence for errors in panel with short T and large N emerges, as will be discussed in the next subsection. Also in the case of random effects estimation robust standard errors, after applying a Breusch-Pagan LM test for individual effects, are used.

Finally, we use a heterogeneous estimators' method, the random coefficients model, known as Swamy's (1970) model. This relies on the idea that the cross-section coefficient vectors are "drawn" from a distribution with a common mean (Hildreth and Houck, 1968; Judge *et al.*, 1988) and is described in Halkos (2003a).

3.2.1 Unit root tests

In order to examine the stochastic nature and properties of the variables a number of unit root tests are applied. The usual Dickey-Fuller (DF) and Augmented Dickey-Fuller (ADF) tests are extended in panel data analysis.

The first tests used in testing stationarity in panel data sets relied on the assumption of cross-section independence. Specifically, Levin, Lin and Chu (LLC, 2002) expanded the ADF test in the case of panel data analysis to examine whether each individual time series presents non-stationarity assuming independence across cross-sections and homogeneity across all i. A test that allows heterogeneity is the one proposed by Im, Pesaran, and Shin (2003) as an average of the ADF tests with serially correlated error and with the assumption of independence across cross-sections. Both LLC and IPS test statistics are distributed asymptotically as N(0,1).

Similarly, the Harris-Tzavalis (1999) test assumes cross-sectional independence. Finally, Hadri (2000) suggested a residual based Lagrange Multiplier test. O' Connell (1998) and Banerjee et al. (2004) claim that panel unit root tests are biased towards concluding in favour of variance stationarity when individuals (units, countries) are cross-section dependent. A number of recent tests take cross-section dependence among units in the panel data set into consideration. It is expected that the countries examined are correlated to each other and probably these countries are influenced by common experienced global shocks, like the oil prices shocks. These common shocks may create a kind of dependence among the countries in the panel data set, with possibly different effects across the various cross-section units. This implies the need for panel unit root tests that take account of cross-sectional dependence.

Recent efforts remove correlations across units as nuisance parameters. O'Connell (1998) and Levin *et al.* (2002) propose the subtraction of the cross-section mean from the data but it still assumes that the influence of cross-section dependence is the same for all units. For this reason we also apply the cross-section ADF (CADF) test suggested by Pesaran (2007) that expands the typical ADF for an individual series using current and lagged cross-section averages of all the series in the panel data set[3]. The Breitung (2000) test that allows cross-section dependence is also presented.

[3] CADF test was applied using STATA's "pescadf" command written by Piotr Lewandoski.

Similarly, panel co-integration tests can be performed using either test based on the Engle and Granger (1987) methodology (Kao, 1999; McCoskey and Kao, 1998; Pedroni, 2000, 2004) or on the most recent approach by Westerlund (2007). Pedroni (1999, 2000, 2004) suggested seven test statistics for the null of no co-integration, with four panel statistics and three group statistics test for testing either panel co-integration or cointegration across cross-sections. The Westerlund test checks for co-integration relying on the significance of the error correction term in the error correction model. The null hypothesis of this test is that there is no error correction with acceptance to imply no co-integration[4]. Specifically we use the four panel cointegration tests as proposed by Westerlund (2007). The G_t and G_a statistics test the null hypothesis of no cointegration for all cross sectional units with rejection implying cointegration for at least one unit. The P_t and P_a statistics test the null hypothesis of no cointegration for all cross sectional units with rejection implying cointegration for the panel in total.

4. Empirical results

Our analysis starts with examination of panel unit root tests for the variables considered in the model formulation. A graphical examination suggested that both a trend and a constant term were to be included in the model formulation with the number of lags to be determined by the use of the Akaike and Schwarz information criteria. The results of the tests applied to the variables involved are presented in Table 1. As such, table 1a presents the results of the variables of interest (i.e. SO_2/c and GDP/c and its square and cubic transformations). From this table it can be seen that there is evidence against non-stationarity in levels. Specifically, in all cases and

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[4] These tests were performed using STATA's "xtwest" command (Persyn and Westerlund, 2008).

according to the tests adopted, our variables are I(1). That is they are stationary in first differences and non-stationary in levels in all levels of statistical significance. Similarly Table 1b presents the unit roots test results for Harris-Tzavalis and Hadri tests where the same result emerges.

