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DO VOLUNTARY INTERNATIONAL ENVIRONMENTAL AGREEMENTS WORK?

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Do voluntary international environmental agreements work?[§]

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Abstract: We consider the effects of international environmental agreements, using the Sofia Protocol on the reduction of nitrogen oxides. Our analysis utilizes panel data from 25 European countries for the period 1980–96. We divide these countries into "participants" and "non-participants"—that is, those that did and those that did not ratify the Sofia Protocol, respectively. Using a difference in difference estimator, we find that signing the treaty has a significant positive impact on emission reduction. The yearly reduction is approximately 2.4 percent greater than it would have been without the Sofia Protocol.

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1. Introduction

Since the detrimental effects of pollution across borders were first recognized in the 1950s, the world has seen an increasing number of international environmental agreements (IEAs) being signed. By 1994, Barrett (1994, p. 878) reports that more than 100 IEAs were in force. There is general agreement that dealing with environmental problems that cross country borders, such as global warming and acidification, requires some form of international co-operation. Without co-operation, each country has an incentive to free-ride on emission reductions from other countries, and countries that would benefit from co-operation end in a prisoners'-dilemma situation. The existence of IEAs is often seen as evidence that these voluntary agreements are successful. However, signing an IEA does not necessarily imply successful realization of co-operative gains. Whether an agreement is successful depends on whether it has an effect on the signatory countries' pollution policies. Thus, we consider an IEA to be successful if the signatory countries reduce their emissions more than they would have done without the agreement. In this paper, we aim to provide a partial answer to the question of whether an agreement has an effect on signatory countries' pollution policies by a case study of the Sofia Protocol for nitrogen oxide reduction.

The bulk of the economics literature on the success of IEAs concludes that they "tend to codify Nash behaviour and, as such, do not present much of a co-operative gain", (Arce and Sandler 2001, p. 494). This conclusion is supported by Murdoch et al. (1997a), who empirically evaluated both the Helsinki Protocol on the reduction of sulfur in Europe and the Sofia Protocol on the reduction of nitrogen oxides, by estimating emission reductions for 25 European countries from 1980 to 1990. Murdoch et al. (1997b) analyse the Montreal Protocol on the reduction of CFCs, and their empirical results show that agreed emission ceilings under this agreement are more in line with non-co-operative Nash behaviour than with the co-operative behaviour of governments.

This view is further supported by simulation studies of IEAs, such as the Helsinki Protocol on the reduction of sulfur (Mähler 1990), the Oslo Protocol on further sulfur reductions (Finus and Tjøtta 2003), and the 1997 Montreal Protocol on limits to the emission of ozone-depleting substances (Barrett 2001).[1]

Finally, most of the theoretical literature on co-operation in IEAs predicts that co-operation is rather limited. Barrett (1994) explores a self-enforcing IEA within a two-period model. In the first period, countries decide whether to participate, and in the second period, participating and non-participating countries determine their emission levels non-co-operatively. This model predicts that the number of participating countries is limited and that self-enforcing international agreements may not be able to improve substantially upon the non-co-operative outcome. Results from similar models by Carraro and Siniscalco (1993, 1998) and Hoel (1992) also predict that co-operation is relatively limited. Lange and Vogt (2003) explain the large number of observed international co-operations by arguing that these are driven by a sense of equity in addition to self-interest. To sum up, the economic literature argues that participation in international agreements does not change countries' pollution policies or realize efficiency gains through co-operation.

In this paper, we take another approach to assessing the potential of IEAs. We consider 'The 1988 Sofia Protocol concerning the Control of Emissions of Nitrogen Oxides or their Transboundary Fluxes'. In a typical agreement, such as the Sofia Protocol, signatory countries agree to stabilize or reduce emissions of a specific pollutant. We focus on emission reductions and, in particular, on the question: do signatory countries reduce their respective emissions more than they would have done without the agreement? The Sofia agreement is well suited as a case study, since there are good data on emissions before and after the agreement.

[1] The formal titles of the protocols are: 'The Protocol on the Reduction of Sulfur Emissions and their Fluxes at least by 30 Percent', signed in Helsinki in 1985, 'The Protocol for further Reduction of Sulfur Emissions', signed in Oslo in 1994, and 'The Montreal Protocol on Substances That Deplete the Ozone Layer', signed in Montreal in 1987.

Nevertheless, the main obstacle to providing an answer to the above question is the lack of a counterfactual. In other words, we do not know what emissions would have emerged without the agreement. Our approach, following the evaluation literature, is to argue that under certain conditions, non-signatory countries constitute a relevant comparison group.

The Sofia Protocol, formally entitled 'The Protocol concerning the Control of Emissions of Nitrogen Oxides or their Transboundary Fluxes', was signed in Sofia on 1 November 1988. It requires the parties to the agreement to freeze their emissions of nitrogen oxides at the 1987 level before 1994. As a comparison group, we use countries that ratified the 'Framework Convention on Long-range Transboundary Air Pollution of 1979' (the LRTAP convention). These countries were invited to join negotiations and to sign the Sofia Protocol but did not do so.

The rest of the paper is organized as follows. In section 2, we explain the historical background for the Sofia Protocol. In section 3, we outline a theoretical model for the emission of a pollutant from a country. In section 4, we present the econometric model, emphasizing program evaluation principles. In section 5, we present a description of the data and our main results. Section 6 concludes the paper.

