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UNMASKING THE POLLUTION HAVEN EFFECT

Arik Levinson
M. Scott Taylor

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ABSTRACT

This paper uses both theory and empirical work to examine the effect of environmental regulations on trade flows. We develop a simple economic model to demonstrate how unobserved heterogeneity, endogeneity and aggregation issues bias measurements of the relationship between regulatory costs and trade. We apply an estimating equation derived from the model to data on U.S. regulations and net trade flows among the U.S., Canada, and Mexico, for 130 manufacturing industries from 1977 to 1986. Our results indicate that industries whose abatement costs increased most experienced the largest increases in net imports. For the 20 industries hardest hit by regulation, the change in net imports we ascribe to the increase in regulatory costs amounts to more than half of the total increase in trade volume over the period.

Arik Levinson
Department of Economics
Georgetown University
Washington, DC 20057-1036
and NBER
aml6@georgetown.edu

M. Scott Taylor
Department of Economics
University of Wisconsin
Madison, WI 53706-1393
and NBER
staylor@ssc.wisc.edu

Unmasking the Pollution Haven Effect

1. Introduction

All sides in recent trade and environmental policy debates seem to share the view that regulatory stringency in developed countries shifts polluting industries to the developing world. While widely believed, this "pollution haven effect" has proven difficult to demonstrate empirically. Some studies examine individual plant location decisions, while others study international trade. Until recently, neither approach found significant evidence of a pollution haven effect. But most of these used cross-sections of data, making it difficult to control for unobserved characteristics of countries or industries that may be correlated with both environmental regulations and economic activity. A few recent studies have used panels of data and industry or country fixed effects, and have demonstrated small but statistically significant pollution haven effects.[1] This paper employs both theoretical and empirical methods to uncover and estimate the magnitude of the pollution haven effect while simultaneously arguing that previous efforts suffer from both inadequate accounting for unobserved heterogeneity and from the endogeneity of pollution abatement cost measures.

Explanations for the failure to find a pollution haven effect often point to the small fraction of costs represented by pollution abatement. While it is possible that more stringent environmental regulations have a small effect on firms' costs and international competitiveness, it seems unlikely that more stringent regulations would have no effect whatsoever. This explanation is further undermined by frequent counter-intuitive empirical results. Some researchers find larger and more significant pollution haven effects for less pollution-intensive industries. A few even find evidence that industries with relatively high pollution abatement costs are leading exporters.[2] In these cases, the Porter hypothesis – that regulation brings cost-

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[1] See, for example, List (2003), Becker and Henderson (2000), and Greenstone (2002) for recent papers on plant locations, and Ederington and Minier (2003) on international trade. Jaffe *et al.* (1995) survey the earlier literature, and Copeland and Taylor (2004) and Brunnermeir and Levinson (2004) review the newer studies.
[2] See for example Kalt (1988) , Grossman and Krueger (1993), or Osang and Nandy (2000).

reducing innovation – is often invoked as the explanation for finding a positive link between regulatory stringency and exports.[3]

The current state of empirical work leaves important questions unanswered. Many trade policy analysts express concern that countries may undercut international tariff agreements by weakening environmental regulations to placate domestic protectionist interests. If this is true, international trade negotiators may need to close this loophole by placing explicit restrictions on the use of domestic environmental policy. This concern, however, rests on the assumption that environmental regulations have significant cost and competitiveness consequences – a disputed empirical point.

In this paper we re-examine the link between abatement costs and trade flows using both theory and empirics, in the hope of identifying and accounting for several important econometric and data issues. We believe that these issues – and not the relatively small costs of pollution abatement nor the Porter hypothesis – are responsible for the mixed results produced thus far.

To do so we develop a simple, multi-sector, partial-equilibrium model where each manufacturing sector (i.e. a 3-digit SIC industry) is composed of many heterogeneous (4-digit) industries. Sectors can differ in their use of primary factors and in their average pollution intensity; one sector's production could be capital intensive and relatively dirty, while another's is labor intensive and relatively clean. Industries within a sector differ only in their pollution intensity, and two-way trade within each 3-digit sector occurs because of these differences. We take factor prices and national incomes as exogenous, and make no attempt to make environmental policy endogenous. We use this simple model for three purposes.

First, we derive an analytical expression for measured pollution abatement costs as a fraction of value-added. This statistic is widely used as a measure of regulatory stringency in empirical work estimating the pollution haven effect. We show how this measure is simultaneously determined with trade flows, and demonstrate how unobserved changes in foreign costs, regulations, or domestic industry attributes can produce a spurious negative correlation between the sector-wide pollution abatement costs and net imports. This correlation is of course opposite to the direct effect predicted by the pollution haven hypothesis, and suggests an explanation for the difficulties encountered by earlier studies.