Table 1a: Summary of panel unit root tests (H_0: Panels contain unit roots)

Levels	**Levin, Lin and Chu t**[*1]	**Breitung t-stat**	**Im, Pesaran, Shin W-stat**	**Pesaran's CADF**
SO_2/c	1.0993 [0.8642]	-0.27611 [0.3912]	-0.62875 [0.2648]	t-bar =-2.160 z-bar = 2.063 P = 0.9800
GDP/c	1.0451 [0.852]	3.15143 [0.9992]	1.20928 [0.8867)	t-bar =-1.798 z-bar = 6.202 P = 1.0000
GDP/c ^{2}	0.93 [0.8238]	3.76456 [0.999]	0.6819] [0.7523]	t-bar =-1.247 z-bar=12.515 P = 1.0000
GDP/c ^{3}	0.62275 [0.733]	4.23399 [1.0000]	0.60553 [0.7276]	t-bar =-0.918 z-bar=13.288 P = 1.0000
First Differences	**Levin, Lin and Chu t**[*]	**Breitung t-stat**	**Im, Pesaran, Shin W-stat**	**Pesaran's CADF**
Δ SO_2/c	-12.5026 [0.0000]	-10.0493 [0.0000]	-12.3862 [0.0000]	t-bar =-4.446 z-bar =-28.033 P = 0.0000
Δ GDP/c	-4.37983 [0.0000]	-4.7753 [0.0000]	-6.09345 [0.0000]	t-bar=-3.852 z-bar= 21.810 P = 0.0000
Δ GDP/c ^{2}	-3.78108 [0.0001]	-3.86762 [0.0001]	-5.81441 [0.0000]	t-bar= -3.590 z-bar=-19.064 P = 0.0000
Δ GDP/c ^{3}	-4.02816 [0.0000]	-3.02462 [0.0012]	-5.91921 [0.0000]	t-bar =-3.271 z-bar=-15.729 P = 0.0000

P-values in brackets.

Table 1b: Panel unit root tests (continuation)

	Harris-Tzavalis[1]	**Hadri**[2]
SO_2/c	ρ=0.9766 Z=12.5742 P=1.0000	Z=213,0239 P=0.0000
GDP/c	ρ=0.9433 Z=9.0304 P=1.000	Z=182.8739 P=0.0000
GDP/c ^{2}	ρ=0.9147 Z=5.9809 P=1.000	Z=157.1438 P=0.0000

[1] H_0: Panels contain unit roots
[2] H_0: All panels are stationary

Table 2a presents the Pedroni Cointegration tests where in eight of the eleven cases we reject the null hypothesis of no cointegration at the conventional statistical significance level of 0.05. Similarly, table 2b presents the computed values of the Westerlund co-integration test. From the G_t and G_a statistics we reject H_0 only in the former, implying cointegration for at least one unit. From the P_t and P_a statistics we reject H_0 implying cointegration for the panel in total.

Table 2a: Pedroni Residual Cointegration Test

	Statistic	Prob.	Weighted Statistics	Prob.
Panel v-Statistic	4.800879	0.0000	0.526756	0.2992
Panel rho-Statistic	-1.882124	0.0299	-1.257785	0.1042
Panel PP-Statistic	-5.433513	0.0000	-4.490219	0.0000
Panel ADF-Statistic	-4.448394	0.0000	-2.465203	0.0068
	Statistic	Prob.		
Group rho-Statistic	1.107611	0.8660		
Group PP-Statistic	-3.987579	0.0000		
Group ADF-Statistic	-1.968379	0.0245		

Table 2b: Westerlund ECM panel cointegration tests (H_0: no cointegration)

