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Reversal of the trend in global anthropogenic sulfur emissions

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Abstract

Global anthropogenic sulfur emissions increased until the late 1980s. Existing estimates for 1995 and 2000 show a moderate decline from 1990 to 1995 or relative stability throughout the decade. This paper combines previously published data and new econometric estimates to show a 22% decline over the decade to a level not seen since the mid-1960s. The decline is evident in North America, Western and Eastern Europe, and in the last few years in East and South Asia. If this new trend is maintained, local air pollution problems will be ameliorated but global warming may be somewhat exacerbated.

Keywords: Sulfate aerosols; Estimates; Emissions; Trends

1. Introduction

Anthropogenic sulfur emissions play a crucial role in three important environmental problems: local air pollution and smog, acid rain and dry deposition, and global climate change. Global emissions increased fairly continuously until the end of the 1980s (Lefohn et al., 1999). Existing global estimates for 1995 and a forecast for 2000 show a moderate decline from 1990 to 1995 (Olivier and Berdowski, 2001) or relative stability throughout the decade (Smith et al., 2001). In this paper, I present data for most countries of the world from 1850 to 2000, which combine previously published data and new econometric estimates. These data indicate a 22% decline in emissions over the decade of the 1990s to a level not seen since the mid-1960s.

The decline is evident in North America, Western and Eastern Europe, and in the last few years in East Asia as well. Emissions per capita in developing countries are far lower than historical emissions in the industrialized world and lower than in all industrialized regions apart from Western Europe today. These results support recent theoretical and empirical research on the relationship between economic development and emissions of pollutants that suggest that emissions are monotonic in income and that reductions in emissions are time-related rather than income-related (Stern, 2004, 2005b). If this new trend is maintained, local air pollution problems will be ameliorated but global warming may be somewhat exacerbated.

As sulfate aerosols increase the planetary albedo both directly and indirectly through increasing cloud cover, sulfur emissions are expected to be correlated with lower solar radiation at the surface. The trends established in this paper conform with recent estimates of changes in solar radiation at the surface (Pinker et al., 2005; Wielicki et al., 2005; Wild et al., 2005). These studies show global dimming up till 1985, 1990, or 1992 and a general trend to global brightening, with some regional exceptions, since then. This paper's estimated changes in anthropogenic sulfur emissions could be an explanation of these trends. However, the changes in radiative forcing that can be conventionally explained by changes in sulfur emissions are an order of magnitude smaller than some of the observations of changes in surface radiation.

ASL and Associates (1997) produced a database of sulfur emissions (documented by Lefohn et al., 1999) for individual countries for the period 1850–1990, which has been used in a number of climate studies. In the following, I refer to this source as "ASL". These estimates were superior to all previous global inventories (e.g. Hameed

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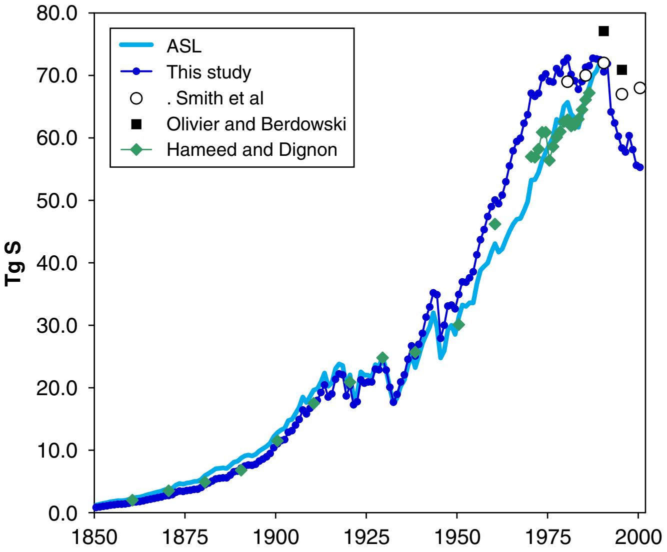

Fig. 1. Estimated global anthropogenic sulfur emissions.

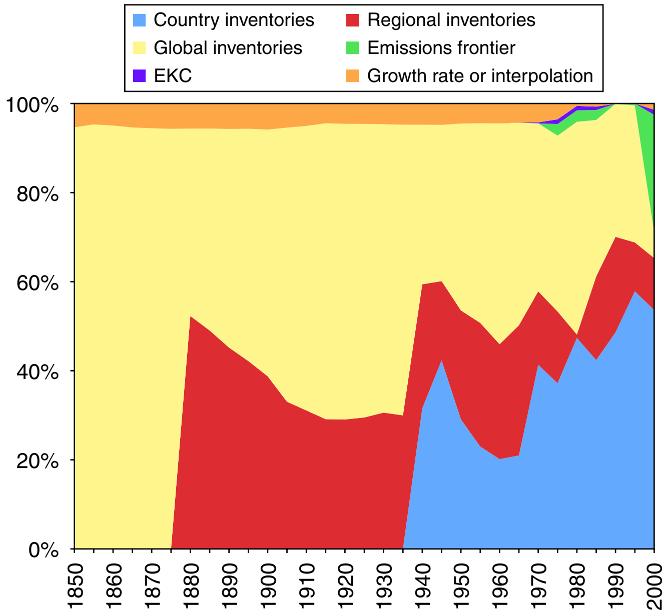

Fig. 2. Methods of estimation.

and Dignon, 1992; Spiro et al., 1992) in terms of the combination of spatial and temporal resolution and extent, though individual country and regional inventories may be superior in quality. These data show a 60-fold increase in global emissions from 1850 to 1989—from 1.2 to 72.2 Tg S. There are some brief reversals in trend, particularly during the Great Depression and towards the end of the First and Second World Wars (see the line marked ASL in Fig. 1).

Two global inventories have been constructed for 1995. Smith et al. (2001) developed estimates of global sulfur emissions for 1980–1995 and a forecast for 2000. But they do not provide data for individual countries, only for regions (gridded data is available for 1990), and estimates are only given for 5-year intervals. Olivier and Berdowski (2001) provide country-by-country estimates for 1990 and 1995 for all countries in the World (referred to in the following as "Edgar"). Both these newer estimates are also shown in Fig. 1. The Edgar data show that emissions declined 8% from 1990 to 1995. Smith et al. (2001) estimate a decline of 7% over the same period but forecasted that emissions would again increase by 2000 and they see relative stability over the period 1980–2000. ASL indicated a decline in emissions during the recession of the early 1980s but a continuation of existing growth trends from then till 1990. The new estimates show stability over the 1980s and then a precipitous decline and reversal of the 140-year trend in the 1990s.

The following section describes the methods used to derive the data presented in this paper while the remaining sections discuss the results, uncertainties in the estimates, and implications.

2. Methods

The estimates combine previously published data with new econometric estimates for countries and years with either no data or apparently poor quality existing estimates. The majority of the total emissions inventory is accounted for by existing estimates that are brought together here for the first time (Fig. 2).

