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Empirical Analysis of National Income and SO_2 Emissions in Selected European Countries

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Abstract. The linkage between per capita GDP and sulfur emissions for 12 Western European countries was analyzed over a period of more than 150 years. The analysis also looked at the impact of air pollution regulations on the shape of the income–pollution relationship. At both the aggregate and country levels, we find an inverted U-shaped relationship and the estimated turning points of most countries are plausible. In addition, environmental regulations are found to lower the EKC and they can also shift the turning point of the curve. In some cases, the shift is to the left and in a few to the right.

Key words: environmental Kuznets curve, panel data, regulation, sulfur dioxide, Western Europe

JEL Classification: C23, O11, Q25, Q28

1. Introduction

The environmental Kuznets curve (EKC) has been a major subject of study in environmental economics in recent years. It establishes the linkage between key development indicators and environmental quality. Most often, environmental quality is measured using variables that correlate negatively with the welfare of society, such as air pollution, water pollution and deforestation. Per capita gross domestic product (GDP) on the other hand is a common measure of development that is used in such studies. Particularly, the EKC proposes, in general terms, that economic growth will eventually rectify the negative environmental impacts of the early stages of economic development, and that growth will lead to further environmental improvements.

The often-cited, first recognized study about an inverted-U shape function of the EKC was conducted by Grossman and Krueger (1995) where their results demonstrated that pollution levels increase as the economy develops but begin to decrease as rising income pass beyond a turning point. The same relationship is found in many other papers (e.g., Shafik and Bandyopadhyay 1992; Selden and Song 1994; Rock 1996), who use a range of econometric techniques and data involving a variety of pollutants. Based on existing studies, one can at least conclude that the conventional EKC function is more complicated than just having income as its determinant variable.

The primary objectives of the study are threefold: (i) to ascertain whether the EKC exists in the selected European countries over a longer historic period than has hitherto been analyzed, and whether the implementation of air pollution regulations over time has any impact on the shape; (ii) if there is an EKC curve, to calculate the "turning point", which is the level of income beyond which pollution begins to decline; and (iii) to offer a theoretical discussion of the shape of the observed EKC. In line with these objectives, we first examine what the raw data show of the relationship between emissions and per capita income; and second, we employ econometric analyses to estimate the impact of income on sulfur emissions. This study finds that the raw data of per capita SO_2 emissions, both at the country and aggregate levels, show an inverted "U-shaped" trend when plotted against per capita GDP. The econometric analysis also upholds this relationship between income and emissions for most of the countries. These findings are further discussed in the following sections.

For the purposes of this study, sulfur dioxide (SO_2) emissions data are used as a proxy for environmental pollution. We make use of *SO_2 emissions per capita* and *GDP per capita* going back to 1870 for twelve European countries: Austria, Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, Sweden, Switzerland and UK. These time series data, extending over 132 years (they go until 2001) are *much* longer than those used by other studies. Furthermore, we also consider the air pollution regulations that these countries have to comply with as enforced by national governments, the European Commission and UNECE.

The choice of the countries was based on their common features in terms of development, emission levels, environmental regulations, culture and history.[1] The aggregated emissions of the selected countries comprise about 90–97% of the total regional emissions between 1870 and 1980; and about 50–80% between 1981 and 2001. In addition, the aggregated real GDP of the same countries comprise more than 85% of the regional total between 1870 and 2001. However, emissions have been declining simultaneously with economic growth in this group of countries and it will be interesting to see what lessons can be derived from the observations from this set of countries.

Section 2 reviews some existing studies of the EKC relating to sulfur emissions. Section 3 describes the data and Section 4 shows the econometric models, tests and results on the relationships of sulfur emissions with per capita income and regulations. Section 5 gives the theoretical discussions about the shape of the EKC that resulted in this study. Section 6 concludes, with some suggestions about the wider relevance of the results of this paper.

2. Related Literature

A rich set of studies have examined empirically the EKC hypothesis and have reviewed and commented on it.[2] Here, we will focus on those that are similar to this study in terms of their use of: (i) sulfur dioxide emissions as pollution variable or proxy variable to environmental degradation; (ii) panel estimation procedures; (iii) real GDP per capita in PPP$; (iv) data of developed countries; and (v) environment policy variables. Examples of studies that used all of the first four variables mentioned are Cole et al. (1997), Selden and Song (1994), Stern and Common (2001) and Halkos (2003). They supported an inverted U-shaped relationship between emissions and income for a sample dominated by, or consisting solely of, OECD countries. Other than the per capita GDP variable, additional variables such as technology level, population density, as well as country and time effects were also used in their EKC models. The *turning points* calculated in the said studies range between $8,200 and $10,600 in 1990 PPP dollars. The key descriptions of selected sulfur EKC studies are given in Table I. The estimated average *turning point* calculated in this study is around $11,900. It does not vary substantially from those calculated for the developed economies by other studies. However, our estimated *turning point* is almost double of that calculated by Halkos (*op. cit.*), which utilized a different econometric method (GMM method) as compared to the other studies listed in the table below.

Another similar study is Ansuategi (2003) which analyzed a sample of 21 countries from the Western and Eastern Europe. However, it used *emission density*[3] as a dependent variable, while the other studies described here (including this study) used *emissions per capita*. It takes into account the role of the spatial dispersion of pollutants in the growth–pollution relationship. Protection of the local environment through pollution abatement measures are called upon as the economy grows, but the speed of adopting such measures depends on the: (i) proportion of sulfur emissions within the national boundaries; and (ii) density of sulfur depositions from foreign countries. For example, suppose that a country has quite high figures for *both* variables. It will generate a stronger incentive to speed up the adoption of abatement measures in production processes as compared to a country that has lower local emissions and higher sulfur depositions.

Environment regulations also play a role in the attempt to improve environmental quality, and measures to reduce pollution levels can have an effect on the shape of the EKC. De Bruyn (1997) looked at environmental

Table I. Selected SO_2 emissions EKC studies

Authors	Turning point[a] (1990 PPP$)	Additional variables	Data source for SO_2	Time period	Estimation method	Countries/cities
Ansuategi (2003)[b]	$4,696–$6,158	Income density, population density, proportion of sulfur emissions within national borders, density of sulfur deposition from foreign countries	Sandnes (1993)	1985, 1987–1992	FE, RE	21 European countries
Cole et al. (1997)	$8,232	Country dummy, technology level	OECD	1970–1992	OLS, FE, RE	11 OECD countries
Halkos (2003)[c]	$4,381–$5,003 (World) $5,648–$6,230 (OECD) $2,805–$3,401 (Non-OECD)	Time and country effects	ASL & Associates	1960–1990	Random coefficients, A–B GMM	73 developed and developing countries
Selden and Song (1994)	$10,391–$10,620	Population density	WRI, OECD	1979–1987	OLS, FE, RE	22 OECD and eight developing countries
Stern and Common (2001)[c]	$101,166 (World) $9,239 (OECD) $908,178 (Non-OECD)	Time and country effects	ASL & Associates	1960–1990	FE, RE	73 developed and developing countries
This Study	$11,197	Country effects, air pollution regulations, technology changes	Stern (2005)	1870–2001	OLS, FE, RE	12 Western European countries

OECD – Organization for Economic Cooperation and Development; WRI – World Resources Institute; OLS – Ordinary Least Squares; FE – Fixed effects; RE – Random effects; A–B GMM – Arellano–Bond Generalized Method of Moments.
[a]The "turning point" is the level of income beyond which the emission level begins to decline.
[b]The study uses the income variable in 'real terms', but it is unclear whether it is in PPP dollars or US dollars.
[c]Both studies use the same data.

policy, particularly, the 1994 Oslo Sulfur Protocol that stipulates the agreed reduction targets in sulfur emissions of 27 signatories[4] for the year 2000. The study found that reductions of sulfur emissions at high income levels are better explained by environmental policy, rather than structural change. Panayotou (1997) used per capita income as a proxy policy variable, which was intended to capture the '"quantitative" aspects of policy (e.g., environmental expenditures by the government). The study also used another policy variable, which was an index of the respect/enforcement of contracts. Results of the study show that effective institutions and policies can significantly lessen environmental degradation at low income levels and can accelerate improvements at higher income levels. In so doing, the EKC becomes flatter and the environmental cost of growth is reduced. Faster economic growth is found to lead to an increase in ambient pollution but these effects are quite small and can be offset by the impact of better policies/institutions. Dasgupta et al. (2002) state three reasons why richer countries tend to have stricter pollution regulations: (i) pollution damage becomes a higher priority once the society has completed basic investments in health and education; (ii) higher income countries can afford to hire more technical personnel and allot larger budgets for monitoring and enforcement; and (iii) higher income and education empower local communities to enforce higher environmental standards.

Our study examines the EKC model in the context of SO_2 emissions in Europe, as was done by Ansuategi (*op. cit.*) but with fewer countries and with focus on those belonging to the Western Europe region. Furthermore, similar to De Bruyn (*op. cit.*) and Panayotou (*op. cit.*), we also account for the influences of qualitative policy variables on pollution. These policies are in the form of EU Directives and other national and international agreements.

3. The Data

3.1. PER CAPITA SULFUR DIOXIDE EMISSIONS (SPC)

Sulfur dioxide emissions data cover the periods from 1850 to 2001 and have a common unit of kilograms per annum. Continuous time-series data for all 12 countries were compiled by Stern (2005a–c) using a combination of published and reported estimates. The primary sources of data were the ASL and Associates database (1997)[5], EMEP website[6], Mylona (1996) and OECD publications. In particular, the data from 1990 to 2001 were obtained from OECD (2004). There is a complete coverage for most of the countries, where Finland and Switzerland are only missing the 1850 data. In this case, the missing observation is interpolated using the regional data.[7]

3.2. PER CAPITA GDP (GDPPC)

The per capita GDP data of the European countries is measured in 1990 international Geary-Khamis dollars[8] and 134 time periods: 1820, 1850 and 1870–2001. These data were compiled by Maddison (2005). In some cases, gaps in the GDP estimates are filled by imputation. For example, per capita GDP movement in Switzerland was assumed to be parallel with that of Germany for 1871–1898. The 1850 data for Finland and Italy were interpolated between the 1820 and 1870 estimates for these countries. Adjustments were also made for changes in frontiers (see Maddison, *op. cit.* for details).