	Value	Z-value	P-value[1]	Robust P-values[2]
$\mathbf{G_t}$	-2.836	-3.600	0.0000	0.0000
$\mathbf{G_a}$	-11.595	2.741	0.9970	0.2200
$\mathbf{P_t}$	-38.764	-17.996	0.0000	0.0200
$\mathbf{P_a}$	-15.469	-7.258	0.0000	0.060

[1] Pvalues for a one sided test based on the normal distribution
[2] P-values for a one sided test based on 100 replications

Table 3 presents the results of both fixed and random effects model formulations first for the full sample of countries (1st and 2nd columns) and then for the EU countries (4th and 5th columns) for the best quadratic and cubic formulations respectively. The Hausman test implies the use of the fixed effects model formulations. As the Pesaran cross-section dependance (CD) test (Pesaran, 2004) rejects the null hypothesis that errors are independently distributed across countries we proceed with the estimation of FE with Driscoll-Kraay standard errors calculated using the formula by the Driscoll-Kraay (1998)[5] which corrects the variance-covariance matrix for the presence of serial as well as spatial correlation (Camarero et al, 2010). Similarly in the case of the cubic specifications the best formulation was the one with the FE regression with AR(1) disturbances. Table 3 presents a number of diagnostic tests. Namely, three tests for heteroskedasticity and two tests for specification errors. In the case of the quadratic formulation all tests indicate no problem of heteroskedasticity and specification errors. In the case of the cubic formulation it seems that we face problems of both hetroskedasticity and misspecification for 10% levels of significance.

Moving now to the examination of the results for the EU countries we can first mention that the Pesaran cross-section dependance (CD) test does not reject the null hypothesis of independently distributed errors across countries. The Hausman test implies the use of the random effects and an inverted U-shape relationship can be observed in the quadratic formulation of RE Maximum Likelihood Estimators (MLE) with statistical significant estimates for GDP/c and GDP/c squared. Again in the case of the quadratic formulation all tests indicate no problem of heteroskedasticity and specification errors while in the case of the cubic formulation it seems that we face problem of misspecification.

We have also tried a number of random coefficients models that differed in two dimensions: whether the variables were in logs or levels and whether a quadratic or cubic GDP/c term was included. In table 3 we present for simplicity only the quadratic formulations for the full sample and the EU countries. In the first case both GDP/c and GDP/c squared are not statistically significant. This implies that there is a huge cross-country variation in β_i's implying that even if an inverted 'U' shape relationship do

[5] Applied using STATA's "xtcsd" command (De Hoyos and Sarafidis, 2006).

exist, its parameters are so extremely heterogeneous across countries that an aggregate summarization is not very useful at all. However the result is exactly the opposite in the case of considering just the EU countries where both GDP/c and GDP/c squared are significant implying an inverted 'U' shape relationship with homogeneous parameters across countries. So in the latter case aggregate summarization is useful and conforms to Pesaran's CD test in the case of EU countries.