The different sources and estimates are prioritized according to the expected level of accuracy of the data. Previously published data are of three types: individual country inventories usually developed by the respective governments, regional inventories (data is provided for individual countries but the same methodology is applied to each country and less detailed modeling is usually undertaken), and global inventories (again, data is provided for each country in each year but, typically, the methods are even less detailed). These three types of published data are used in this order of preference. Less preferred regional or global estimates are only used when official statistics or other single country inventories are not available. The most preferred data is at most available for a few decades and the less detailed estimates are used to estimate the growth rate of emissions in each year by extrapolating or interpolating emissions from a benchmark of the presumed higher quality data. When no previously published data are available, I use my own estimates based on two econometric models and simple linear extrapolation or interpolation, which is the crudest method. Appendices A, D, and E explain in detail the sources of the data or the estimation method used for each country in each year.

Fig. 2 shows the percentage of global emissions contributed by each method at 5-year intervals, which is the frequency of the Mylona and Edgar data. It is impossible to attribute many of the data points to a single method as many data points have been adjusted so that individual country time series smoothly transition between sub-series derived from different sources. I attribute each data point to the primary source used before any scaling or adjustment was applied. The annual time series appear much noisier because of the 5-year frequency of the Mylona and Edgar data. Other methods or data sources were used to interpolate between the available observations, but, because they were adjusted to provide a perfect interpolation, the overall level of the interpolated sections is dependent on the data source at the endpoints. Therefore, Fig. 2 provides a better indication of the primary source of the estimates than a chart of the annual series would.

With the exception of the last 5 years, over 90% of emissions are accounted for by existing inventories. The ASL database is the primary source in the first few decades, after which the Mylona and then the US EPA data are added. From 1970 onwards, progressively more inventories are available. After 1995 the emission frontier method accounts for a significant percentage of emissions with the 1995 Edgar estimates providing the benchmark for extrapolation.

2.1. *Previously published data*

For Europe, the former Soviet Union, Japan, the US, Canada, Mexico, Australia, New Zealand, and China data for the 1980s and 1990s, and in some cases earlier years, is available from a series of official sources, including national governments and international organizations, that collect information in the form of reports from member governments. These sources are described in detail in Appendix A. For East and South Asia, Streets, (2000b) and Carmichael et al. (2002) report estimates for 23 countries for 1985–1997 and 2000. Mylona (1996) provides estimates at 5-year intervals from 1880 to 1980 for most countries in Europe. For 1990 and 1995 I use Olivier and Berdowski's (2001) estimates for all countries not covered by the preceding sources. For years from 1850 to the earliest years provided by each of the preceding sources I estimate emissions by using the growth rates implied by the ASL data.

2.2. *Econometric emissions frontier model*

Where no data is available post 1990 or data appears to be particularly poor for 1971–89 (as is the case of some Eastern European countries and for all Sub-Saharan African countries except South Africa), I use one of three econometric methods. Where sufficient data are available, I estimate an updated version of the econometric emissions frontier model described in Stern (2002). The new version of the model includes an expanded number of explanatory variables and is estimated using a sample of 73 countries for the period 1971–1990 from the updated database described in Appendices A and C. The model estimates sulfur emissions S in country i and year t using the following function of economic outputs y and inputs x:

$$S_{it} = \gamma_i A_t \prod_{j=1}^{J} y_{jit}^{\alpha_j} \left(\sum_{k=1}^{K} \beta_k x_{it} \right) \varepsilon_{it}, \tag{1}$$

where the α's, β's, γ's, and A's are regression coefficients to be estimated using nonlinear panel data estimation and ε is a random error term. The outputs are value-added in services, manufacturing, non-manufacturing industry, and agriculture in country i and year t. The inputs are the primary energy inputs: coal, refined oil, natural gas, hydroelectric power, nuclear energy and biomass inputs; primary crude oil supply which is equal to oil refined in country; and primary smelting of copper, lead, zinc, and nickel. The α_j coefficients sum to zero. γ_i represents a country specific effect that models the relative efficiency of each country compared to the best practice frontier and A_t a time specific effect that is intended to model technological change. When estimates are extrapolated it is assumed that technology progresses at the average rate of progress in the estimation period. When a period between available estimates is interpolated, the rate of technological change is adjusted to create a perfect interpolation. For example, I use this model to interpolate estimates for 1998 and 1999 for some East Asian countries. The rate of technological progress is set so that emissions in 2000 are predicted correctly given the 1997 base year. The predictions of the model for 16 OECD countries in the 1990s were compared to the actual published emissions for those countries with the rate of technological change adjusted to match the 1995 observation. A regression of the logarithms of the published estimates on the logarithms of the predictions yields a coefficient of determination of 0.99 and a slope coefficient that is insignificantly different from unity (Stern, 2005a). Obviously, this model's forecasts are weakest when extrapolating rather than interpolating as the rate of technological change is assumed to be constant over the forecast interval and, therefore, the model will fail to capture any significant changes in the rate of increase in abatement, which expert opinion, if it were available, might provide. As shown in Appendix E, the longest periods of extrapolation are in countries and periods where such changes in technology are unlikely to be important, i.e. mostly in sub-Saharan Africa. Another potential source of bias in extrapolations is if there are significant differences between the relationship of emissions to the explanatory variables in the economies for which forecasts are produced and the relation between the variables in the sample used for estimation. Forecasts are produced for several former Soviet Republics, which do not have good analogues in the estimation sample (see Table 1). But the other countries not included in the estimation sample seem to have good analogues.[1]

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[1] Forecasts are produced using the emissions frontier method for the following countries that are not included in the estimation sample: Albania, Angola, Azerbaijan, Bahrain, Bangladesh, Benin, Bolivia, Cameroun, Congo, Cuba, Ethiopia, Kazakhstan, Lebanon, Macedonia,

Table 1
Econometric emissions frontier model

Variable	Coefficient	Standard error
Agricultural GDP	−0.0504	0.0307
Manufacturing GDP	0.2249	0.0358
Non- manufacturing GDP	0.0310	0.0230
Coal	11.9827	1.8108
Refined Oil	−0.0219	0.0031
Natural Gas	1.8347	0.5141
Hydropower	0.4616	0.3495
Nuclear Power	−3.0496	0.3169
Biomass	1.4906	0.2352
Crude Oil	5.2993	0.4170
Copper Smelting	0.0741	0.0333
Lead Smelting	0.1526	0.0501
Nickel Smelting	0.2431	0.0898
Zinc Smelting	−0.0250	0.0721
Maximum time effect (1974)	−0.0133	0.0368
Minimum time effect (1990)	−0.4054	0.0404
Maximum country effect (Zambia)	2.8138	0.3225
Minimum country effect (Singapore)	−0.7803	0.1321
R Bar Squared	0.985	
Pedroni cointegration test	−3.879	
Average change in time effect	−2.11% p.a.	

Sample: 1971–2000, Algeria, Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, China, Colombia, Costa Rica, Cote D'Ivoire, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Finland, France, Gabon, Germany, Ghana, Greece, Guatemala, Honduras, Hong Kong, India, Indonesia, Iran, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kenya, Korea South, Kuwait, Luxembourg, Malaysia, Mexico, Morocco, Mozambique, Nepal, Netherlands, New Zealand, Nicaragua, Nigeria, Norway, Paraguay, Peru, Philippines, Portugal, Saudi Arabia, Senegal, Singapore, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Taiwan, Tanzania, Thailand, Trinidad and Tobago, Tunisia, Turkey, United Kingdom, USA, Uruguay, Venezuela, Zambia, Zimbabwe.