2. Historical background

The damaging effects of acidification in Europe were discovered in the 1950s and 1960s in relation to their effect on fish stocks in Scandinavia. Since then, the situation has deteriorated. In southern Norway, for example, fish populations have sustained extensive damage or even disappeared over an area of about 86,000 square kilometres. The affected area has roughly doubled in size since 1970. The process of acidification also results in the increased presence of aluminium and other toxic metals in the ground water, and these effects are considered to be among the causes of forest decline in Europe. In addition, nitrogen oxides and their transboundary fluxes cause serious health threats to vulnerable persons by reducing air quality.

For many European countries, deposits of nitrogen oxides are caused by winds blowing them in from other countries. The deposits either fall to earth or combine with water vapour, which is later deposited as rain or snow. These air pollutants can be carried by winds for hundreds or even thousands of kilometres before being deposited in soil or water. The deposition process is a clear case of rivalry because one ton of deposition in one country cannot be deposited in another country. Air quality and transboundary fluxes, however, are not rival goods, since the same airborne particles can influence persons at risk not just inside one country but also in different countries. Clearly, nitrogen oxide emissions create externalities across countries. Emission decisions in one country have environmental and health consequences in other countries. In the absence of a market mechanism to adjust for these externalities, this will lead to an inefficient resource allocation. The transboundary aspects of nitrogen emissions as well as other environmental problems call for some form of co-operation between countries.

The Stockholm Conference of 1972 made the decision to establish the United Nations Environmental Programme (UNEP) to adopt recommendations on international co-operation on a broad range of environmental problems. One of the first agreements in this programme was the LRTAP convention of 1979, which constituted a declaration of goodwill and served as a framework for follow-up protocols.[2] In 1984, 22 countries signed the monitoring and evaluation protocol, 'The Cooperative Programme for Monitoring and Evaluation of Long-Range Transmission of Air Pollution in Europe' (EMEP). This protocol requires that signatories report their emission to the treaty secretariat. Subsequent protocols followed, regulating the specific pollutants that cause acidification. The Helsinki Protocol of 1985 and

[2] http://www.unece.org/env/lrtap/welcome.html and its follow-up protocols.

the Sofia Protocol of 1988, which is the object of this study, were the first of nine protocols signed between the time of the LRTAP convention and 2001.

The Sofia Protocol requires the parties to the agreement to freeze their emissions of nitrogen oxides or their transboundary fluxes at the 1987 level before 1994. Like most of the environmental agreements, the Sofia Protocol is a voluntary agreement with no economic transfers or compensations explicitly stated in the protocol texts. Hence, there are no explicit sanction possibilities. In the case of disagreement between the parties, according to Article 12 in the Protocol, "(i) f a dispute arises between two or more Parties as to the interpretation or application of the present Protocol, they shall seek a solution by negotiation or by any other method of dispute settlement acceptable to the parties to the dispute". An important exception to this general rule is the Montreal Protocol, which explicitly mentions compensation in the form of side payments.

According to the Protocol homepage, in 1994 or a previous year where no recent data are available, the parties to the Protocol had reduced their total emissions by 9% compared to the reference year, which was 1987 for all countries except for the United States, which joined in 1978.[3] Furthermore, 19 of the 25 parties to the Protocol have reached the target or reduced emissions below that level.

3. A model for emissions from a country

We describe a model for emission of a pollutant in a country i with N_i individuals. To conserve notation, we omit time subscripts. The environmental quality Q_i in country i depends on the country's own emission Y_i as well as emissions $\{Y_j\}_{j\neq i}$ from other countries j.

We define the coefficient α_{ji} as the proportion of total emissions released by emitter j, which are deposited at receptor i. The α parameters capture the *external* aspects of airborne pollution, such as nitrogen oxides, as a one ton deposit at receptor *j* cannot be deposited at other receptors. In addition, these coefficients capture negative public aspects of airborne pollution, as the same ton of a pollutant may be aloft over other countries and hence may put many *different* persons at risk. We use the total deposit of the pollutant as a proxy for the total consequence on the environmental quality in country *i*:

$$Q_i = Q_i(\alpha_{ii} Y_i + \sum_{j \neq i} \alpha_{ji} Y_j) \, . \tag{1}$$

The coefficients α_{ji} reflect annual wind patterns, meteorological conditions and the geographical distribution of sources of pollutant.

We define emissions in a country *i* as pollution less abatement. The pollutant is a by-product in the production of a private consumer good, and c_i denotes the average consumption of the private good. Resources available for abatement are nation *i*'s income I_i (gross national income) less total consumption $N_i c_i$. Emissions are then:

$$Y_i = P_i(N_i c_i) - A_i(I_i - N_i c_i) \, , \tag{2}$$

where we assume $P'_i(.) > 0$, $P''_i(.) < 0$, and $A'_i(.) > 0$. The abatement technology is characterized by decreasing (increasing) returns to scale if $A''_i(.) > 0$ ($A''_i(.) < 0$). Substituting (2) into (1), we define the technological and ecological set *conditional* on exogenous variables income I_i, population N_i, emissions Y_j from the other countries, and the share of deposits of domestic emission α_{ii}:

[3] See http://www.unece.org/env/lrtap/nitr_h1.htm.

$$\Gamma_i(c_i, Q_i) = 0 \quad . \tag{3}$$

Finally, we assume that the decision process inside the country leads to a Pareto-efficient allocation of resources. We assume that a representative individual obtains utility from the consumption of the private good c_i and the environmental quality Q_i, which we assume is a pure domestic public good. The efficient allocation of private consumption and environmental quality is characterized by maximizing the representative utility:

$$u_i = u_i(c_i, Q_i) \quad , \tag{4}$$

given the conditional set (3).