Table 3: Parameter estimates for the panel data models

	Full Sample			**EU countries**		
Model	**FE Driskoll-Kraay s.e.**	**FE with AR(1)**	**Random Coefficients**	**RE MLE**	**RE**	**Random Coefficients**
Constant	0.006322 (5.09) [0.0000]	-0.02206 (-194.41) [0.0000]	0.03364 (0.97) [0.3300]	-0.02482 (-0.53) [0.5970]	-0.02062 (-4.08) [0.0000]	-0.0087 (-1.26) [0.209]
GDPc	4.27E-06 (11.29) [0.0000]	3.88E-06 (4.86) [0.0000]	-5.75E-06 (-0.41) [0.681]	8.63E-06 (22.60) [0.0000]	0.0000157 (16.81) [0.0000]	0.0000116 (3.83) [0.0000]
$GDPc^2$	-1.52E-10 (-11.43) [0.0000]	-1.27E-10 (-2.89) [0.0040]	7.52E-10 (0.41) [0.679]	-4.15E-10 (-25.35) [0.0000]	-1.16E-09 (-12.68) [0.0000]	-6.92E-10 (-2.11) [0.0350]
$GDPc^3$		1.18E-15 (1.75) [0.0800]			2.24E-14 (8.26) [0.0000]	
Hausman Test	10.58 [0.0011]	10.75 [0.0010]		0.55 [0.4603]	0.55 [0.4603]	
Pesaran's cross-sectional dependence	48.549 [0.0000]	27.483 [0.0000]		1.959 [0.0501]	0.761 [0.4469]	
Wooldridge serial correlation LM test		41.587 [0.0000]				
Test 1 (heteroskedasticity)	1.08 [0.3411]	1.14 [0.3308]		0.31 [0.753]	1.06 [0.289]	
Test 2 (heteroskedasticity)	0.82 [0.4423]	2.90 [0.0338]		1.41 [0.159]	0.29 [0.775]	
Test 3 (heteroskedasticity)	2.01 [0.1561]	2.77 [0.0962]		1.46 [0.144]	0.86 [0.391]	
Test 4 (RESET 1)	1.30 [0.2730]	3.12 [0.078]		0.43 [0.67]	2.97 [0.0516]	
Test 5 (RESET 2)	1.42 [0.2411]	2.40 [0.0962]		0.11 [0.912]	5.66 [0.0000]	
Turning Points	14046	22055 and 49700	-	10413.6	9240.5 and 25283.3	8381.5

Test 1: Regression of the squared residuals on X. That is, $u_t^2 = x_t'\gamma_1 + v_{t,1}$

Test 2: Regression of absolute residuals on X. That is, $| u_t |= x_t'\gamma_2 + v_{t,2}$ (a Glejser test)

Test 3: Regression of the squared residuals on $\hat{Y}$

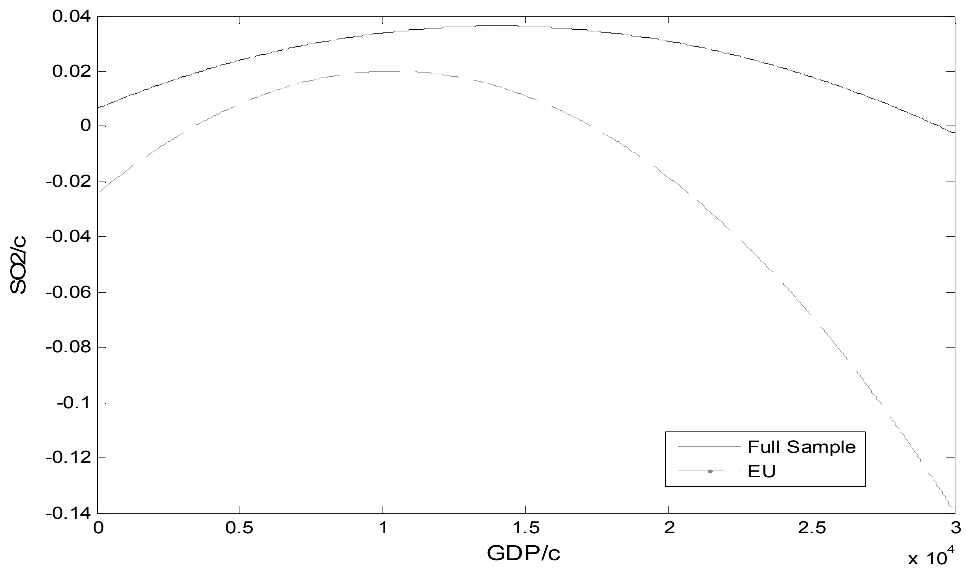
Test 4: Regression of residuals on $\hat{Y}^2$ Test 5: Regression of residuals on $\hat{Y}^3$

t statistics in parentheses; p-values in brackets.