The results of the econometric estimation are presented in Table 1. It is important to note that these effects are the average partial derivatives in the sample. Therefore, the small coefficient on copper smelting, for example, could indicate that the ore types and technologies differ substantially across countries and that this effect is largely picked up in the country effects. Similarly, the refined oil coefficient is negative and reflects a relative effect holding oil-refining (crude oil) constant. Also, all effects are relative to the base case, which is Algeria in 1971. Given these caveats, the overall pattern of results is somewhat expected with large effects from coal use and oil refining indicated by the crude oil variable. The total technological change effect is a 40% decline in emissions, *ceteris paribus*, from 1971 to 1990. The most emissions efficient country in the sample is Singapore and the least is Zambia, which makes sense. The implied relative efficiencies are very large. Singapore emits 46 times less sulfur, *ceteris paribus*, than Zambia. The Pedroni cointegration statistic is a model diagnostic that rejects ($P = 0.0001$) the hypothesis that the relation between the non-stationary variables in the model is spurious and purely due to stochastic trending behavior in the variables included in the model.

2.3. Environmental Kuznets curve model

When insufficient data are available to estimate (1), I use an environmental Kuznets curve model (EKC). An environmental Kuznets curve is a quadratic in logarithms relating emissions or concentrations of a pollutant to national income per capita. Such a model also includes country and time specific effects with the latter representing technological progress in reducing emissions. Stern (2004) provides an extensive discussion of the EKC literature. Sulfur emissions in year t and country i are given by

$$\ln(S/P)_{it} = \gamma_i + A_t + \beta_1 \ln(Y/P)_{it} + \beta_2(\ln(Y/P)_{it})^2 + \varepsilon_{it}, \tag{2}$$

where Y/P is GDP per capita in 1995 US dollars adjusted for purchasing power parity (PPP dollars). S/P is sulfur emissions per capita in kilograms of sulfur. The γ_i are country specific constants or effects and the A_t are time specific constants or effects that represent technological progress in reducing emissions that is common to all countries. ε_{it} is a random error term. This model assumes that all countries follow the same emissions trajectory as income per capita increases, holding the time effect constant, though the level of emissions differs across countries to the extent of the country fixed effect. Therefore, this model is likely to produce less accurate extrapolations than the frontier model as the model assumes that changes in economic input–output structure occur in the same way in each country and can be proxied by the level of GDP per capita.[2]

The sample includes 82 countries for the period 1971–90. The results are presented in Table 2. As found by Stern and Common (2001) and Stern (2002), the EKC is monotonic in income within the income range of the sample as the turning point level of income per capita where emissions begin to decline is \$52 590 per capita. The effect of a 1% increase in income is a 0.85% increase in emissions at the sample mean. The reduction in emissions due to time effects is more than twice as great as found by Stern and Common (2001)—a 45% total reduction, *ceteris paribus*. The most efficient country is Hong Kong and the least Zambia, which, again, are not surprising results.

(*footnote continued*)
Myanmar, Namibia, Pakistan, Panama, Siberia, Syria, Tajikistan, Togo, UAE, Uzbekistan, Vietnam, and Yemen.

[2] As in the case of the emissions frontier model projections are made for many countries that were not included in the estimation sample: Angola, Antigua and Barbuda, Bahamas, Bahrain, Barbados, Bhutan, Botswana, Cambodia, Cape Verde, Cuba, Fiji, Guyana, Haiti, Kazakhstan, Laos, Lebanon, Liberia, Macedonia, Madagascar, Malawi, Malta, Mauritania, Mauritius, Mongolia, Niger, Oman, Papua New Guinea, Qatar, Rwanda, Siberia, Sierra Leone, Sudan, Surinam, Swaziland, Togo, Turkmenistan, Uganda, and Uzbekistan. Again, it appears that the countries without good analogues in the estimation sample (see Table 2) are former Soviet Republics.

Table 2
Environmental Kuznets curve estimate

Variable	Coefficient	Standard error
ln(GDP/P)	3.9878	0.5979
$(\ln(GDP/P))^2$	−0.1834	0.0346
Maximum time effect (1971)	0.2363	NA
Minimum time effect (1990)	−0.2613	NA
Maximum country effect (Zambia)	−14.24	NA
Minimum country effect (Hong Kong)	−21.91	NA
Statistics		
$\bar{R}^2$	0.0974	
Hausman Statistic	6.9925 ($p = 0.0303$)	
Pedroni cointegration test	−3.6291 ($p = 0.00028$)	
Turning point	$52590	
Mean income elasticity	0.85	
Average change in time effect	−2.65% p.a.	

Sample: 1971–90, Algeria, Argentina, Australia, Austria, Belgium, Bolivia, Brazil, Canada, Chile, China, Colombia, Costa Rica, Cote D'Ivoire, Cyprus, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Ethiopia, Finland, France, Gabon, Germany, Ghana, Greece, Guatemala, Honduras, Hong Kong, Hungary, India, Indonesia, Iran, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kenya, Korea South, Kuwait, Luxembourg, Malaysia, Mexico, Morocco, Mozambique, Namibia, Nepal, Netherlands, New Zealand, Nicaragua, Nigeria, Norway, Panama, Paraguay, Peru, Philippines, Portugal, Romania, Saudi Arabia, Senegal, Singapore, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Syrian Arab Republic, Taiwan, Tanzania, Thailand, Trinidad and Tobago, Tunisia, Turkey, United Kingdom, USA, Uruguay, Venezuela, Zaire, Zambia, Zimbabwe.

The Hausman statistic ($p = 0.03$) tests whether the null hypothesis that the explanatory variables are not correlated with the time and country effects (see Stern (2004) for discussion). In the case of rejection, consistent estimation of a fixed effects model is possible, but the results are conditional on the effects present in the sample. The cointegration test statistic (Pedroni, 1997) rejects the null hypothesis of no cointegration, which means that the estimated relation is statistically valid despite the stochastically trending nature of the variables involved (see Stern, 2004).

Emissions are projected using the sample mean rate of technological progress of −2.65% per annum. Raw predictions were modified as necessary as described for the emissions frontier model.

2.4. Growth rate method

In cases where the data to estimate even model (2) are not available, I use the mean growth rate of sulfur emissions in the previous decade in the country in question to extrapolate the growth in emissions in the 1990s. Where interpolation is required, I use a simple linear curve. For extrapolation back to 1850 from the earliest other datapoint, I assume that emissions in the country in question grew at the same rate as total emissions in the country's region, using the eight global regions described in Appendix F. This model is obviously extremely crude and only used as a last resort.