3.3. AIR POLLUTION REGULATIONS (REG)

The air pollution regulation variables are intended to capture the roles of both national and international policies, monitoring and enforcement. Annex Table I gives the key dates of legislation from 1972 until 2001 that could have affected sulfur emissions in the European countries, while Annex Table II gives similar legislations in the UK from 1874 onwards.[9] The interesting question is how these regulations have affected the sulfur-GDP relationship. Figure 1 plots the per capita emissions and per capita GDP in the UK with the dates of some of the key Acts. The most pronounced decline in per capita emissions took place in 1926 following the Smoke Abatement Act, but this was only a temporary drop. Emissions returned to previous levels after that. Regulations from 1956 onwards show a steady decline in emissions but no

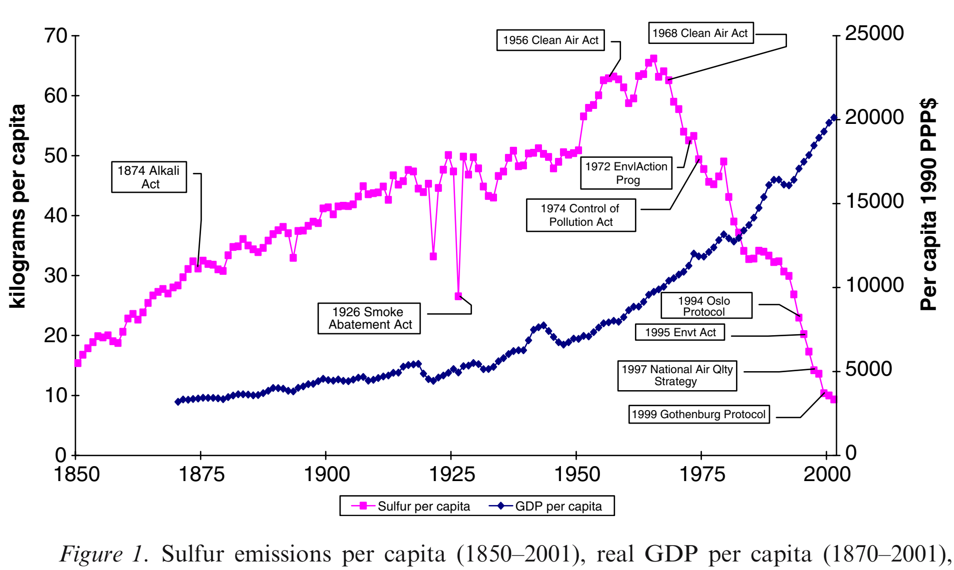


Figure 1. Sulfur emissions per capita (1850–2001), real GDP per capita (1870–2001), and selected air pollution regulations in UK.

Table II. Descriptive statistics, 12 Western European countries

Country	kg SO_2 per capita[a]					Real GDP per capita (1990 PPP$)[b]				
	Min	Year	Max	Year	Ave	Min	Year	Max	Year	Ave
Austria	1.00	1850	46.97	1912	14.70	1,725	1945	20,225	2001	6,318
Belgium	5.55	1850	59.38	1965	25.35	2,682	1871	20,924	2001	7,242
Denmark	0.64	1851	58.23	1970	15.16	1,993	1871	23,161	2001	7,834
Finland	0.01	1850	61.09	1980	13.26	1,110	1881	20,344	2001	5,684
France	1.09	1850	38.27	1973	11.56	1,876	1870	21,092	2001	7,008
Germany	3.05	1850	67.97	1944	28.58	1,817	1871	18,677	2001	6,639
Italy	0.02	1850	33.28	1980	6.59	1,467	1881	19,040	2001	5,808
Netherlands	2.82	2001	39.44	1965	12.20	2,649	1944	21,721	2001	7,546
Norway	0.11	1850	31.04	1949	9.08	1,432	1870	24,577	2001	6,859
Sweden	0.14	1850	60.37	1968	16.23	1,662	1870	20,562	2001	7,143
Switzerland	0.02	1850	26.99	1967	6.56	2,102	1870	22,263	2001	9,271
UK	9.34	2001	66.20	1965	40.00	3,190	1870	20,127	2001	7,825
All	4.20	2001	42.25	1970	21.41	2,088	1870	20,024	2001	6,914

[a]1850–2001.
[b]1870–2001.
Sources: Stern (2005), Maddison (2005).

sudden drop in the per capita GDP series. The graph is remarkable in showing steady per capita income growth, combined with declining emissions after a peak in 1956. This strongly suggests that the succession of regulations have made a big contribution to reducing SO_2 emissions, but have not made a major dent in the growth of real living standards.

Table II gives the descriptive statistics for per capita GDP and per capita sulfur emissions of the twelve countries, individually and as a group. Per capita GDP, which is a measure of economic living standards, rose by an average of 11.4 times over the 132 years from 1870 to 2001, with a minimum of 6.3 for the UK and 17.9 for Finland. The average annual growth rate for the 12 countries is 1.8 percent, with a range from 1.7% (Belgium) to 2.3% (Finland). Unlike GDP, the emissions do not show a general upward trend, but rather an increase up to a certain year and then a decline. The year of maximum emissions varies but it lies in the period 1912–1980, e.g., for Austria it was 1912; for Switzerland, 1967; and for France, 1973.

The changes in the growth rates of income and emissions will be better examined through different phases as many influential events have occurred since the 1800s (see Tables III and IV). Five distinctive phases of development are used, where the first four are adopted from Maddison (1995):

(i) 1870–1913 – The average growth rates of real GDP and sulfur emissions are positive within this period, which is considered as a

Table III. Average growth rates of per capita income by different phases of development, 1870–2001

Country	1870–1913	1913–1950					1950–1973	1973–1994	1994–2001
		1913–1918	1918–1939	1939–1945	1945–1950	1913–1950			
Austria	1.48%	−4.94%	2.35%	−5.94%	4.16%	1.32%	5.28%	2.26%	2.04%
Belgium	1.06%	−5.84%	− 2.01%	1.32%	− 4.85%	0.94%	3.63%	2.03%	2.37%
Denmark	1.58%	−1.47%	2.41%	−1.40%	4.05%	1.78%	3.27%	1.80%	2.56%
Finland	1.49%	−6.01%	3.77%	−0.41%	2.52%	2.21%	4.22%	1.83%	4.00%
France	1.55%	−5.76%	2.55%	−7.08%	14.79%	1.75%	4.15%	1.75%	1.96%
Germany	1.63%	−2.50%	3.13%	−0.78%	−2.74%	1.28%	5.59%	1.79%	1.52%
Italy	1.33%	5.55%	0.45%	−6.99%	7.28%	1.34%	5.06%	2.37%	1.86%
Netherlands	0.95%	−2.62%	2.12%	−8.28%	16.40%	1.89%	3.42%	1.70%	2.55%
Norway	1.32%	−0.61%	3.07%	−0.84%	7.10%	2.37%	3.25%	3.02%	2.70%
Sweden	1.50%	−3.01%	3.14%	2.42%	3.54%	2.19%	3.13%	1.28%	2.76%
Switzerland	1.77%	−2.23%	2.43%	3.23%	7.30%	2.10%	3.12%	0.67%	1.04%
UK	1.04%	2.33%	0.75%	1.85%	−1.03%	1.09%	2.32%	1.92%	2.58%
All	1.34%	−0.75%	1.73%	−1.95%	1.13%	0.98%	4.03%	1.89%	2.05%

Source: Maddison (1995, 2005).
Notes:
1870–1913 – Pre-war era and era of improved communications and significant factor mobility.
1913–1950 – Era of war and depression (World War I – 1913–1918; World War II – 1939–1945).
1950–1973 – Golden age of prosperity.
1973–1994 – Era of financial system difficulties and OPEC oil shock.

Table IV. Average growth rates of per capita sulfur emissions by different phases of development, 1870–2001

Country	1870–1913	1913–1950					1950–1973	1973–1994	1994–2001
		1913–1918	1918–1939	1939–1945	1945–1950	1913–1950			
Austria	3.34%	−14.03%	−0.34%	−13.08%	20.13%	−0.41%	3.06%	−8.65%	−5.43%
Belgium	1.66%	−7.75%	5.20%	−9.93%	15.09%	2.47%	1.79%	−5.68%	−8.46%
Denmark	4.63%	−7.33%	5.31%	−10.64%	28.49%	5.17%	3.03%	−3.85%	−17.32%
Finland	10.67%	−8.38%	11.58%	−5.68%	18.17%	8.17%	5.19%	−5.80%	−3.95%
France	2.86%	−1.54%	3.24%	−3.75%	19.87%	3.33%	3.01%	−5.26%	−8.04%
Germany	2.88%	0.83%	1.22%	−2.16%	9.69%	3.96%	2.00%	−4.80%	−17.01%
Italy	3.55%	−5.51%	5.03%	−26.69%	54.90%	6.22%	11.55%	−3.43%	−8.24%
Netherlands	3.06%	−10.35%	3.43%	−12.83%	18.67%	2.20%	2.62%	−6.64%	−7.36%
Norway	4.71%	−0.94%	7.12%	−14.79%	30.69%	6.33%	−0.25%	−6.60%	−4.58%
Sweden	6.14%	−3.38%	10.20%	−4.60%	25.95%	9.00%	0.46%	−9.02%	−5.05%
Switzerland	5.30%	−6.64%	4.92%	−22.17%	139.60%	21.36%	3.40%	−7.07%	−3.90%
UK	1.25%	0.85%	2.37%	−0.08%	0.39%	1.80%	0.30%	−3.55%	−12.11%
All	2.19%	−0.77%	1.26%	−3.98%	0.89%	1.34%	1.90%	−4.78%	−11.79%

Sources: Stern (2005a), Maddison (2005).
Notes:
1870–1913 – Pre-war era and era of improved communications and significant factor mobility.
1913–1950 – Era of war and depression (World War I – 1913–1918; World War II – 1939–1945).
1950–1973 – Golden age of prosperity; First EC directive on air quality was implemented in 1972.
1973–1994 – Several EC directives and international regulations on air quality were implemented during this period.

pre-war era and an era of improved communications and significant factor mobility. Nine of the focus countries (excluding Italy) moved to fixed exchange rates by adopting the gold standard that has been practiced by the UK since 1921.

(ii) 1913–1950 – This period was disturbed by war and depression, which caused a significant drop in GDP in some Western European countries. This is also an age of quantitative restrictions on trade and foreign exchange. Looking closely at the figures during World War I (1913–1918) and World War II (1939–1945), the growth rates of per capita emissions are either negative or lower compared to the preceding years. On the other hand, the growth rates of per capita income during war time are negative or lower than the rates during earlier periods for majority of the focus countries.

(iii) 1950–1973 – This period is described as the 'golden age of prosperity', where development greatly sped up in Europe and labor productivity in West European countries accelerated faster than the United States. As shown in Table III, the average growth rates of income in this period are highest as compared to the other periods in the focus countries (except UK). This is also the period where Western economies created a functioning international order and institutions for cooperation, such as the OECD, World Bank, and IMF. Almost all of the focus countries have lower per capita emission growth rates compared to their rates in 1913–1950. The first EC directive on air pollution was implemented in 1972.

(iv) 1973–1994 – This is the era where the governments of the world had to deal with strong inflationary pressure, a breakdown in the Bretton Woods fixed exchange rate system and the OPEC oil shock. GDP, per capita GDP and labor productivity slowed down in the 12 focus countries. The degree of instability, however, was modest compared to the period before the "golden age". Ratio of trade to GDP increased after 1973 as the countries increased the openness of their economies. The growth rates of per capita emissions during this era are negative and lower than the earlier years in all countries studied. Several EC Directives limiting emissions (including sulfur) from motor vehicles, power stations, waste incinerators and large combustion plants have been implemented within this phase.

(v) 1994–2001 – Economic development was greater during this period as compared to earlier years (excluding the 'golden age') for most countries. Also, per capita emission growth rates remained to be negative. Two international air pollution regulations were implemented: Oslo Protocol in 1994, where the Western European countries should reduce sulfur emissions by 70–80% of 1980 levels; and

Gothenburg Protocol in 1999, where sulfur emissions should be cut by at least 63% with respect to 1990 levels.

Looking at the general picture, per capita GDP started to grow quite sharply after the Second World War. On the other hand, sulfur emissions, which hitherto had grown faster than GDP in a number of countries, started to grow more slowly and eventually to decline. The pattern is similar in each country, with pronounced reductions post 1970s, except in Norway where the decline began much earlier. Figure 2 plots the real per capita GDP against the level of SO_2 emissions for each of the twelve countries. As expected, the relationship shows something of an "inverted U". Emissions rise against per capita GDP to some point, after which as the GDP increases, emissions tail off. This is of course the well-known "Environmental Kuznets Curve" relationship. In the next section, we will estimate how sensitive the emissions are to changes in income as well as to the environmental regulations.

