The Pollution Haven Hypothesis: Significance and Insignificance

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Abstract

Theory and intuition tell us that the imposition of stringent environmental policies by a given country will reduce its net exports of commodities produced using pollution-intensive industries. It is therefore surprising that many empirical studies of international commodity trade have failed to find evidence of this effect. This study offers a new, highly focused test of the pollution haven hypothesis, by investigating the link between international factor trade in coal and urban air concentrations of SO_2. I find statistically significant evidence that countries with poor air quality do have higher net factor exports of coal; however, the magnitude of the impact is small, casting doubt on the economic significance of the pollution haven effect as a guide to policy.

In the spring of 2005, as the U.S. Congress debated the Clear Skies Act, which aimed to reduce SO_2, NO_x, and mercury emissions from coal power plants, the Washington Post reported that "several Republicans said that overly stringent measures would...cause polluting industries to leave U.S. shores for countries with lower standards." This concern, known as the pollution haven hypothesis, is based on the concept that countries which are relatively tolerant of environmental degradation place their pollution-intensive industries at a comparative advantage, and therefore have relatively high net exports of pollution intensive goods. Put another way, increased stringency of environmental protection on the part of "clean" countries is offset by increases in the production of pollution-intensive goods for export by "dirty" countries. The policy implication is that the rationale for tightening pollution restrictions in countries such as the U.S. is weakened.

While the pollution haven hypothesis has strong roots both in its intuitive plausibility and in a body of theoretical work (see, for example, Pethig 1976, Siebert 1977, and McGuire 1982), it has generally failed to garner strong empirical support across several studies. The empirical literature in this area has generally followed one of two paths: the first examines the relation between environmental policies and the location decisions of firms (industrial flight), while the second examines the impacts of environmental policies on patterns of trade in dirty goods. Empirical studies of industrial flight have yielded mixed results, with some studies finding evidence of industry location away from jurisdictions with stringent pollution regulations, and most studies not.[1] Empirical investigations of the relation between environmental policies and trade patterns of dirty goods, the concern of this paper, have until very recently also failed to support the pollution haven hypothesis. The two most widely cited studies, by Tobey (1990) and Grossman and Kruger (1993), test for an effect of the stringency of environmental regulation on international commodity trade (in cross-country and cross-industry settings, respectively), and find no statistically significant effect.

Recent research by Levinson and Taylor (2002) and Ederington and Minier (2003), however, has critiqued these studies on the grounds that environmental regulations are not exogenous in a regression with commodity trade on the left hand side, and that prior estimates of the pollution haven effect have been biased towards zero. Levinson and Taylor argue that the endogeneity arises because, in industries with high levels of import competition, firms with high abatement costs are forced to relocate or shut down, leaving only low abatement cost firms behind. Ederington and Minier meanwhile argue that the endogeneity is due to trade protection of high abatement cost industries. Using instrumental variables, both sets of authors find that pollution abatement costs have a statistically significant effect on net imports. However, they are careful to caveat the magnitudes of their estimates, which vary significantly across papers: Levinson and Taylor's findings suggest that an industry with pollution abatement costs (taken as a share of industry total costs) that are one percentage point higher than those of an otherwise identical industry will have net imports (taken as a share of industry total production) that are 7.3 percentage points higher, while Ederington and Minier (2003) find a corresponding value of 35 percentage points (the elasticities corresponding to these estimates are 0.52 and 5.8, respectively). Further research (Ederington, Levinson, and Minier 2005) presents evidence that, while the pollution haven effect is not a statistically significant driver of U.S. imports for the average industry, high costs of pollution abatement are associated with increased imports for geographically "footloose" industries; that is, those industries for which relocation costs are relatively low.

In this research, I confront the difficulties inherent in empirical investigation of the pollution haven hypothesis by formulating a new approach based not on commodity trade, the dependent variable in all prior work, but on factor trade, and argue that this approach provides a clearer view into the relation between a society's tolerance of environmental degradation and its patterns of international trade. Specifically, I test the proposition that countries with high levels of urban SO_2 concentrations will have higher net factor exports of coal than countries with low urban SO_2 concentrations, controlling for each country's total trade (factor trade plus direct trade)^2 in coal. That is, I test whether countries with air pollution problems will tend to first burn their coal and then export it as coal embodied in finished goods, rather than simply export raw coal (or, in the case of countries with high SO_2 concentrations and relatively small coal endowments, that they tend to import coal directly and burn it at home rather than import coal as an embodied factor in imports of other goods). This test is intuitively rooted in the fact that it is the burning of coal that generates SO_2 pollution, not its direct export.

This approach offers several advantages. First, even absent any regression analysis, the calculation of factor trade in coal is informative in itself, because an understanding of the volume of this trade provides insight into the economic significance of a pollution haven effect: if this trade is not large, as I ultimately find, then the magnitude of the pollution haven effect must necessarily be small. The second advantage is that the factor trade calculation considers not only the coal needed to directly produce each traded commodity, but also the coal that is indirectly required.[3] This approach therefore allows for the pollution haven effect to manifest itself through changes in trade patterns of goods produced by industries that, while not significant direct users of coal, are significant indirect users (e.g. primary aluminum manufacturing). This "indirect use" pollution haven mechanism has not been considered by prior work that has investigated commodity trade. Finally, the test I propose is focused in that it directly relates trade in a polluting factor of production, coal, to urban air concentrations of one of its major pollutants, SO_2. This serves to isolate the pollution haven effect from other industry-specific variables that impact trade.

The disadvantage of this approach is that urban SO_2 concentrations and net factor exports are simultaneously determined. That is, while I aim to test whether high levels of urban SO_2 concentrations cause positive net factor exports of coal, it may be that the causality operates in the reverse direction. To deal with this concern, I instrument for SO_2 concentrations with an index measure of the stability of each country's political institutions. As I discuss at greater length later in this paper, the intuition behind the use of this instrument is that (1) there is no intuitively straightforward causal effect of net factor exports of coal on political stability, and (2) political stability should be correlated with the presence of social and political institutions that reflect a low tolerance of pollution.