3. Results

Fig. 1. presents these new estimates at the global level of aggregation.[3] As Mylona's (1996) estimates are lower in the earlier decades than ASL's for the countries she considered my global estimates are lower than ASL's up till 1930. From 1930 to 1990 my estimates are higher than ASL's estimates due to the inclusion of more sources of emissions, particularly for developing countries. However, the gap reduces. In particular, from 1980 to 1989 there is essentially no change in my estimated global emissions while the ASL estimates increase from 65.7 to 72.2 Tg S. The reason for this slowing trend in my estimates is the beginning of widespread sulfur abatement across many developed countries that was not sufficiently accounted for in ASL's modeling. After 1989, with the exception of 1991 when 4.7 Tg S was emitted by the Kuwait oil fires (Husain, 1994),[4] the trend reverses sharply downwards. The declining trend is due to the collapse of the Soviet Union and Eastern European economies, continued increases in abatement in developed countries, the East Asian financial crisis in 1997, and the beginning of significant efforts to reduce sulfur emissions in China and some other developing countries. Fig. 3 illustrates the regional trends for the last three decades for eight major world regions, defined in Appendix F. Emissions in North America and Western Europe decline throughout the period and emissions in Eastern Europe and the former Soviet Union reverse direction in the late 1980s. Asian emissions increase until 1997 when emissions began to decline, particularly in China. Emissions only rebounded slightly after these economies recovered from the 1997 Asian financial crisis. The big increase in Asian emissions in 1997 is entirely due to increased reported emissions for that year in China. Emissions elsewhere increase over time or decrease in the case of Africa as average incomes fell across the continent. Emissions shifted southward and eastward on a global basis. Fig. 4 shows the trends for the northern and southern hemisphere. An increasing proportion of emissions is in the Southern Hemisphere and so far no reversal of trend is evident in either South America or Oceania. Estimated emissions do, however, fall in South America in 2000 due to a reduction in copper smelting in Chile.

Interestingly, Oceania is now the "dirtiest" region in terms of emissions per capita (Fig. 5) an "honor" formerly held by North America. Fig. 5 also shows that prior to 1980 Eastern Europe including the former Soviet Union was not the dirtiest region in terms of per capita emissions, contrary to popular impressions. More spectacularly, the

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[3] Detailed country by country and year by year estimates are available from the author's website at http://www.rpi.edu/~sternd/ or on request. These results supersede earlier estimates described in Stern (2005a).

[4] This quantity was added to the model projection for Kuwait.

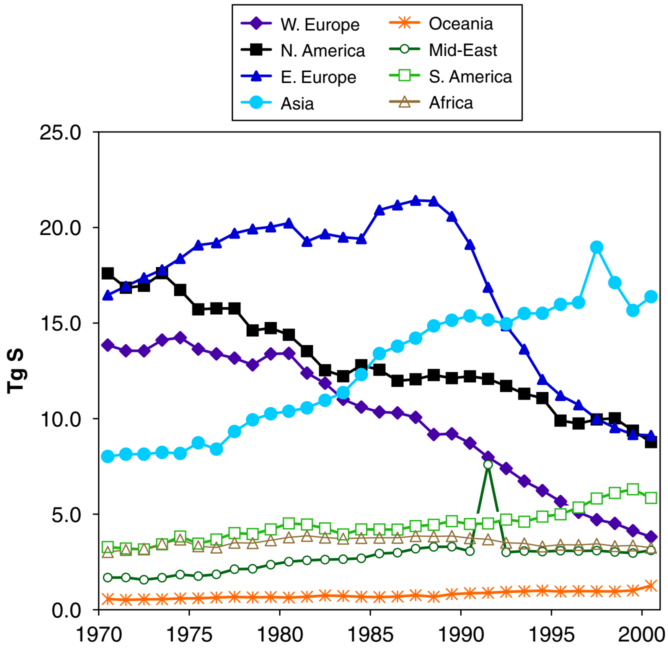

Fig. 3. Regional trends in sulfur emissions in the 1980s and 1990s.

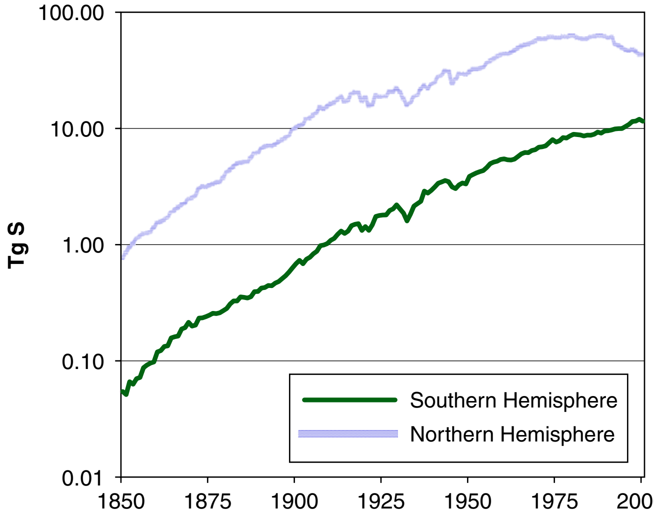

Fig. 4. Northern and southern hemisphere emissions 1850–2000.

figure shows that per capita emissions in Asia are the World's lowest and yet appear to be beginning to decline.

From 1987 to 2000 global emissions decline by 24% and since 1989 global emissions have fallen at an average rate of 2.4% per annum. The percentage decline in the Great Depression from 1929 to 1932 is around 28% in these data, while the post Second World War decline is 21%. However, those declines are not sustained over such long periods. By 1936 emissions were close to their 1929 level and by 1950 emissions were close to those in 1943.

4. Uncertainties

This section discusses the substantial uncertainties in the estimates. It is not possible to systematically estimate the standard error of the estimates given the disparate sources of uncertainty. Instead, I first discuss the potential relative uncertainties of the different data sources and then compare alternative estimates for the world and important countries to give an idea of how much difference the different assumptions and errors make. Finally, I look at the available post-2000 data to determine if the decline till 2000 is likely to be maintained.

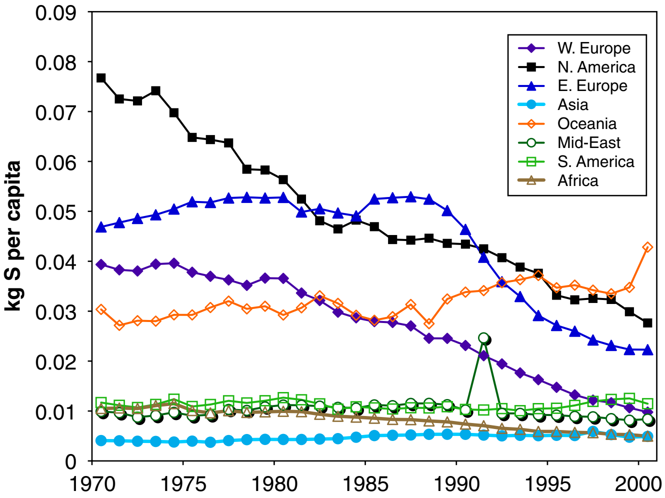

Fig. 5. Regional per capita emissions.