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[3] Porter (1995).

Second, we use the model to derive an estimating equation linking industry net imports to domestic and foreign measures of regulations, factor costs and tariffs. We then estimate the pollution haven effect, taking account of the unavailability of many control variables and the implications of employing pollution abatement costs as a proxy for direct measures of regulation.

Third, our use of a theoretical model forces us to be explicit regarding our estimating equation's error term. We detail the set of conditions a successful instrument must exhibit and then construct instrumental variables relying on the geographic distribution of dirty industries around the U.S. Geographic location has of course been used before as a source of exogenous variation (see Frankel and Romer (1999) in particular), but here it poses some new challenges because of the mobility of industries within the U.S.

We then estimate the effect of regulations on trade flows using data on U.S. imports in 133 three-digit manufacturing industries from Mexico and Canada over the 1977-1986 period. We are limited in coverage by changes in SIC codes after 1987 and by the discontinuation of the pollution abatement cost data.

Our empirical results consistently show a positive, statistically significant, and empirically plausible relationship between industry pollution abatement costs and net imports into the U.S. This is true for imports from both Mexico and Canada. In our fixed-effects estimations we find that a 1 percent increase in pollution abatement costs is associated with a 0.2 percent increase in net imports from Mexico (or decrease in net exports), and a 0.4 percent increase in net imports from Canada.

Our theoretical model suggests several reasons why these fixed-effects estimates mismeasure the pollution haven effect, and in our instrumental variables estimation we find larger effects. The same 1 percent increase in pollution abatement costs predicts a 0.4 percent increase in net imports from Mexico and a 0.6 percent increase from Canada.

To preview the magnitudes of the effects we are finding, consider that the 20 three-digit industries whose costs rose most from 1977 to 1986 experienced a 2.7 percentage point increase in pollution abatement costs as a share of value added. According to our fixed-effects results, increased environmental costs, on average among these 20 highly affected industries, were associated with a $38 million increase in net imports from Mexico. The instrumental variables results suggest an $85 million increase. For comparison, two-way trade with Mexico in these same hardest-hit industries rose by an average of $143 million over the period.

Before describing the details of these estimates, we need to outline a model of trade and derive the estimating equation. Along the way, we will point out biases that may have affected previous work using similar data.

2. A Model of Pollution Costs and Trade

Consider two countries, "Home" and "Foreign," with foreign attributes denoted by a star (*). Each country has identical technologies. The model is partial equilibrium, in the sense that factor prices and environmental policies in the form of pollution taxes (τ,τ^*) are exogenous. To generate a basis for trade arising from differences in regulation, we assume Home has more stringent regulations: $\tau > \tau^*$.

In each country there are N sectors, indexed by i, and within each sector are many industries. Empirically, "sectors" correspond to 3-digit SIC codes and "industries" correspond to 4-digit SIC codes.[4] We denote output available for sale or consumption in the i-th sector by x_i, and since each sector contains numerous industries we denote industry output by $x_i(\eta)$, where η is an index running from zero to one. We assume consumers spend a constant fraction of their income on goods from each sector with spending shares given by b_i . Consumers spread this fraction of spending across all industries within the x_i sector uniformly.

2.1 Technologies and Abatement

Production is CRS and uses both labor L, and an industry-specific factor K_i. Production of output creates pollution as a byproduct, but firms have access to an abatement technology that can be used to reduce emissions. We assume firms can allocate part of their factor use to abatement, and denote this fraction by $\theta(\eta)$. Production for sale in a typical industry in the x_i sector is then (dropping the i subscripts for clarity)

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[4] Technically, 3-digit SIC codes are referred to as "industry groups." We use the term "sector" for convenience.

$$x(\eta) = \left[1 - \theta(\eta)\right] F\left(K_X(\eta), L_X(\eta)\right) \tag{2.1}$$

where F is increasing, strictly concave, and CRS, and $\eta \in [0,1]$ labels industries within the x_i sector. Given CRS and free entry, total revenue equals total costs, and since there are no intermediate goods, value added equals total revenues. This implies $\theta(\eta)$ is the share of pollution abatement costs in value added in industry η -- a commonly used empirical measure of regulatory costs.