A discussion is warranted regarding the choice of urban SO_2 concentrations as this study's measure of the stringency of a country's environmental policies. SO_2 measurements are, to borrow terminology from van Beers and van den Bergh (1997, 2000), "output-oriented" indicators of pollution tolerance rather than "input-oriented". Input-oriented indicators, such as those used by all the other papers referenced above, measure policies and expenditures related to abatement of pollution. As pointed out by van Beers and van den Bergh, such indicators fail to capture the aggregate effects of countries' environmentally-related policies, as they often do not incorporate the impacts of taxes, subsidies, or poor enforcement of regulations. An output-oriented indicator, on the other hand, implicitly takes all such impacts into account.

Amongst potential output-oriented measures, urban SO_2 concentrations present an ideal choice for several reasons. First, SO_2 is a noxious gas that warrants regulation: it has been associated with respiratory illness, aggravation of respiratory problems such as asthma, and acid rain (U.S. EPA 2002). Second, it can be tied to production of goods that have high factor intensities of coal: its primary anthropogenic sources are the burning of coal and oil, and primary metal smelting (U.S. EPA 2002). Third, there exist well-known abatement technologies (e.g. flue gas scrubbers) for controlling its emissions. Finally, there exist international panel data on urban SO_2 concentrations via the Global Environment Monitoring System (GEMS). Other pollutants that meet the first three criteria, such as nitrogen oxides or particulate matter, are unfortunately not as well represented in the GEMS data and do not present a sufficient number of observations for use in this study.

In the next section I describe a theoretical model for the pollution haven hypothesis in the context of factor trade, drawing from the HOV literature. I then discuss the calculation of the model's dependent variable: factor trade in coal. The data section provides a summary of the data, presenting evidence that the volume of factor trade in coal is small, particularly relative to coal production. A discussion of estimation and results follows.

Theoretical Model

The reduced form model that underlies this paper is based on the intuitive implications of the pollution haven hypothesis in the setting of factor trade in coal. Because one needs to actually burn coal to generate SO_2, the comparative advantage of a country with a high tolerance of SO_2 pollution lies in the production and export of coal-intensive products, rather than in the export of coal itself. Therefore, if the pollution haven hypothesis is true, we should expect that a country with a high SO_2 tolerance and a large endowment of coal would tend to export more of its coal as factor content in finished or intermediate goods, rather than as raw coal. Similarly, a country with a low endowment of coal but a high SO_2 tolerance should be expected to import its coal as raw coal rather than as factor content, because it will be relatively cheap to burn the coal at home rather than pay for it to be burned abroad.

This intuition motivates the following reduced form:

$$\text{FactorTrade} = \beta_1 + \beta_2 \cdot \text{TotalTrade} + \beta_3 \cdot \text{SO}_2 \cdot |\text{TotalTrade}| + \varepsilon \qquad (1)$$

Controlling for total trade (equal to factor trade plus direct trade) in coal, factor trade should increase with the tolerance of SO_2 pollution–as measured by its urban air concentration–within a given country. Therefore, the pollution haven hypothesis implies that β_3 is a positive number. The natural intuition that factor trade should increase with total trade implies that β_2 is positive as well.[4]

Model (1) as written suffers from three endogeneity problems. First, it does not take into account variations in the sulfur content of coal across countries, which may be correlated both with factor trade in coal and with the $\beta_3 \cdot \text{SO}_2 \cdot |\text{TotalTrade}|$ term (the "pollution term") on the right hand side. Second, it may suffer from simultaneity bias, in that high factor exports of coal may cause high urban SO_2 concentrations rather than vice-versa. As I discuss later in this paper, I deal with these two problems by instrumenting for the pollution term with an index measure of the stability of each country's political institutions.

The third endogeneity problem results from the simultaneity of factor trade and total trade. Because these two variables are linked by an additive identity (TotalTrade = FactorTrade + DirectTrade), I cannot consistently estimate (1) as written: random disturbances to factor trade will be correlated with random disturbances to total trade. However, the Heckscher-Ohlin-Vanek (HOV) model of factor trade offers a solution to this problem, by which total trade in coal may be proxied for with information on coal production and GDP. Conveniently, the proxy contains no information regarding how total coal trade will be divided between factor trade and direct trade, and therefore eliminates the simultaneity problem caused by the additive identity.

I next review some background regarding the theoretical and empirical HOV literature, and then discuss how I adapt this body of work to develop an HOV proxy for total trade in coal.

Review of HOV Theory and its Empirical Tests

The basic HOV model is underpinned by the following assumptions:

1) No barriers to trade and zero transport costs

2) The number of tradable goods (n) is larger than the number of primary factors (m)

3) Markets for goods and factors are perfectly competitive

4) Identical and homothetic consumer preferences across all countries

5) Identical and constant returns to scale technologies across all countries

6) Factor price equalization across all countries[5]

It can easily be shown (see, for example, Leamer 1980) that the above assumptions imply the HOV factor trade relation (2) below, in which T^c is country c's n-vector of net commodity exports, P^c is its m-vector of factor endowments, α^c is its share of world GDP, and P^w is the world's m-vector of factor endowments. A is a $m \times n$ technology matrix of direct and indirect factor requirements common to all countries. The interpretation of (2) is that the factor trade of country c, as measured by the factor content of its net exports, must equal its factor endowment less its "share" of the global factor endowment.

$$AT^c = P^c - \alpha^c P^w \tag{2}$$

The right hand side of (2) is often referred to as predicted factor trade. Empirical tests have consistently shown that (2) is not in agreement with factor trade data, beginning with Leontief's (1953, 1956) famous "paradox" that the HOV model mispredicts the signs of U.S. factor trade of labor and capital (though, as Leamer (1980) points out, with an incorrect model assuming balanced trade). Numerous studies followed in Leontief's path, notably Bowen et al (1987), who find in a multicountry, multifactor test that the HOV theorem predicts the sign of net factor trade no better than a coin toss.