4.1. Data and model uncertainties

Uncertainties are present in the existing estimates that I have used, in the input data I have used to construct forecasts for those countries I forecast, and in the parameter estimates of my econometric models. I believe that the input data for the emissions frontier model forecasts have relatively low uncertainty. Data on energy use and commodities production are probably some of the most reliable of economic statistics. Additionally, the shares of different sectors in GDP change slowly. However, the econometric estimates in Table 1 show that the standard errors of the regression parameters are in many cases very large. In addition, the dependent variable in the regression analysis—estimated sulfur emissions—is uncertain and subject to measurement error—which is likely to reduce the efficiency of estimation, though not bias the estimates (Hausman, 2001). For the EKC model, the explanatory variable—GDP per capita in purchasing power parity dollars—is much more uncertain, but the growth rates of GDP over a 4 year time horizon, which is the maximum length of extrapolation for most countries, are much more accurate. Fig. 2 shows that a substantial proportion of emissions in the last 5 years were estimated using the emissions frontier method. The critical uncertain factor in this method is the estimated rate of technological change. The assumed rate in 1996–2000 was the rate derived from interpolating the 1990 and 1995 Edgar data using the emissions frontier model. To the extent that the

1995 Edgar data are incorrect or that the rate of technological change changed between the two periods, the estimates for 1996–2000 may be biased. The direction of this bias is unknown, a priori.

As explained above, I believe that some of the published data I used are more reliable than others. Official estimates for individual countries are mostly based on more detailed models and better data than estimates from regional and global assessments. Additionally, one might believe estimates for more recent years to be more accurate than for earlier years. However, the introduction of sulfur abatement technologies has introduced a new uncertainty to estimates for recent years. Several authors note that they make limited allowance for sulfur-retention (e.g. Mylona, 1996; Lefohn et al., 1999). Mylona (1996) estimates that true emissions in each country may differ from estimated emissions by ±30–45% due to uncertainty concerning the sulfur content of fossil fuels. If errors in different countries are not correlated with each other then they may cancel out at the global level, leading to the global estimates being more accurate than those for most individual countries. Smith et al. (2001) state that the estimated uncertainty of their global estimate is ±8%.

4.2. Comparing different estimates

Fig. 1 compares estimated global emissions for the present study, three other recent global assessments, and the earlier estimates of Dignon and Hameed (1989) and Hameed and Dignon (1992). The studies indicate similar levels of sulfur emissions in the 1980s and 1990s with Olivier and Berdowski (2001) estimating the highest level. They include more sources of emissions than the other two estimates. My estimates use individual country estimates that account for much more sulfur abatement in developed countries than the other global assessments include. The different assumptions do not, however, result in extremely different estimates of the level of global sulfur emissions in 1990. Both Smith et al. (2001) and Olivier and Berdowski (2001) estimate that emissions declined between 1990 and 1995. Though their estimated decline is not as radical as mine, the direction of change is established by all three estimates. Smith et al. (2001)'s prediction of an increase in emissions from 1995 to 2000 is a forecast and is not based on observations. Smith et al. (2001)'s estimates for the 1980s and 1990s are very close to my own. I have discussed the differences between my estimates and ASL's above. Dignon and Hameed (1989)'s estimates are very close to mine in the period before the Second World War, after which they are closer to the ASL estimates. However, the overall picture is one in which different estimates do not provide very different pictures of global emissions.

Table 3 presents estimates of emissions for the top 20 emitters and Japan in 1990, which according to my estimates contributed 56 Tg S of the total 70 Tg S emitted in that year. According to Edgar, the total emissions for this group was 63 Tg S, while according to ASL emissions were 60 Tg S. Taking the lowest estimate for each country, the group would have emitted 50 Tg S while taking the highest figure for each country results in a total of 69 Tg S. Edgar estimates, therefore, are not always the highest and my estimates are not always the lowest. The biggest

Table 3
Alternative estimates for key countries in 1990 (Gg S)

	Stern	EMEP/Official				Mylona	Min	Max
		Estimate	Streets	Edgar	ASL			
Australia	818	818		742	853		742	853
Brazil	946			946	527		527	946
Bulgaria	1004	1004		880	332	791	332	1004
Canada	1630	1630		1263	1366		1263	1630
Chile	998			1148	998		998	1148
China	9523		11 113	12 688	14 214		9523	14 214
Czecho-slovakia	1209	1209		1576	1574	1345	1209	1576
France	663	663		902	626	630	626	902
Germany	2663	2663		3643	3218	3118	2663	3643
India	2219		2219	2510	2193		2193	2510
Italy	886	886		1211	579	991	579	1211
Japan	488	488	417	1042	1579		417	1579
Mexico	1159	1159		1053	1028		1028	1159
Poland	1605	1605		2050	1681	1894	1605	2050
South Africa	1520			869	1520		869	1520
South Korea	853		853	1215	577		577	1215
Spain	1091	1091		1031	828	1509	828	1509
Turkey	797			797	1358	711	711	1358
United Kingdom	1861	1861		2062	1763	1686	1686	2062
USA	10 477	10 477		11 228	12 516		10 477	12 516
USSR	13 226			14 524	10 910	13 732	10 910	14 524
Total of above	55 619			63 382	60 241		49 761	69 049

Table 4
Post-2000 estimates (Gg S)

	China	USA	Mexico	Canada	Australia	Others with 2002 Data	Others with 2001 Data	All others
2000	9976	7422	1378	1190	1212	4728	2211	27173
2001	9740	7233	1322	1202	1259	4614	2160	
2002	9635	6970	1177	1197	1402	4414		
2003	10 794	7238	1082					

percentage variation across estimates is for Japan. Streets et al. (2000b)'s estimate concurs with the official estimate that I use, as does that of Smith et al. (2001). It is widely accepted that Japan sharply cut emissions in the early 1970s (Smith et al., 2001; Stern, 2005b). In absolute terms though, China and the former Soviet Union have the widest range of emissions estimates. For the former Soviet Union, ASL's estimate is the (low) outlier. The other estimates are close to each other. For China, the official estimate that I use is the lowest, while ASL's estimate is highest. Smith et al. (2001)'s estimate for China appears to be close to the Edgar estimate. Streets et al. (2000b) come closest to the official figure and are the most aware of the policy, economic, and technological developments in China that are leading to reduced emissions growth. All but one of the other estimates for China reported by Streets et al. (2000b) are lower than their own estimate. Therefore, I contend that even if the official estimate is exaggeratedly low, emissions from China are still probably in the lower part of the range and the error contributed to the global emissions estimate is of the order of 2%.

4.3. Post-2000 trends

How sure can we be that the trend of declining emissions till 2000 will be maintained beyond that year? Some rebound would seem likely in the current business cycle, especially as the downtrend in the 1990s was strongly affected by the collapse of the Soviet Bloc economies. Table 4 reports the available post-2000 data. Data is available for the US, Mexico, and China through 2003. Data is available for Canada, Japan, Australia, New Zealand, and many European countries through 2002. Many other European countries have data through 2001. The countries with post-2000 data had about half the total global emissions in 2000. In the US, China, Mexico, and the group of other countries with 2002 data, emissions decline through 2002. But in Canada and Australia emissions are flat and increasing, respectively. Emissions also decline in 2001 in the group with just 2001 data. This year was a recession in many countries. According to State Environmental Protection Agency (SEPA) data, emissions rebounded by more than 1 Tg S in China in 2003. Also in 2003, emissions rose by a few percent in the US but declined strongly in Mexico. We can conclude that global emissions likely declined through 2002 but that in 2003 and following years emissions could be rebounding moderately.

