Comments Appreciated

Globalization and Emissions in Europe*

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Abstract

International trade is just one facet of the global economy that impacts the environment. Countries' emissions are also determined by other international interactions, i.e. cross-border pollution, foreign direct investment, market potential and participation in international environmental agreements. This study determines the robustness of the estimated impact of trade on the environment to the omission of these other effects. Using a panel data set of sulfur dioxide and nitrogen oxides emissions in Europe, I find that openness to trade reduces emissions. But this effect is significantly biased if other international interaction variables are excluded. Therefore, my estimates suggest that previous studies may be plagued by omitted variable biases.

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I. Introduction

Today interactions between countries are more abundant and varied than ever. One of the most hotly debated outcomes from these interactions is their effect on the environment. The international interactions that affect countries' pollution emissions are not limited to trade but also include cross-border pollution, international factor movements, market potential and international environmental agreements.[1] These interactions are related and may be used strategically by countries. For example, countries can use trade restrictions on their polluting neighbors in order to influence them to lower emissions. Therefore, it is possible that the estimated effect of trade on emissions is biased when these other interactions are omitted.

This study adds to the empirical literature that estimates the net effect of openness to trade on the environment in two ways. First, unlike previous studies that include at most three international interaction effects, my study includes five. In addition to trade, I include cross-border pollution, foreign direct investment, market potential and treaty effects in a unified empirical model, and explore the potential omitted variable biases caused by only including a subset of these effects. In particular, this is the first study to include cross-border pollution and market potential alongside trade intensity. Importantly, I find that omission of these other variables does bias the included coefficients. While the direction of trade's effect on the environment is robust to these omissions, its magnitude is greatly biased when the additional variables are left out.

[1] Examples of models that include at least one of the *other* four interactions in estimation of emissions or air quality are presented in Antweiler et al. (2001) and Maddison (2006).

Second, to my knowledge, this is only the second study after Cole and Elliott (2003) to use international emissions data when estimating the impact of trade on the environment. Most previous studies use air quality data, but the theoretical link between trade and the environment emerges through emissions, not air quality.[2] Using air quality instead of emissions data may be problematic because air quality does not only depend on local emissions but is also a function of many geo-spatial factors and cross-border pollution. Aggregating air quality data across cities to form an air quality index for a country may also not be appropriate.[3] Figure 1 plots sulfur dioxide (SO_2) emissions against mean SO_2 concentrations in 1995 for twenty eight countries. The correlation between these two variables is only 0.048, suggesting that air quality data may not be an appropriate proxy for emissions. In Figure 2 nitrogen oxides (NO_X) emissions are plotted against nitrogen dioxide (NO_2) concentrations for twenty six countries in 1995.[4] Again, there is only a 0.098 correlation between emissions and air quality. While controlling for monitoring-site specific characteristics alleviates some of the problems with air quality data, emissions data provide a better test of the existing theories. With this in mind, I use an unused dataset of sulfur dioxide (SO_2) and nitrogen oxides (NO_X) emissions in Europe.

An important aspect of these emissions is that they themselves introduce an international interaction. Nitrogen oxides and sulfur dioxide are both production byproducts

[2] See for example Antweiler et al. (2001), Harbaugh et al. (2002) and Frankel and Rose (2005).
[3] For example, the average standard deviation in SO_2 concentrations is 57 percent of the mean SO_2 concentrations for the sixteen countries that report concentrations for more than one monitoring station. That for NO_X concentration levels is 32 percent for the twelve countries with more than one reporting monitoring stations. The 1995 data used in this footnote are reported by World Bank's 1998 World Development Index available online at http://www.worldbank.int/nipr/wdi98/index.htm.
[4] Dropping the two outliers in these figures from correlation calculation does not increase the correlation significantly.

that pollute the air. Once in the air, these pollutants may travel great distances resulting in acid rain and worsened air quality not only in the country of origin but in other countries as well. Three international environmental agreements are in effect to control their emissions. The Helsinki Protocol required a 30 percent reduction of the 1980 sulfur emissions by 1990. In contrast, the Oslo Protocol on sulfur emissions provides individual sulfur reduction targets for each country and a longer timeline—target dates extend from 2000 to 2010. The Sofia Protocol concerning nitrogen oxides calls on the participating nations to reduce their emissions to 1987 levels by 1994 and provides other guidelines for controlling NO_X emissions. It is important to note that although these agreements are written and signed at international meetings nations are not bound by an agreement until they ratify it. While Murdoch, Sandler, and Sargent (1997) find that the Helsinki Protocol was successful at reducing sulfur emissions, no such evidence was found for the Sofia Protocol effect on nitrogen emissions. However, their model does not control for country-specific trends. Using a shorter time series of the emissions data that I use, Ringquist and Kostadinova (2005) find that after controlling for country fixed effects and country-specific trends, there are no significant Helsinki Protocol effects on sulfur emissions. With longer time series I find that ratification of all three Protocols reduced emissions even with country fixed effects and country-specific trends. Furthermore, participation in the Oslo and Sofia Protocols also increased the rate of reduction of emissions, while the Helsinki Protocol did not.

A number of studies explicitly estimate the impact of openness to trade on the environment. Antweiler, Copeland and Taylor (2003), Harbaugh, Levinson and Wilson (2000), and Frankel and Rose (2005) use international air quality data collected by Global

Environmental Monitoring System (GEMS) and find that trade improves the environment. However, for reasons outlined above, using air quality to measure the impact of trade on emissions may not be appropriate. To improve upon these studies, I use a dataset of sulfur dioxide and nitrogen oxides emissions in Europe.

Cole and Elliott (2003) also use international emissions data in their study and find mixed results regarding trade's net impact on the environment. Their estimation only includes the trade aspect of international interactions of countries. My study addresses this issue. As mentioned above and discussed in detail in Section 2, I include other international interaction variables to ensure that the omitted cross-border, FDI, market potential and treaty effects are not biasing the estimated trade impact. In particular I find that omitting these four international interaction effects alters the estimated trade effect considerably, suggesting that Cole and Elliott's results may be plagued by omitted variable biases. [5]

The next section outlines the empirical methodology. Section 3 presents the results and Section 4 concludes.

II. Empirical Model

Following Frankel and Rose (2005), pollution emissions are estimated as a function of trade, income, and other country-specific factors:

$$\begin{aligned} E_{it} = \beta_0 + \beta_1 (Trade/GDP)_{it} + \beta_2 Ln(Inc_{it}) + \beta_3 [Ln(Inc_{it})]^2 + \\ \beta_4 X_{it} + \kappa_t + \varepsilon_{it}, \quad i = 1,\ldots,n \end{aligned} , \qquad (1)$$

[5] Dean (2002) also studies the impact of openness to trade on emissions. Using data on Chinese provinces, she finds that openness to trade lowers water pollution emissions. Her study omits the other international interaction variables as well.

where E_{it} is either SO_2 or NO_X emissions in country *i* at time *t*; *Trade/GDP* is trade intensity (or openness) measured by imports plus exports over GDP; *Inc* is national income measured by GDP per capita; X_{it} captures other country specific characteristics; κ_t are year fixed effects; and ε_{it} is the i.i.d. error term.