A necessary condition for efficiency is the familiar Samuelson rule for provision of the public good: the sum of marginal willingness to pay across individuals equals the marginal cost of providing environmental quality, $N_i MRS^i_{c_i Q_i} = MRT^i_{c_i Q_i}$. This condition defines the efficient private consumption and environmental quality. Substituting the efficient allocation into (2) gives us emissions as a function of the exogenous variables I_i, N_i, Y_j, and α_{ii}. We assume that this function may be described by a linear approximation:

$$Y_i = \theta_0 + \theta_1 I_i + \theta_2 N_i + \theta_3 \alpha_{ii} + \theta_4 (\sum_{j \neq i} \alpha_j Y_{ji}) \quad , \tag{5}$$

where the θ parameters summarize our prediction of how emissions vary across countries and time.

The impact of income on emissions is ambiguous if both private consumption and environmental quality are normal goods; for mathematical details, see the appendix. Increased private consumption will induce greater pollution from the production of the private good. On the other hand, an increase in income will induce higher demand for environmental quality, and some of the income increase will be used for abatement. Clearly, the net impact of income on emissions is positive if the first effect dominates, otherwise it is negative. Increasing returns to scale in the abatement technology will strengthen the negative effect.

The effect of an increase in population, *N*, on emissions is also ambiguous. On the one hand, an increase in population increases the total consumption—given that the average consumption is constant—and, therefore, both factors increase the pollution-generating production of the private good and reduce the resources used for abatement. Both effects will increase domestic emissions. On the other hand, increased population reduces the average consumption and reduces emissions. Finally, increased emissions from other countries *j* or an increase in one of the parameters α_{ii} reduce emissions in country *i* as long as private consumption and environmental quality are substitutes.

Empirical evidence suggests that, for some pollutants, emission per capita and average incomes per capita follow an inverted U-shaped pattern. This relationship is called an "environmental Kuznets curve" after Kuznets (1955), who found evidence that inequality follows an inverted U-shaped form of per capita income over time. Both the World Bank (1992) and Grossman and Krueger (1995) find empirical evidence for environmental Kuznets curves for some pollutants, whereas Harbaugh et al. (2001) find little support using an updated and revised version of the data set used by Grossman and Krueger.[4] To capture the possibility of an environmental Kuznets curve, we include a quadratic term in income.

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[4] One explanation for the inverted U-shaped curve is that this reflects the natural progression of economic development from clean agricultural economies, to polluting industrial economies, to clean service economies. A second explanation is that environmental quality is an inferior good for low-income earners and a normal good for high-income earners. A third theoretical explanation is that it is due to economies of scale in abatement technologies; see Andreoni and Levinson (2001).

4. Evaluating the agreement effect

The purpose of the empirical part of the paper is to assess the effect of the Sofia Protocol on nitrogen oxide (NOX) emissions. We aim to accomplish that goal using methods from the microeconometric program evaluation literature.[5] Let Y_{it}^{1} denote country *i*'s emissions in year *t* (measured in logs) if it *has* signed the treaty, and let Y_{it}^{0} denote its emissions if it has not. The parameter of interest is $\Delta = E(Y_{it}^{1} - Y_{it}^{0})$, where *E* is the expectation operator. Clearly, this entity may not be observed directly, as the same country cannot be observed as both having signed the treaty and not having signed it in the same period. It is therefore necessary to use non-signatory countries to observe the behaviour of signatory countries. Rewriting the linearized emission equation from the previous section for a country that has *not* signed as:

$$Y_{it}^{0} = \theta_0 + \theta' X_{it} + U_{it}^{0}, \tag{6}$$

where we have gathered the right-side variables in the vector *X*, θ is the corresponding coefficient vector, and θ_0 is the intercept. *U* is a random variable with zero expectation that picks up the effect of unobserved factors. Assume that the corresponding equation for a country that *has* signed the treaty is:

$$Y_{it}^{1} = \gamma + \theta_0 + \theta' X_{it} + U_{it}^{1}. \tag{7}$$

In other words, we assume that the effect of observable variables (θ) is the same for signatory and non-signatory countries, but the effect on unobservable variables is not necessarily the same. The effect of signing the treaty is picked up by γ.