5. Discussion and conclusion

This study has revealed that changes in the pattern of global sulfur emissions have been more dramatic than previously believed (Smith et al., 2001). These results are supported by evidence on the diffusion of pollution abatement technologies to developing countries such as China (Dasgupta et al., 2002; Stern, 2004; Hilton, 2006). Success in reducing emissions and concentrations of pollutants such as sulfur dioxide in the developed countries in the 1970s and 1980s helped generate the idea of the environmental Kuznets curve in the early 1990s. This concept supposes that pollution in less developed countries rises as income per capita increases but after a threshold is passed ambient concentrations or per capita emissions decline with increasing per capita income. This concept strengthened pre-existing beliefs that developing countries were "too poor to be green" (Martinez-Alier, 1995) and that the only way to attain a decent environment in most countries is to become rich (Beckerman, 1992). These views have also permeated media and policy debates (Stern, 2004). However, extensive econometric evidence now shows that this model is not statistically robust (e.g. Stern, 2004; Day and Grafton, 2003; Dijkgraaf and Vollebergh, 1998; Harbaugh et al., 2002; Millimet et al., 2003; Perman and Stern, 2003). Instead, emissions of sulfur dioxide, carbon dioxide, and other pollutants appear to increase with rising income but to decrease over time with technological improvements (Stern, 2004).[5] The elasticity of emissions with respect to income is likely to fall with rising income but never to become negative.[6] The rate of technological change has been faster on average among developed countries than developing countries (Stern and Common, 2001; Stern, 2005c) but is occurring across a broad range of income levels. Income is not the only nor the most important factor determining to what degree best practice technology is adopted (Stern, 2005b) and poverty appears to delay but not prevent the adoption of abatement technology (Hilton, 2006). The fact that

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[5] Ambient concentrations of some pollutants may fall with income after a threshold is passed because of the suburbanization and industrial decentralization that accompanies the development process. This decentralization reduces peak and average urban population densities and spreads economic activity and pollution sources more uniformly across space (Stern, 2004).

[6] The elasticity is defined as the percentage response of emissions to a 1% increase in income.

emissions of some pollutants are already falling in East Asia, particularly in China, partly as a result of explicit environmental policies (Dasgupta et al., 2002; Stern, 2004), will eventually have to result in a change in the attitude that only wealthy countries can make environmental improvements and that maybe even wealthy countries cannot afford to make such moves.

A recent set of papers published in *Science* examines a change from a trend towards declining solar radiation at the Earth's surface ("global dimming") to one of increasing radiation or "global brightening". From 1960 to 1990 various surface observations indicated a decline of 6–9 $\mathrm{W\,m^{-2}}$ (Wild et al., 2005). Wild et al. (2005) find a significant brightening in Europe from 1985 to 2000 as measured by ground-based instruments. Other areas of the world also saw a brightening or leveling off in the decline (China, Australia) with only India showing continued dimming. Surface-based BSRN data showed an increase in radiation at the surface of 6.6 $\mathrm{W\,m^{-2}}$ in the period 1992–2001. Earthshine data (reflection from the moon) show a similar trend until 2002. Satellite data examined by Pinker et al. (2005) show an increase of 0.16 $\mathrm{W\,m^{-2}}$ per year from 1983 to 2001 with a minimum in 1990. The CERES satellite data show a 0.9 $\mathrm{W\,m^{-2}}$ brightening over 2000–04 (Wielicki et al., 2005).

Both the date of the turning point and the relative changes in 1960–90 versus the 1990s in this solar radiation and albedo data closely match the sulfur emission results in this paper. However, the magnitude of the albedo/radiation changes is much greater than conventional estimates of the changes in radiative forcing due to changes in anthropogenic sulfur emissions. Using a standard formula for the direct and indirect effects of sulfur emissions and setting the radiative forcing due to this forcing at a relatively strong $-2\,\mathrm{W\,m^{-2}}$ (Harvey and Kaufmann, 2002) in 1990, I find that the increase in radiative forcing from 1985 to 2000 should be 0.35 $\mathrm{W\,m^{-2}}$ with an average annual rate of increase of 0.04 $\mathrm{W\,m^{-2}}$ from 1991 on. Taking into account changes in solar irradiance at the top of the atmosphere (Lean, 2000) results in an estimated total increase in radiative forcing of 0.50 $\mathrm{W\,m^{-2}}$. These maximal potential effects are much less than even the most conservative measurements discussed above. The maximum forcing from the Mount Pinatubo eruption is around $-3\,\mathrm{W\,m^{-2}}$. This might explain a brightening trend over the 1990s as the emissions from the eruption dissipated. However, the dimming observed in the previous decades cannot be explained by an increase in stratospheric sulfates. In any case, the magnitude of the observational values for global dimming and brightening are puzzling as they are much larger than any of the accepted factors that are believed to cause global climate change.

In conclusion, the data presented in this paper, despite some uncertainties, is compatible with existing estimates for earlier periods, can be explained in terms of economic theory and econometric results, and seems to match trends in surface solar radiation though it cannot explain the extreme magnitude of those changes.

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Appendix A. Sources of published sulfur data

The countries and sources of the published data are described in the following. The sectoral coverage of the different sources is described in Appendix B.

A.1. East and South Asia

Streets et al. (2000b) report data for 23 countries in East and South Asia: Bangladesh, Bhutan, Brunei, Cambodia, PRC, Hong Kong, India, Indonesia, Japan, North Korea, South Korea, Laos, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Taiwan, Thailand, and Vietnam. The period of the data is 1985–97. Carmichael et al. (2002) update this data for 2000 and also include data on emissions from ships in Asia. These data are available online at:

http://www.cgrer.uiowa.edu/people/carmichael/ACESS/Emission-data_main.html.

Data for emissions from **ships** in Asian waters for 1988, 1990, 1993, 1994, and 1995 are available in Streets, et al. (2000a). Earlier figures that appear in a chart in Carmichael et al. (2002) were supplied by David Streets.

For **Japan** there are also partial OECD data for 1970–89 and for 1990–2000 Japan has data submitted to the UNFCCC. I interpolate this data using the Streets and ASL data to derive a consistent series.

For **China** for 1995–2003 I use the *State of the Environment Report and State Environmental Statistics Report* published by the State Environmental Protection Agency (SEPA) in English or Chinese and available from their website http://www.zhb.gov.cn/english/chanel-2/index.php3?chanel = 2. I assumed that Streets et al. (2000b)'s data was correct for 1985 and I used the percentage changes in Streets et al. (2000b)'s data for 1986–94 with a 3.003% p.a. rate of technological change deducted in order to match up the two series in 1995.

A.2. Europe and the Former Soviet Union

Data is available from the EMEP website (www.emep.int) for 1980–2001 for the following countries: Armenia, Austria, Belarus, Belgium, Bosnia and Hercegovina, Bulgaria, Canada, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Kazakhstan, Kyrgyzstan, Latvia, Liechtenstein, Lithuania, Luxembourg, Macedonia, Moldova, Monaco, Netherlands, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, European Turkey, Ukraine, United Kingdom and Yugoslavia.

Most Western European countries have a complete data set as does the Russian Federation and many other eastern European and former Soviet Union countries. Coverage in other countries is variable, from a few missing years to only a few years of observations. Data for some countries in this region (such as Uzbekistan) were obtained from the UNFCCC website.