4. Econometric models, tests and results

4.1. DATA DIAGNOSTICS

Before carrying out any econometric estimations, the data series for gross domestic product per capita (GDPPC) and sulfur dioxide emissions per capita (SPC) were examined. Both data series were found to be non-stationary (i.e., have a unit root), and are integrated of order two or I(2). This means that each data series has to be differenced twice for them to be stationary. Regressions involving non-stationary variables will lead to spurious results, which means that t and F testing procedures are invalid. One way to avoid the problem of non-stationarity is to regress the second-differenced GDPPC on the second-differenced SPC. Estimating differenced variables, however, would mean that valuable information from the long-run equilibrium properties of the levels data may be lost.

A cointegration test was employed to determine whether a linear combination of GDPPC and SPC is stationary or I(0), even if they are individually I(2). First, a regression was run on a conventional EKC model and the residuals of the regression were derived ($\hat{\mu}_t$). Second, in order to test for cointegration, the augmented Dickey–Fuller test of unit root was applied to the estimated residuals ($\hat{\mu}_t$) under the null hypothesis of non-stationarity (with unit root). Test results using the aggregated data of the twelve countries and panel data rejected the null hypothesis.[10] This implies that the linear combination of GDPPC and SPC is cointegrated or stationary; hence, a regression on the levels of the two variables is *not spurious*. Also, we do not lose any valuable long term information, which would result if their second differences were used instead.

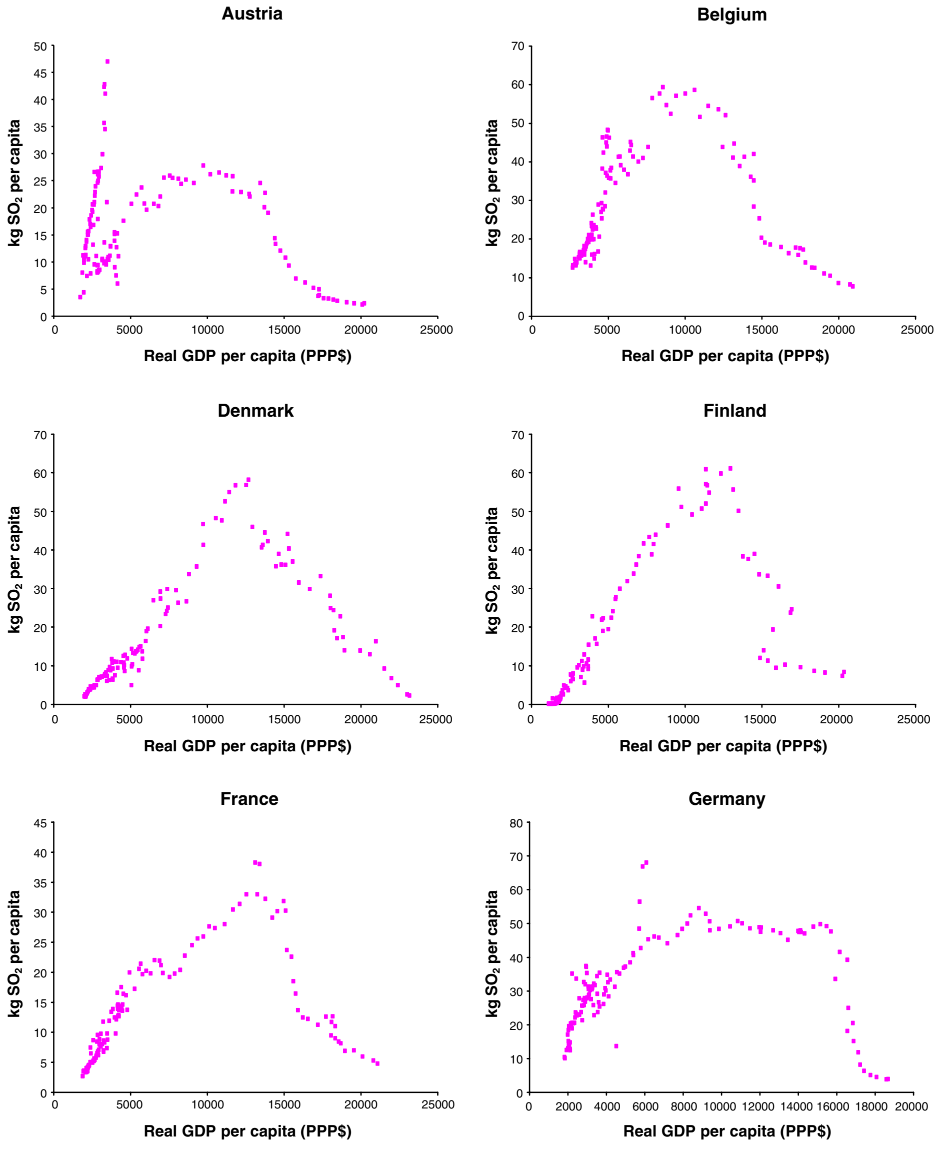


Figure 2. Sulfur emissions per capita (kg) and real GDP per capita (1990 PPP$) in selected Western European countries, 1870–2001.

4.2. INDIVIDUAL COUNTRIES: PANEL ESTIMATION

4.2.1. *Econometric models*

Using the information from all countries, the panel data estimation technique was employed to deal with inter-country heterogeneity in the analysis. An

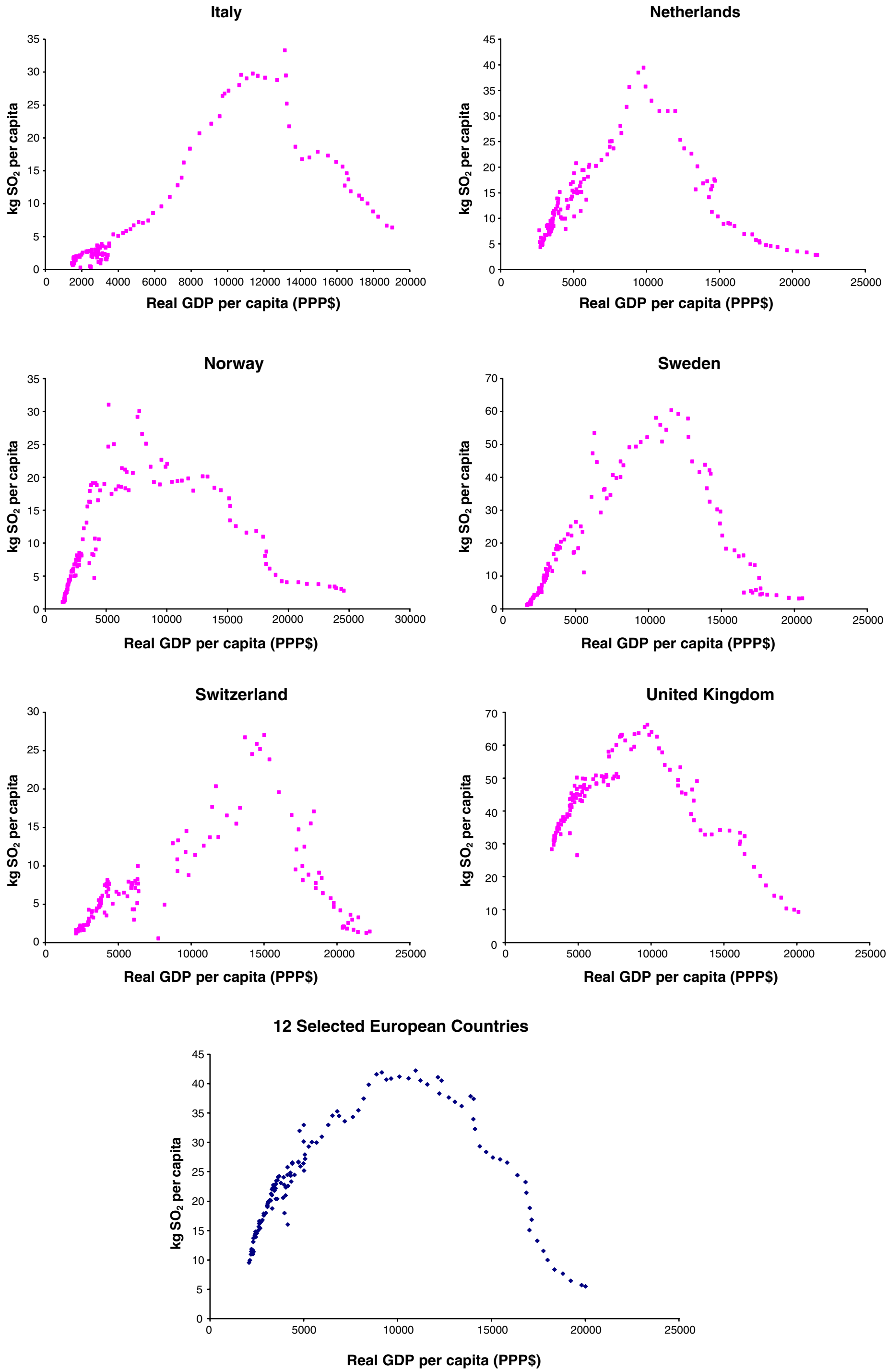


Figure 2. Continued.

attractive facet of panel data is the creation of more variability by combining variation across countries thus alleviating multicollinearity problems and providing a more efficient estimation (Kennedy 1998). Several other advantages of using the panel data are mentioned in the literature.

There are two panel data estimations: *fixed effects* and *random effects*. The *fixed effects* estimator allows the intercept to differ across the cross-section units by estimating different constants for each cross-section (Equation 1). The *random effects* model also assumes a different intercept for each cross-section, but the intercepts may be taken as random and treated as if they were part of the error term. As a result, the specification has an overall intercept, a set of explanatory variables with their respective coefficients, and a composite error term (Equation 2). The composite error has two parts: a random intercept term and the traditional random error (Greene 1993; Kennedy 1998).

The fixed and random effects models are shown below. A logarithmic functional form was used because it yields more statistically significant results, compared to a functional form in levels. Also, higher order GDPPC variables ($GDPPC^3$, $GDPPC^4$) were initially included but it was found that: (a) including the log of $GDPPC^4$ resulted in perfect multicollinearity; and (b) the coefficient estimate of $GDPPC^3$ was statistically insignificant. When $GDPPC^3$ was omitted, the statistical significance of the other variables improved. Hence, these two variables were dropped in the following econometric models:

$$\begin{aligned}\ln\ \mathrm{SPC}_{it} = {} & \alpha + \beta \mathrm{CS}_i + \chi \ln(\mathrm{GDPPC}_{it}) + \delta(\ln \mathrm{GDPPC}_{it})^2 \\ & + \phi \mathrm{TREND} + \gamma_j \mathrm{REG}_k + \eta \mathrm{WWI} + \iota \mathrm{WWII} + \varepsilon_{it}\end{aligned} \tag{1}$$

$$\begin{aligned}\ln\ \mathrm{SPC}_{it} = {} & \alpha + \chi \ln(\mathrm{GDPPC}_{it}) + \delta(\ln \mathrm{GDPPC}_{it})^2 + \phi \mathrm{TREND} \\ & + \gamma_j \mathrm{REG}_k + \eta \mathrm{WWI} + \iota \mathrm{WWII} + \mu_{it} + \varepsilon_{it}\end{aligned} \tag{2}$$

where CS refers to country effects; i – 1, ..., 11 (1-Austria, 2-Belgium, 3-Denmark, 4-Finland, 5-France, 6-Germany, 7-Italy, 8-Netherlands, 9-Norway, 10-Sweden, 11-Switzerland, Base country-UK), SPC-SO_2 emissions per capita, GDPPC – gross domestic product per capita, REG – dummy variable for an EU directive or regulation on air pollution reduction at k period (k = 1972, 1975, 1979, 1980, 1984, 1985, 1987, 1988, 1989, 1992, 1993, 1994, 1996, 1999 and 2001); j = 1, ..., 12; The dummy variable is equal to ‘1’ from the year the directive was implemented and the years after that, and ‘zero’ otherwise, *trend* – trend variable, WW1 – dummy variable for World War I – ‘1’ for 1914–1918; zero otherwise, WW2 – dummy variable for World War II – ‘1’ for 1939–1945; zero otherwise, ε_{it} – traditional random error term, μ_{it} – composite error term or a random error characterizing the ith observation and constant through time.