Let $D_{it} = 1$ if country i has signed in period t, and 0 otherwise. Simply subtracting the average of (6) from the average of (7), with period t data, yields a biased estimator unless $E(U_{it}^1 \mid D_{it} = 1) = E(U_{it}^0 \mid D_{it} = 0)$. This is the well-known selection bias problem. However, with panel data available, we may use the difference in differences estimator:

$$\hat{\Delta} = E(Y_{it}^1 - Y_{i,t-1}^0 \mid D_{it} = 1) - E(Y_{it}^0 - Y_{i,t-1}^0 \mid D_{it} = 0) \quad (8)$$

To evaluate (8), we need data on countries that had signed in t but not in $t - 1$. Using (6) and (7) to rewrite (8) as $\hat{\Delta} = \gamma + E(U_{it}^1 - U_{i,t-1}^0 \mid D_{it} = 1) - E(U_{it}^0 - U_{i,t-1}^0 \mid D_{it} = 0)$, we see that the necessary assumption for unbiasedness is:

$$E(U_{it}^1 - U_{i,t-1}^0 \mid D_{it} = 1) = E(U_{it}^0 - U_{i,t-1}^0 \mid D_{it} = 0) \quad (9)$$

Note that (9) is equivalent to:

$$E(Y_{it}^0 - Y_{i,t-1}^0 \mid D_{it} = 1) = E(Y_{it}^0 - Y_{i,t-1}^0 \mid D_{it} = 0) \quad (10)$$

In other words, the identifying assumption is that in the absence of the agreement, the change over time would be the same for countries that signed the treaty and countries that did not. To obtain the difference in differences estimator, we run the regression:

$$Y_{it} - Y_{i,t-1} = \tilde{\theta}_0 + \gamma(D_{it} - D_{i,t-1}) + \theta'(X_{it} - X_{i,t-1}) + \varepsilon_{it}. \quad (11)$$

[5] See, for example, Moffitt (1991) for a simple exposition of the most commonly applied methods, or Heckman et al. (1999) for a comprehensive overview.

The constant term allows a common trend. To identify the effect, it is necessary to have at least one pre-agreement and one post-agreement observation for countries that signed and countries that did not.

An additional econometric problem is posed by the spatial nature of the data. Rewriting the linearized emission equation as:

$$Y_{it} = \theta_0 + \theta_W W_{it} + \theta_3 \alpha_{ii,t} + \theta_4 \widetilde{Y}_{-i,t} + U_{it}, \qquad (12)$$

where $\widetilde{Y}_{-i,t} = \sum_{j \neq i} \alpha_{ji,t} Y_{jt}$ and the vector *W* contains variables other than emissions and transport coefficients, it is clear that the variable $\widetilde{Y}_{-i,t}$ (country *i*'s imported emissions) is correlated with U_{it}. Consider some country $k \neq i$: Y_{it}, and thus U_{it}, is included in $\widetilde{Y}_{-k,t}$ and thereby in Y_{kt}. Therefore, $\widetilde{Y}_{-i,t}$ is correlated with U_{it}, and the standard OLS assumptions are violated. In previous contributions based on cross-section data, for example, Murdoch et al. (1997, 2003) the problem has been addressed by applying spatial autoregression methods (Anselin 1988). Here, however, we use panel data and thus we are able to use lagged value variables as instruments, assuming that the errors are not serially correlated.[6]

5. Data and variables

Our analysis utilizes data from 25 European countries for the period 1980–96. As noted, the Sofia Protocol is one of nine (to date) follow-up protocols of the LRTAP convention, which was signed in Geneva in 1979. All of our 25 countries have signed and ratified the Geneva Convention. The Sofia Protocol was signed on 1 November 1988 and came into force on 25

[6] As the model is estimated in first differences, the instruments are lagged twice.

November 1990.[7] For countries ratifying at a later date, the Protocol comes into force nine days after their respective ratification dates (Article 15 part 2).

We classify countries as "participants" if they ratified the Sofia Protocol by the end of 1994 and "non-participants" if they did not. There are 18 participant countries and seven non-participant countries. Greece (1998) and Belgium (2000) have ratified the Protocol, but since their ratifications occurred after the time of the agreement goal, we classify them as "non-participants".[8]

(Table 1 about here)

As mentioned above, the Sofia Protocol was signed on 1 November 1988, but since we only have annual data, we use 1989 as the signing year. If we assume that countries rationally expected to ratify the Protocol at a later date, the signing year 1989 seems a natural choice for the "treatment" year. An alternative arrangement of the data is to use the year in which the Protocol "came into force" as the "treatment" year. For most of the countries, this is 1991 (13 countries). For the rest of the participants, the Protocol came into force in later years, but always before 1994, as shown in Table 1. Using this alternative definition of the "treatment" year left the results did not change the results much, however.

The political geography of Europe has changed since the LRTAP convention was signed in 1979. Some countries have been split up, and two German states have been unified into one country. Owing to data limitations, both before and after the political changes, we treat the Czech Republic and Slovakia as one unit, and the same applies to the former Soviet Union states.[9] Furthermore, Germany is treated as one unit during the whole period, since

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[7] According to Article 15, the protocol comes into force nine days after the sixteenth country ratifies it.
[8] Liechtenstein is excluded owing to a lack of data.
[9] We only have data for Belarus, Ukraine, the Russian Federation, Lithuania and Moldova.

there are no separate data for East and West Germany after the reunion. The Former Republic of Yugoslavia is omitted from our analysis since the data are poor.

Data on NOX emissions are taken from Table 2 on EMEP's homepage.[10] We use the source-receptor matrix in EMEP (1997) to derive the import of NOX deposits and the share of a country's NOX emission deposit in the specific country's own geographical area (α_{ii}). As part of the EMEP Protocol, transportation matrices between parties for different pollutants such as nitrogen oxides and sulfur are calculated.