Previous literature decomposes the trade effect on emissions into scale, composition and technique effects (Grossman and Krueger, 1993; Copeland and Taylor, 1994 and 1995; and Antweiler, Copeland and Taylor, 2001). The positive scale effect arises because trade tends to increase GDP, which in turn increases industrial production and emissions. The composition effect accounts for the changes in emissions due to changes in the composition of national output (shifts of production from clean to dirty or from dirty to clean industries). This may increase or decrease emissions depending on the industries in which a country has a comparative advantage. Finally, the negative technique effect is due to increased income which results in higher demand for cleaner production techniques. Because of these opposing effects the theoretical relationship between trade and emissions is ambiguous and remains an empirical question.[6]

To allow for the inverse-U shaped environmental Kuznets curve (EKC), I include the log of income and the square of the log of income. The EKC hypothesis implies that as poorer countries' incomes grow their emissions rise, while rich countries' incomes would

[6] Previous empirical evidence finds that openness to trade tends to improve air quality, this impact may or may not hold for emissions. The only other study using international emissions data by Cole and Elliott's (2003) finds mixed results regarding the net effect of trade on emissions.

decrease emissions. The EKC would be supported if the linear term of income has a positive coefficient and the quadratic term has a negative coefficient.[7]

Following Frankel and Rose's (2005) methodology, I instrument for openness to trade, income and income squared because of a potential simultaneity problem. There is a two-way link between each of the three variables. First, trade impacts the environment through the scale, composition and technique effects. On the other hand, the pollution haven hypothesis implies that countries with lower environmental regulations export dirty goods. Second, the effect of income on environmental quality can be presented as the environmental Kuznets curve. But environmental regulation may also impact income through productivity—either by dampening it or by stimulating it.[8] Finally, the gains-from-trade hypothesis implies a positive effect of trade on income while the gravity models of trade predict that higher income increases trade.

Country-specific characteristics are captured by the matrix X_{it} which includes four non-trade international interaction effects, a corruption index, a repression index, and population density. The international interaction effects include the spatial lag (or the weighted average) of other countries' emissions, FDI, market potential and treaty effects. These, along with the trade intensity variable, are the variables of interest in this study. All of these country-specific characteristics are described in detail below.

[7] See for example Grossman and Krueger (1993) for a discussion of the EKC.
[8] Porter and Linde (1995) argue that environmental regulation may stimulate productivity.

The spatial lag variable is calculated as the weighted sum of other countries' emissions, $\sum_{j \neq i}^{n} \omega_{ji} \bullet E_{jt}$. The weight, ω_{ji}, is the percent of country *j*'s emissions, E_{jt}, that cross over to country *i*. These weights are calculated for European countries by the Co-operative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe (EMEP) using atmospheric chemistry models of source and receptor relationships that take into account the geography, prevailing winds, forest cover of both the emitting and receiving countries. Missing weights limit the included countries to Europe. The geo-spatial factors contributing to cross-border pollution have not changed greatly over the last couple of decades, so I use the same weights for all years. Using E_{jt} in estimation of E_{it} and E_{it} in the estimation of E_{jt} introduces an endogeneity problem. Therefore, I instrument for cross-border pollution using the standard instruments for this type of problem, the weighted sums of other exogenous variables. The weights used in construction of instruments are the same as the ones used in the spatial lag. A similar approach was used by Murdoch et al. (1997) and Murdoch et al. (2003) to determine the effect of cross-border pollution on emission-reductions and treaty participation. Both these studies omit trade, FDI and market potential. Using a similar method but a different weighting scheme, Maddison (2006) also estimates a spatial lag in emissions. His weights are based on a negative function of distance. Again, his estimated spatial lag may be biased because of omissions of the other relevant international interaction variables.

A positive coefficient on the spatial lag could be driven by coordination in environmental regulation across countries. For example, Naughton (2006) develops a model that illustrates how cross-border pollution intensifies competition in emissions taxes and increases gains from cooperation for nearby countries. Hence, if environmental regulations tend to move in the same direction in both countries, then emissions should also move in the same direction. On the other hand, a country with high levels of cross-border pollution will have a higher marginal cost of polluting. This effect, also captured by the spatial lag, would decrease domestic pollution. Because I am unable to distinguish between these two interactions, the estimated spatial lag will provide the net effect of the two.

As most FDI flows from richer countries, it may on average be cleaner than domestic capital because multinational firms often bring the less-polluting technology from the relatively richer economy (Antweiler et al., 2001).[9] But FDI also increases total industrial output and emissions. Similar to trade and the spatial lag, FDI has two effects on emissions working in the opposite direction. Therefore, the coefficient on FDI will be the estimated net effect.

The potential for future trade is measured by market potential. This is a weighted average of other counties' GDP, where the weights are declining in distance. While there is no theory to guide me in the choice of this weight function, I chose the weight of 100 divided by distance.[10] Countries with large market potential have an incentive to produce more and pollute more. Therefore, the expected sign is positive. To illustrate this point, consider the Eastern European countries that opened up for international trade during late 1980s early

[9] This effect could also be driven by FDI occurring in cleaner industries.

[10] Head and Mayer (2004) introduce a measure of market potential with inverse distance function. Previous studies using market potential find that the choice of the functional form for the weights has little effect on their results. See for example Blonigen et al. (2006a), Blonigen et al. (2006b) and Naughton (2006).

1990s. The ones with larger potential (closer to large economies) had more incentives to build industries and produce because of high hopes for increased trade.

Similar to Ringquist and Kostadinova (2005), I include the Helsinki and Oslo Protocol ratification and participation effects in the SO_2 equations and the Sofia Protocol effects in the NO_X equations. Protocol ratification effects are introduced as dummy variables to capture the potential intercept shift caused by ratifying the Protocol. Protocol participation is captured through a variable indicating the number of years since ratification. The participation effect captures the Protocol's effects on emissions trends. The expected signs for all treaty effects are negative. On this count, it is important to note that my time series is 1980 to 2000, six years longer than that of Ringquist and Kostadinova's (2005) who use data from 1980-1994. Thus, as discussed below in Section 3 my longer time series is important in capturing the treaty effects that they were unable to find. Furthermore, Naughton (2006) finds that treaty participation is impacted by market potential, suggesting that the omission of this latter variable can bias the effect of treaties.

To control for differences in environmental regulations across countries I construct a repression index from the civil liberties and political rights indices provided by Freedom House. This index proxies for people's ability to assert their preferences about environmental policy. Civil liberties and political rights take on values between one and seven, where lower numbers are associated with higher civil liberties and political rights. The repression index I use is the sum of the two divided by fourteen.[11] The expected coefficient on the repression index is positive—more repression is expected to lead to lower emissions. While it is difficult to obtain environmental regulation enforcement data for different countries, I use corruption as a proxy for enforcement. Higher corruption should imply lower enforcement and higher emissions. Therefore the expected sign on corruption is negative. Finally, a standard control included in the model is the log of population density. More densely populated countries have higher energy and production needs and hence are expected to have higher emissions. The data sources are described in Appendix A and the descriptive statistics are summarized in Table 1.

Construction of Instruments

There is simultaneity between openness to trade, income and emissions, as discussed above. Therefore, following Frankel and Rose's (2005) methodology I construct instruments for the trade and income variables in that order. First, I estimate equation (2) of bilateral trade using the gravity model of trade.

$$\begin{aligned} Ln(Trade_{ijt} / GDP_{it}) &= \alpha_0 + \alpha_1 Ln(Dist_{ij}) + \alpha_2 Ln(GDP_{jt}) + \alpha_3 Ln(Pop_{it}) + \alpha_4 Ln(Pop_{jt}) \\ &+ \alpha_5 Lang_{ij} + \alpha_6 Border_{ij} + \alpha_7 Ln(Area_i) + \alpha_8 Ln(Area_j) + \alpha_9 Landlocked_{ij} \\ &+ \alpha_{10} X_i + \alpha_{10} X_j + \nu_t + \varepsilon_{ijt} \end{aligned} \quad (2)$$

Log of trade as a share of GDP from country *i* to country *j* is estimated as a function of log of distance between the two countries, log of country *j*'s GDP, log of each of the countries' population, dummies for common language and land border, log of each of the countries'

[11] The correlation between the civil liberties and political rights indices is very high (0.8). Combining the two into one index allows for both to impact emissions without introducing multicollinearity problems. Including either index on its own instead of the repression index does not qualitatively change the results.

areas, and a variable indicating whether neither country, one country or both countries are landlocked. Equation (2) is a modified version of Frankel and Rose's (2005) specification—I have added country *j*'s GDP and country *i*'s population. In addition, I have included all the exogenous variables from equation (1) for each country (X_i and X_j). The latter modification moves this method closer to netting out the effects of *X* from the instrument for Trade/GDP in equation (1). Furthermore, I do not restrict the coefficients on the two countries' areas to be the same as Frankel and Rose's original specification does.