Pollution emitted is a function of total output and the abatement intensity θ,

$$z(\eta) = \phi\left(\theta(\eta)\right) F\left(K_X(\eta), L_X(\eta)\right) \tag{2.2}$$

where ϕ is a decreasing function of θ. With no abatement, $\theta = 0$, $\phi(0)=1$, and by choice of units, pollution emitted equals output : $z = x = F(K,L)$. When abatement is active, $\theta > 0$ and pollution is reduced.[5]

Following Copeland and Taylor (2003) we adopt a specific formulation for $\phi(\cdot)$ letting $\phi(\theta) = \left(1-\theta\right)^{1/\alpha}$, where $0<\alpha<1$. Then, assuming abatement is undertaken, we can employ equations (2.1) and (2.2) to write output as if it were produced via a Cobb-Douglas function of pollution emitted and traditional factors.

$$x(\eta) = z(\eta)^{\alpha(\eta)} \left[F(K_X(\eta), L_X(\eta))\right]^{1-\alpha(\eta)}. \tag{2.3}$$

Finally, it will be helpful to rank the industries within each sector in terms of their pollution intensity, $\alpha(\eta)$, so that high-η industries are the most pollution-intensive: $\alpha'(\eta) > 0$.[6]

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[5] See Copeland and Taylor (2003) chapter 2 for a similar model and further details on abatement.

[6] When pollution taxes are costly relative to abatement inputs, we can both (1) ensure that active abatement occurs and (2) extend the ranking on the primitive $\alpha(\eta)$ to ensure that pollution abatement costs as a fraction of value-added and emissions per unit of output rise with η. Since these rankings are important to our empirical work we will assume that this is true throughout.

2.2 Within and Across-Sector Trade Patterns

To determine which set of industries is produced at home and abroad, we compare their unit costs. From equation (2.3), the unit cost function for good x_i is

$$c(\eta) = k(\eta)\tau^{\alpha(\eta)}\left(c^F\right)^{1-\alpha(\eta)} \tag{2.4}$$

where $k(\eta) \equiv \alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)}$ is an industry-specific constant, and $c^F = c^F(w, r_i)$ is the unit cost of producing one unit of F_i, assuming the two factors of production (K_i, L) sell at prices (w, r_i).[7] A similar unit cost function describes foreign costs; hence, if good η is produced at home, free entry implies it must sell at price (2.4). If it is produced abroad, it must sell at

$$c^*(\eta) = k(\eta)\left(\tau^*\right)^{\alpha(\eta)}\left(c^{F*}\right)^{1-\alpha(\eta)} \tag{2.5}$$

The Home country produces and exports all industries η such that $c(\eta) \leq c^*(\eta)$. Industries η are produced domestically if

$$\left(\frac{c^F}{c^{F*}}\right) \leq \left(\frac{\tau^*}{\tau}\right)^{\alpha(\eta)/1-\alpha(\eta)} \equiv \Gamma(\eta; \tau, \tau^*) \tag{2.6}$$

Note by construction the left side of (2.6) is independent of η and only varies across sectors. The right side is falling in η because we have assumed $\tau > \tau^*$ and ordered the industries such that $\alpha(\eta)$ is increasing in η.[8]

Figure 1a depicts the basic setup. The x_1 sector faces factor costs c_1^F at home and c_1^{F*} abroad, and pollution taxes τ and τ^*. The function Γ determines the threshold industry $\overline{\eta}_1$, defined by taking (2.6) with equality and solving to find:

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[7] Since every sector has its own specific factor *Ki* we can be assured that both countries will be actively producing at least some industries in every sector.

[8] To see this, take the log of the right side and differentiate.

$$\bar{\eta} \equiv g\left(c^F, c^{F*}, \tau, \tau^*\right) \tag{2.7}$$

Since $\tau > \tau^*$, Γ is declining and industries to the left of $\bar{\eta}_1$ have $c(\eta) < c^*(\eta)$. These industries are produced at home and exported. Industries to the right of $\bar{\eta}_1$ have $c(\eta)^* < c(\eta)$ and are produced abroad and imported. There is two-way trade within this 3-digit sector because of differences in comparative advantage at the 4-digit industry level.

Having solved for the marginal industry, $\bar{\eta}_i$, we can now write Home net imports (imports minus exports) in the x_i sector. Let b_i denote the fraction of income spent on x_i, and I and I^* represent home and foreign aggregate incomes respectively. Home has income I, spends the fraction b_i on x_i, and of this expenditure the fraction $1-\bar{\eta}_i$ is spent on imported foreign goods. The foreign country likewise spends the fraction b_i of income on x_i, has income I^*, and of this expenditure the fraction $\bar{\eta}_i$ is used to purchase Home exports. Home net imports are thus:

$$\text{Net Imports}_i = b_i I[1-\bar{\eta}_i] - b_i I^* \bar{\eta}_i \tag{2.8}$$

Equations (2.7) and (2.8) give us a relationship between trade flows and pollution regulations by sector.