Aside from the income variables, policy variables were included, as well as a trend variable that describes the general movement of sulfur dioxide emission levels over time. The influences of the first and second World Wars on the emissions were also considered. The policy variables are expressed as dummy variables and introduced in the model to capture the long-run effects of each policy. This makes sense because the impact of a regulation will not only be evident on the year it was implemented, but it will also be carried over the succeeding years.

4.2.2. *Model specification test and regression diagnostics*

To determine which estimation method is appropriate given the available information, we performed several diagnostic tests on Equations 1 and 2. First, an F-test was performed on the country dummy variables to determine whether a pooled or panel regression is appropriate. The F-test rejected the null hypothesis of homogeneity across each country. This indicates that OLS is not applicable but panel data estimation via fixed effects or random effects should be used. Next, the Hausman test was employed to test the null hypothesis that there is no correlation between the composite error and explanatory variables, i.e., the random effects model is applicable. The Hausman test fails to reject the null hypothesis, which means that the random effects model is more appropriate. Table V compares the estimation results from the fixed and random effects, as well as the results of the mentioned tests for model specification.

The estimated disturbances between SPC and GDPPC were also examined for heteroskedasticity and autocorrelation. Heteroskedasticity means that the regression errors do not have the same variance. On the other hand, autocorrelation in time series data refers to the correlation between members of series of observations ordered in time. The classical model assumes that the disturbance relating to any observation is not influenced by the disturbance term relating to any other observation. OLS estimators remain to be unbiased and consistent even with the presence of heteroskedasticity and autocorrelation. However, these estimators are no longer efficient (i.e., with minimum variance). As a result, the usual t and F tests of significance cannot be applied legitimately.

Test results after initial regressions showed that the independent variables of the regression have heteroskedasticity, and that the regression error at time $t(\hat{\mu}_t)$ is correlated with the value of its immediate past $(\hat{\mu}_{t-1})$ in both the aggregate data and panel estimation.[11] The latter means that we have a first-order serially correlated residuals or AR(1). In light of this, the final

Table V. Fixed and random effects, regression results

Variables	Fixed effects		Random effects	
	Coefficient	SE	Coefficient	SE
Intercept	−80.432	2.546	−80.655	2.552
ln (GDPPC)	17.990	0.604	18.047	0.605
ln $(GDPPC)^2$	−0.953	0.036	−0.956	0.036
TREND	−0.009	0.001	−0.009	0.001
REG1972	−0.016	0.088	−0.011	0.089
REG1975	−0.102	0.099	−0.101	0.100
REG1980	0.026	0.145	0.027	0.146
REG1984	−0.142	0.145	−0.142	0.146
REG1985	−0.222	0.145	−0.221	0.146
REG1987	−0.066	0.159	−0.066	0.160
REG1988	−0.071	0.159	−0.071	0.160
REG1989	−0.060	0.184	−0.059	0.184
REG1992	−0.177	0.150	−0.177	0.151
REG1993	−0.200	0.150	−0.200	0.150
REG1994	−0.105	0.184	−0.105	0.184
REG1996	−0.079	0.159	−0.079	0.160
REG1999	−0.156	0.119	−0.156	0.119
REG2001	−0.264	0.119	−0.263	0.119
WWI	−0.045	0.159	−0.044	0.160
WWII	0.050	0.061	0.049	0.061
F-test (fixed effects = 0)		179.60 (0.00)		
Hausman test				0.85 (1.00)

Figures in parentheses are the *p*-values of the *t*-statistics for the *F* and Hausman tests.

regressions described in the succeeding sections (Equations 3 and 4) were performed by allowing for the transformation of standard errors so they will be heteroskedasticity-consistent (Huber/White estimator), and by correcting the regression estimators for AR(1) through Prais–Winsten transformation (Prais and Winsten 1954; Greene 1993; Gujarati 1995).

4.2.3. *Final model: fixed effects*

We should point out that we are interested to obtain the effects of the explanatory variables on per capita emissions that are specific to individual countries. To derive the impacts of income, regulations and wars on SO_2 emissions *by country*, we employ the fixed effects model because the use of dummy variables make it easy to calculate the parameters for a given country (Equation 3). Also included in the model are the interaction dummy variables. The normal fixed effects model only allows intercepts to vary across countries, but in our model, we take into account the slope coefficients that may also differ across countries. Table VI shows the summary of coefficient estimates with robust standard errors by country. It also shows that the overall or joint influence of the explanatory variables is significant at 5% level. Another test was also carried out to determine if a relevant variable was omitted from the model. This is called a regression specification error test (RESET), which is done by regressing the estimated residuals on the square, cube and fourth power of the predicted dependent variable, SPC ($S\hat{P}C^2, S\hat{P}C^3, S\hat{P}C^4$). These variables are used to proxy relevant variables that may have been omitted. The residuals of a false model incorporate the influence of the omitted variable/s. Hence, when a model is appropriately specified, the said variables, either individually or jointly introduced, should not have statistically significant influences on the residuals. RESET results *fail to reject* the null hypothesis of "no omitted relevant variables" as the coefficient estimates of the proxy variables were found to be statistically insignificant at 5% level.

$$\begin{aligned}
\ln \mathrm{SPC}_{it} = {} & a + b\ln(\mathrm{GDPPC}_{it}) + c(\ln \mathrm{GDPPC}_{it})^2 + d\mathrm{TREND} \\
& + e_i\mathrm{CS}_i + f_i\mathrm{CS}_i * ln(\mathrm{GDPPC}_{it}) + g_i\mathrm{CS}_i * (\ln \mathrm{GDPPC}_{it})^2 \\
& + h_i\mathrm{CS}_i * \mathrm{TREND} + i\mathrm{REG1972} + j\mathrm{REG1975} + k\mathrm{REG1979} \\
& + l\mathrm{REG1980} + m\mathrm{REG1984} + n\mathrm{REG1985} + o\mathrm{REG1987} \\
& + p\mathrm{REG1988} + q\mathrm{REG1989} + r\mathrm{REG1992} + s\mathrm{REG1993} \\
& + t\mathrm{REG1994} + u\mathrm{REG1996} + v\mathrm{REG1999} + w\mathrm{REG2001} \\
& + x_i\mathrm{REG1972} * \mathrm{CS}_i + y_i\mathrm{REG1975} * \mathrm{CS}_i + aa_i\mathrm{REG1979} * \mathrm{CS}_i \\
& + ab_i\mathrm{REG1980} * \mathrm{CS}_i + ac_i\mathrm{REG1984} * \mathrm{CS}_i + ad_i\mathrm{REG1985} * \mathrm{CS}_i \\
& + ae_i\mathrm{REG1987} * \mathrm{CS}_i + af_i\mathrm{REG1988} * \mathrm{CS}_i + ag_i\mathrm{REG1989} * \mathrm{CS}_i \\
& + ah_i\mathrm{REG1992} * \mathrm{CS}_i + ai_i\mathrm{REG1993} * \mathrm{CS}_i + aj_i\mathrm{REG1994} * \mathrm{CS}_i \\
& + ak_i\mathrm{REG1996} * \mathrm{CS}_i + al_i\mathrm{REG1999} * \mathrm{CS}_i + am_i\mathrm{REG2001} * \mathrm{CS}_i \\
& + an\mathrm{WW1} + ao_i\mathrm{WW1} * \mathrm{CS}i + ap\mathrm{WW2} + aq_i\mathrm{WW2} * \mathrm{CS}i \\
& + \text{error term} \qquad (3)
\end{aligned}$$

The country level data show:

(a) In each country, the air pollution regulations that are found to be statistically significant have negative impacts on the per capita emissions.
(b) All individual countries, except Italy, show an inverted U-shaped relationship between per capita income and per capita SO_2 emissions. However, a statistically significant pollution–income relationship (at

Table VI. Fixed effects regression results, individual countries

Variables	Austria		Belgium		Denmark		Finland	
	Coeff. Est.	t-stat	Coeff. Est.	t-stat	Coeff. Est.	t-stat	Coeff. Est.	t-stat
Intercept	−20.417**	−1.825	−39.942*	−3.357	−64.309*	−2.273	−50.187*	−3.682
ln(GDPPC)	4.920**	1.814	9.474*	3.463	13.799*	3.671	11.209*	3.527
$\ln(\text{GDPPC})^2$	−0.247	−1.493	−0.520*	−3.313	−0.688*	−3.405	−0.630*	−3.520
TREND	−0.008*	−2.158	0.007*	2.490	−0.010	−0.851	0.042*	3.643
REG1972	0.012	0.197	0.014	0.204	−0.142*	−1.956	−0.107	−1.248
REG1975	−0.124*	−2.131	−0.240*	−3.168	−0.083	−0.965	−0.112	−0.979
REG1979	0.028	0.286	−0.012*	−0.137	0.043	0.463	−0.020	−0.143
REG1980	−0.137	−1.166	−0.048*	−0.444	0.036	0.327	−0.103	−0.608
REG1984	−0.154*	−2.420	−0.179*	−4.183	−0.141*	−2.014	−0.168**	−1.699
REG1985	−0.169*	−2.290	−0.285*	−7.286	0.025	0.319	−0.106	−0.923
REG1987	−0.209*	−3.679	−0.064*	−2.402	−0.179*	−3.218	−0.130	−1.365
REG1988	−0.357*	−5.296	−0.052**	−1.821	−0.075	−1.203	−0.190**	−1.685
REG1989	−0.179*	−2.180	−0.106*	−4.447	−0.292*	−3.903	−0.314*	−2.283
REG1992	−0.294*	−7.164	−0.044	−1.294	−0.336*	−2.365	−0.509*	−6.124
REG1993	−0.086*	−1.959	−0.128*	−3.199	−0.303**	−1.700	−0.303*	−3.567
REG1994	−0.155*	−2.936	−0.155*	−3.007	−0.120	−0.539	−0.167**	−1.717
REG1996	−0.105**	−1.749	−0.046	−0.988	0.063	0.214	−0.017	−0.218
REG1999	−0.116*	−3.101	−0.212*	−7.801	−0.500*	−2.483	−0.112*	−2.141
REG2001	0.056*	3.008	−0.082*	−5.311	−0.265*	−2.637	0.052**	1.788
WWI	0.088	1.211	−0.200	−1.600	0.033	0.230	−0.052	−0.262
WWII	−0.109	−0.995	−0.228*	−2.022	−0.284	−1.257	−0.267**	−1.801
Variables	**France**		**Germany**		**Italy**		**Netherlands**	
	Coeff. Est.	t-stat	Coeff. Est.	t-stat	Coeff. Est.	t-stat	Coeff. Est.	t-stat
Intercept	−28.508*	−3.776	6.283	0.275	−9.575	−0.665	−41.324*	−3.726
ln(GDPPC)	6.555*	3.754	−1.163	−0.213	0.841	0.248	9.511*	3.650