Equation (2) is estimated for 1980-2000 with year fixed effects. Each trade flow is only included once in the estimation equation. That is, if $Trade_{ijt}/GDP_{it}$ is included in the estimation, then $Trade_{jit}/GDP_{jt}$ is excluded from the analysis. When constructing the instrument each observation is used twice—once for estimation of total trade flows of each country. The instrument for openness in country *i* is constructed by taking the exponent of the estimated log of trade flows to each country *j* and summing over all *j* countries as presented in equation (3)[12]:

$$\overset{Estimated}{(Trade/GDP)}_{it} = \sum_{j \neq i} \exp\left[\overset{Estimated}{Ln(Trade_{ijt}/GDP_{it})} \right] \tag{3}$$

The second step involves constructing an instrument for income and income squared. I instrument for openness in the income equation below because of the potentially endogenous relationship between trade and income. Log of income is estimated using IV estimation as a function of openness to trade, log of population, log of income lagged twenty

[12] Taking the exponents provide the median not the mean of $Trade_{ijt}/GDP_{it}$. For comparability of methods across studies I use this method of constructing the instrument.

years, investment rate, population growth rate, log of education and the set of exogenous variables from equation (1), *X*:

$$Ln(Inc_{it}) = \delta_1 (Trade/GDP)_{it} + \delta_2 Ln(Pop_{it}) + \delta_3 Ln(Inc_{i,t-20}) + \\ \delta_4 Inv_i + \delta_5 PopGR_{it} + \delta_6 Ln(Educ_{it}) + \delta_6 X_{it} + \gamma_t + \varepsilon_{it} \quad (4)$$

Equation (4) is also estimated for 1980-2000 and includes year fixed effects. The major modification from Frankel and Rose (2005) is again the addition of the exogenous variables from the final equation of interest. As before, this gets me closer to netting out the effects of *X* from the instruments for the income variables in equation (1).[13] The predicted values from equation (4) are used to instrument for log of income and the square of these predicted values are used to instrument for square of log of income as in Frankel and Rose (2005).

III. Results

This section first presents the full model when different transformations of the dependent variable are used. Next the model is altered by sequentially removing one of the five variables of interest to determine the potential omitted variable bias. To further explore this bias, I present models with only one of the variables of interest included. Results for both SO_2 and NO_X are examined. The section concludes with discussion of additional findings and robustness checks.

Baseline Results for SO_2

While most would agree that emissions data are more appropriate for this type of analysis than air quality data, the functional form of emissions varies by study. Table 2

[13] Please see Frankel and Rose (2002) for further discussion of developing these instruments.

presents results of the preferred specification for eight different transformations of the SO_2 emissions. I consider four types of emissions variables: total emissions, per capita emissions, emissions intensity (emissions relative to GDP) and the ratio of emissions over the land area of the country. Each of the four provides a different interpretation of the results. For example, the coefficient on log of FDI in the total (per capita) emissions equations gives the change in a country's total (per capita) emissions if FDI increases by one percent. The first four columns use the logarithmic forms while the last four columns use the linear forms of these four emissions variables.[14]

Regardless of what transformation of emissions is used trade intensity reduces emissions. For all but one equation, this result is also statistically significant. When the emissions are measured in aggregate (the equations for Ln(SO_2) or SO_2), the estimated elasticity of emissions with respect to trade intensity is -2.1 or -2.2 at the means of the data. The elasticity for the other equations varies between -.5 and -1.3. Thus, an increase in trade intensity by one percent decreases emissions by more than 0.5 percent.

With the exception of the SO_2/GDP equation, the coefficients on income variables have the expected signs—positive for the linear term and negative for the quadratic term. The estimated environmental Kuznets curves peak at about $6,500 to $8,500 for all but the logged and linear emissions intensity equations. The equations based on emissions intensities include GDP in the calculation of the dependent variable and also in the independent variable set causing large differences in coefficients and the EKC peaks.

[14] I use the same specification for all transformations of the dependent variable to ensure comparability of results across equations. Changing the right hand side with the dependent variable introduces another dimension to this problem and may prove to be an interesting exercise for future work. Note that when the right hand side changes, so do the specifications of the first stage equations.

As the dependent variable is altered, so is the meaning of the spatial lag. In the equation for Ln(SO_2) the spatial lag is the weighted average of other countries Ln(SO_2) and in the per capita emissions equation the spatial lag is the weighted average of other countries per capita emissions. Therefore, it is not entirely surprising that the sign of the cross-boundary pollution coefficient changes with transformations of the dependent variable. The equations estimating the log-transformations of emissions have statistically significant coefficients. The positive spatial lag in the Ln(SO_2) equation may be indicative of clustering of countries with high emissions. On the other hand, the negative spatial lags in Ln(SO_2/Pop), Ln(SO_2/GDP) and Ln(SO_2/Area) equations support the increasing marginal costs of pollution effect outweighing the competitive or cooperative forces.

FDI also has a different effect on emissions if it is measured in aggregate instead of being measured as a ratio over population, GDP or area. The results for column (1) and (5) suggest that FDI increases aggregate emissions while the other six columns imply that FDI decreases per capita emissions, emissions intensity and emissions over area. So, even though FDI seems to encourage cleaner production (lower per capita emissions, etc.), because FDI increases output, aggregate emissions rise. This may suggest that as the dependent variable is transformed perhaps so should the right hand side of the equation. In particular, it may be more appropriate to include per capita FDI or FDI intensity (relative to GDP) in per capita emissions or emissions intensity equations. Replacing FDI with per capita FDI or FDI intensity does not change the sign pattern for FDI in these equations.

The potential for new trade in a country is measured by the market potential variable. As expected, I find that market potential increases emissions. This effect is statistically significant in all but one equation. The first four columns using the log transformed emissions variables imply that an increase in the market potential by one percent, increases emissions by approximately 1.4 percent. This elasticity estimated at the means of the data for the linear models ranges between 0.9 and 3.5.

The Helsinki and Oslo Protocols are two international environmental treaties that specifically target sulfur emissions. The Helsinki ratification effect has the expected negative sign in seven equations and it is statistically significant in six of the seven cases, implying that countries that ratified the Helsinki Protocol polluted less after ratification than they did before. Furthermore, the four statistically significant negative coefficients on the Helsinki participation variable suggest that parties to the Protocol continue to reduce their emissions relative to non-parties as time passes. Similar but less significant effects are detected for the Oslo Protocol.

It is possible that the participating countries were on a fast-track to lower emissions prior to joining these Protocols and the treaty itself had no impact on these countries emissions. To further examine the treaty effects, I also estimated Table 2 with country fixed effects and country-specific trends. These results are available on request. The evidence of treaty effectiveness in these models is more limited. While the Helsinki and Oslo ratification effects and the Oslo participation effect still end up with negative coefficients across the board (each coefficient being statistically significant three or four times), the Helsinki participation effect is now positive and statistically significant in seven of the eight equations. This does not necessarily imply that Helsinki Protocol encourages sulfur emissions. Rather it may be an artifact of this treaty's structure. As discussed earlier, the

Helsinki Protocol had a specific target of emissions reductions to be met by 1990 but outlined no further goals or guidelines. Countries participating in the Helsinki Protocol may have reduced their emissions by targeted date of 1990 but then started increasing their emissions again. The equivalent regression results for NO_X reveal that the Sofia ratification and participation effects are negative across the board (and statistically significant in four and two cases, respectively). When I run these regressions for the shorter time period from 1980 to 1994 I find no significant treaty effects just as Ringquist and Kostadinova (2005) do.[15] Therefore, the longer time period is necessary for capturing the treaty effects.