The GDP data are based on UN Statistical Yearbooks for 1993 and 1995. To ensure consistency in the entire time series, we compare the observations for 1987 for each country in the two editions. If the deviations are substantial, we use growth rates in the 1993 edition to calculate GDP numbers for 1980–86, using the figure for 1987 in the 1995 edition as a starting point. Population data are from the UN Statistical Yearbook for 1995, using GDP and GDP per capita to calculate the size of the population.

(Table 2 about here)

Summary statistics in Table 2 reveal noticeable differences between participating and non-participating countries. For the Sofia Protocol, the participant countries have more than twice the GDP per capita of the non-participating countries. Furthermore, the participating countries have more NOX emissions, and average emissions per capita are higher than for non-participating countries. However, NOX emissions per GDP for participators are considerably lower. This indicates a more intensive use of NOX in industry in non-participating than in participating countries.

[10] The Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (the EMEP programme) monitors emissions regulated by the LRTAP convention. The data are from Table 2 in http://projects.dnmi.no/~emep/emis_tables/tab2.html.

The political changes in Europe might have had an effect on emission behaviour. Therefore, we include a control dummy variable for the former communist countries of Eastern Europe, reflecting the transition process. We use 1991 as the transition year, indicating post-transition with a dummy. Sensitivity analysis of the transition year (1988, 1989, 1990) reveals small changes in numbers and did not alter the results. We classify Germany among the transition countries as well, since the former East Germany was a communist country. This gives the reunited Germany the same characteristics as other East European countries, with a relatively large amount of polluting, inefficient industry to close.[11] As we can see from the summary statistics, there are slightly more transition countries among the non-participating countries.

(Figure 1 about here)

For a first impression of the potential effect of the agreement, let us have an exploratory look at the data. In Figure 1, we have normalized NOX emissions by indexing on 1987, the target year for emissions until 1994. The data are sorted according to whether countries belong to the group of signatory or non-signatory countries. Looking at the average participating country, there seems to be no clear trend before 1987. If anything, the tendency is increasing from 1984 and decreasing from 1987. There actually seems to be a clearer downward trend from 1989, the year that we define as the agreement year. In 1994, all but three signatory countries had emissions below the target level. The picture for the average of the non-signatory countries—seven by our definition—is noisy, but there seems to be an increase until 1987, with no clear trend thereafter. Even so, we must note that only two of the non-participating countries for which we have data in 1994 had not decreased emissions below the 1987 level. We recall from the previous section that the identifying assumption of

[11] Classifying Germany as a non-transition country did not change the results.

the difference in differences estimator is that the pre-agreement trend for signatory and non-signatory countries should be the same. With the possible exception of 1980–82, and taking into account the small sample size, we contend that the data do not reject that assumption.[12]

(Figure 2 about here)

The impression that the agreement countries perform better is reinforced by Figure 2, which shows the NOX growth rated in order of size (the change in the log of emissions). After 1990, the growth of the median signatory country is clearly below that of the median non-signatory country, but we also see an upward trend for both groups. Summing up, the message from the raw data seems to be that the agreement worked. However, the decision process modelled in section 3 has not been taken into account. To accomplish that, we now turn to results from our econometric model.

6. Results

Table 3 shows results from estimating equation (11) with NOX emissions in logs and explanatory variables as detailed in the previous section. Except for the participation and transition country dummies, the independent variables are in logs, and their coefficients may be interpreted as elasticities. OLS and IV estimates are reported. In addition, we report results from a regression simply on the participation dummy and a constant term. This is tantamount to comparing the average outcomes, and gives an impression of the potential bias in the treaty effect that results from not taking the economic model into account.

(Table 3 about here)

[12] Owing to missing background information, the first year used in the regressions is 1986.

First, we comment on the OLS results. The coefficient on the "Signed treaty" variable is significant at the 0.01% level in the OLS results, confirming the impression from the descriptive statistics and Figure 1 that signing the treaties had an effect on the participating countries' emissions. The estimated coefficient of –0.024 means that yearly average reductions in NOX emissions were approximately 2.4% greater for participating than for non-participating countries. This can be interpreted as the effect of the Sofia Protocol. In addition, we note that simply comparing mean outcomes without controlling for country characteristics overestimates the treaty effect by more than 40%—the coefficient decreases to –0.034. On the other hand, *including* country characteristics *decreases* the treaty effect by about 30%, which gives an estimate of how much of the difference between signatory and non-signatory countries is accounted for by country characteristics.

Turning to the other results, we unexpectedly find that there is no significant effect from imported NOX on own emissions. However, the sign is negative as expected. The same is the case for the part of a country's emissions that is deposited on its own soil (α_{ii}). The statistical insignificance may be a consequence of first-differencing, which takes out much of the cross-sectional variation in the data—there is not much time-variation in α_{ii} and α_{ji}.[13] The effect of GDP, the empirical counterpart to income in the theoretical model, is positive but decreasing (the turning point at log GDP = 5.4 is outside the sample). This is consistent with the predicted counteracting effects of pollution increasing with increased production, at the same time as increased income leads to a greater demand for environmental quality. However, the first effect dominates. The concave shape is consistent with the idea of an "environmental Kuznets curve". Population size has a negative and significant effect on emissions. This variable, too, has an ambiguous effect in the theoretical model. Our result indicates that the dominant effect of population is that, at a given income level, it reduces average consumption

[13] In a pooled OLS regression in levels, both variables came out as significant.

and thus the polluting by-product of consumption production. Finally, we note that the estimated –0.028 for the "Transition country" variable means that NOX emission reductions are approximately 2.8% greater in the transition economies than in other countries. Taking into account the high pre-transition pollution levels in these countries, the result is reasonable and indicates that the potential for improvement was greater in those economies.