Intercept	−28.508*	−3.776	6.283	0.275	−9.575	−0.665	−41.324*	−3.726
ln(GDPPC)	6.555*	3.754	−1.163	−0.213	0.841	0.248	9.511*	3.650
ln(GDPPC)^2	−0.349*	−3.480	0.093	0.282	0.069	0.349	−0.516*	−3.359
TREND	0.011*	3.071	0.006	0.433	−0.009	−1.113	0.007*	2.687
REG1972	0.046	1.316	−0.193	−1.205	−0.054	−0.559	−0.148	−1.645
REG1975	−0.181*	−2.214	−0.143	−1.314	0.017	0.154	−0.339*	−4.765
REG1979	−0.021	−0.192	−0.060	−0.599	−0.210*	−1.953	0.033	0.344
REG1980	−0.140	−1.034	−0.088	−1.114	−0.015	−0.115	−0.114	−0.963
REG1984	−0.212*	−3.730	−0.057	−0.682	−0.289*	−4.934	−0.163*	−3.331
REG1985	−0.268*	−4.522	−0.080	−0.861	−0.239*	−3.754	−0.222*	−4.681
REG1987	−0.082*	−2.109	−0.130	−1.210	−0.077	−1.295	−0.073	−1.591
REG1988	−0.139*	−3.349	−0.250**	−1.816	−0.174*	−2.441	−0.111*	−2.040
REG1989	0.062	1.375	−0.184	−1.088	−0.179*	−2.112	−0.252*	−3.716
REG1992	−0.189*	−4.394	−0.340*	−2.787	−0.138*	−2.133	−0.099*	−2.188
REG1993	−0.204*	−3.943	−0.244**	−1.650	−0.106	−1.351	−0.110*	−2.141
REG1994	−0.104	−1.622	−0.331**	−1.923	−0.176**	−1.810	−0.145*	−2.287
REG1996	−0.089	−1.338	−0.530*	−3.112	−0.143	−1.408	−0.098	−1.329
REG1999	−0.205*	−4.712	−0.275*	−3.041	−0.205*	−2.772	−0.091**	−1.850
REG2001	−0.139*	−5.947	−0.088**	−1.770	−0.136*	−3.537	−0.059*	−2.446
WWI	−0.115	−0.997	0.098	1.191	−0.241**	−1.680	−0.102	−1.221
WWII	−0.088*	−2.004	−0.446	−0.871	−0.071	−0.304	0.024	0.204

Variables	Norway		Sweden		Switzerland		UK	
	Coeff. Est.	t-stat	Coeff. Est.	t-stat	Coeff. Est.	t-stat	Coeff. Est.	t-stat
Intercept	−84.091*	−6.166	−101.701*	−5.117	−17.556	−0.825	−92.039*	−4.090
ln(GDPPC)	19.447*	6.327	22.829*	5.251	4.332	1.055	20.910*	4.310
ln(GDPPC)^2	−1.079*	−6.483	−1.224*	−5.400	−0.259	−1.387	−1.127*	−4.400
TREND	−0.004	−0.445	−0.008	−0.585	0.027	1.011	−0.010	−1.520
REG1972	0.030	0.535	−0.185*	−2.350	−0.230**	−1.685	−0.034	−1.120

Table VI. Continued

Variables	Norway		Sweden		Switzerland		UK	
	Coeff. Est.	t-stat	Coeff. Est.	t-stat	Coeff. Est.	t-stat	Coeff. Est.	t-stat
REG1975	−0.055	−1.261	−0.087	−0.799	−0.500*	−3.026	−0.047**	−1.750
REG1979	0.015	0.247	−0.141	−1.322	−0.037	−0.334	0.051	1.330
REG1980	−0.031	−0.450	−0.106	−0.807	−0.080	−0.597	−0.153*	−3.420
REG1984	−0.032	−0.784	−0.088	−1.372	−0.204*	−2.771	−0.041*	−1.990
REG1985	0.070**	1.717	−0.171*	−2.445	−0.204*	−2.405	0.014	0.680
REG1987	−0.228*	−6.518	−0.225*	−2.484	−0.209*	−2.936	0.025	0.870
REG1988	−0.119*	−3.008	−0.080	−0.714	−0.198*	−2.604	0.015	0.460
REG1989	−0.183*	−3.811	−0.407*	−2.930	−0.221*	−2.390	−0.024	−0.740
REG1992	−0.182*	−6.361	−0.163*	−2.501	−0.252*	−3.456	−0.043	−1.280
REG1993	−0.012	−0.480	−0.160*	−2.607	−0.331*	−4.219	−0.108*	−2.570
REG1994	0.075*	2.398	−0.024	−0.409	−0.069	−0.865	−0.138*	−2.570
REG1996	0.080*	2.680	0.012	0.282	−0.135**	−1.690	−0.159*	−3.330
REG1999	−0.063*	−3.703	−0.179*	−5.187	−0.258*	−5.617	−0.264*	−9.550
REG2001	−0.059*	−3.981	0.040**	1.773	0.092*	3.271	−0.053*	−2.670
WWI	0.146**	1.899	0.099	1.380	0.056	0.346	−0.108	−1.610
WWII	−0.360	−1.414	−0.464	−1.342	−1.007	−1.234	−0.057**	−1.690

Notes:
Numbers are rounded off to the nearest thousandth.
Standard errors are White heteroskedasticity-consistent.
*Coefficient estimates imply statistical significance at 5% level (critical value of t statistic ≈ 1.96).
**Coefficient estimates imply statistical significance at 10% level (critical value of t statistic ≈ 1.65).
R-squared = 0.77.
F-test statistic on the joint significance of all explanatory variables = 92.98, p-value = 0.00.
RESET: Regression of residuals on SPC^2 – t-stat = 0.19, p-value = 0.85.
RESET: Regression of residuals on SPC^3 – t-stat = −0.05, p-value = 0.96.
RESET: Regression of residuals on SPC^4 – t-stat = −0.05, p-value = 0.96.
RESET: Regression of residuals on SPC^2, SPC^3, SPC^4 – F-stat = 2.47, p-value = 0.07.

5% level) can only be observed for *eight* countries: Belgium, Denmark, Finland, France, Netherlands, Norway, Sweden and UK. These findings are illustrated by plotting the predicted emissions per capita given the levels of per capita income, *ceteris paribus* (see Figure 3).

(c) The environmental regulations considered in the study start from 1972. Taking into account the average per capita income of each country between 1970 and 2001, the estimated "turning points" are plausible except in the case of Denmark.

(d) At 5% level of significance, there are no statistically significant impacts found for WW1. For WW2, however, the war caused a significant downward shift in emissions for Belgium and France (−0.20% and −0.08% change in SPC, respectively) and no significant upward shifts. The negative impact of the second world war on SPC can be attributed to the lower economic activities during the said period.

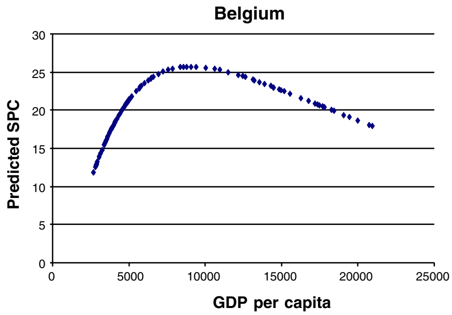
(e) There are no consistent findings with respect to the time trend. It is significant and negative for Austria, significant and positive for Belgium, Finland, France and the Netherlands and insignificant in all other cases (all at the 5% level).

4.3. ALL COUNTRIES

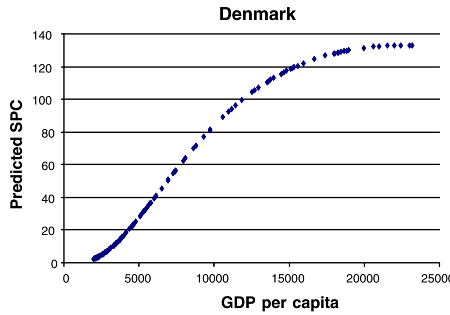
We also estimate a logarithmic quadratic EKC for the aggregate of the 12 countries by OLS (Equation 4).[12] As mentioned earlier, the emissions and income of the selected countries comprise more than 50% and more than 85% of the regional total, respectively. Therefore, this estimation was done in order to examine the relationship among the dependent and explanatory variables when the countries are taken as a group to represent the Western Europe region.

$$\begin{aligned}\ln\ \mathrm{SPC}_t =& \alpha_0 + \alpha_1 \ln \mathrm{GDPPC}_i + \alpha_2 (\ln \mathrm{GDPPC}_t)^2 + \alpha_3 \mathrm{trend} \\ & + \beta_j \mathrm{REG}_k + \omega_t\end{aligned} \tag{4}$$

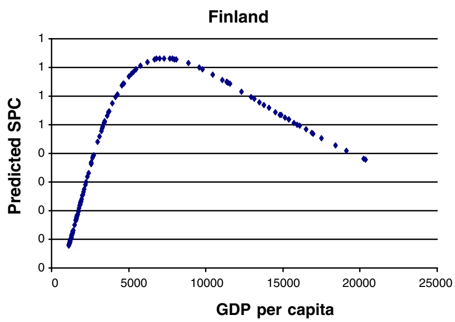
The joint influence of the explanatory variables in Table VII were found to be statistically significant at the 5% level, as well as the coefficient estimates of per capita income variables. Furthermore, regression results show that several EU directives implemented have statistical significance (at 5% level) and long-term negative impacts on *per capita SO_2 emissions*. These are the directives implemented in 1984, 1985, 1988, 1992, 1993, 1994, 1996, 1999 and 2001. The negative impact of a regulation on per capita emissions is given by a change in SPC of " $\exp(\hat{\beta}_t) - 1$" percent. For example, the coefficient estimate of REG1996, $\hat{\beta}_{1996}$, is about −0.256. This implies that when the EU



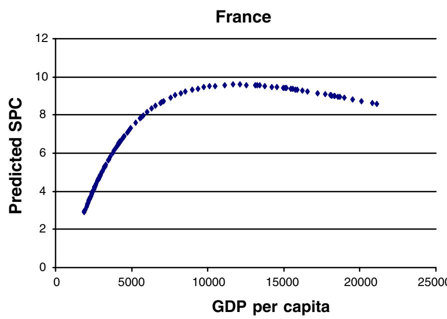
BELGIUM Turning Point: GK$9,077
Ave GDPPC (1970-2001): GK$15,600



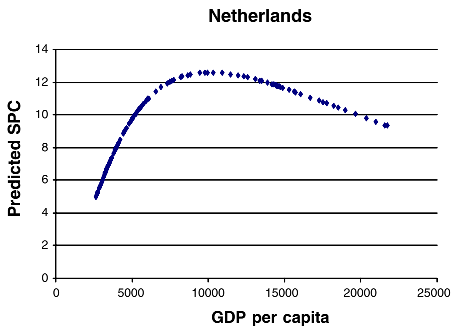
DENMARK Turning Point: GK$22,700
Ave GDPPC (1970-2001): GK$17,400



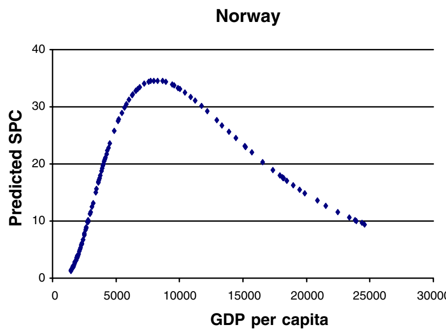
FINLAND Turning Point: GK$7,300
Ave GDPPC (1970-2001): GK$14,400