The repression index tends to be statistically insignificant. When statistically significant, it has the expected positive sign implying that countries with fewer civil liberties and political rights pollute more. Corruption was included in the model to control for environmental regulation enforcement. Thus, the negative coefficients suggesting that corruption decreases emissions are unexpected. In unreported results where I add the corruption index interacted with per capita GDP, I find a positive coefficient on corruption and a negative coefficient on this interaction variable. This suggests that corruption in poor countries increases emissions more than in richer countries.

Density has the expected positive and statistically significant coefficients in equations estimating the log and linear versions of SO_2 and SO_2/Area. In the other four equations this coefficient is negative, although insignificant. The negative density effect may be driven by

[15] Ringquist and Kostadinova (2005) find no significant Helsinki Protocol ratification or participation effects once country fixed effects and trends are included. There are at least two possible explanations. First, they use data for a shorter period from 1980 to 1994. Second, they omit trade, FDI and market potential from their estimation equation.

savings from living in more densely populated communities in terms of per capita energy and production needs.

Baseline Results for NO_X

Table 3 presents the equivalent results to Table 2 using NO_X emissions data. The results are qualitatively similar in most respects. As before, I find again that trade reduces emissions regardless of how emissions are measured. The coefficients on the income variables result in similar patterns for the nitrogen oxides. Excepting the equations of logged and linear emissions intensity, I find that the estimated EKC peaks between $8,500 and $12,500. In addition, the sign patterns for FDI, market potential, repression index and corruption are not too different from those of sulfur dioxide equations. The negative effects of density on per capita emissions and emissions intensity are now statistically significant, further suggesting that living in close quarters may reduce the environmental footprint per person.

The only major difference between these results and those for sulfur dioxide are for the spatial lag. In particular, when using the logged equations of per capita emissions, emissions intensity and emissions over area I now find significantly positive coefficients. For both pollutants the economic size of these coefficients is small and may reflect the countervailing effects described in Section 2.

Omission of One Relevant Variable

This is the first study that includes five variables characterizing countries global activities. To examine the potential omitted variable bias in previous studies I sequentially exclude one of the five variables of interest. Table 4 presents the results for the log of per capita SO_2 emissions equations.[16] Column (1) repeats column (2) from Table 2. Each consecutive column sequentially omits the trade, cross-border pollution, FDI, market potential and treaty effects.

The estimated trade effect on emissions is reduced by half when FDI, market potential or treaty variables are omitted. This alone warrants the main purpose of this study—exploring the biases caused by omitting relevant variables. The only other study that employs international emissions data (Cole and Elliott, 2003) only includes the trade dimension of international interactions. Cole and Elliott's omission of these other international variables may be in part driving their mixed results regarding trade's impact on emissions.

Also, the spatial lag of emissions drops in magnitude and becomes statistically insignificant when FDI, market potential or treaty variables are omitted. Clearly, this suggests that underlying correlations can create biases in an improperly specified model. Here is an incomplete list of four avenues through which these variables are related. First, FDI and trade may act as complements or substitutes depending on the type of FDI that occurs.[17] While the data used in this study are highly aggregated it seems that some of these effects may still be present. Second, a fairly new theory of FDI predicts that countries with

[16] Cole and Elliott (2003) claim that "per capita emissions is the standard way to express emissions when cross-country comparisons […] are required."
[17] Vertical FDI generates trade because it relocates production abroad to take advantage of lower production costs and then imports final products back home (Helpman, 1984). On the other hand, horizontal FDI reduces total trade between countries. Instead of exporting final goods, firms relocate production to the export markets thereby jumping tariffs and lowering transportation costs (Markusen, 1984).

larger market potential receive more FDI and serve as export platforms for nearby markets.[18] This introduces correlations across countries' market potential, FDI and trade dimensions. Third, if participation in treaties is a signal of countries' environmental regulation then firms' investment and trade decisions are impacted by treaty participation. Finally, countries' decision to join treaties is partly determined by cross-border pollution as illustrated by Naughton (2006). Because these (and other) correlations are occurring in so many dimensions, it would be difficult to predict the net effect of omitting some or all of these interactions.

Omitting trade intensity from the equation has the most significant effect on the market potential coefficient, which is reduced by half in magnitude. Because countries with higher market potential are also on average more open to trade (positive correlation), the omitted negative trade effect biases the market potential coefficient down. Finally, the Helsinki ratification and Helsinki participation effects are also biased downward when the spatial lag, FDI or market potential is excluded. My results suggest that treaty effects are actually higher than previously estimated because FDI and market potential have always been excluded from existing studies.

For nitrogen oxides, the omitted variable biases caused by omissions of just one variable are, for the most part, less severe.[19] Table 5 presents the results for the log of per capita NO_X emissions with all five variables of interest included in the first column and then sequentially dropping one variable in each column. The most significant changes occur when

[18] For an example of a theoretical model of export-platform FDI see Ekholm, Forslid, and Markusen (2003). Blonigen et al. (2006) find evidence of export-platform FDI at the industry level in US outbound FDI.
[19] Murdoch et al. (1997) also find that sulfur and nitrogen emissions behave somewhat differently.

trade intensity is dropped from the equation—the spatial lag flips from positive to negative and the market potential coefficient drops by two thirds. A similar change in market potential effect in the sulfur dioxide equations was discussed above. At closer inspection, the spatial lag became more negative in the sulfur dioxide equation as well when I drop trade. Countries can exert power through trade relations over their polluting neighbors and not accounting for this type of relationship may explain the latter bias.

Inclusion of Only One Relevant Variable

The next exercise further explores the potential biases on coefficients if only one of the five variables of interest is included in the model, as in many previous studies. The first column in Table 6 again repeats column (2) from Table 2. The second column includes trade but not the spatial lag, FDI, market potential or the treaty effects. The third column includes the spatial lag, the fourth FDI, the fifth market potential and the sixth treaty effects without the other variables of interest. Trade and the spatial lag, when included by themselves, lose their economic and statistical significance. FDI and market potential are still statistically significant and have the same signs as before but now are only half their original size. Helsinki ratification and participation effects both fall and lose their significance. Thus, the omitted variable bias is present and severe in these misspecified equations. Previous studies, all of which omit two to four of these international interaction variables, are also subject to these omission biases.

Similar patterns of bias can be found in Table 7 which provides the equivalent equations to Table 6 for per capita nitrogen oxide emissions. While trade on its own remains statistically significant, the economic significance is cut by half. The spatial lag loses its statistical and economic significance, as it did in the sulfur dioxide case. The FDI coefficient is the only one of the five effects in this table that remains qualitatively unchanged. The economic size of the market potential coefficient is reduced by two thirds and the Sofia Protocol participation effect is cut by half with the omission of the other variables.

Additional Findings and Robustness Checks

The models discussed so far employ cross-country variation. Including country fixed effects to Table 2 and Table 3 allow me to focus on time-series forces driving the changes in emissions between 1980 and 2000. Openness to trade is still a major factor in lowering emissions—being negative and statistically significant six times for SO_2 and seven times for NO_X. The signs and the significance of the other variables in the model are less robust across the eight dependent variables. These results are available on request.