These empirical failings led research in the 1990s to focus on testing HOV while relaxing assumptions 1-6 above. Trefler (1993) had some success in allowing for Hicks-neutral differences in technology across countries; however, Gabaix (1997) cast doubt on these results. Davis et al (1997) use both international trade and inter-regional Japanese trade data to show that, while the assumption of identical homothetic preferences appears to work well, the assumptions of identical technology and identical factor productivity bear responsibility for much of HOV's problems. Davis and Weinstein (2001, hereafter referred to as DW) then discard these two assumptions altogether and test HOV allowing the technology matrix A to vary across a cross-section of OECD countries, yielding a dramatic improvement in the fit of data on factor trade of labor and capital[6].

Applying the HOV Model to Factor Trade in Coal

My approach in this study follows that of DW in loosening the identical productivity and factor price equalization assumptions to yield a relation between actual total coal trade and predicted total coal trade. The predicted trade from this HOV model then becomes the proxy for total trade in the original reduced form (1).

The HOV model I construct differs from DW's model in two respects. First, I allow for direct factor trade, which DW assumed to be zero for their factors of labor and capital. Second, while DW calculate net factor trade for any particular country as the difference of the factor content of its exports and imports, I instead calculate the difference of the factor content of its exports and import *replacements*. That is, I calculate the coal content of imports based on the importing country's technology, rather than the source country's technology. This change of approach is appropriate for testing the pollution haven hypothesis, because the degree of each country's tolerance of SO_2 pollution should be reflected in the amount of domestic consumption of coal that is displaced by imports, rather than in the incremental quantity of coal burned abroad.

To develop the model, I restrict attention to only one factor: coal, so that A^c becomes a $1 \times n$ technology vector (specific to each country), and P^c and P^w become scalars indicating country and world coal production, respectively. Let X^c and C^c represent n-vectors of commodity production and consumption, and let D^c represent direct net exports of coal. Then, commodity balance implies that net commodity exports are equal to production minus consumption, and factor balance implies that coal production is equal to coal used in commodity production plus direct net exports:

$$T^c = X^c - C^c$$

$$P^c = A^c X^c + D^c$$

Combining these two relations yields that net total trade (factor trade plus direct trade) in coal is equal to coal production less coal used for consumption:

$$A^c T^c + D^c = P^c - A^c C^c$$

Applying assumption 4, which implies that $C^c = \alpha^c C^w$, and noting that global commodity balance implies $C^w = X^w$, it follows that we can replace country c's coal used for consumption with its "share" of coal used in global commodity production:

$$A^c T^c + D^c = P^c - \alpha^c A^c X^w$$

Define $\bar{A}$ to be the world "average" coal technology vector, so that $P^w = \bar{A}X^w$. For each country c, I approximate A^cX^w by $g^c\bar{A}X^w = g^cP^w$, where g^c represents the ratio of country c's percentage of electricity generated from coal to the global percentage of electricity generated from coal. This approximation is accurate to the extent that direct use of coal is confined to electricity generation. While this seems reasonable for some countries in my sample such as the U.S., in which 87% of total coal consumption was for the purpose of electricity generation (EIA 2002), it is strained for China, for which the corresponding figure is 29%, largely because a significant quantity of Chinese coal is used for residential heating and cooking (LBNL 2004). Therefore, this approximation will carry a cost in terms of reduced HOV model accuracy for such countries, as will be discussed in the estimation section of this paper. However, given the available data, the approximation allows for the following tractable HOV model, which I now write as a regression:

$$A^cT^c + D^c = \alpha \cdot (P^c - \alpha^c g^c P^w) + \eta \tag{3}$$

The left hand side of (3) represents actual total trade of coal, while the right hand side represents the HOV prediction of total trade of coal. Because (3) does not take costs of trade into account, it is anticipated that a regression of actual trade on predicted trade will yield a positive slope less than unity.

Pollution Haven Model

With an HOV model now specified, I may incorporate its result into the original pollution haven model. The right hand side of (3) offers a prediction of total coal trade that carries no information regarding how total trade is divided between factor trade and direct trade. I may therefore use this prediction as a substitute for total trade in the pollution haven model (1), thereby eliminating the simultaneity problem between factor trade and total trade. Doing so yields the reduced form below, in which I now denote factor trade by A^cT^c:

$$A^c T^c = \beta_1 + \beta_2 \cdot (P^c - \alpha^c g^c P^w) + \beta_3 \cdot SO_2^c \cdot |P^c - \alpha^c g^c P^w| + \varepsilon \tag{4}$$

Recall that, according to the pollution haven hypothesis, high urban SO_2 concentrations (reflective of a high tolerance of SO_2 pollution) should drive a comparative advantage in the production of coal-intensive goods, resulting in relatively high net factor exports of coal. A positive estimate of the coefficient β_3 is therefore to be taken as evidence in support of a pollution haven effect. Total HOV-predicted trade in coal, $P^c - \alpha^c g^c P^w$, is a controlling variable in this model, and the estimate of β_2 is expected to be positive, as higher predicted total trade in coal should be associated with higher factor trade in coal.

As already noted, estimation of (4) must still deal with the endogeneity of SO_2 concentrations. In particular, (4) omits variations in the sulfur content of coal, and factor trade may be simultaneously determined with SO_2. My solution to this problem is to instrument for the pollution term in (4) with an index measure of the stability of each country's political institutions.

The next section of the paper describes, for the interested reader, the method by which the dependent variable in (4), $A^c T^c$, is calculated. Readers who are more immediately interested in the results should skip ahead to the data section, in which I summarize the data and note that coal factor trade is of small magnitude. This is followed by a discussion of the identification strategy and estimation results.