What is worth mentioning is that the turning points are not so different between the full sample and the EU estimations. Specifically, the turning point for the full sample is $14406 while for the EU it is estimated as $10414 in the case of the RE estimates and $8382 in the case of the random coefficients.

Finally, Figure 1 presents the estimated EKC in the case of the full sample as well as in the case of the EU country members.

Figure 1: The EKC for the full sample and the EU country members



5. Discussion

5.1 Justifying the inverted U-shape of the EKC

Our empirical findings indicate the existence of an inverted U-shaped curve in both cases of the full sample and the EU countries. A number of possible explanations exist for this inverse U-shape relationship. Panayotou (2003) decomposed the EKC into three effects that lead to an EKC: the scale of economic activity or geographical intensity of the production, the composition or structure of the production and the effect of income on demand and the supply of abatement efforts.

More specifically, 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). Rothman (1998) claims that the shape of the EKC is the result of high income countries importing polluting intensive commodities and at the same time exporting their pollution to lower income countries.

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 as well as rise in 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, as 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. Panayotou (2003) explores the question if environmental improvement at higher income levels is automatic or it requires proper institutional or policy reforms. He finds that improvement in policy institutions may result to higher payoffs at higher levels of income. 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 to 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 another explanation. Torras and Boyce (1998) argue that greater equality of incomes results in lower level of environmental degradation. This claim is challenged by Scruggs (1998).

Acceptance of an EKC hypothesis means that there is an inevitable level of environmental damage that follows up a country's development at the earlier stage, followed by a significant improvement at a later stage of this country's economic growth. A part of the steepness of the inverted U-shaped relationship between economic growth and pollution is due to policy distortions (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, internalizing environmental costs to the sources that generate them.

It may be expected that required abatement will be greater at higher income level countries as we may expect stricter abatement standards. An issue that arises from the calculation of the turning points is associated with the level of damage done so far and if the critical loads are violated in an irreversible way before the turning down of the curve takes place.

5.2 Abatement options for sulphur emissions reduction

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. Desulphurisation processes exist to reduce the sulphur content of the fuel in use. The extent of removal is dependent on the physical and chemical characteristics of the sulphur in the fuel. Control technologies can be classified into three categories (Halkos, 1992, 1993):

1. pre-combustion (physical coal washing and oil desulphurisation);
2. during-combustion (sorbent injection and fluidized bed combustion); and
3. post-combustion (flue gas desulphurisation, 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 use of fossil fuels in the generation of electricity from conventional power stations is connected with a number of environmental problems. Specifically, generation using coal or oil creates air pollution due to sulphur and nitrogen oxides emissions, carbon dioxide, and particulates. Highton and Webb (1980) claim that in the UK a 2000 MW power station burning coal at a 60% load factor uses approximately 4.4 million tonnes of coal yearly and emits into the atmosphere (with no abatement control) about 130,000 tonnes of sulphur dioxide, 40,000 tonnes of nitrogen oxides, 10 million tonnes of carbon dioxide, and between 4,000 and 40,000 tonnes of particulate matter. The sulphur dioxide emissions are of concern as the use of tall stacks to disperse emissions may lead to problems of transnational pollution, characterized as externality. It can be said that about 1 tonne of sulphur burned produces 2 tonnes of sulphur dioxide (SO_2) while sulphur is present, in varying quantities, in both oil and coal.

The cost of cleaning coal before combustion is a function of the level of cleaning, per cent energy recovery, washability and physical characteristics of the coal, plant configuration and waste treatment. Each plant must be considered individually due to location, terrain, cleaning objectives, raw coal delivery arrangements etc (UNECE, 1982). Operating costs mainly arise from thermal losses.