Additional data for the 1970s is available from earlier OECD (various issues) publications for: Canada, Denmark, Finland, France, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom. This data was interpolated where necessary in the same manner as the data for Japan.

For the years 1880–1980 data is available for each fifth year from Mylona (1996) for most countries in Western and Eastern Europe. I interpolated the missing years using the annual growth rates implied by the ASL database adjusted to match the growth over each 5-year period in the Mylona data.

A.3. United States

Data for 1940–2001 are available from United States EPA (US EPA) (2000, 2003) and updated to 2003 from the EPA website.

A.4. Australia

Estimates for 1990–2002 are from the Australian Greenhouse Office (2002).

A.5. New Zealand

Estimates for 1990–2002 are from the UNFCCC website.

A.6. Mexico

Data for 1985–2003 are from various editions of *Sistema de Cuentas Economicas y Ecologicas de Mexico* published by the Instituto Nacional de Estadística, Geografía e Informática (INEGI).

A.7. Shipping

Carmichael et al. (2002) provide estimates of emissions from shipping in Asian waters. Estimates for the world as a whole are provided by Smith et al. (2001).

A.8. Global

Olivier and Berdowski (2001) provide estimates for all countries for 1990 and 1995. These are used for 1990 and 1995 for all countries not mentioned above. These data are available online at:

http://arch.rivm.nl/env/int/coredata/edgar/data32_so2.html

and are referred to as Edgar data. For years from 1850 to 1990, data are available from the ASL database described by LeFohn et al. (1999). The growth rates implied by this database are used for all observations where the other published estimates described above are not available. For years after 1990 where there is no published data the econometric estimates described in the methods section in this paper were used.

Appendix B. Sectoral coverage of sulfur emissions data sources

This appendix notes differences in the emissions sources coverage of the different emissions data publications used in this study. This information is not available for a large number of countries where I used data submitted by member governments to international organizations who then reported the data. In many cases, even though a source category is included in a study or database, information is missing on that emissions source for some (or many) countries in some (or many) years.

The Edgar data set (Olivier and Berdowski, 2001) is very comprehensive in source coverage and includes all the major sources of sulfur emissions. US EPA (2000, 2003) is also a comprehensive data set.

Mylona (1996) includes the following sources in her estimates: combustion of solid and liquid fossil fuels; production of copper, lead, and zinc; production of wood pulp; production and consumption of coke in the iron and steel industry; cement production. The ASL database (LeFohn et al., 1999) includes: coal, petroleum, copper, lead, nickel, and zinc. Therefore, neither of these sources includes biomass and ASL includes fewer industrial processes.

Streets et al. (2000b) and Carmichael et al. (2002) base their estimates on the RAINS–ASIA inventory, which includes fossil fuel, biomass, and in theory industrial processes. However, data for the latter important source seems to be missing in practice.

Australian Greenhouse Office (2002) does not include emissions from biomass burning, cement production, or pulp and paper production. Many other more minor sources have not been estimated either.

The Mexican and Chinese government data is organized on a sectoral basis rather than a fuel or process basis. INEGI (1996, 1999, 2000, 2002, 2004) lists emissions from electricity generation, oil refining, industry, residential and commercial, agricultural, fisheries, mining, and construction sectors, and miscellaneous sectors, but further details on specific sources is not provided. SEPA (various years) lists industrial and municipal emissions.

Appendix C. Data sources for explanatory variables used in econometric estimates

Energy use. Data are from the International Energy Agency (2002, 2003) for 1986–2000 for non-OECD and for OECD for 1999–2001 (both have select earlier years) and IEA online data. Data were collected for total primary energy supply of crude oil, refined petroleum products, natural gas, coal, hydropower, nuclear power, and biomass fuels. Other energy use categories were considered small enough to ignore. Primary supply of refined petroleum products is equivalent to actual end use oil consumption in a country, while primary supply of crude oil is the quantity of oil refined in a country. Some countries such as the Netherlands carry out extensive oil refining for export, while other countries, such as Germany import significant amounts of refined product.

GDP and population. I obtained the data from the Penn World Table version 6.1 (Heston et al., 2002). Any gaps were filled from the *World Development Indicators Online*.

Economic Structure. The structure of value added by industry for non-OECD countries was obtained from the *World Development Indicators Online* published by the World Bank (2003). For OECD countries I used data obtained from the *SourceOECD* website.

Metal Smelting. Data on primary production of refined copper, lead, zinc, and nickel for 1980–2000 were received from the United Nations Industrial Development Organization. These data are reported in the *Yearbook of Industrial Statistics*. For copper, lead, and zinc I obtained the same data for 1971–1979 from the hardcopy version. For nickel I obtained data for 1971–1979 from the United States Bureau of Mines *Minerals Yearbook*.

Appendix D. Boundary changes and transcontinental countries

My general approach is to make borders as comparable as possible to those of the present day. Therefore, where countries have merged—for example Germany—I report the figures for the merged country for all years. Where countries have split I report separate figures as far back as possible. This section also reports on methods of interpolation for these countries that were not described above.

Czechoslovakia. From 1980 I report the Czech Republic and Slovakia separately and as a single country before 1980. Estimates for Slovakia for 1981–84 were estimated by interpolating total emissions for Czechoslovakia using the growth rates in the ASL data and subtracting the EMEP data for the Czech Republic.

Korea. The ASL database gives separate figures for North and South Korea from 1947.

Pakistan. Bangladesh and Pakistan are treated as separate countries starting in 1972 and a single country before that date. Pakistan is included in India for years before 1948.

Turkey. Emissions estimates for Turkey as a whole for 1990 and 1995 are provided by Edgar. I estimate emissions for 1991–2000 for Turkey as a whole using the emissions frontier method fine-tuned to fit the 1995 Edgar estimates. EMEP data are available for European Turkish emissions for 1980–2000. I extrapolate estimates for 1880–1989 for the whole of Turkey using ASL estimates. Before 1980 estimates for European Turkey are available from Mylona (1996). I interpolate these five yearly figures using the ASL data. Estimates for Asian Turkey are found by subtracting the estimates for European Turkey from those for the whole of Turkey.

USSR. For 1990 and 1995, I use the Edgar estimates for those republics/countries without EMEP estimates (Tajikistan, Turkmenistan, Kazakhstan, Azerbaijan, Uzbekistan) and interpolate using the frontier and EKC methods. EMEP data for Russia only cover European Russia. To estimate Asian Russia or Siberia in 1990 and 1995 I subtract the EMEP estimate for Russia from the Edgar estimate for Russia. Total Russian emissions are then interpolated using the EKC and frontier methods. The Edgar estimate for Russia looks very plausible—using the frontier method it would imply that Russia has a similar emissions efficiency to other middle income countries and some less emissions efficient high income countries. Data are reported for the USSR and for constituent republics where available. Estimated emissions for the Soviet Union in 1990 are 23% greater than the ASL estimate. As ASL figures cover the entire USSR, while Mylona only covers the European USSR since the revolution I use the growth rates in the ASL data for years till 1990.

Vietnam, Germany, and Yemen. Are each reported as a single country in all years.