Calculating Factor Trade in Coal

Construction of the dependent variable of (4), factor trade in coal, is itself a major project, the starting point for which is the calculation of the coal technology vector for the U.S., A^{US}. In what follows, I first outline the input-output model used to estimate energy factor trade of the U.S. I then describe the data inputs to this calculation, and finally discuss how the vectors A^c are arrived at for the other countries in my sample.

Input-Output Model

The calculation of the n-row vector A^{US} requires the construction of the following two $n \times n$ matrices:

1. $\tilde{U}$: The commodity by industry Use Shares matrix. Cell $\tilde{u}_{ij}$ indicates the direct amount of commodity i used to produce one unit of output of industry j.
2. $\tilde{M}$: The industry by commodity Make Shares matrix. Cell $\tilde{m}_{ij}$ indicates the production of commodity j by industry i as a fraction of total production of commodity j.

Letting q represent the n-vector of total commodity production, and e represent the n-vector of final commodity demand, the following must hold:

$$q = \tilde{U}\tilde{M}q + e$$

Rearranging yields the following, in which I is the $n \times n$ identity matrix:

$$q = (I - \tilde{U}\tilde{M})^{-1}e$$

$(I-\tilde{U}\tilde{M})^{-1}$ is the direct and indirect requirements matrix, and A^{US} is taken as the row of this matrix corresponding to the factor coal. Thus, the product $A^{US}T^{US}$ represents the total direct and indirect amount of coal required to produce the United States' net commodity exports.

One crucial feature of the Make and Use Shares matrices in this application is that they are in hybrid units; that is, energy commodities and outputs are measured in energy units (trillion btu (tbtu))[7], and non-energy commodities and outputs are measured in dollars. There is widespread agreement in the energy input-output literature (see Hillman et al 1978, Hannon et al 1983, Miller and Blair 1985, and Machado et al 2001) that hybrid units are required to accurately model energy factor requirements, because energy prices are not identical across sectors. For example, electric generators generally pay lower rates for natural gas than do smaller industrial and commercial customers.

I construct an input-output model using $n = 64$ sectors, seven of which are energy sectors. Concordance tables from SIC, NAICS, and SITC Rev.2 industry codes were developed to permit mapping of the raw data discussed below into the model.

Data Sources

Input-Output Matrices (Make, Use, and Capital Use)

This study utilizes the Bureau of Economic Analysis (BEA) benchmark Make, Use, and Capital Use matrices for 1982, 1987, 1992, and 1997, measured in nominal U.S. dollars, and with industries classified by SIC codes for years 1982, 1987, and 1992, and by NAICS codes for 1997. To estimate these matrices for non-benchmark years, a combination of linear interpolation and indexing is used, based on a method utilized by the Energy Information Administration (EIA 1992). Capital Use matrices are required, because, as recognized by Leontief (1956), the Use matrices alone only tabulate current use of commodities by industries. Thus, to accurately capture long-run commodity use, the Use and Capital Use matrices are summed.

Energy Use and Production

Energy use and production data are drawn primarily from two EIA sources: the 2002 Annual Energy Review (AER) and the Manufacturing Energy Consumption Survey (MECS). The AER provides a historical summary of annual energy use in tbtu by fuel type for five major economic sectors: residential, industrial, commercial, transportation, and electricity. The MECS data break out energy use by fuel type in the manufacturing sector (a subset of the industrial sector) into manufacturing subsectors by NAICS codes, and are available for survey years 1985, 1988, 1991, 1994, and 1998. Missing years are interpolated per EIA methodology.

Both MECS and BEA data are available for 1985-1997, and for each of these years are combined to form hybrid unit matrices from which the technology vectors A^{US} are calculated via the matrix inversion described above. Sample values are indicated in Table 1.

International Trade Data

International trade data are provided by Feenstra et al (1997). Bilateral trade data for 72 countries are available for 1984-2000, with commodities classified by SITC Rev. 2 codes.

Direct and Indirect Requirements: Non-U.S.

A comparably rich dataset of input-output tables and energy use is not available for most countries; however, coal use outside the U.S. can be estimated through application of each country's percentage of electricity that is generated from coal, data for which are available through the World Bank's database of World Development Indicators (WDI). For the 17 countries in my final sample, averaged over the years 1985-1997, this percentage varies from a low of 1.9% (New Zealand) to a high of 77.2% (Australia). The world mean is 38.3%, and the value for the U.S. is 54.3%.

The Use Shares matrix $\tilde{U}^c$ is calculated for non-U.S. countries by first substituting each country's level of coal use in electricity generation into the appropriate cell of $\tilde{U}^{US}$. I then find A^c by re-calculating country c's direct and indirect requirements matrix: $(I-\tilde{U}^c\tilde{M}^{US})^{-1}$. This procedure, while affecting the coal factor intensity of all commodities that are produced in industries using electricity, leaves unaffected both the amount of coal directly used in production of cement and steel, and intermediate commodity usage. These omissions ultimately reduce the precision of the HOV prediction in (3), as discussed below.

Data Summary

International coal production and direct coal trade data in units of tbtu are obtained from the EIA's International Energy Annual. GDP data at purchasing power parity (GDP$_{ppp}$), for use in calculating the factors α^c, are taken from the WDI database. Urban air concentrations of SO_2 are reported by the Global Environment Monitoring System (GEMS)[8], data for which are provided via the U.S. EPA through its Aerometric Information Retrieval System (AIRS). Participation in GEMS has varied over time, with participation higher in the 1980s than the 1990s. In 1985, 61 cities in 25 developed and developing countries participated in the program. In 1990, there were 50 cities in 15 countries, and in 1995 there were 32 cities in 3 countries.