We noted in the previous section that, owing to the spatial nature of the data, the OLS assumption that explanatory variables are uncorrelated to the error term is violated. However, the IV results, and in particular the treaty effect, are quite similar to OLS. A Hausman test does not reject OLS in favour of IV. Admittedly, our instruments (lagged values of the right-side variables) are only weakly correlated to the problematic variable, imported NOX. On the other hand, they pass the Sargan test for not being correlated to the error term. Furthermore, the endogenous variable is insignificant. This could be a consequence of endogeneity but, as noted above, we think that it results from the first-difference transformation. For this reason, we believe that the endogeneity of this variable does not seriously affect the estimate of the treaty effect, which is the focus of interest in this paper.

How do our findings compare to the received literature? The results seem to differ from Murdoch et al. (1997a), who consider the Helsinki and Sofia Protocols and find that the latter has no effect on emissions, in the sense that the participation dummy was insignificant. However, their approach differs from ours, in that they estimate a model derived from a Nash representation on cross-sectional data for the pre- and post-agreement periods separately.[14] Thus, their results test the relevance of their behavioural model rather than the effect of the treaty. Their key variable is spillins (imported NOX in our notation), which is interpreted as a strategic response variable. When this variable comes out as significant and negative, it is interpreted as confirming strategic free riding. By contrast, we use the time- and cross-section variations in the full panel, before and after signing the Sofia agreement, for a direct assessment of the agreement effect. As noted above, it is difficult to identify the effect of spillins with the panel data estimator. Our focus and empirical approach are different, and therefore the results are not necessarily at odds.

As a final caveat, it is clear that the credibility of our results hinges on the identifying assumption that, in the absence of the treaty, the change-over time would be the same for participating and non-participating countries. The graphic inspection of data in the previous section at least did not provide evidence against the hypothesis. It may be problematic that the sample size is small, particularly for the non-participating countries. However, that criticism also applies to previous work in this field.

7. Conclusions

We started out by asking if environmental agreements do have effects on emissions. In relation to the Sofia Protocol, our answer is "yes". Analysing annual data for ratifiers of the LRTAP convention before and after the Sofia Protocol, we find that annual reductions in emissions were approximately 2.4 percent greater then they would have been if the Sofia agreement had not been signed. If one accepts the fundamental assumption of the empirical analysis, this may be interpreted as the effect of countries signing the treaty and thus committing themselves to meeting the targets. Admittedly, this conclusion may be placed in question by the somewhat limited data. Nevertheless, our conclusions bear some promise for the future of international co-operation in controlling damage to the environment. A topic for future research should be the application of similar methods to assess the effects of other international agreements.

[14] Their outcome variables are emission reductions during 1985–87 and 1988–90.

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Appendix

Note that if both the private good and environmental quality are normal goods, then:

$$0 < N_i dc_i^* < dI_i \Leftrightarrow 0 < N_i \frac{dc_i^*}{dI_i} < 1 .$$

We find the impact of income on emissions by substituting efficient private consumption into (2) and differentiating with respect to income:

$$\frac{dY_i^*}{dI_i} = N_i P_i' \frac{dc_i^*}{dI_i} + A_i'(N_i \frac{dc_i^*}{dI_i} - 1) . \quad \text{(A1)}$$

The first term in (A1) is positive and the second is negative. Hence, the net effect of income on emissions is ambiguous. The effect of an increase in the population is given by:

$$\frac{dY_i^*}{dN_i} = (P_i' + A_i')(c_i^* + N_i \frac{dc_i^*}{dN_i}) .$$

The direct effect—the first term in the second set of parentheses—of an increase in population is to increase the production of the pollution-generating consumption good and to reduce abatement. The indirect effect depends on the reduction of average consumption $\frac{dc_i^*}{dN_i} < 0$.

Clearly, the net effect depends on the relative magnitude of the direct and indirect effects.

Finally, increased emissions from another country *j* or an increase of α_{ii}, described by $dY_{-ij} > 0$, reduces emissions in country *i* as long as private consumption and environmental quality are substitutes. To see this, we differentiate efficient emission with respect to emission from other countries Y_{-ij}:

$$\frac{dY_i^*}{dY_{-ij}} = N_i(P_i' + A_i')\frac{dc_i^*}{dY_{-ij}} \leq 0 \text{ if } \frac{dc_i^*}{dY_{-ij}} \leq 0,$$

since the expression in the parentheses is positive by assumption. As long as private consumption and environmental quality are substitutes, then $\frac{dc_i^*}{dY_{-ij}} < 0$.