By construction the model allows trade flows to reflect both differences in factor endowments and regulations. Differences across countries in their abundance of primary factors, capital, land or skilled human capital, will be reflected in the relevant ratio of home to foreign costs, (c^F/c^{F*}), and hence trade patterns. Sectors may also differ in their pollution intensity so that a very dirty sector, J, will have $\Gamma_J > \Gamma_I$ for all η, even if firms in both I and J face the same pollution taxes. Despite this, a country with high pollution taxes may still produce and export a large fraction of the world's dirty J goods, and import a large fraction of its I goods, if the primary factors used in J are relatively cheap in the tightly regulated country. By allowing sectors to differ in their use of primary factors, we allow for the possibility that tight regulation countries produce and export dirty goods. But to capture the effect of regulation on trade flows cleanly, we have assumed that within-sector trade is determined solely by relative pollution taxes. This ensures that within each sector the dirtiest industries are located in the low regulation country, and changes in pollution taxes alter the composition of the industries remaining at home in a clear way. An increase in home pollution taxes decreases Γ() and moves $\overline{\eta}_i$ to the left in figure 1a, increasing net imports.

To examine this relationship empirically, we need to derive an estimating equation and discuss several data-related complications.

3. From Theory to Estimation

Since sectors differ greatly in size, empirical work typically scales net imports by domestic production or value shipped.[9] In our model these are the same, and noting the value of domestic production must be $b_i\, \eta_i(I+I^*)$, net imports in the x_i industrial sector, scaled by domestic production, is simply

$$N_i = \frac{I - \overline{\eta}_i(I+I^*)}{\overline{\eta}_i(I+I^*)} = -\left[1 - \frac{s}{\overline{\eta}_i}\right] \tag{3.1}$$

where N_i is net imports over the value of production, and s is Home's share of world income. Net imports in sector i are positive so long as $s > \overline{\eta}_i$; i.e. Home is a net importer if its share of world income exceeds its share of world production in x_i.

Equation (3.1) can be rewritten as a linear regression, adding time subscripts, as

$$N_{it} = \beta_0 + \beta_1 \left(\frac{s_t}{\overline{\eta}_{it}} \right) \tag{3.2}$$

where β_0= -1 and β_1=1. Then we can use (2.7) to rewrite (3.2) as

$$N_{it} = \beta_0 + \beta_1 \left[\frac{s_t}{g\left(c_{it}^F, c_{it}^{F*}, \tau_{it}, \tau_{it}^*\right)} \right] \tag{3.3}$$

Take a linear approximation of (3.3), rewriting it as:

$$N_{it} = \beta_0 + \beta_1 s_t + \beta_2 c_{it}^F + \beta_3 c_{it}^{F*} + \beta_4 \tau_{it} + \beta_5 \tau_{it}^* + \varepsilon_{it} \tag{3.4}$$

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[9] This is to ensure that any excluded right-hand-side variable that is correlated with industry size does not automatically contaminate the error. See Leamer and Levinsohn (1996) on this point.

where we have introduced the error ε_{it} to reflect both approximation error in linearizing (3.3) and standard measurement error in obtaining data on net imports, N_{it}.

The only component of foreign costs ($c^{F}*$) that we observe empirically is tariffs on foreign products, so we include those at the industry level and denote them by (T_{it}). We do not observe other components of ($c^{F}*$) or foreign pollution taxes ($\tau*$). To capture changes in Home's share of world income s_t, and any other economy-wide change in the U.S. propensity to import, we include a set of unrestricted time dummies (D_t) in our estimation. In addition, we add sector dummies (D_i) to control for sector-specific but time-invariant differences in foreign and domestic unit costs. Since we have a relatively short panel, and the stocks of primary factors such as physical and human capital that determine (c^{F}) and ($c^{F}*$) are only slowly moving, industry fixed effects may capture most if not all unobserved differences in the ratio of home to foreign costs.