Because electricity fuel use, coal production, and trade data are not available for all countries covered by GEMS, a merge of all available data reduces the sample to an unbalanced panel of 17 countries[9] spanning the years 1985-1997, with a total of 83 country-year pairs. Amongst these 83 pairs, there exist 898 GEMS observations, covering 147 monitors in 56 cities. Each GEMS observation is the average annual mean SO_2 concentration at an individual monitoring station. For each country-year pair, the observations from multiple monitors are averaged, yielding the final sample size of 83.[10]

Summary data are reported in Table 2. The striking feature of these data is that factor trade in coal is significantly smaller in magnitude than direct trade in coal. For this sample, the sum of the factor trade magnitudes is 29% of the sum of the direct trade magnitudes, and only 4% of total coal production. Given these results, it is not surprising that prior empirical studies have experienced difficulty finding evidence supporting the pollution haven hypothesis. The polluting factor content of trade, at least with regards to coal, is simply too small for a regression using commodity trade to easily pick up any significant relationship. In addition, if the pollution haven effect truly does influence factor trade in coal, these data strongly suggest that its magnitude is limited.

Estimation and Results

HOV Model

Prior to testing the pollution haven hypothesis, it is necessary to verify the precision of the HOV model, reproduced below:

$$A^c T^c + D^c = \alpha \cdot (P^c - \alpha^c g^c P^w) + \eta \tag{3}$$

That is, I need to check that predicted total coal trade ($P^c - \alpha^c g^c P^w$) is in fact correlated with actual total coal trade ($A^c T^c + D^c$), prior to using it as a regressor in the pollution haven model (4). An informal verification is attained via inspection of the summary data, while a formal test is obtained via a regression of actual total coal trade on predicted total coal trade, in which the coefficient on predicted coal trade should be positive and statistically significant.

Data for actual and predicted total coal trade are shown in Table 2. Encouragingly, the signs of actual and predicted trade match for most countries; across all 83 observations these signs match 77% of the time, significantly better than a coin toss at the 1% level. Actual trade magnitudes are generally less than predicted trade magnitudes, likely an effect of omitted costs of trade in coal and coal-intensive products. The only two countries for which the match appears seriously weak are China and the United States. As suggested earlier, the poor fit for China is likely caused by the fact that a significant amount of coal in China is used directly for residential cooking and heating. The poor fit for the U.S., however, is unexpected, as this is the country for which the richest dataset is available. It seems that the $\alpha^c g^c P^w$ term overstates the consumption of coal in the U.S. economy, perhaps due to U.S. consumption patterns which differ from those of other countries.

The intuitions attained via inspection are confirmed in a regression analysis, the results of which are shown in Table 3. In a random effects regression of actual trade on predicted trade, the slope coefficient is 0.081, with a standard error of 0.032, significant at the 2% level.

A fixed effects estimate also yields a positive and significant slope coefficient, demonstrating that even after discarding cross-country variation, the HOV prediction of factor trade is positively correlated with measured factor trade.

While the successful sign matching and the positive, significant slope coefficient (results many early HOV studies were unable to find–see Bowen et al 1987) indicate that the use of predicted trade as a regressor in the estimation of the pollution haven model (4) is valid, the low value for R^2 in the random effects regression is disappointing. To a large extent, the poor fit is due to the inaccurate predictions for China and the U.S.; removing these two countries from the dataset increases R^2 to 0.331 for the random effects estimate. For this reason, I later report results of robustness tests of the pollution haven model to the exclusion of these countries from the data.

Pollution Haven Model

Identification

As a reference case empirical model, I estimate the following version of (4), in which time subscripts have been added and the error term has been broken into time-invariant and time-varying components. As discussed in the theory section, a positive estimate of β_3 is to be taken as evidence supporting the pollution haven hypothesis.

$$(A^cT^c)_t = \beta_1 + \beta_2 \cdot (P^c - \alpha^c g^c P^w)_t + \beta_3 \cdot \ln(SO_2)_t^c \cdot |P^c - \alpha^c g^c P^w|_t + \mu^c + \varepsilon_t^c \qquad (5)$$

I use the natural logarithm of SO_2 concentration here, because, as discussed by Antweiler et al (2001) in their empirical study of the environmental Kuznets curve, the log transform is appropriate given that SO_2 concentrations are distributed log-normally.

The reference case estimate of (5) uses a random effects estimator, which assumes μ^c to be a country-specific, normally distributed error term, uncorrelated with the right-hand side variables, and ε_t^c to also be normally distributed and uncorrelated. I also employ a fixed effects estimator in an alternate specification. However, because both right-hand side variables vary little over time within each country, precise fixed effects estimation is difficult with this small sample. The cost of a random effects regression, of course, is the possibility that the estimates will be biased due to omitted country-specific variables that are correlated with the covariates. In fact, in this model it is possible that, without instrumentation, even fixed effects estimates may suffer from endogeneity problems. I now discuss identification of this model in detail.

There are two reasons to be concerned that SO_2 concentrations may be endogenous in estimation of (5). First is the potential presence of omitted variables–particularly the sulfur content of each country's coal–that are correlated both with SO_2 concentrations and with μ^c. Second, there is a simultaneity concern: if SO_2 concentrations are directly related to coal factor exports in that countries with large, positive net factor exports of coal also burn more coal and have higher SO_2 emissions as a result, then the coefficient on the pollution term will be biased upwards, even in a fixed effects estimate.

Considering the omitted variables problem, it is well-known that there is considerable international variation in the sulfur content of coal. However, data for this variable are unavailable. While it is therefore impossible to directly test for any bias in the estimation of β_3 that is caused by the omission of sulfur contents from (5), I assert that this bias will be negative for two reasons. First, a country's sulfur content of coal should be positively correlated with its SO_2 concentrations. Second, for any given level of SO_2 concentration, the required pollution abatement to reach that concentration will be higher for a country with high-sulfur coal than for one with low-sulfur coal. A country with high-sulfur coal will therefore have a comparative disadvantage in the production of coal-intensive goods, driving a reduction in that country's net factor exports of coal, and implying that a country's sulfur content of coal should be negatively correlated with net factor exports. These two rationales taken together imply that β_3 will be biased downwards due to the omission of coal sulfur contents from (5).