FRANCE Turning Point: GK$11,900
Ave GDPPC (1970-2001): GK$16,300

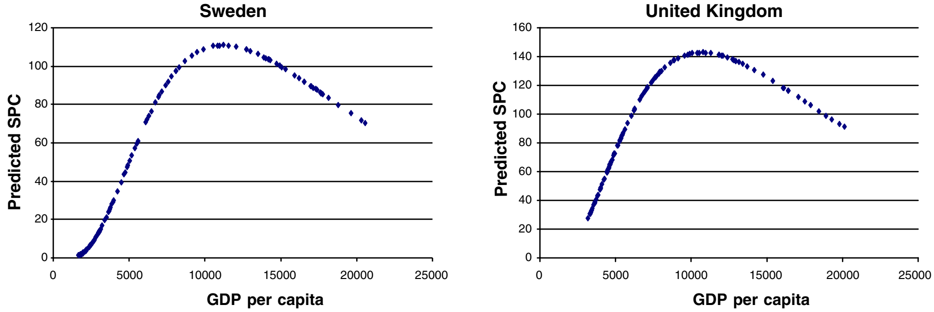


NETHERLANDS Turning Point: GK$10,100
Ave GDPPC (1970-2001): GK$16,100



NORWAY Turning Point: GK$8,200
Ave GDPPC (1970-2001): GK$17,200

Figure 3. Turning points from regression results (Table VI). Turning points and average GDPPC are rounded off to the nearest hundred. *Predicted SPC* is in kilograms of sulfur emissions per capita; *GDP per capita* (GDPPC) is in Geary-Khamis 1990 dollars (PPP).



SWEDEN Turning Point: GK$11,200
Ave GDPPC (1970-2001): GK$16,100

UK Turning Point: GK$10,700
Ave GDPPC (1970-2001): GK$14,900

Figure 3. Continued

Table VII. Regression results, aggregate of 12 countries

Variable	Coefficient	SE	t-Statistic	Probability
Intercept	−57.675	15.302	−3.770	0.000
ln (GDPPC)	13.251	3.333	3.980	0.000
ln $(GDPPC)^2$	−0.706	0.175	−4.040	0.000
TREND	−0.008	0.006	−1.300	0.197
REG1972	0.019	0.028	0.690	0.491
REG1975	−0.045	0.027	−1.680	0.095
REG1980	−0.056	0.067	−0.820	0.411
REG1984	−0.078	0.035	−2.210	0.029
REG1985	−0.049	0.022	−2.250	0.026
REG1987	−0.023	0.022	−1.050	0.298
REG1988	−0.088	0.041	−2.130	0.035
REG1989	−0.083	0.073	−1.140	0.257
REG1992	−0.170	0.043	−3.930	0.000
REG1993	−0.162	0.050	−3.230	0.002
REG1994	−0.181	0.089	−2.040	0.044
REG1996	−0.259	0.116	−2.240	0.027
REG1999	−0.258	0.081	−3.200	0.002
REG2001	−0.077	0.038	−2.030	0.045
WWI	0.035	0.023	1.490	0.140
WWII	−0.116	0.104	−1.120	0.267
R-squared	0.9269			
N	132			

Standard errors and covariance are White heteroskedasticity-consistent.
F-test statistic on the joint significance of all explanatory variables = 2,738.60, p-value = 0.00.
RESET: Regression of residuals on SPC^2 – t-stat = 0.05, p-value = 0.96.
RESET: Regression of residuals on SPC^3 – t-stat = −0.08, p-value = 0.93.
RESET: Regression of residuals on SPC^4 – t-stat = −0.12, p-value = 0.91.
RESET: Regression of residuals on SPC^2, SPC^3, SPC^4 – F-stat = 0.13, p-value = 0.94.

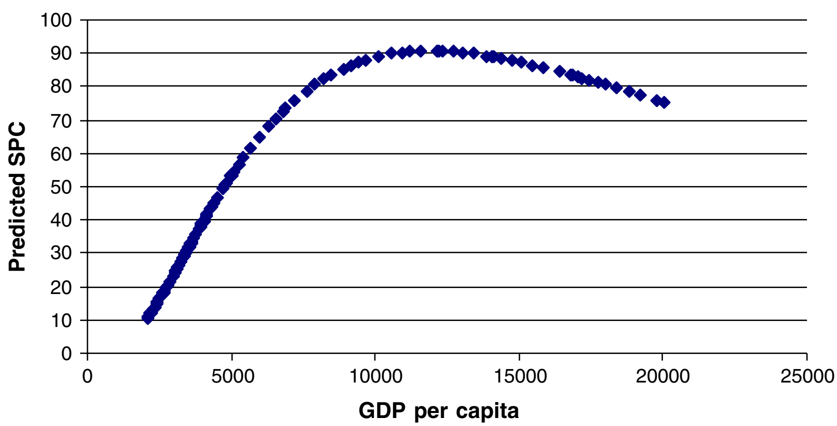
Directive in 1996 was implemented, SPC changes by -0.23% (i.e., $\exp(-0.256)$ *minus* 1). World War I and World War II do not have a statistically significant influence on the emissions. The model appears to be adequately specified as shown by the RESET results.

Figure 4 plots the predicted dependent variable against per capita income, *ceteris paribus*, which shows a pollution–income path that is shaped like an inverted U. The "turning point", or the level of income beyond which emission begins to decline, is approximately equal to GK$11,900. It is attainable given the average per capita income of the country group from 1970 to 2001, which is about GK$15,400. Finally the time trend is not significant at the 10% level.

5. Discussion about the impact of environmental regulations on the EKC shape

The results in the previous section show that statistically significant air pollution regulations have negative impacts on the per capita emissions. At a 10% level of significance, the years with the most number of negative recorded impacts in the individual countries are:[13]

- 1984 – EC Directive establishing a common framework on combating pollution from industrial plants.
- 1985 – Helsinki Protocol on reduction of sulfur emissions by at least 30% with respect to 1980 levels.
- 1987 – EC Directive limiting the emissions from heavy duty vehicles.



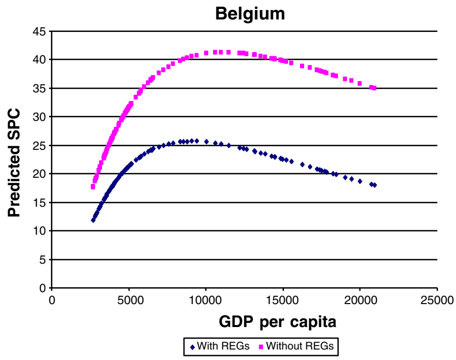
Turning Point: GK$11,900
Ave GDPPC (1970-2001): GK$15,400
(Note: The dollar values are rounded off to the nearest hundred.)

Figure 4. Plot of *predicted sulfur emissions per capita* (SPC) and *income per capita*.

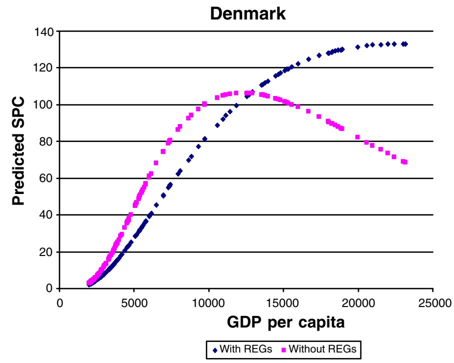
- 1988 – EC Directive limiting the emissions of sulfur dioxide, nitrogen oxide and particulates from power stations and other large combustion plants.
- 1989 – EC Directive on air pollution from new and existing municipal waste incinerators; and Air Quality Standards for UK.
- 1992 – EC Directive limiting emissions of hydrocarbons (as well as CO and NO_x) from new passenger and light goods vehicles.
- 1993 – EC Directive reducing the emissions of sulfur dioxide from the combustion of certain types of liquid fuels.
- 1994 – Second Protocol on Reduction of Sulfur Emissions (Oslo Protocol) where Western Europe is required to reduce 70–80% of 1980 levels.
- 1999 – Gothenburg Protocol, where emissions ceilings for sulfur, NO_x, VOC, and ammonia are established. Sulfur emissions should be cut by at least 63% compared to its level in 1990.
- 2001 – EC Directive to set national emission ceilings for pollutants that cause acidification and eutrophication and for ozone precursors (regardless of pollution sources)) in order to provide fuller protection for the environment and human health against their adverse effects. These pollutants are *sulfur dioxide* (SO_2), nitrogen oxide (NO_x), volatile organic compounds (VOC) and ammonia (NH_3).

Changes in GDP–emissions relationship come from several factors, such as changes in the scale and composition of economic activity, technological developments, income effects, or regulation on pollution reduction (Grossman and Krueger 1993; Panayotou 1997; Copeland and Taylor 2004). However, a number of studies in Section 2 have noted the substantial influence of regulation on abating the emissions. Figure 5 illustrates the GDP–emissions relationship with and without the EU directives and international regulations that limit sulfur emissions from various sources.[14] The EKC is substantially flattened by implementing the policies in all countries, but only up to a certain income level in Denmark and Netherlands. The result is similar to Panayotou (1997) where environmental policies dramatically lower the EKC, but unlike that study, the turning points are different for the cases with and without the policies. In Belgium, Finland, France, Norway, Sweden and as a group, the turning points are lower when there are policies implemented. The opposite is observed in the case of Denmark, Netherlands and the UK.

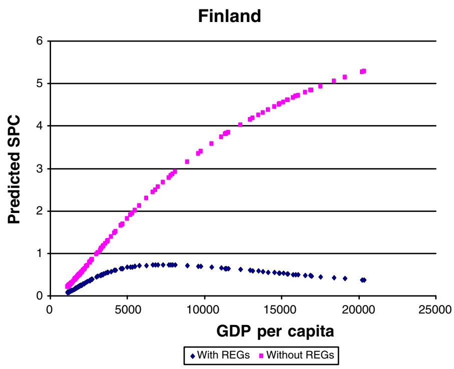
The results can also be interpreted in the light of the theoretical discussion of the EKC by Copeland and Taylor (2004). They identify four sets of factors that influence the GDP–emissions relationship: sources of growth, income effects, threshold effects and increasing returns to abatement. The first of these would result in an inverted 'U' if early stages of development were



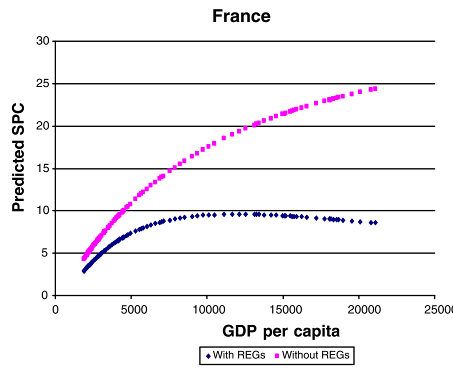
BELGIUM Turning Point (W/ REGs): GK$9,077
(W/o REGs): GK$11,200



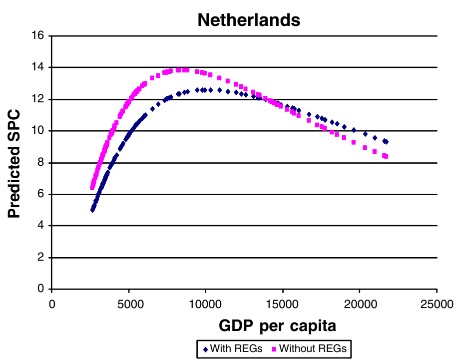
DENMARK Turning Point (W/ REGs): GK$22,700
(W/o REGs): GK$12,300