While the typical sources of comparative advantage adjust slowly over time, U.S. environmental regulations changed dramatically over our sample period, and dramatically relative to most trading partners. Importantly, we do not observe domestic pollution taxes or other measures of environmental regulation to represent (τ_{it}). We do however observe pollution abatement costs as a fraction of value added (θ_{it}). Making this substitution yields our estimating equation:

$$N_{it} = a\theta_{it} + bT_{it} + \sum_{i=1}^{N} c_i D_i + \sum_{t=1}^{T} d_t D_t + e_{it} \tag{3.5}$$

where we note the error term e_{it} contains our original measurement and approximation error reported in (3.4), plus any industry-specific time varying elements of the ratio $c^{F}*_{\text{it}}/c^{F}_{\text{it}}$ not captured by our industry dummies, foreign pollution taxes τ_{it}, and measurement error introduced by employing θ_{it} rather than τ_{it}. This observation raises several econometric issues.

3.1 Econometric Issues

Because getting direct measures of pollution taxes or industry-specific pollution quotas for a broad spectrum of industries is infeasible, researchers have relied on indirect measures of stringency such as pollution abatement costs. To see one major problem with this approach, note that total revenues (at producer prices) for any industry in the x_i sector are given by $p(1-\alpha_i)x_i$. Total pollution abatement costs (PACs) are just a fraction of this given by $p(1-\alpha_i)x_i\theta$.[10] To find the sector-wide measure of PACs, integrate over all the industries in the x_i sector that are active in the Home country:

$$\int_0^{\bar{\eta}} p(\eta)x(\eta)\big(1-\alpha(\eta)\big)\theta(\eta)d\eta$$

Total PACs as a share of value added (again measured at producer prices) is

$$\int_0^{\bar{\eta}} p(\eta)x(\eta)\big(1-\alpha(\eta)\big)\theta(\eta)d\eta \Big/ \int_0^{\bar{\eta}} p(\eta)x(\eta)\big(1-\alpha(\eta)\big)d\eta$$

Since spending ($p(\eta)x(\eta)$) is a constant fraction (b_i), of world income ($I+I^*$), we can simplify the above and write pollution abatement costs as a share of value added for the x_i sector as

$$\theta_i(\bar{\eta}_i) \equiv \frac{PAC_i}{VA_i} = \frac{\int_0^{\bar{\eta}_i}(1-\alpha(\eta))\theta(\eta)d\eta}{\int_0^{\bar{\eta}_i}(1-\alpha(\eta))d\eta} \tag{3.6}$$

where $\theta_i(\bar{\eta}_i)$ is the fraction of value added in sector x_i that is spent on pollution abatement when the Home country produces goods in the range $[0, \bar{\eta}_i]$.

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[10] Producers pay the fraction α of revenues as pollution taxes (recall (2.4)) hence the producer price, net of tax payments, is $p(1-\alpha)$. From (2.3) we have $p(1-\alpha)x=c^F F$. Pollution abatement costs are $\theta c^F F$; hence, pollution abatement costs can be written $\theta p(1-\alpha)x$. Pollution abatement costs as a fraction of value added are then just θ.

Once we introduce time subscripts, (3.6) is our proxy for τ_{it} in (3.5). Because this measure is readily available in the U.S. from the mid-1970s until 1996 it is also the measure of regulatory stringency used by numerous studies examining the effect of pollution regulation. Unfortunately the measure introduces several significant problems. To see why, it is useful to totally differentiate (3.6) with respect to a generic parameter *y*. This generic parameter could be anything that affects trade flows across industries: transportation costs, non-tariff barriers, factor costs, etc. With some rearrangement we find variation in measured pollution costs comes from two sources.

$$\frac{d\theta_i}{dy} = \frac{\left[\int_0^{\bar{\eta}_i} (1-\alpha(\eta))\big(d\theta(\eta)/dy\big)\,d\eta\right]}{\left[\int_0^{\bar{\eta}_i} (1-\alpha(\eta))\,d\eta\right]} + \frac{\left[\int_0^{\bar{\eta}_i} (1-\alpha(\eta))[\theta(\bar{\eta})-\theta(\eta)]\,d\eta\right](1-\alpha(\bar{\eta}))\left(d\,\bar{\eta}_i\big/dy\right)}{\left[\int_0^{\bar{\eta}_i} (1-\alpha(\eta))\,d\eta\right]^2} \tag{3.7}$$

The first source of variation is created by the change in abatement costs of existing domestic industries (this is the $d\theta/dy$ term integrated over $[0, \bar{\eta}_i]$). If the change in *y* raises pollution abatement costs at the industry level, then all the elements in this first integral are positive and our sector-wide measure rises. For example, if *y* represents the cost of factors used to abate pollution, the pollution abatement costs incurred by those industries within sector *i* increase, and our sector-wide measure of pollution costs increases.