I also ran the equations equivalent to those in Tables 4 through 7 using log of emissions as the dependent variable instead of log of per capita emissions. While the patterns of omitted variable biases for those additional equations are different, the biases are again significant and sometimes more severe than in the reported results. In two cases the coefficient on market potential flips from positive and significant in the full model to negative and significant in the model with omitted relevant variables. First, just omitting trade intensity from the equation flips the sign on market potential. Second, when moving from the full model to a model with just market potential the sign on the market potential coefficient flips again. Both of these negative omitted variable biases are also evident in the tables included in the paper. Maddison (2006) estimates emissions equations with a variable equivalent to the market potential here. His variable is a similarly constructed weighted average of nearby countries GDP per capita. He finds an unexpected negative sign on this market potential. I believe my results may explain why—he omits all other international interaction effects included here. For brevity I do not report these tables but make them available on request.

IV. Conclusion

Empirical work is always a balancing act between choosing a simple model that answers the question of interest and ensuring that all the relevant variables are included in the model. This study brings together different strands of literature that estimate the impacts of international interactions on emissions. Of central focus in the past has been the effect of trade on emissions. The bulk of the previous literature has focused on trade's impact on air quality. One previous study that uses emissions data and finds mixed results regarding trade impact on emissions (Cole and Elliott, 2003). When I include four additional international interaction variables in the model I find robust results of trade intensity reducing emissions.

The international interaction effects included in my model are openness to trade, spatial lag, FDI, market potential and treaty effects. Previous studies usually include these effects on their own and no one has included more than three effects in one model. My results suggest that excluding any of the international interaction variables one at a time or in groups can severely bias the included coefficients. This may explain the unexpected or mixed results of previous authors.

References

Antweiler, Werner, Brian R. Copeland, and M. Scott Taylor. (2001) "Is Free Trade Good for the Environment?" *The American Economic Review*, 91(4), 877-908.

Barro, R., and J.W. Lee. (2001) "International data on educational attainment: updates and implications," *Oxford Economic Papers* 53 (3), 541-563.

Blonigen, Bruce A., Ronald B. Davies, Helen T. Naughton, and Glen R. Waddell. (2006a) "Spacey Parents: Spatial Autoregressive Patterns in Inbound FDI," NBER Working Paper 11466.

Blonigen, Bruce A., Ronald B. Davies, Glen R. Waddell, and Helen T. Naughton. (2006b) "FDI in Space: Spatial Autoregressive Relationships in Foreign Direct Investment," *European Economic Review*.

CEPII (Centre d'études prospectives et d'informations internationals), *Distance Database On-Line*.

Cole, Matthew R., and Robert J.R. Elliott. (2003) "Determining the trade-environment composition effect: the role of capital, labor and environmental regulations," *Journal of Environmental Economics and Management*, 46, 363-383.

Copeland, Brian R., and M. Scott Taylor. (1994) "North-South Trade and the Environment," *Quarterly Journal of Economics*, 109(3), 755-787.

Copeland, Brian R., and M. Scott Taylor. (1995) "Trade and Transboundary Pollution," *The American Economic Review*, 85(4), 716-737.

Dean, Judith M. (2002) "Does Trade Liberalization Harm the Environment? A New Test," *Canadian Journal of Economics*, 35(4), 819-842.

Ekholm, Karolina, Rikard Forslid, and James R. Markusen. (2003) "Export-Platform Foreign Direct Investment," NBER Working Paper No. 9517.

EMEP. (2005) "Transboundary Acidification, Eutrophication and Ground Level Ozone in Europe in 2003," EMEP Status Report 2005, July 20, 2005.

Feenstra, Robert C., Robert E. Lipsey, Haiyan Deng, Alyson C. Ma, and Hengyong Mo. (2005) "World Trade Flows: 1962-2000," NBER Working Paper 11040.

Frankel, Jeffrey A., and Andrew K. Rose. (2002) "An Estimate of the Effect of Common Currencies on Trade and Income," *The Quarterly Journal of Economics*, May 2002.

Frankel, Jeffrey A., and Andrew K. Rose. (2005) "Is Trade Good or Bad for the Environment? Sorting Out the Causality," *The Review of Economics and Statistics*, 87(1), 85-91.

Freedom House, 2005. *Freedom in the World Country Rankings: 1972-2005 Dataset Online*.

Grossman, Gene M., and Alan B. Krueger. (1993) "Environmental Impacts of a North American Free Trade Agreement," in Peter M. Garber, ed., *The U.S.—Mexico free trade agreement*, Cambridge, MA: MIT Press, 13-56.

Harbaugh, William T., Arik Levinson, and David M. Wilson. (2002) "Reexamining the Empirical Evidence for an Environmental Kuznet's Curve," *The Review of Economics and Statistics*, 84(3), 541-551.

Head, Keith and Thierry Mayer. (2004) "Market Potential and the Location of Japanese Investment in the European Union," *Review of Economics and Statistics*, 86(4), 959-972.

Helpman, Elhanan. (1984) "A Simple Theory of International Trade with Multinational Corporations," *Journal of Political Economy* 92(3), 451-71.

Heston, Alan, Robert Summers, and Bettina Aten, 2002. *Penn World Table Version 6.1*, Center for International Comparisons at the University of Pennsylvania (CICUP), October 2002.

Maddison, David. (2006) "Environmental Kuznet's curves: a spatial econometric approach," *Journal of Environmental Economics and Management*, 51, 218-230.

Markusen, James R. (1984) "Multinationals, Multi-Plant Economies, and the Gains from Trade," *Journal of International Economics* 16(3-4), 205-26.

Murdoch, James C., Todd Sandler, and Keith Sargent. (1997) "A Tale of Two Collectives: Sulfur versus Nitrogen Oxides Emission Reduction in Europe," *Economica*, 64, 281-301.

Murdoch, James C., Todd Sandler, and Wim P.M. Vijverberg. (2003) "The Participation Decisions Versus the Level of Participation in an Environmental Treaty: A Spatial Probit Analysis," *Journal of Public Economics*, 87, 337-362.

MSC-W. (2002) "Emission Data Reported to UNECE/EMEP: Quality Assurance and Trend Analysis & Presentation of WebDab," MSC-W Status Report 2002, July 2002.

Naughton, Helen T. (2006) "Cooperation in Environmental Policy: A Spatial Approach," University of Oregon working paper.

Porter, Michael, and Claas van der Linde. (1995) "Toward a New Conception of the Environment-Competitiveness Relationship," *Journal of Economic Perspectives* 9(4), 97–118.

Ringquist, Evan J., and Tatiana Kostadinova. (2005) "Assessing the Effectiveness of International Environmental Agreements: The Case of the 1985 Helsinki Protocol," *American Journal of Political Science*, 49(1), 86-102.