Regarding the desulphurisation of oils, costs depend mainly on the size of the refinery, the degree of desulphurisation obtained and the nature of the initial crude. For controlling sulphur emissions during combustion the primary advantage of these systems is that they are relatively simple and easier to retrofit at existing power plants when compared to larger more complex conventional dry and wet scrubbing systems. A Fluidized Bed Combustion (FBC) unit tackles pollutant emissions at source in the furnace; high and low-grade coal can be used. An FBC boiler takes up less space than boilers with other firing systems, construction is simple, personnel requirements are low, and overall investment costs are low. Two types of FBC systems have been developed: the Atmospheric (AFBC) and the Pressurized (FFBC). Total energy losses amount to approximately 0.5-1.0%. Capital costs are not greatly affected by sulphur dioxide removal. The main elements in operating cost are operation and maintenance, energy costs of the process, limestone/dolomite raw material costs and waste disposal. PFBC disposal costs are nearly twice that of AFBC due to the additional volume of waste. Energy costs arise from electrical requirements for material preparation and feeding as well as removal and gas clean up.

Finally, the costs of controlling sulphur emissions after combustion and by using a wet FGD will vary, depending on the process adopted. Capital costs are highly sensitive to plant size. The most important determinant of cost is the fuel sulphur content. The biggest disadvantage with wet FGD systems is the sludge they produce, which is difficult to store and handle. A 500 MW boiler would produce about 600 tonnes per hour. In a typical 1,000 MW plant, burning coal with 3.5% sulphur, wet FGD produces about 225,000 tonnes of sludge annually (Regens and Rycroft, 1988). Barrett (1986) gives an output of 520,000 tonnes of gypsum for a 2,000 MW plant. The annual sludge production from a 2,000 MW power station could exceed 300,000 m^3 (Elsworth, 1984). The sludge is difficult to dewater which makes it difficult to dump.

The cost of an emission abatement option is given by the total annualised 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 sulphur content of fuel used, the annual operating hours, removal efficiencies of the control methods, etc) and consists of a fixed portion that is dependent on the use of the plant (e.g. maintenance and labour costs) and a variable portion dependent on the prices for electricity, labour, sorbents and waste disposal and the specific demand for energy due to abatement process (Halkos, 1994).

6. Conclusions and Policy Implications

In this paper, we use a large database to test the EKC hypothesis applying both homogeneous and heterogeneous methods and comparing the results derived. As with inequality, environmental degradation tends to become worse before it becomes better along a country's development path. Specifically, we find that:

i. Using fixed and random effect models produce inverted U-shaped curves with well within the sample turning points in both cases.

ii. Using a random coefficients method does not support an EKC hypothesis in the case of the full sample.

iii. The opposite result is found in the case of the EU countries where an EKC is evident. This means that there is no significant cross-country variation in β_i's and this implies that their parameters are homogeneous across countries making this aggregate summarization useful. This is in line with the result of the Pesaran's CD test.

iv. Specifically, using here fixed and random effect models produces an EKC for both the full and the EU countries with turning points at the levels of \$14046 and \$10414 respectively. In the case of the random coefficients and for the EU countries the turning point is lower and reaches a level of \$8382.

As discussed before, 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). Thus, an EKC is the result of structural change that follows economic growth, but this may not be optimal if environmental critical loads are crossed irreversibly.

There is obviously a need for technology transfer in order to help developing countries to achieve sustainability as sulphur abatement methods in developed countries are cleaner and more advanced. Currently available technologies for SO_2 are classified as pre-combustion, during combustion and post combustion. 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.

FGD is the most commercially developed technology and the only one available for achieving very high removal efficiency at all types of installation. The general trend is for sorbent injection to have the lowest capital costs, with 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, sulphur content of fuel, new or retrofit application and labour, construction and electricity cost factors (Halkos 1992, 1995).

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, improper allocation of property rights may result to market failure. The economic efficiency of growth policies has to be taken into consideration to avoid any possible inconsistencies and inefficiencies as shown in Halkos and Tzeremes (2009). It is accepted that economic development is not uniform across regions and may substantially differ (Halkos and Tzeremes, 2010). At the same time areas may also differ in terms of social, economic, environmental and urban-planning levels (Halkos and Salamouris, 2003b).

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