To identify (5) given the potential for both omitted variable bias and simultaneity, I instrument for $\ln(SO_2)$ using the International Country Risk Guide (ICRG) political risk index,[11] a measure of the stability of countries' political institutions (possible scores range from zero to 44, with zero being extremely unstable and 44 being risk-free). I have selected this instrument for four reasons. First, political stability will be uncorrelated with international variations in the sulfur content of coal, and this instrument will therefore eliminate the bias caused by omitting this variable. Second, there is no straightforward simultaneity bias story that can be crafted between net factor exports of coal and political stability–there is no clear mechanism by which the coal factor content of a country's net exports would influence its political stability.

Third, the exclusion restriction should be valid, though one may be concerned that political stability might directly influence coal net factor exports through its effect on capital accumulation. I address this concern by estimating a specification of (5) that includes national capital stocks as a regressor. It is not clear ex-ante how doing so will impact the estimate of β_3, if at all. The SO_2 polluting industries that most intensely use coal, such as electricity generation and primary steel manufacturing, are also capital intensive, suggesting that $\hat{\beta}_3$ may decrease (i.e., it is upward biased if capital stocks are excluded); however, many non-SO_2 polluting industries that use coal-intensive intermediate products, such as primary aluminum manufacturing and machine shops, are capital intensive as well, suggesting that $\hat{\beta}_3$ may increase.

Finally, countries with high political risk scores should also have social and political institutions that reflect a low tolerance of pollution, and should therefore have low urban SO_2 concentrations. Indeed, the first stage of an IV regression reveals a strongly significant and negative relationship between $\ln(SO_2)$ and the ICRG index: the coefficient on ICRG is -0.117 with a t-statistic of -55.2.

Reference Case Results

The reference case estimator is an IV, random effects (RE) regression of (5), results for which are indicated in the first column of Table 4. The reference case estimate supports the pollution haven hypothesis: coefficients on both predicted HOV trade and on the pollution term are positive and significant at the 1% level. The inclusion of capital stock in the regression has only a negligible effect on the point estimates for the predicted trade and pollution coefficients. In fact, the coefficient on capital stock itself is insignificant,[12] supporting the exclusion restriction on the ICRG instrument.

I also present the fixed effects estimate, the point estimates of which are near the random effects estimates, though statistically insignificant. As discussed above, the limited variation of the covariates within each country and the small sample size render the fixed effects model unable to sharply estimate the pollution haven effect.[13] Hausman tests comparing the fixed effects estimate to the random effects estimate are reassuring: a joint test for all coefficients fails to reject the random effects assumption with a p-value of 0.815 (the test χ^2 statistic is 0.41), and a single-variable test on the pollution term coefficient has a t-statistic of 0.55. Though the Hausman test is a low-power test, these low test statistics offer evidence that omitted country-specific variables are not biasing the random effects estimate.

Non-instrumented results, presented in the fourth column of Table 4, also indicate a statistically significant pollution haven effect, with a lower magnitude than the instrumented estimate. Hausman tests comparing the instrumented vs non-instrumented estimates offer only a weak failure to reject the exogeneity of the non-instrumented estimate: the joint test p-value is 0.220 (the test χ^2 statistic is 3.03), and a single-variable test on the pollution term coefficient has a t-statistic of 1.25. These test results can be taken as weak evidence of negative bias in the non-instrumented results, possibly associated with omission of coal sulfur contents from the regression.

The finding of a statistically significant pollution haven effect agrees with other recent studies; however, as one would expect from examination of the summary data in Table 2, the magnitude of the estimated coefficient β_3 is very small. To illustrate, the reference case estimation implies that, for the average country in this sample, a 50% reduction in urban SO_2 concentration would reduce net factor exports of coal by only 24 tbtu, relative to the average magnitude of coal factor trade of 127 tbtu, and average coal production of 3296 tbtu. The corresponding elasticity of factor trade with respect to SO_2 concentration is 0.27, while the elasticity with respect to $\ln(SO_2)$ is 1.23 (these elasticities bracket Levinson and Taylor's (2002) result of 0.52). Specifically, for the U.S., a 50% reduction in urban SO_2 concentration would increase its factor imports of coal by 73 tbtu, only 0.3% of total U.S. coal production. When these results are taken in combination with the findings from inspection of the summary data, the evidence is that the pollution haven effect has a limited practical significance in the context of coal factor trade.

Robustness Tests

With a small sample such as this, it is important to verify whether the estimates are robust to various weighting schemes, particularly given the variance in both the size of the economies of the sampled countries and the number of GEMS monitoring stations in each. This is accomplished in three separate tests, across which the results of the reference case model remain robust.

First, I scale the dependent and independent variables in (5) by each country's share of world GDP_{ppp}. While this clearly dampens the influence of large countries such as China and the U.S. on the regression, it also neutralizes the impact of heteroskedasticity.[14] Second, I weight each observation by the square root of the number of monitoring stations recording SO_2 concentrations for each country-year pair. Such a weighting scheme would, for a country-year with many monitors, reflect the decreased variance of the mean SO_2 concentration. Finally, I combine the the first two weighting schemes. Across all three scaling methods, the coefficient on the pollution term remains positive and significant, as shown in the last three columns of Table 4.[15]

Influential Observations

Finally, I investigate whether certain countries exert undue influence on the results. As China and the U.S. are often viewed as major exporters and importers of pollution-intensive goods, respectively, it is useful to understand how excluding these countries affects the regressions, particularly given the weak fit of the HOV model for these two countries. In addition, concerns with Germany arise because the four years of data for this country cover the period immediately after reunification, during which time transition dynamics and large within-country differences in coal use possibly skew the data.