The second source of variation is created by the change in the composition of domestic industries (this is the term involving $d\bar{\eta}_i/dy$). The change in *y* will likely alter the threshold industry $\bar{\eta}_i$. Since $\theta(\eta)$ is increasing in η the integral in this second term is positive and hence the sign of this term hinges on $d\bar{\eta}_i/dy$. Measured pollution abatement costs rise when $\bar{\eta}_i$ rises because in this case relatively more polluting industries are being produced at home, rather than imported. This raises average pollution intensity and pollution abatement costs at the sector level. It is this second term, the effect of changes in the composition of the sector, that causes econometric problems. Loosely, the problems can be labeled "unobserved heterogeneity," "unobserved foreign regulations," and "aggregation bias."

3.2 Unobserved Heterogeneity

One obvious problem confronting empirical work in this literature is the likelihood of unobserved but fixed characteristics of states/industries/countries that are correlated with both the propensity to export and to pollute. As our derivation of (3.5) makes clear, researchers typically have only a subset of the potentially relevant covariates, and this makes unobserved heterogeneity a key problem. The biases involved in the effect of unobserved factors on measured pollution costs θ_i , calculated in (3.7), exacerbate this problem.

To demonstrate, suppose we compare two sectors, x_1 and x_2 , depicted in figure 1a. Assume that they face the same pollution taxes, are equally dirty, and have identical costs at home given by $c_1^F = c_2^F$. They are observably equivalent to the econometrician, but assume production of x_2 in the foreign country is relatively cheaper than x_1. That is, $c_1^{F*} > c_2^{F*}$. Again use (3.7) but now let dy be replaced by the change in foreign costs across sectors at a point in time. Foreign pollution taxes have no direct effect on home pollution abatement costs, and hence $d\theta(\eta)/d\tau^* = 0$ for all η and the first term in (3.7) is zero. From (3.7) we find:

$$\frac{d\theta_i}{dc_i^F *} = \frac{\left[\int_0^{\bar{\eta}_i} (1-\alpha(\eta))[\theta(\bar{\eta})-\theta(\eta)]d\eta\right](1-\alpha(\bar{\eta}))\left(d\,\bar{\eta}_i \big/ dc_i^F *\right)}{\left[\int_0^{\bar{\eta}_i} (1-\alpha(\eta))d\eta\right]^2} > 0 \qquad (3.8)$$

measured pollution abatement costs will be higher in sector 1 than in sector 2 because $\bar{\eta}_1 > \bar{\eta}_2$. This is because sector 2 has higher net imports, and the dirtiest industries in sector 2 are imported, and not counted in domestic pollution costs. Since foreign costs are unknown, we only observe that sector x_1 has higher pollution abatement costs and lower net imports than x_2 – a seeming contradiction of a negative link between environmental control costs and competitiveness.

Note that (3.8) establishes a theoretical rationale for a positive covariance between foreign costs of production and home pollution abatement costs, and this suggests the coefficient on the pollution cost coefficient is downwardly biased. In fact, there is some evidence of this symptom in existing work. Grossman and Krueger's (1993) original study of NAFTA found a negative and significant relationship between pollution abatement costs and imports in some of their cross-section regressions. And several studies have reported a smaller coefficient on pollution cost variables in resource-intensive or dirty industries than in other industries; i.e. coefficients are smaller in just those industries where unmeasured industry-specific factors may loom large in determining production costs.

To show that this is a real concern in our data, consider Canada and Mexico (since it is clear that these countries differ in comparative advantage vis-à-vis the U.S.). In table 1 we describe pollution abatement costs and net imports from Canada and Mexico for various groups of U.S. industries, for the period 1977-86. In the top panel of the table we report that the 20 sectors (3-digit SIC codes) with the lowest pollution abatement operating costs (PAOC) spent 0.12 percent of their value added on abatement. By contrast, the 20 sectors with the highest PAOC spent 4.8 percent. But column 2 of the table clearly shows that net imports from Mexico are *higher* in those industries with lower abatement costs, although this difference is not statistically significant. For Canada, the pattern is reversed. Column 3 shows that the U.S. imports from Canada significantly more goods with high pollution abatement costs.

The top panel of table 1 thus seems to imply that the U.S. imports pollution-intensive goods from a rich country (with ostensibly tight regulation) and clean goods from a poor developing country (with presumably lax regulation), belying a link between environmental control costs and international competitiveness. Most likely, these correlations reflect the fact that Canada has an unobserved comparative advantage in natural resource industries that are relatively pollution intensive, while Mexico has an unobserved comparative advantage in labor-intensive and relatively clean industries.[11] But this trade pattern prediction is not inconsistent with the result that increases in U.S. pollution abatement costs, *ceteris paribus*, raise net imports from both countries at the margin: a pollution haven effect.