UNCTAD. *Foreign Direct Investment Database On-Line.*

Table 1 Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max
Ln(SO_2)	5.87	1.43	2.96	8.49
Ln(SO_2/Pop)	-10.57	0.84	-12.83	-8.93
Ln(SO_2/GDP)	-20.41	1.29	-23.58	-16.36
Ln(SO_2/Area)	-6.17	1.29	-9.42	-3.92
SO_2^*	0.85	1.06	0.02	4.86
SO_2/Pop*	3.49	2.61	0.27	13.27
SO_2/GDP*	3.09	6.08	0.06	78.13
SO_2/Area*	3.88	3.98	0.08	19.90
Ln(NO_X)	6.10	1.02	3.32	7.93
Ln(NO_X /Pop)	-10.34	0.41	-11.55	-9.20
Ln(NO_X /GDP)	-20.19	0.58	-21.98	-18.04
Ln(NO_X /Area)	-5.94	0.92	-8.22	-4.24
NO_X^*	0.75	0.75	0.03	2.79
NO_X /Pop*	3.49	1.32	0.96	10.11
NO_X /GDP*	2.01	1.29	0.28	14.67
NO_X /Area*	3.90	3.52	0.27	14.38
Trade/GDP*	0.69	0.26	0.30	1.82
Ln(GDP per capita)	9.84	0.68	7.34	10.75
GDP per capita	22,315.64	10,449.45	1,538.49	46,815.50
Square of Ln(GDP per capita)	97.38	12.65	53.85	115.65
Ln(Inbound FDI Position, 1995 USD)	10.01	1.48	4.06	12.99
Ln(Market Potential)	7.00	0.30	6.36	7.67
Helsinki Ratification	0.50	0.50	0.00	1.00
Helsinki Ratification	3.42	4.53	0.00	14.00
Oslo Ratification	0.17	0.37	0.00	1.00
Oslo Participation	0.28	0.88	0.00	5.00
Sofia Ratification	0.47	0.50	0.00	1.00
Sofia Participation	2.31	3.27	0.00	11.00
Corruption	2.62	1.75	0.00	8.37
Repression Index	0.20	0.11	0.14	0.71
Ln(Density)	4.44	1.00	1.01	6.15

* These variables are scaled as detailed in Appendix A.

Table 2 SO_2 Emissions Equations for Different Transformations of the Dependent Variable

	(1) Ln(SO_2)	(2) Ln(SO2/Pop)	(3) Ln(SO_2/GDP)	(4) Ln(SO_2/Area)	(5) SO_2	(6) SO_2/Pop	(7) SO_2/GDP	(8) SO_2/Area
Trade/GDP	-3.037***	-0.964***	-0.963***	-1.022***	-2.702***	-2.916***	-4.949	-7.434***
	(0.366)	(0.264)	(0.264)	(0.269)	(0.437)	(0.968)	(3.578)	(1.580)
Ln(GDP per capita)	19.635***	15.207***	14.225***	15.259***	13.480***	44.734***	-17.574	53.168***
	(2.863)	(2.406)	(2.404)	(2.401)	(2.419)	(9.522)	(41.856)	(9.751)
Square of Ln(GDP per capita)	-1.104***	-0.848***	-0.849***	-0.850***	-0.746***	-2.467***	0.562	-3.016***
	(0.144)	(0.121)	(0.121)	(0.121)	(0.123)	(0.480)	(2.098)	(0.496)
Spatial Lag ($W*E_{it}$)	0.424***	-0.060**	-0.031**	-0.097**	0.388	0.167	0.589	0.114
	(0.065)	(0.028)	(0.014)	(0.049)	(0.648)	(0.255)	(1.135)	(0.478)
Ln(Inbound FDI Position, 1995 USD)	0.066	-0.229***	-0.229***	-0.219***	0.184***	-0.989***	-1.622***	-0.702***
	(0.042)	(0.031)	(0.031)	(0.030)	(0.060)	(0.125)	(0.311)	(0.200)
Ln(Market Potential)	1.462***	1.356***	1.349***	1.466***	0.788	4.386***	10.693***	8.781***
	(0.327)	(0.273)	(0.274)	(0.281)	(0.543)	(1.080)	(2.844)	(1.875)
Helsinki Ratification	-0.132	-0.258**	-0.259**	-0.294**	-0.383**	-1.311***	0.324	-1.347*
	(0.136)	(0.113)	(0.114)	(0.114)	(0.174)	(0.456)	(0.785)	(0.768)
Helsinki Participation	-0.056**	-0.044**	-0.044**	-0.044**	0.027	0.038	0.056	0.029
	(0.026)	(0.019)	(0.019)	(0.019)	(0.027)	(0.062)	(0.116)	(0.101)
Oslo Ratification	-0.223	-0.314**	-0.315**	-0.332**	-0.251	-0.681	-0.128	-0.506
	(0.188)	(0.140)	(0.140)	(0.143)	(0.190)	(0.437)	(0.845)	(0.677)
Oslo Participation	-0.233**	-0.213***	-0.213***	-0.233***	-0.172**	-0.463*	-0.984	-0.319
	(0.091)	(0.070)	(0.069)	(0.070)	(0.084)	(0.247)	(0.951)	(0.346)
Corruption	-0.030	-0.083***	-0.083***	-0.060*	-0.123**	-0.237**	0.337	-0.538***
	(0.036)	(0.030)	(0.030)	(0.031)	(0.049)	(0.114)	(0.223)	(0.193)
Repression Index	1.704	-0.221	-0.213	-0.183	1.956*	3.838	-8.746	0.503
	(1.127)	(0.933)	(0.932)	(0.928)	(1.024)	(3.724)	(14.983)	(4.125)
Ln(Density)	0.343***	-0.065	-0.063	0.907***	0.187*	-0.088	-0.434	1.564***
	(0.069)	(0.057)	(0.057)	(0.060)	(0.110)	(0.217)	(0.447)	(0.406)
Observations	306	306	306	306	306	306	306	306
R-squared	0.858	0.704	0.875	0.869	0.657	0.608	0.606	0.616
EKC peak	7,274	7,858	4,364	7,941	8,384	8,668	$6*10^6$	6,738

Robust standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

All equations include a constant and year fixed effects.

Table 3 NO_X Emissions Equations for Different Transformations of the Dependent Variable

	(1) Ln(NO_X)	(2) Ln(NO_X /Pop)	(3) Ln(NO_X /GDP)	(4) Ln(NO_X /Area)	(5) NO_X	(6) NO_X /Pop	(7) NO_X /GDP	(8) NO_X /Area
Trade/GDP	-2.935***	-1.005***	-0.988***	-1.052***	-1.919***	-3.061***	-1.520***	-3.971***
	(0.260)	(0.130)	(0.129)	(0.132)	(0.221)	(0.442)	(0.259)	(0.810)
Ln(GDP per capita)	10.773***	7.152***	6.119***	7.210***	8.618***	17.630***	-2.905	24.844***
	(1.860)	(1.547)	(1.533)	(1.571)	(1.647)	(4.046)	(6.836)	(6.121)
Square of Ln(GDP per capita)	-0.593***	-0.379***	-0.377***	-0.382***	-0.472***	-0.941***	0.044	-1.378***
	(0.094)	(0.078)	(0.077)	(0.079)	(0.083)	(0.205)	(0.343)	(0.317)
Spatial Lag ($W*E_{it}$)	0.217***	0.033**	0.015**	0.054**	1.006***	-0.187	0.035	-0.389***
	(0.029)	(0.013)	(0.006)	(0.024)	(0.244)	(0.126)	(0.316)	(0.145)
Ln(Inbound FDI Position, 1995 USD)	0.234***	-0.054**	-0.055***	-0.046**	0.245***	-0.254***	-0.226***	-0.036
	(0.034)	(0.021)	(0.021)	(0.021)	(0.030)	(0.068)	(0.085)	(0.123)
Ln(Market Potential)	0.864***	0.895***	0.886***	0.994***	0.685***	2.340***	1.403***	3.024***
	(0.233)	(0.151)	(0.150)	(0.148)	(0.202)	(0.442)	(0.314)	(0.886)
Sofia Ratification	0.138	-0.039	-0.041	-0.048	0.216**	-0.218	-0.076	0.073
	(0.113)	(0.069)	(0.069)	(0.067)	(0.097)	(0.232)	(0.171)	(0.473)
Sofia Participation	-0.040	-0.047***	-0.047***	-0.056***	-0.047*	-0.178***	-0.041	-0.115
	(0.027)	(0.015)	(0.014)	(0.015)	(0.025)	(0.051)	(0.041)	(0.097)
Corruption	-0.042	-0.081***	-0.081***	-0.060***	-0.022	-0.341***	-0.115***	-0.928***
	(0.026)	(0.017)	(0.017)	(0.016)	(0.024)	(0.058)	(0.036)	(0.129)
Repression Index	1.743***	-0.313	-0.324	-0.369	1.374**	-1.504	-1.910	-0.081
	(0.659)	(0.529)	(0.525)	(0.534)	(0.606)	(1.431)	(2.271)	(2.202)
Ln(Density)	0.236***	-0.214***	-0.211***	0.760***	0.105**	-0.656***	-0.178*	2.615***
	(0.050)	(0.032)	(0.032)	(0.032)	(0.042)	(0.100)	(0.105)	(0.206)
Observations	306	306	306	306	306	306	306	306
R-squared	0.823	0.570	0.788	0.924	0.820	0.562	0.753	0.740
EKC peak	8,745	12,491	3,320	12,391	9,266	11,679	3*1014	8,216

Robust standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

All equations include a constant and year fixed effects.