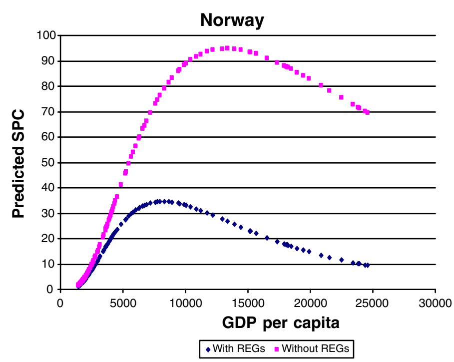
FINLAND Turning Point (W/ REGs): GK$7,300
(W/o REGs): GK$50,200



FRANCE Turning Point (W/ REGs): GK$11,900
(W/o REGs): GK$57,600

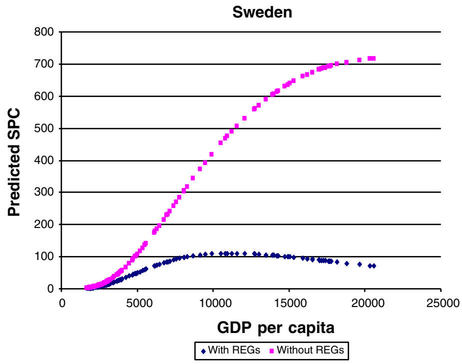


NETHERLANDS Turning Point (W/ REGs): GK$10,100
(W/o REGs): GK$8,500

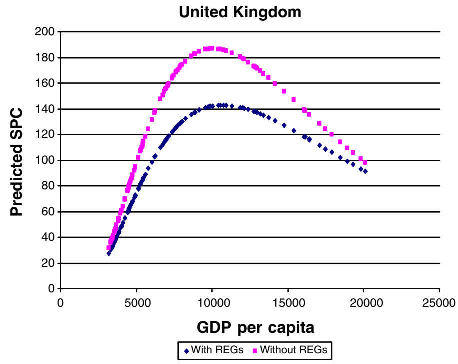


NORWAY Turning Point (W/ REGs): GK$8,200
(W/o REGs): GK$13,300

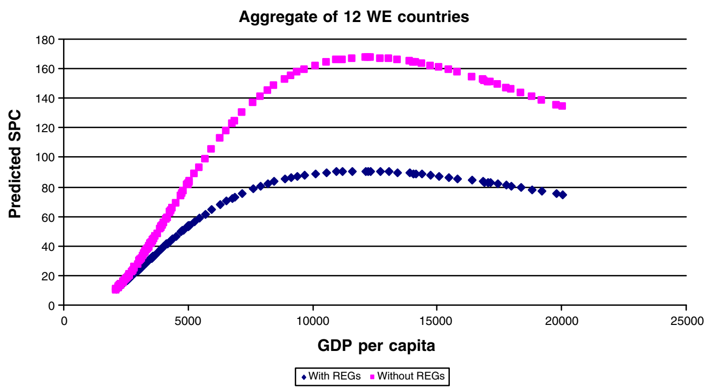
Figure 5. Pollution–income relationship with and without environmental policies (REGs). Turning points are rounded off to the nearest hundred. *Predicted SPC* is in kilograms of sulfur emissions per capita; *GDP per capita* is in Geary-Khamis 1990 dollars (PPP).



SWEDEN Turning Point (W/ REGs): GK$11,200
(W/o REGs): GK$21,600



UK Turning Point (W/ REGs): GK$10,700
(W/o REGs): GK$10,000



GROUP Turning Point: (W/ REGs): GK$11,900
(W/o REGs): GK$12,20

Figure 5. Continued.

based predominantly on physical capital accumulation and later stages predominantly on human capital/knowledge accumulation. This has broadly been the pattern of development during the sample period in Europe. The second factor results in an inverted ‘U’ if the income elasticity of demand for lower pollution increases with income, and if the growth process is ‘neutral’ – i.e., it does not favor the polluting industries over the non-polluting ones. The third factor, threshold effects, implies that options for abatement emerge discontinuously and there may be one or more periods when technological developments result in a sharp decline in the costs of abatement. If there is one such dominant period, the curve will tend towards an inverted ‘U’. Whether each of these conditions holds is hard to confirm, but a plausible case can be made for each of them for the period and countries analyzed. The fourth factor – increasing returns to abatement – should show up in a negative time trend. Our initial prior assumption was that we would indeed find evidence for such increasing returns but in the end the empirical evidence does not generally seem to support it.

Another interpretation of the Copeland and Taylor (*op. cit.*) decomposition of the EKC is in terms of the ‘composition’, ‘technique’ and ‘scale’ effects (the composition effect arising from the sources of growth and income elasticity factors mentioned above, and the ‘technique’ effect from the growth process and the threshold factors). In the ‘simple’ EKC, per capita income is assumed to capture all three of these effects. In our case the technique effect is partly picked up by the regulations (at least insofar as techniques are influenced by regulations). Hence the per capita income term is now largely picking up composition effects, which point to an inverted ‘U’, thus lending support for the underlying assumptions that would generate such a shape on those grounds.

6. Conclusions

This analysis is interesting and instructive about long-term relationships between emissions of a pollutant, such as SO_2 and economic growth. One important lesson here is that it is possible to reduce emissions that are byproducts of a modern economy, without sacrificing long-term growth.[15] All 12 European countries in the sample have observed steady growth over the last 140 years and more, while SO_2 emissions increased in the early years but declined sharply in the later years. Superficially, this would suggest that a conventional EKC between SO_2 and per capita GDP would hold and more detailed analysis does indeed support such a relationship. Taking the 12 countries as one entity, we also find an inverted ‘U’’ (i.e., quadratic or second order polynomial) relationship. Apart from per capita income, the emissions have been driven down by some of the environmental regulations. The paper also finds that the presence of the regulations shifts the turning point of the EKC to the left – i.e., at a lower per capita income in some countries (Belgium, Finland, France, Norway, Sweden) and to the right – i.e., at a higher level of income in others (Denmark, Netherlands and the UK). For the 12 countries as a whole, the move is to the left.

The support for the effectiveness of regulations in shifting the EKC, while encouraging, is not as strong as it might have been. The regulation dummies are not always significant, for example. The regulations act with different levels of strength over time and a dummy variable approach cannot pick up these variations. The fact that the dummy variables for the regulations work a little better at the aggregate level probably reflects an averaging out of national differences[16]. More work is needed to make this modeling more sophisticated.

Further work is also needed to identify other causal effects for the observed shape, and work on these lines is going on elsewhere. What this paper offers is support for the EKC shape as a whole and a confirmation of the importance of regulations in the dynamics of the EKC, in a context of the very long term view of the EKC relationship (i.e., over periods exceeding one century).

Acknowledgements

A version of this paper was presented at the Environmental and Resource Economists' Conference in Budapest, in June 2004. We would like to thank participants there for useful comments, which improved the paper. We also thank our colleague Tim Taylor for his suggestions on how to interpret the results. Finally, we thank two anonymous referees who provided valuable comments that have also resulted in a better final product. No one apart from ourselves is, of course, responsible for any errors.

Notes

1. Other Western European countries were not included in the final dataset for this study because either they do not have complete time series data for GDP between 1870 and 2001 (e.g., Ireland and Greece) or they do not have individual time series data as the data have been aggregated with other remaining countries in the region. In contrast, Portugal and Spain have complete GDP time series over the study period. When we tried to perform the regressions including these two countries: (a) they did not show an EKC; and (b) the estimated coefficients and corresponding statistical significance for the selected 12 countries remained unchanged. Hence, we maintained to use the original 12 countries.
2. e.g., Arrow et al. (1995), Stern et al. (1996), Stern (1998), Levinson (2000)
3. Dependent variable is calculated as the ratio between total emissions and total area of a country.
4. Austria, Belgium, Bulgaria, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Russia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, UK and USA.
5. This is documented by Lefohn et al. (1999).
6. http://www.emep.int
7. Suppose Country A is missing the sulfur emission observation in 1850 (SE_{1850}): $SE_{1850} = SE_{1851} \times (\text{Region } SE_{1850}/\text{Region } SE_{1851})$ where Region SE_t refers to the total sulfur emissions of the Western European countries (or regional total) for period t.
8. Or purchasing power parity (PPP) dollars
9. Fourteen regulations listed in Appendix A apply to the EU and five (those for 1972, 1979, 1985, 1994 and 1999) apply to all European countries. However, since some non-EU members, like Norway, respect EU environmental directives and others are indirectly affected, it is not clear to what extent they have been influenced by these regulations.

10. The augmented Dickey Fuller (ADF) test statistic for the residuals of the estimation with aggregated data is equal to an absolute value of 5.41, which is greater than the critical value of 1.95 at 5% level of significance. With panel data estimation, the ADF test statistic is equal to -2.51 with p-value $= 0.00$. Therefore, the null hypothesis of non-stationarity is rejected.
11. The Breusch–Pagan/Cook–Weisberg test for heteroskedasticity yields a chi-squared statistic of 1,029.4 (p-value $= 0.00$), which rejects the null hypothesis of 'constant variance of residuals'. The Wooldridge test for autocorrelation in panel data yields an F-statistic of 51.76 (p-value $= 0.00$), which rejects the null hypothesis of 'no first-order autocorrelation or AR (1)'.
12. The variables are obtained by summing up the data of the 12 countries. For example, to get the SPC variable, the sulfur emissions of the 12 countries were added up and divided by the total population of the 12 countries. The same method is done for GDPPC.
13. These are the regulations whose coefficient estimates are negative in seven or more countries. For reference, see Table VI.
14. The EKC without the regulations was derived for each country by running a regression on Equations 3 and 4 with no REG variables.
15. This may have implications for the potential to reduce CO_2 as well.
16. The other factor that could be relevant at the national level, but not at the aggregate level, is intra-European trade. If the process of development has resulted in specialization, with emissions intensive production shifting to low emissions countries, we would observe a weaker EKC effect in the countries to which such production shifted. Since environmental regulations, at least in the last 40 years or so have converged, the incentives for such shifts have been diminishing.

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Appendix A. Key European legislations relevant to sulfur emissions

Year	Regulation
1972	Environmental Action Program
1975	Directive 75/716/EEC: Concerned with the sulfur content of certain liquid fuels. Defined two types of gas oil (diesel and heating oil). Introduced in two stages the sulfur limits for these fuels. Amended in 1987: EC Directive 87/219/EEC: (a) The motor fuel (sulfur content of gas oil); and (b) the oil fuel (sulfur content of gas).
1979	International Convention on Long Range Transboundary Pollution: Introduced to control the transboundary effects of acid rain and to limit emission of acidifying pollutants.
1980	Directive 80/779/EEC on limit values for sulfur dioxide and suspended particulates: Over a year, the average level of black smoke (or fine particulates) cannot exceed eighty micrograms per cubic meter. The level of sulfur dioxide is dependent on the concentration of smoke. If there are less than or equal to forty micrograms per cubic meter of black smoke, the amount of sulfur dioxide cannot exceed 120 micrograms per cubic meter. When the amount of smoke exceeds forty micrograms per cubic meter, then the top limit of sulfur dioxide is reduced to eighty micrograms per cubic meter. Similar standards are set for wintertime ... and peak concentrations. (Manning chap. 4)
1984	Directive 84/360/EEC: Establishes a common framework directive on combating pollution from industrial plants.
1985	Helsinki Protocol on Reduction of Sulfur emissions: Reduce by 30% compared to 1980 levels. The target year is 1993.
1987	Directive 88/77/EC: Specified the measures to be taken against the emission of gaseous pollutants from diesel engines for use in vehicles. Controlled emissions of gaseous pollutants from heavy duty vehicles. Amended in 1991: EC Directive 91/542/EEC.
1988	Directive 88/609/EEC: Limited emissions of sulfur dioxide, nitrogen oxide and particulates from power stations and other large combustion plants.
1989	Directive 89/429/EEC: Directive on air pollution from existing municipal waste incinerators. Set limits on new waste incinerators.