The results of regressions dropping these countries or combinations of these countries, as shown in Table 5, generally confirm these intuitions. Dropping China or the U.S. from the sample obscures the pollution haven effect: while the point estimate of β_3 is still positive, it is no longer statistically significant, suggesting that these two countries play a large role in driving the reference case results. However, dropping Germany from the sample suggests that post-reunification noise does indeed hinder statistical inference of a pollution haven effect; dropping Germany alone improves the precision of the β_3 estimate relative to the reference case, while dropping Germany in addition to China and the U.S. yields a significant positive estimate of β_3 despite a sample size of only 59. These results suggest that, though China and the U.S. are indeed major drivers of the pollution haven effect, it may be at least weakly inferred in other countries as well.[16]

Conclusions

Given the intuitive and theoretical appeal of the pollution haven hypothesis, the difficulties experienced by prior empirical studies in finding support for it through analysis of commodity trade has been puzzling. This paper offers an explanation: while environmental standards do affect trade flows, the magnitude of this impact is so small that it is difficult for tests involving commodity trade to tease it out. Via input-output analysis using detailed energy consumption data, I first find that factor trade of coal is small relative both to direct trade in coal and to coal production. Regression analyses then provide evidence that increases in ambient SO_2 concentrations drive increases in net factor exports of coal; however, the estimated magnitude of this impact is small.

Of course, this study does not imply that the pollution haven hypothesis is of no economic significance in any setting. For example, these results cannot be extrapolated to the case of U.S. interstate factor trade in coal, which can take place readily via the electricity transmission grid. It may also be that, even in an international trade setting, a more robust pollution haven effect may be observed for some industry-specific toxins. However, in the case of coal, which has garnered a great deal of attention in pollution haven discussions, this study indicates that international variations in air quality have little bearing on coal factor trade.

This result shifts the pollution haven discussion from one of statistical significance to one of economic significance. While the predicted sign of the effect of environmental policies on international trade is supported by the data, the hypothesis' significance as a guide to policy making is questionable given the limited size of the effect. The results of this study imply that, should a country such as the United States desire to have a high standard of environmental quality, then the environmental benefits of this decision will not be significantly offset by increased pollution in other countries that are not willing to take on abatement expenditure. In a policy setting, this is a much more comfortable place to be. Prior results allowed for the possibility that the pollution haven hypothesis is an economically significant driver of international trade flows. This concern has contributed much controversy to U.S. environmental legislation, WTO trade liberalization negotiations, and the Kyoto Protocol, where "carbon leakage" from non-signatory to signatory countries through imports of carbon-intensive goods could in theory offset the CO_2 emissions reductions of signatories. The findings presented here suggest that such fears are unfounded.

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Notes

[1] For examples of this literature, see Ederington, Levinson, and Minier (2004), Eskeland and Harrison (2003), Levinson (1996), List and Co (1999), Smarzynska and Wei (2001), Wheeler (2000), and Xing and Kolstad (1998).

[2] Throughout this paper, I use the term "factor trade of coal" to describe the coal embodied as a factor of production in the trade of non-coal commodities, the term "direct trade of coal" to describe trade of raw coal, and the term "total trade of coal" to describe the sum of factor trade and direct trade.

[3] For example, the direct and indirect coal factor requirement of automobiles measures not only the coal required directly in the assembly of automobiles (essentially zero), but also the coal required in the smelting of steel inputs, the generation of electricity needed to operate the assembly plant and the plants of intermediate suppliers, the production of cement required in plant construction, etc.

[4] While it is tempting to attempt a probit specification instead of (1), with factor trade's share of total trade on the left hand side and SO_2 pollution on the right, such a specification is infeasible here becuase factor trade and total trade do not necessarily have the same sign (imports vs exports).

The sign problem also necessitates the absolute value operator in (1). This ensures that increases in SO_2 concentrations always have a positive effect on factor trade, even for countries that are net importers of coal. That is, were I not to take the absolute value, then for any country with negative total trade, an increase in SO_2 concentration would actually drive a *decrease* in net factor exports of coal in the model.

[5] According to the Factor Price Equalization Theorem (see Samuelson (1948)), assumptions 1-5, in addition to the assumptions that there are no factor intensity reversals and incomplete specialization, are sufficient to imply factor price equalization.

[6] DW in a further treatment also discard the zero costs of trade assumption to further improve their fit. I am unable to adopt such an approach here due to a lack of sufficient data for some countries in my sample. The implications of this omission are discussed in the results section of this paper.

[7] One trillion btu (British Thermal Units) is the approximate energy content of 172,000 barrels of crude oil.

[8] See Bennett et al (1985) for a history and analysis of GEMS data.

[9] While a full set of data is available for Japan, it is not included in the sample for two reasons: (1) Japan is located downwind of China and its SO_2 levels are therefore not reflective of pollution generated by Japanese firms, and (2) Japan's reported SO_2 measurements suddenly change by nearly an order of magnitude in 1992. This is clearly not realistic and renders the Japanese data suspect. Still, the reference case results discussed later remain significant at the 1% level when, as a robustness check, Japan is included in the dataset.

[10] The influence of outliers within the GEMS data was tested via estimations using the median of SO_2 concentrations reported for each country-year, rather than the mean. The results of these regressions are essentially unchanged from those presented in this paper.

[11] Technically, I am instrumenting for the product $\ln(SO_2)_t^c \cdot |P^c - \alpha^c g^c P^w|_t$ with the product $ICRG_t^c \cdot |P^c - \alpha^c g^c P^w|_t$.

[12] The capital stock variable was created by accumulating national investment for each country (taken from the WDI database) over time, with a depreciation rate of 5%. The results indicated in Table 4 are insensitive to the choice of depreciation rate.

[13] In the random effects regression, 78% of the variance of the total residual is due to the μ^c term.

[14] The impact of heteroskedasticity on the reference case estimates was also checked by obtaining standard errors from a non-parametric bootstrap. The point estimates on predicted trade and the pollution term remain significant at the 1% level (the bootstrapped standard errors are 0.0127 and 0.0044, respectively).

[15] As a further robustness test, I adjusted the individual SO_2 pollution monitor readings for location effects (residential vs industrial, coastal vs inland, and urban vs rural) and year effects, and re-ran the reference case model. The resulting estimates were essentially unchanged from those presented in Table 4.