Table 1. The Sofia agreement

	Date of signature	Ratification	% of 1987 emissions[a]
Austria	01.11.1988	15.01.1990	80.9
Bulgaria	01.11.1988	30.03.1989	60.5
Czech Republic	01.11.1988	01.01.1993	n.a.
Slovakia	01.11.1988	28.05.1993	58
Denmark	01.11.1988	01.03.1993	86.5
Finland	01.11.1988	01.02.1990	93.5
France	01.11.1988	20.07.1989	102
Germany	01.11.1988	16.11.1990	61.4
Hungary	03.05.1989	12.11.1991	72.2
Ireland	01.05.1989	17.10.1994	102.3
Italy	01.11.1988	19.05.1992	98.2[c]
Luxembourg	01.11.1988	04.10.1990	103.2[b]
Netherlands	01.11.1988	11.10.1989	84
Norway	01.11.1988	11.10.1989	95.5
Russia	01.11.1988	21.06.1989	79.8
Spain	01.11.1988	04.12.1990	137.1[d]
Sweden	01.11.1988	27.07.1990	71.2
Switzerland	01.11.1988	18.09.1990	77.6
United Kingdom	01.11.1988	15.10.1990	81.3
Belgium	01.11.1988	31.10.2000	100.5
Greece	01.11.1988	24.04.1998	118.7[b]
Poland	01.11.1988		73.6
Iceland			125[c]
Portugal			415.6[b,c]
Romania			55[e]
Turkey			162.4[f]

Source: United Nations Economic Commission for Europe web page

Notes:

[a] Average NOX emissions 1994–96 as % of 1987 unless otherwise noted

[b] Reference year 1985

[c] Average emissions 1994–95

[d] 1993 emissions

[e] 1994 emissions

[f] 1995 emissions

Table 2. Descriptive statistics, before and after the Sofia protocol was signed

	All countries				*Signatory countries*				*Non-signatory countries*			
	Before		*After*		*Before*		*After*		*Before*		*After*	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Full sample												0.418
Nox emissions	0.972	1.043	0.893	1.027	1.089	1.113	0.990	1.114	0.492	0.445	0.524	0.026
Nox em. per capita	0.044	0.028	0.042	0.023	0.048	0.028	0.044	0.023	0.032	0.022	0.037	0.074
Nox em./GDP	0.052	0.067	0.049	0.060	0.043	0.061	0.040	0.052	0.087	0.079	0.083	
Observations	178		176		143		134		35		35	
Estimating sample												
Nox emissions	0.973	1.062	0.890	1.035	1.096	1.154	0.990	1.122	0.574	0.529	0.519	0.423
Nox em. per capita	0.045	0.027	0.042	0.023	0.049	0.028	0.044	0.023	0.035	0.022	0.037	0.026
Nox em./GDP	0.052	0.067	0.049	0.060	0.041	0.056	0.040	0.053	0.090	0.088	0.085	0.074
Nox import	0.102	0.130	0.093	0.125	0.111	0.143	0.100	0.136	0.073	0.064	0.065	0.061
Nox domestic	0.313	0.166	0.323	0.168	0.326	0.173	0.338	0.172	0.269	0.139	0.263	0.139
GDP	37.382	46.259	39.177	49.033	46.268	49.530	46.731	52.494	8.355	6.271	9.100	7.604
Population	24.245	21.724	22.942	21.100	23.852	22.248	22.497	21.666	25.528	20.599	23.709	19.286
Observations	64		166		49		132		15		34	

Before: 1980–1987; After: 1988–1996
The estimating sample is smaller than the full sample owing to differencing and missing observations on Nox imports
Emissions in 100,000 tons

Table 3. Regression results (first differences)

	OLS						IV		
	Coef	SE	t	Coef	SE	t	Coef	SE	t
Signed treaty	–0.024	0.008	–3.16	–0.034	0.009	–3.96	–0.023	0.008	–2.73
Imported NOX	–0.021	0.027	–0.78				–0.039	0.209	0.19
Domestic NOX	–0.020	0.028	–0.71				–0.035	0.079	–0.44
GDP	0.947	0.163	5.81				0.902	0.247	3.66
$(GDP)^2$	–0.089	0.029	–3.11				–0.086	0.039	–2.21
Population	–1.894	0.663	–2.86				–1.953	0.869	–2.25
Transition country	–0.028	0.012	–2.35				–0.027	0.013	–2.12
Constant	0.002	0.007	0.30	0.008	0.007	1.21	0.002	0.009	0.26
R-squared		0.310			0.060			0.281	
Sargan test								2.896 (p=0.41)	
Wu–Hausman test								0.090 (p=0.76)	
Observations		230			230			208	

Dependent variable is log of Nox emissions
All variables except "Signed treaty" and "Transition country" are in logs
IV: Imported NOX (first differenced) instrumented by imported NOX and exogenous variables in levels, lagged twice