Appendix A. Continued

Year	Regulation
1989	Directive 89/369/EEC: Directive on air pollution from new municipal waste incinerators. Set emission limits on new waste incinerators.
1992	Directive 91/441/EEC (see SI 1992 No. 2137): Limits emissions of carbon monoxide, hydrocarbons and oxides of nitrogen from new passenger and light goods vehicles.
1993	Directive 93/12/EEC: To reduce emissions of sulfur dioxide resulting from the combustion of certain types of liquid fuels, and to limit the harmful effects of such pollution on human beings and the environment. Amended by the following acts: Directive 98/70/EC and Council Directive 99/32/EC. The reduction in sulfur dioxide emissions applies to heavy fuel oils (liquid fuels derived from petroleum) and gas oil. The Directive does not apply to: • liquid fuels derived from petroleum used by sea-going ships; • gas oil for maritime use used by ships crossing a frontier between a third country and a Member State; • fuels intended for processing before final combustion; • fuels intended for processing in refineries.
1993	Directive 93/59/EEC: Limits emissions from new light commercial vehicles and vans (see McEldowney and McEldowney 1996, p. 269 for further directives limiting vehicular emissions).
1994	Second Protocol on Reduction of Sulfur Emissions (Oslo Protocol) • W. Europe to reduce 70-80% if 1980 levels. • E. Europe to reduce to 40-50%.
1996	Directive 96/61/EC (Integrated Pollution Prevention and Control Directive): To prevent or minimize emissions to air, water and soil, as well as waste, from industrial and agricultural installations in the Community, with a view to achieving a high level of environmental protection. Accordingly, the Directive: (i) lays down a procedure for applying for, issuing and updating operating permits; and (ii) lays down minimum requirements to be included in any such permit (compliance with the basic obligations, emission limit values for pollutants, monitoring of discharges, minimization of long-distance or transboundary pollution). A transitional period (30 October 1999 - 30 October 2007) is decreed during which existing installations can be brought into conformity with the requirements of the Directive.
1996	Directive 96/62/EC: This provides a statutory framework for controlling levels of sulfur dioxide, nitrogen dioxide, particulate matter, lead and ozone, benzene, carbon monoxide and other hydrocarbons.

Appendix A. Continued

Year	Regulation
1999	Gothenburg Protocol. Emissions ceilings for sulfur, NO_x, VOC, and ammonia. Sulfur should be cut by at least 63%, NO_x by 41%, VOC by 40% and ammonia by 17% compared to 1990.
1999	Directive 1999/30/EC: Aims to maintain or improve the quality of the ambient air by establishing limit values for the concentrations of sulfur dioxide, nitrogen dioxide and nitrogen oxides, particulates and lead, together with alert thresholds for concentrations of sulfur dioxide and nitrogen dioxide in the ambient air by evaluating those concentrations on the basis of common methods and criteria, and by bringing together suitable information on such concentrations in order to keep the public informed.
2001	Directive 2001/81/EC: Aims to set national emission ceilings for pollutants that cause acidification and eutrophication and for ozone precursors (regardless of the sources of pollution) in order to provide fuller protection for the environment and human health against their adverse effects. These pollutants are sulfur dioxide (SO_2), nitrogen oxide (NO_x), volatile organic compounds (VOC) and ammonia (NH_3) – causing acidification, eutrophication and tropospheric ozone formation (also referred to as "bad ozone", present at low altitudes, as contrasted with stratospheric ozone). The purpose of the emission ceilings is broadly to meet the following interim environmental objectives: • the areas with critical loads of acid depositions will be reduced by at least 50% compared with 1990; • ground-level ozone loads above the critical level for human health will be reduced by two-thirds compared with the 1990 situation. An absolute limit is also set. The guide value set by the World Health Organization may not be exceeded on more than 20 days a year; and ground-level ozone loads above the critical level for crops and semi-natural vegetation will be reduced by one-third compared with 1990. An absolute limit is also set. Member States are required to draw up programs, by 1 October 2002, for the progressive reduction of their annual national emissions. The programs must be updated and revised as necessary in 2006. They must be made available to the public and to appropriate organizations and submitted to the Commission. Moreover, Member States must prepare and annually update national emission inventories and emission projections for SO_2, NO_x, VOC and NH_3. These inventories and projections must be reported to the Commission and the European Environment Agency each year by 31 December at the latest.

Sources: European Union (2005); United Nations Economic Commission for Europe (2005).

Appendix A. Key legislations relevant to sulfur emissions in UK

Year	Regulation
1874	Other noxious gases added to Alkali Act.
1875	Public Health Act: Contained a section on smoke abatement from which legislation to the present day has been based.
1906	Alkali, etc. Works Regulation Act
1926	Smoke Abatement Act
1953	Grit came under control of Alkali inspectors. Reduce emissions to 0.5 grains per cubic foot and install precipitators.
1955	Environment Act. Became law in 1956. 7 years to re-equip, 10 years later, industry had reduced emissions 74%.
1956	Clean Air Act. ‘‘Subject to the provisions of this Act, dark smoke shall not be emitted from a chimney of any building, and if, on any day, smoke is so emitted the occupier of the building shall be guilty of an offence.’’ Section 1. Dark smoke is one whose color is equal to or darker than shade 2 of the Ringlemann Chart – a subjective measure. (Manning 1993 chap. 3) Smokeless zones allowed – not instituted until 1960.
1968	Clean Air Act. Extended the smoke control provisions of the 1956 Act and added further prohibitions on dark smoke emission.
1972	EC Directive 72/306/EEC: Measures to be taken against emissions from diesel engines for use in motor vehicles. Limited black smoke emissions from heavy duty vehicles.
1974	Control of Pollution Act: Allowed for the regulation of the composition of motor fuels. In addition, the Act limited the sulfur content of oil in furnaces and engines.
1975	EC Directive 75/716/EEC: Concerned with the sulfur content of certain liquid fuels. Defined two types of gas oil (diesel and heating oil). Introduced in two stages the sulfur limits for these fuels. Amended in 1987: EC Directive 87/219/EEC: (a) The motor fuel (sulfur content of gas oil); and (b) the oil fuel (sulfur content of gas).
1979	International Convention on Long Range Transboundary Pollution: Introduced to control the transboundary effects of acid rain and to limit emission of acidifying pollutants.
1980	EC Directive 80/779/EEC on limit values for sulfur dioxide and suspended particulates: OJ 1980 No. L229/30. Over a year, the average level of black smoke (or fine particulates) cannot exceed eighty micrograms per cubic meter. The level of sulfur dioxide is dependent on the concentration of smoke. If there are less than or equal to forty micrograms per cubic meter of black smoke, the amount of sulfur dioxide cannot exceed 120 micrograms per cubic meter. When the amount of smoke exceeds forty micrograms per cubic meter, then the top limit of sulfur dioxide is reduced to eighty micrograms per cubic meter. Similar standards are set for wintertime (18) and peak concentrations (19). (Manning chap. 4)

Appendix A. Continued

Year	Regulation
1984	EC Directive 84/360/EEC: Establishes a common framework directive on combating pollution from industrial plants.
1985	Helsinki Protocol on Reduction of Sulfur emissions. Reduce by 30% by 1993 compared to 1980 levels (Europa link).
1987	EC Directive 88/77/EC: Specified the measures to be taken against the emission of gaseous pollutants from diesel engines for use in vehicles. Controlled emissions of gaseous pollutants from heavy duty vehicles. Amended in 1991: EC Directive 91/542/EEC.
1988	EC Directive 88/609/EEC: Limited emissions of sulfur dioxide, nitrogen oxide and particulates from power stations and other large combustion plants. • Power stations to reduce emissions of sulfur dioxide and nitrogen oxide. • UK to reduce SO_2 by 60% of 1980 levels by 2003. • NO by 30% of 1980 levels by 1998. • UK Stated target of 30% for sulfur was an 'aim of policy' (Manning 1993 chap. 4)
1989	Air Quality Standards Regulations (S.I. 1989 No. 317). • One year: limit SO_2 to 120 microg/m^3if smoke less than 40 microg/m^3 (median of daily values) 80 microg/m^3, if smoke more than 40. • Winter: 180 if smoke less than 60 (median of winter values), 130 if smoke more than 60. • Year, peak 350 if smoke less than 150 (98 percentile of daily values), 250 if smoke more than 150. • From Leeson 1995: 229-230: these figures are the same as for Directive 80/779. Other EC directives to go into effect in the Air Quality Standards Regulations are 82/884/EEC (lead), 85/203/EEC (nitrogen dioxide) and 92/72/EEC (ozone)
1989	EC Directive 89/429/EEC: Directive on air pollution from existing municipal waste incinerators. Set limits on new waste incinerators.
1989	EC Directive 89/369/EEC: Directive on air pollution from new municipal waste incinerators. Set emission limits on new waste incinerators.
1990	Environmental Protection Act: Brings many smaller emission sources under air pollution control by local authorities for the first time and establishes a system of integrated pollution control for the most potentially polluting processes.
1992	Directive 91/441/EEC (see SI 1992 No. 2137). Limits emissions of carbon monoxide, hydrocarbons and oxides of nitrogen from new passenger and light goods vehicles.
1993	Directive 93/59/EEC. Limits emissions from new light commercial vehicles and vans (see McEldowney and McEldowney page 269 for further directives limiting vehicular emissions).

Appendix A. Continued

Year	Regulation
1993	Clean Air Act. Consolidation of 1955 and 1963 Acts.
1993	Stubble burning banned.
1994	Second Protocol on Reduction of Sulfur Emissions (Oslo Protocol) • W. Europe to reduce 70-80% of 1980 levels. • E. Europe to reduce to 40–50%.
1995	Environment Act (came into practice 1997 NAQA): This provides a statutory framework for controlling levels of sulfur dioxide, nitrogen dioxide, particulate matter, lead and ozone, benzene, carbon monoxide and other hydrocarbons.
1996	EC Directive 96/62/EC: This provides a statutory framework for controlling levels of sulfur dioxide, nitrogen dioxide, particulate matter, lead and ozone, benzene, carbon monoxide and other hydrocarbons.
1997	National Air Quality Strategy: The first National Air Quality Strategy was published in response to the Environment Act on March 12, 1997, with commitment to achieve new air quality objectives throughout the UK by 2005. It is renewed periodically. There are standards and objectives set for CO, NO_2, SO_2, particulates, ozone, lead, benzene and 1,3- butadiene. The government adopted the standard of 100ppb at 99.9% compliance. (electricity.org)
1999	Gothenburg Protocol. Emissions ceilings for sulfur, NO_x, VOC, and ammonia. Sulfur should be cut by at least 63%, NO_x by 41%, VOC by 40% and ammonia by 17% compared to 1990.
2000	The Air Quality Strategy for England, Scotland, Wales and Northern Ireland: The second National Air Quality Strategy was published with new air quality objectives for local authorities.

Source: European Union (2005).