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[11] If true, this would fit the results of Antweiler et al. (2001) who argue that other motives for trade, in particular capital abundance, more than offset the effect of pollution regulations, leading rich developed countries to have a comparative advantage in many dirty-good industries.

To confirm this, in the bottom panel of table 2 we present the *change* in net imports for the 20 sectors whose pollution abatement costs *increased least* from 1977 to 1986, compared with those whose pollution costs *increased most*. In contrast to the top panel, the sectors whose pollution costs increased most saw the largest increase in net imports from both Canada and Mexico. Though statistically significant only for Canada, these results suggest a link between higher environmental control costs and increased net imports, whereas the top panel suggested the opposite.

Table 1 only confirms that unobserved heterogeneity drives much of the differences in trade patterns across industries. The problem highlighted by equation (3.8) and figure 1a is that those unobserved industry differences will bias empirical findings against finding a pollution haven effect.

3.3 Unobserved Foreign Environmental Regulation

Next consider the empirical consequences of not observing foreign pollution taxes. Equation (3.6) demonstrated that θ_{it} is function of the threshold $\bar{\eta}_i$. Meanwhile, the threshold is a function of unobserved foreign pollution taxes, τ_{it}* (recall (2.7)). Consequently, the error e_{it} in (3.5) is almost surely correlated with the right-hand-side variable θ_{it} making estimation by OLS biased and inconsistent. To investigate the direction of the bias, consider (3.7). Again, foreign pollution taxes have no direct effect on home pollution abatement costs and $d\theta(\eta)/d\tau^* = 0$. The first term in (3.7) is zero. But when foreign pollution taxes rise, the home country begins producing industries that were previously imported, and $d\bar{\eta}_i/d\tau_i^* > 0$. This implies

$$\frac{d\theta_i}{d\tau_i^*} = \frac{\left[\int_0^{\bar{\eta}_i}(1-\alpha(\eta))[\theta(\bar{\eta})-\theta(\eta)]d\eta\right](1-\alpha(\bar{\eta}))\left(d\bar{\eta}_i \big/ d\tau_i^*\right)}{\left[\int_0^{\bar{\eta}_i}(1-\alpha(\eta))d\eta\right]^2} > 0 \qquad (3.9)$$

Measured sector-wide pollution abatement costs rise when foreign pollution taxes rise.[12] But from (3.1), we can conclude that when $\bar{\eta}_i$ rises net imports fall. Unobserved foreign pollution

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[12] In a full general equilibrium setting with endogenous policy setting, both Home factor costs and pollution taxes may vary, which would add additional terms to consider. These complications would not, however, eliminate the term discussed here.

taxes introduce a negative correlation between pollution abatement costs and net imports. More concretely, if home and foreign pollution taxes were the only time-varying determinants of net imports we could then use the standard omitted variable formula to conclude that β_4 in (3.4) is biased downward, because β_5 is negative and (3.9) establishes a positive covariance between the measure of home stringency and unobserved foreign pollution taxes. Whether this covariance is positive in the data is unknown; nevertheless, our discussion provides a suggestive explanation for the small or even counterintuitive signs found on pollution costs in previous research.

3.4 Aggregation bias

A third problem with estimating (3.5) arises from the fact that the unit of observation (3-digit sectors) is a heterogeneous mix of 4-digit industries.[13] This heterogeneity means that when pollution taxes rise at home and raise production costs, some of the industries lose out to foreign competition and shut down. If the industries most sensitive to pollution taxes are in fact the dirtiest, then measured sector-wide pollution abatement costs fall from this change in the composition of the industry. To demonstrate, replace y in (3.7) with τ, to find:

$$\frac{d\theta_i}{d\tau} = \frac{\left[\int_0^{\bar{\eta}_i} (1-\alpha(\eta))\left(d\theta(\eta)/d\tau\right)d\eta\right]}{\left[\int_0^{\bar{\eta}_i} (1-\alpha(\eta))d\eta\right]} + \frac{\left[\int_0^{\bar{\eta}_i} (1-\alpha(\eta))[\theta(\bar{\eta})-\theta(\eta)]d\eta\right](1-\alpha(\bar{\eta}))\left(d\bar{\eta}_i/d\tau\right)}{\left[\int_0^{\bar{\eta}_i} (1-\alpha(\eta))d\eta\right]^2} \tag{3.10}$$