[16] In an earlier version of this paper, results were also robust to the exclusion of Belgium, Finland, the Netherlands, Portugal, and the U.K. (at the time, data for these five countries had not yet been obtained).

Table 1: Coal Direct and Indirect Requirements, Selected U.S. Industries and Years

Units are trillion btu required per $billion of final output

Year	Textiles	Pulp Mills	Basic Chems	Cement	Primary Metals	Auto Manuf	Computer Manuf
1985	10.91	19.69	15.61	77.72	32.94	7.26	4.60
1990	8.60	15.94	11.46	82.30	23.45	5.92	3.43
1995	7.65	12.31	10.19	58.49	20.42	4.97	3.17

Table 2: Sample Data Summary

Data presented for each country are averaged over time

	Coal Production and Trade in tbtu					Reported SO2 Concentrations in ppm					
Country	Prod-uction	Factor Trade	Direct Trade	Total Actual Trade	Total [1] Predicted Trade	# of Years	# of Obs	Mean	Std Dev	Min	Max
Australia	2974.5	126.4	2402.0	2528.4	1209.0	1	3	0.0052	0.0030	0.0019	0.0079
Belgium	204.4	82.2	-304.5	-222.3	-194.0	2	6	0.0150	0.0017	0.0123	0.0173
Brazil	111.3	77.7	-293.9	-216.2	-54.0	10	30	0.0165	0.0050	0.0096	0.0331
Canada	1631.3	149.3	417.1	566.4	860.8	9	114	0.0070	0.0028	0.0023	0.0186
Chile	38.7	36.3	0.0	36.3	-18.3	1	1	0.0273	0.0000	0.0273	0.0273
China, P.R.	19685.0	-82.0	238.9	156.9	11299.9	7	134	0.0308	0.0210	0.0027	0.1264
Finland	0.0	67.2	-128.8	-61.5	-150.5	2	2	0.0020	0.0001	0.0019	0.0021
Germany	3547.4	66.8	-397.3	-330.5	-3557.7	4	4	0.0092	0.0012	0.0077	0.0106
Greece	246.0	-47.9	-46.0	-93.9	-419.2	3	7	0.0134	0.0038	0.0101	0.0211
India	3232.3	-49.3	-49.0	-98.3	-2040.1	1	9	0.0169	0.0084	0.0074	0.0327
Netherlands	0.0	52.9	-284.5	-231.6	-620.9	2	6	0.0104	0.0023	0.0081	0.0135
New Zealand	69.1	-2.6	10.2	7.6	62.2	10	22	0.0040	0.0046	0.0011	0.0169
Portugal	3.0	-65.5	-108.0	-173.5	-341.4	1	1	0.0170	0.0000	0.0170	0.0170
Spain	529.8	-88.7	-325.3	-413.9	-1160.4	8	24	0.0094	0.0043	0.0028	0.0211
Thailand	103.3	-71.5	-9.4	-80.8	-268.9	8	11	0.0046	0.0019	0.0009	0.0076
USA	21309.4	-997.5	2282.0	1284.4	-5600.6	13	520	0.0085	0.0040	0.0018	0.0242
UK	2350.7	-100.4	-202.0	-302.4	-2762.6	1	4	0.0160	0.0031	0.0121	0.0191

[1] Prediction from HOV model

Table 3: Determinants of Total Factor Trade

	Random Effects	Fixed Effects
Constant	152 (186)	- -
Predicted Trade	0.081^{**} (0.032)	0.119^{***} (0.039)
$R^2_{overall}$	0.061	0.890
# Obs	83	83

Parenthetical values indicate standard errors

,* indicate significance at the 5% and 1% levels, respectively

Table 4: Determinants of Factor Trade in Coal							
	Reference Case IV, RE Estimator	IV, RE, includes capital stock	IV, fixed effects	non-IV, random effects	IV, RE, scaled by $(GDP_{PPP})^{-1}$	IV, RE, scaled by $(\# obs)^{1/2}$	IV, RE, scaled by $(GDP_{PPP})^{-1}$ * $(\# obs)^{1/2}$
Constant	101.8 * (60.3)	112.6 ** (52.4)	- -	81.6 * (49.3)	15456 *** (3835)	191.8 (85.4)	19363 (4986)
Pred Trade	0.0532 *** (0.0123)	0.0536 *** (0.0104)	0.0809 * (0.0468)	0.0532 *** (0.0104)	0.0713 *** (0.0278)	0.0708 *** (0.0036)	0.0839 *** (0.0176)
$\ln(SO_2)$ * |Pred Trade|	0.0189 *** (0.0035)	0.0190 *** (0.0030)	0.0127 (0.0117)	0.0166 *** (0.0030)	0.0479 *** (0.0110)	0.0228 *** (0.0010)	0.0325 *** (0.0061)
Capital Stock	- -	-0.0062 (0.0101)	- -	- -	- -	- -	- -
$R^2_{overall}$	0.775	0.786	0.627	0.772	0.075	0.928	0.396

Parenthetical values indicate standard errors

*,**,*** indicate significance at the 10%, 5%, and 1% level, respectively, for a two-tailed t-test

Table 5: Determinants of Factor Trade in Coal					
	Reference Case IV, RE Estimator	Drop China	Drop USA	Drop Germany	Drop China, USA, Germany
Constant	101.8 * (60.3)	97.2 (66.1)	29.1 (16.2)	78.1 ** (36.3)	73.0 *** (27.7)
Pred Trade	0.0532 *** (0.0123)	0.0527 (0.068)	0.0025 (0.0062)	0.0614 *** (0.008)	0.0482 ** (0.0244)
$\ln(SO_2)$ * |Pred Trade|	0.0189 *** (0.0035)	0.0175 (0.0164)	0.0030 (0.0020)	0.0212 *** (0.0024)	0.0129 * (0.0068)
$R^2_{overall}$	0.775	0.793	0.055	0.890	0.306
# obs	83	76	70	79	59

Parenthetical values indicate standard errors

*,**,*** indicate significance at the 10%, 5%, and 1% level