Table 4 Ln(SO2/Pop) Equations with One Missing International Interaction Effect

	(1) All	(2) No Trade	(3) No Lag	(4) No FDI	(5) No MktPot	(6) No Treaties
Trade/GDP	-0.964***		-1.093***	-0.464*	-0.571**	-0.580*
	(0.264)		(0.302)	(0.242)	(0.223)	(0.296)
Ln(GDP per capita)	15.207***	14.713***	16.098***	15.265***	15.138***	16.785***
	(2.406)	(2.443)	(2.514)	(2.424)	(2.611)	(2.693)
Square of Ln(GDP per capita)	-0.848***	-0.813***	-0.894***	-0.845***	-0.837***	-0.934***
	(0.121)	(0.124)	(0.127)	(0.122)	(0.132)	(0.135)
Spatial Lag ($W*E_{it}$)	-0.060**	-0.092***		-0.009	-0.041	-0.018
	(0.028)	(0.025)		(0.026)	(0.025)	(0.028)
Ln(Inbound FDI Position, 1995 USD)	-0.229***	-0.210***	-0.189***		-0.233***	-0.175***
	(0.031)	(0.031)	(0.027)		(0.034)	(0.036)
Ln(Market Potential)	1.356***	0.756***	1.285***	1.131***		0.647**
	(0.273)	(0.209)	(0.285)	(0.286)		(0.279)
Helsinki Ratification	-0.258**	-0.265**	-0.184	-0.043	-0.138	
	(0.113)	(0.125)	(0.121)	(0.118)	(0.128)	
Helsinki Participation	-0.044**	-0.035**	-0.035*	-0.029*	-0.030	
	(0.019)	(0.016)	(0.018)	(0.017)	(0.019)	
Oslo Ratification	-0.314**	-0.286**	-0.333**	-0.384***	-0.300**	
	(0.140)	(0.133)	(0.143)	(0.143)	(0.150)	
Oslo Participation	-0.213***	-0.186***	-0.222***	-0.224***	-0.204***	
	(0.070)	(0.063)	(0.070)	(0.069)	(0.068)	
Corruption	-0.083***	-0.058*	-0.093***	-0.039	-0.162***	-0.090***
	(0.030)	(0.030)	(0.035)	(0.031)	(0.028)	(0.029)
Repression Index	-0.221	0.413	0.219	1.241	0.169	0.583
	(0.933)	(0.840)	(0.879)	(0.863)	(0.960)	(1.000)
Ln(Density)	-0.065	0.002	-0.097*	-0.209***	0.136***	-0.009
	(0.057)	(0.048)	(0.055)	(0.058)	(0.036)	(0.060)
Observations	306	306	306	306	306	306
R-squared	0.704	0.690	0.689	0.662	0.678	0.632

Robust standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

All equations include a constant and year fixed effects.

Table 5 Ln(NO_X/Pop) Equations with One Missing International Interaction Effect

	(1) All	(2) No Trade	(3) No Lag	(4) No FDI	(5) No MktPot	(6) No Treaties
Trade/GDP	-1.005***		-1.106***	-0.784***	-0.975***	-0.897***
	(0.130)		(0.193)	(0.139)	(0.133)	(0.132)
Ln(GDP per capita)	7.152***	6.359***	6.842***	7.179***	6.967***	7.370***
	(1.547)	(1.390)	(1.447)	(1.514)	(1.723)	(1.457)
Square of Ln(GDP per capita)	-0.379***	-0.329***	-0.365***	-0.377***	-0.367***	-0.393***
	(0.078)	(0.070)	(0.074)	(0.077)	(0.087)	(0.074)
Spatial Lag (W^*E_{it})	0.033**	-0.024*		0.036***	0.045***	0.040***
	(0.013)	(0.013)		(0.013)	(0.014)	(0.014)
Ln(Inbound FDI Position, 1995 USD)	-0.054**	-0.057***	-0.075***		-0.091***	-0.060***
	(0.021)	(0.020)	(0.020)		(0.021)	(0.021)
Ln(Market Potential)	0.895***	0.291**	1.010***	0.869***		0.696***
	(0.151)	(0.117)	(0.200)	(0.155)		(0.133)
Sofia Ratification	-0.039	-0.110*	-0.067	-0.060	0.075	
	(0.069)	(0.067)	(0.077)	(0.060)	(0.068)	
Sofia Participation	-0.047***	-0.030**	-0.061***	-0.043***	-0.031**	
	(0.015)	(0.013)	(0.018)	(0.015)	(0.014)	
Corruption	-0.081***	-0.064***	-0.083***	-0.061***	-0.157***	-0.101***
	(0.017)	(0.015)	(0.018)	(0.016)	(0.019)	(0.018)
Repression Index	-0.313	0.148	-0.684	0.113	-0.306	-0.146
	(0.529)	(0.437)	(0.464)	(0.399)	(0.576)	(0.525)
Ln(Density)	-0.214***	-0.118***	-0.198***	-0.253***	-0.057**	-0.187***
	(0.032)	(0.030)	(0.036)	(0.025)	(0.024)	(0.029)
Observations	306	306	306	306	306	306
R-squared	0.570	0.612	0.533	0.593	0.499	0.564

Robust standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

All equations include a constant and year fixed effects.

Table 6 Ln(SO_2/Pop) Equations with One International Interaction Effect

	(1) All	(2) With Trade	(3) With Lag	(4) With FDI	(5) With MktPot	(6) With Treaties
Trade/GDP	-0.964***	-0.159				
	(0.264)	(0.260)				
Ln(GDP per capita)	15.207***	16.649***	16.647***	15.727***	16.923***	15.504***
	(2.406)	(2.705)	(2.780)	(3.059)	(2.491)	(2.478)
Square of Ln(GDP per capita)	-0.848***	-0.914***	-0.910***	-0.864***	-0.929***	-0.848***
	(0.121)	(0.138)	(0.141)	(0.156)	(0.127)	(0.127)
Spatial Lag ($W{*}E_{it}$)	-0.060**		0.017			
	(0.028)		(0.023)			
Ln(Inbound FDI Position, 1995 USD)	-0.229***			-0.150***		
	(0.031)			(0.031)		
Ln(Market Potential)	1.356***				0.617***	
	(0.273)				(0.216)	
Helsinki Ratification	-0.258**					0.003
	(0.113)					(0.135)
Helsinki Participation	-0.044**					-0.012
	(0.019)					(0.016)
Oslo Ratification	-0.314**					-0.392***
	(0.140)					(0.150)
Oslo Participation	-0.213***					-0.217***
	(0.070)					(0.070)
Corruption	-0.083***	-0.078**	-0.059**	-0.076***	-0.018	-0.084***
	(0.030)	(0.031)	(0.023)	(0.024)	(0.032)	(0.023)
Repression Index	-0.221	1.938**	2.180**	1.224	2.019***	1.866**
	(0.933)	(0.789)	(0.864)	(0.892)	(0.742)	(0.804)
Ln(Density)	-0.065	-0.044	-0.055	0.051	-0.145***	-0.047
	(0.057)	(0.035)	(0.036)	(0.037)	(0.050)	(0.030)
Observations	306	306	306	306	306	306
R-squared	0.704	0.577	0.576	0.617	0.588	0.628

Robust standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

All equations include a constant and year fixed effects.