Yugoslavia. Estimates from 1980 on are given for the separate former Yugoslav republics based on EMEP data and until 1980 for Yugoslavia based on Mylona (1996) and ASL. I interpolate values for Croatia for 1981–89 and for Bosnia and Macedonia for 1980–89 as a constant proportion of Yugoslavia's total EMEP emissions solved iteratively. In the 1990s for Bosnia-Hercegovina I use the Edgar estimate for 1995 and the EMEP value for 2000 and interpolate the other values in the missing years based on the rate of change in the former Yugoslavia as a whole. For Macedonia I use Edgar estimates for 1990 and 1995 and EMEP for 1997 and 2000 and the same method of interpolation. I report estimates for all these countries separately from 1980 on. Emissions for Serbia for 1851 to 1912 are attributed to Yugoslavia.

Others. I added Cape of Good Hope to the ASL estimates for South Africa between 1926 and 1935. French Equatorial Africa is attributed to Gabon during 1950–57. French-Indo China refers to Laos. Emissions for French West Africa are attributed to Senegal. Estimates for the Leeward Islands are attributed to Antigua and Barbuda. Rhodesia-Nyasaland is split between Zimbabwe and Malawi from 1950 to 1963 (mostly attributed to Zimbabwe, but allowing for exponential growth in emissions in this period in Malawi). The various states of Malaysia, which appear separately in the ASL database, are reported as a single country. Japan includes the Ryuku Islands when these are listed separately by ASL. Newfoundland data are included in Canada when they are listed separately by ASL. Rwanda and Burundi are reported as separate countries. Hungarian Kingdom data in Mylona are attributed to Hungary.

Shipping. Data for shipping in Asian waters were subtracted from the estimates of Smith et al. (2001) for global shipping to derive an estimate for shipping in the rest of the World.

Appendix E. Methods used to estimate emissions

In this section, I note which of the three methods was used to estimate emissions in each country in each year. When not otherwise specified, the data for that country and those years is from the published sources.

E.1. Emissions frontier method

1971–89, 1991–94, and 1996–2000 Benin, Cameroun, Congo, Cote d'Ivoire, Gabon, Ghana, Kenya, Mozambique, Nigeria, Senegal, Tanzania, Zambia, Zimbabwe

1971–76, 1981–89, 1991–94, 1996–2000 Togo

1971–89, 1991–2000 Zaire

1975–76, 1991–94, and 1996–2000 UAE

1981–89, 1991–94, and 1996–2000 Ethiopia

1985–89, 1991–94, and 1996–2000 Angola

1991–93 and 1996–2000 Jamaica

1991–93, 1995–97, 1999–2000 Uruguay

1991–94 and 1996–2000 Nicaragua

1991–95 Bahrain

1991–94 and 1996–2000 Albania, Algeria, Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, Egypt, El Salvador, Guatemala, Honduras, Iran, Jordan, Kuwait (For 1991 data from Husain, 1994, is added), Morocco, Namibia, Panama, Paraguay, Peru, Saudi Arabia, South Africa, Syria, Trinidad and Tobago, Tunisia, Turkey, Venezuela, Yemen

1992–93 and 1995–2000 Uzbekistan

1992–2000 Tajikistan

1992–94 and 1996–2000 Azerbaijan

1996–2000 Cuba, Kazakhstan, Lebanon, Macedonia, Siberia

1998–99 Bangladesh, Hong Kong, India, Indonesia, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Singapore, South Korea, Sri Lanka, Taiwan, Thailand, Vietnam

E.2. EKC method

1958–89, 1991–94, and 1996–2000 Guyana

1960–89, 1991–94, and 1996–2000 Burundi, Rwanda

1961–89, 1991–94, and 1996–2000 Cape Verde

1969–84 Angola

1971–80 Ethiopia

1971–89 Namibia

1971–89, 1991–94, and 1996–2000 Botswana, Madagascar, Malawi, Mauritania, Mauritius, Niger, Sierra Leone, Swaziland

1972–89, 1991–94, and 1996–2000 Haiti

1975–89, 1991–94, and 1996–2000 Malta, Sudan

1977–89, 1991–94, and 1996–2000 Antigua and Barbuda

1978–89, 1991–94, 1996–2000 Uganda

1980–89 Latvia

1982–88 Liberia

1985–89 and 1991 Tajikistan

1986–89, 1991–94, and 1996–2000 The Bahamas

1987–89, 1991–94, and 1996–2000 Oman, Turkmenistan

1991 Uzbekistan

1991–93 Cuba, Lebanon

1991–94 Kazakhstan, Macedonia, Siberia

1991–94 and 1996–2000 Israel

1991–94 and 1996–2000 Barbados, Fiji, Papua New Guinea, Qatar, Surinam

1996–2000 Bahrain

1998–99 Bhutan, Cambodia, Laos, Mongolia

E.3. Growth rates method

1989, 1991–94 1996–2000 Liberia.

1991–94 and 1996–2000 Afghanistan, Bermuda, Burkina Faso, Central African Republic, Chad, Djibouti, Eritrea, Faeroe Islands, Gibraltar, Greenland, Guam, Guinea, Guinea-Bissau, Iraq, Libya, Macao, Mali, Martinique, Netherlands Antilles and Aruba, New Caledonia, Puerto Rico, Reunion, Saint Pierre and Miquelon, Somalia, US Virgin Islands

1996–99 Bosnia and Hercegovina

1998–99 Brunei, North Korea

Appendix F. Regions

The regions include the following countries:

W. Europe. Austria, Belgium, Cyprus, Denmark, Faeroe Islands, Finland, France, Germany, Gibraltar, Greece, Iceland, Ireland, Italy, Liechtenstein, Luxembourg, Malta, Monaco, Netherlands, Norway, Poland, Portugal, Spain, Sweden, Switzerland, European Turkey, United Kingdom.

E. Europe and the Former Soviet Union. Albania, Armenia, Asian USSR, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Czechoslovakia, Estonia, European Russia, FYR Macedonia, Georgia, Hungary, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Romania, Serbia, Serbia-Montenegro, Siberia, Slovakia, Slovenia, Tajikistan, Turkmenistan, Ukraine, USSR, Uzbekistan, Yugoslavia.

Middle East and North Africa. Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, Asian Turkey, UAE, Yemen.

Asia. Afghanistan, Bangladesh, Bhutan, Brunei, Cambodia, China, Hong Kong, India, Indonesia, Japan, Korea, Laos, Macau, Malaysia, Mongolia, Myanmar, Nepal, North Korea, Pakistan, Philippines, Singapore, South Korea, Sri Lanka, Taiwan, Thailand, Vietnam.

Africa. Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Congo, Cote d'Ivoire, Djibouti, Eritrea, Ethiopia, Gabon, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Senegal, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zaire, Zambia, Zimbabwe.

Oceania. Australia, Fiji, Guam, New Caledonia, New Zealand, Papua New Guinea.

North America. Bahamas, Bermuda, Canada, Greenland, Puerto Rico, St Pierre et Miquelon, USA, US Virgin Islands.

Latin America. Antigua and Barbuda, Argentina, Barbados, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Rep., Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Netherlands Antilles and Aruba, Nicaragua, Panama, Paraguay, Peru, Surinam, Trinidad, Uruguay, Venezuela.

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