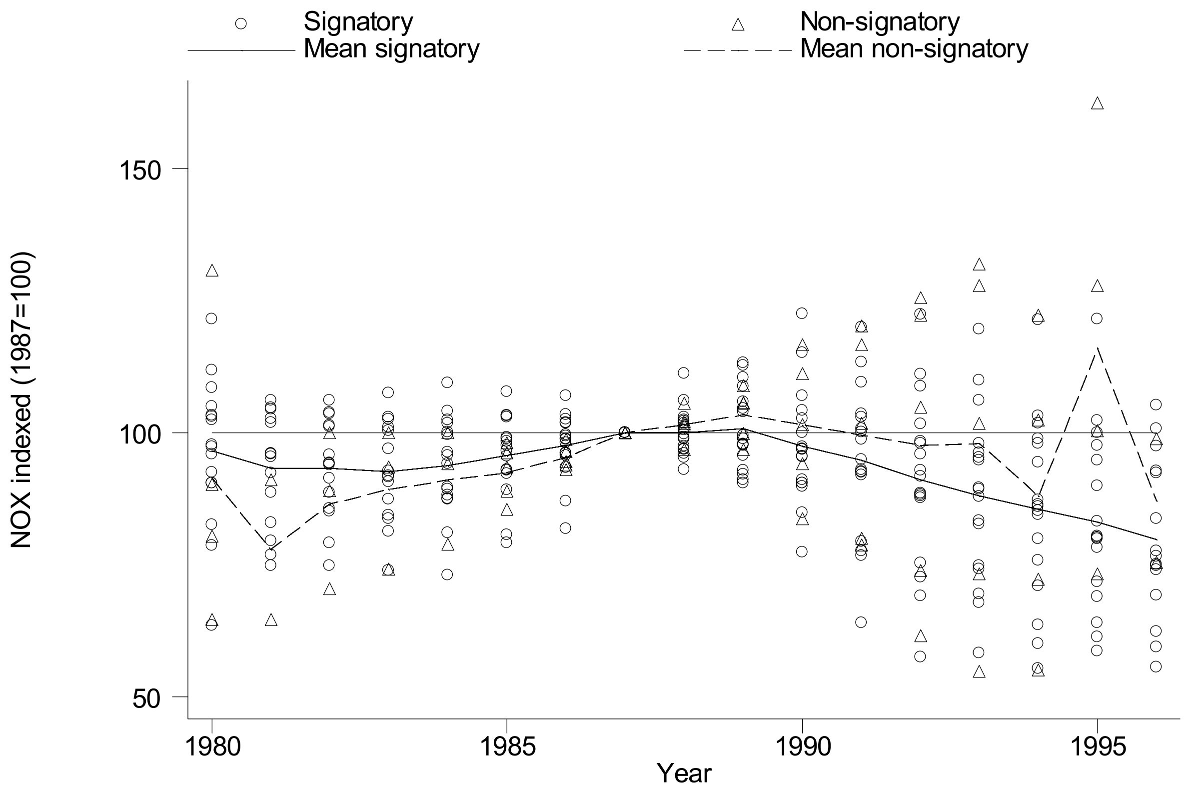

Figure 1. NOX emissions 1980–1996 for signatory and non-signatory countries

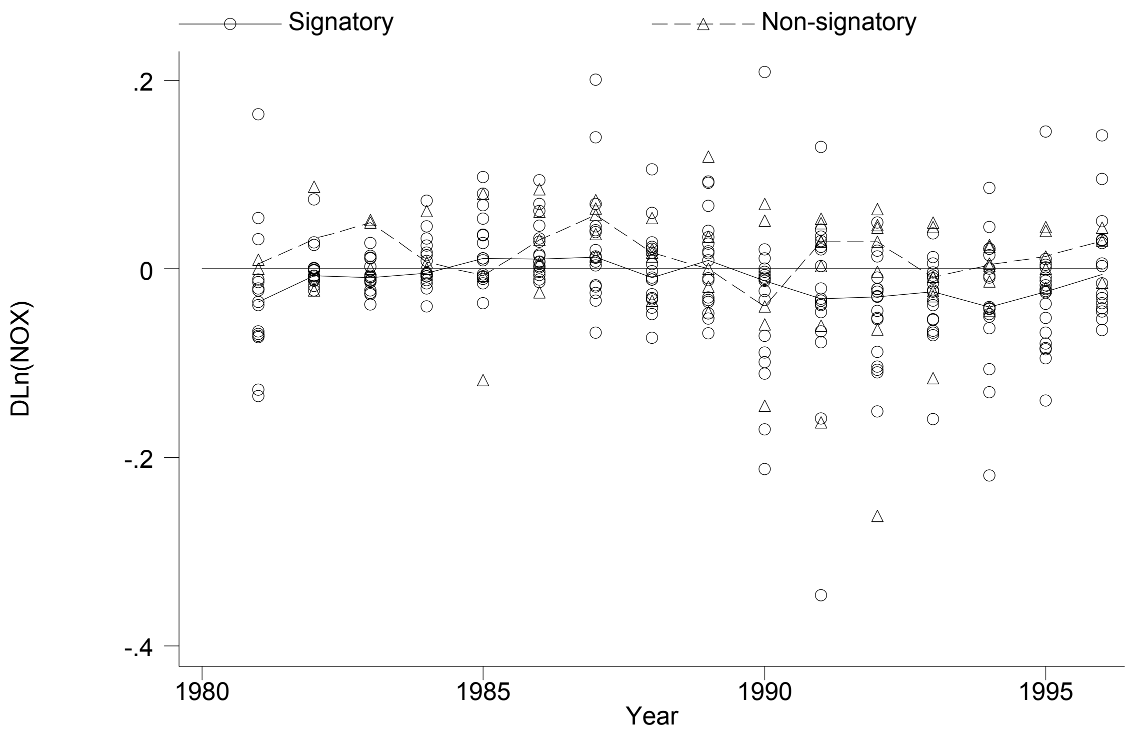

Figure 2. NOX growth rates 1981–1996, with median bands