Table 7 Ln(NO_X/Pop) Equations with One International Interaction Effect

	(1) All	(2) With Trade	(3) With Lag	(4) With FDI	(5) With MktPot	(6) With Treaties
Trade/GDP	-1.005***	-0.568***				
	(0.130)	(0.141)				
Ln(GDP per capita)	7.152***	6.807***	6.893***	6.668***	6.636***	6.601***
	(1.547)	(1.333)	(1.364)	(1.533)	(1.158)	(1.428)
Square of Ln(GDP per capita)	-0.379***	-0.357***	-0.353***	-0.342***	-0.342***	-0.336***
	(0.078)	(0.069)	(0.070)	(0.079)	(0.060)	(0.073)
Spatial Lag (W^*E_{it})	0.033**		0.017			
	(0.013)		(0.011)			
Ln(Inbound FDI Position, 1995 USD)	-0.054**			-0.061***		
	(0.021)			(0.015)		
Ln(Market Potential)	0.895***				0.268***	
	(0.151)				(0.089)	
Sofia Ratification	-0.039					-0.083
	(0.069)					(0.066)
Sofia Participation	-0.047***					-0.024*
	(0.015)					(0.014)
Corruption	-0.081***	-0.123***	-0.072***	-0.078***	-0.051***	-0.066***
	(0.017)	(0.020)	(0.013)	(0.013)	(0.015)	(0.013)
Repression Index	-0.313	0.291	0.846**	0.492	0.720**	0.715*
	(0.529)	(0.426)	(0.415)	(0.428)	(0.338)	(0.388)
Ln(Density)	-0.214***	-0.109***	-0.135***	-0.086***	-0.169***	-0.125***
	(0.032)	(0.017)	(0.014)	(0.016)	(0.020)	(0.014)
Observations	306	306	306	306	306	306
R-squared	0.570	0.509	0.564	0.587	0.575	0.571

Robust standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

All equations include a constant and year fixed effects.

Figure 1 SO_2 Emissions and Mean SO_2 Concentrations, 1995[21]

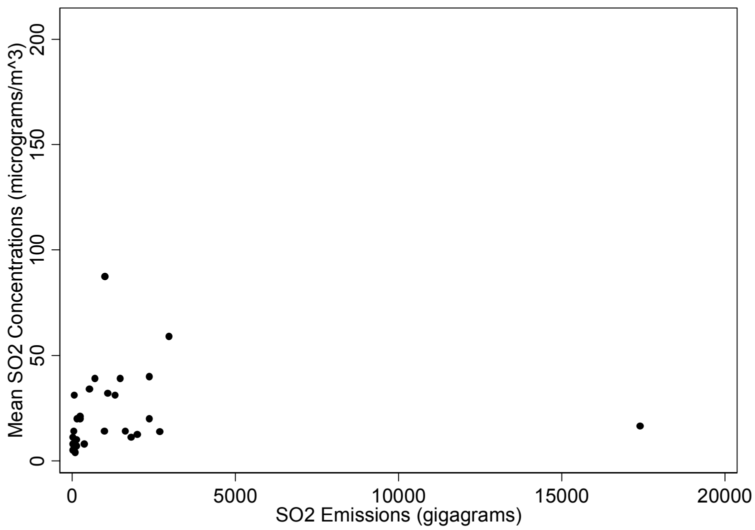
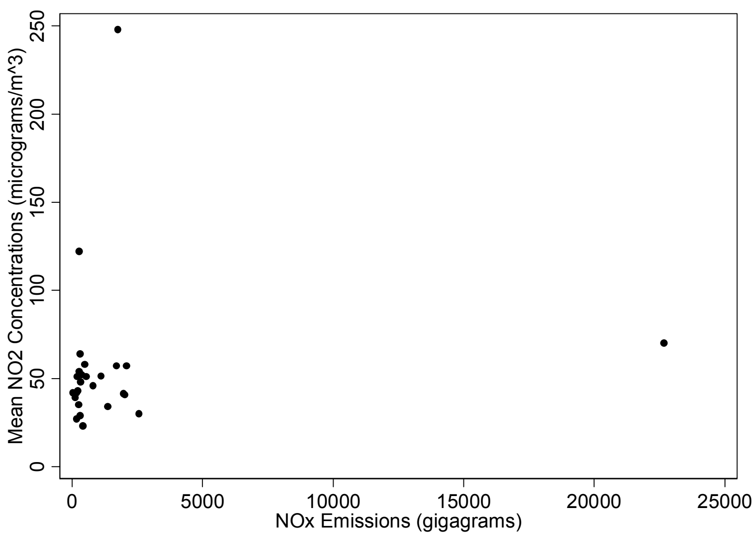


Figure 2 NO_X Emissions and Mean NO_2 Concentrations, 1995



[21] The SO_2 and NO_2 concentrations data are from 1998 World Development Indicators compiled by the World Bank available online at http://www.worldbank.int/nipr/wdi98/index.htm.

Appendix A Data Sources

The emissions data come from the EMEP (2005) and are country level sulfur dioxide (SO_2) and nitrogen oxides (NO_X) emissions for nineteen European countries for 1980-2000 measured in gigagrams. The spatial lag is constructed using emissions transport matrices, or blame matrices, for SO_2 and NO_X as reported by the Meteorological Synthesizing Centre—West (MSC-W, 2002). When calculating the dependent variables, the logarithmic versions always use emissions in gigagrams, population in thousands, GDP in dollars and area in km^2. The linear versions of the variables were scaled so that the coefficients would be easier to look at. Total emissions were scaled down by 1000. Per capita emissions, emissions intensity and emissions over area were scaled up by 10^5, 10^9 and 1000, respectively.

Trade as a fraction of GDP, GDP per capita, population and density come from 2004 World Development Indicators compiled by World Bank. Note that all money values used in this analysis are in 1995 US dollars. FDI is measured as inbound FDI stock and is obtained from United Nations Conference on Trade and Development online at http://stats.unctad.org/fdi/. Corruption is measured by 10-CPI, where CPI is the Corruption Perceptions Index decreasing in corruption provided by Transparency International online at http://www.transparency.org/. The civil liberties and political rights indices that I use in construction of the repression index are reported by Freedom House online at http://www.freedomhouse.org/ratings/index.htm. The treaty-related data come from the United Nations' Treaty Database. Table 1 reports the descriptive statistics.

Additional Data Sources for the Bilateral Trade and Income Equations

Bilateral trade data are reported by Feenstra et al. (2005) online at http://cid.econ.ucdavis.edu. To convert the trade data into constant 1995 US dollars I use the US GDP deflator as reported by the Economic Report of the President. Data for distances between countries, common language, common border, area and whether or not a country is landlocked come from Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) available online at http://www.cepii.fr/anglaisgraph/bdd/distances.htm.

Investment as a share of GDP is reported by Penn World Tables 6.1 and is averaged over all available years. Population growth rate for a given year in a country is calculated based on the preceding twenty years. Education measured as average years of schooling for people aged over 25 come from the Barro and Lee (2001) dataset available online at http://www.nber.org/pub/barro.lee/. These data are reported every five years between 1960 and 2000. I interpolate the data for intermittent years.