The direct effect of an increase in the pollution tax is that industries at home respond by abating more pollution, devoting a larger share of output to abatement, and increasing $\theta(\eta)$ for each industry η within sector x. This cost increase then drives up prices which in turn lowers the

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[13] We recognize, of course, that 3-digit SIC codes aggregate 4-digit industries that are heterogeneous in many ways, not only pollution intensities. The econometric issues we describe here would apply equally if we were trying to estimate, say, the effect of labor standards or capital costs on trade, and aggregating across industry groups with different levels of labor and capital intensities. We can only hope that differences in these other characteristics are of second order, relative to the changes in pollution regulations that occurred from 1977 to 1986, and that they can be absorbed by the industry fixed effects.

quantity demanded by foreigners. This is the first element in (3.10) and it raises θ_i in equation (3.6). This first (positive) element tells us what the measured change in sector-wide pollution abatement costs would be if we held constant the composition of industries.

There is, however, a second effect, which is depicted in figure 1b. The increase in the pollution tax lowers the function Γ, and as a consequence there is a new lower threshold industry $\tilde{\eta}$. Industries between $\tilde{\eta}$ and $\bar{\eta}$ are now imported rather than being produced domestically. Since these industries were the dirtiest produced in the x_i sector, this second effect is negative and it works to *lower* θ_i in equation (3.6).[14] Pollution abatement costs in x_i have fallen, and net imports have risen, another seeming violation of the pollution haven hypothesis.

This second effect is essentially a form of endogeneity. Studies seeking to measure the effect of pollution costs on trade inadvertently also capture the effect of trade on measured pollution costs.[15]

To demonstrate this aggregation bias, in figure 2 we plot pollution abatement operating costs per dollar of value added in the U.S. manufacturing sector over 1974-1994. These plots compare $\theta_{it}(\bar{\eta}_{it})$ from (3.6) where we allow industry composition within the *i*-th sector to vary, with $\theta_{it}(\bar{\eta}_{i1974})$ where industry composition is fixed within the *i*-th sector. Our analysis of (3.10) tells us that rising home pollution taxes lower measured sector-wide costs by altering the composition of the remaining industry (i.e. the second term is strictly negative). By fixing the composition of industry we should observe higher sector-wide pollution abatement costs, as we are then only measuring the first term.

The bottom line in figure 2 shows the aggregate value for the entire manufacturing sector. It rises sharply through the late 1970s, and then remains relatively flat. Note, however, that if the composition of U.S. manufacturing shifted away from polluting industries, this bottom line understates what pollution abatement costs would have been had all industries remained as they were in 1974. To see this, the second line in figure 2 plots pollution abatement operating costs,

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[14] There may be conditions under which the second term is sufficiently negative as to make the overall derivative negative. We have not pursued this possibility, because the existence of the second negative term is sufficient to generate an aggregation bias.

[15] In general though, the direction of this bias is unclear. In our model, an increase in pollution costs causes the most pollution-intensive industries to move abroad, reducing the average pollution costs of the industries remaining at home, but it is unclear whether this is true in the data. For example, some very dirty natural resource industries may have little or no international mobility whereas relatively clean assembling operations may move quite easily.

divided by value added, where the composition of U.S. industries by 2-digit SIC code is held constant as of 1974. This line is higher because U.S. manufacturing has shifted towards less polluting 2-digit industries. Similarly, the third line holds the industrial composition constant at the 3-digit SIC code level. It is higher still because within each 2-digit industry, the composition has shifted towards less-polluting three-digit industries. We strongly suspect, but cannot prove because of data limitations, that a similar process is at work at the 4-digit level making our 3-digit sector-wide measures similarly suspect. Furthermore, the problem cannot be solved by disaggregating, because any practical industry definition will include heterogeneous sub-industries that differ in their pollution intensities and their propensity to be imported.

Figure 2 shows why pollution haven effects are so difficult to observe. Aggregate measures of pollution abatement costs per dollar of value added understate the rise in regulatory stringency in the U.S., because the composition of output has become relatively cleaner over time. While we cannot say that this change in composition is due solely to rising U.S. pollution control costs, the change in composition alone poses a major problem for research on the effect of environmental costs on trade: industries whose regulations increased most are increasingly likely to be imported, which then lowers measured increases in pollution costs. Researchers trying to estimate the effect of costs on trade can be misled by the effect of trade on measured costs.

4. Instruments

The preceding section has detailed the problems involved in estimating (3.5): unobserved heterogeneity, unobserved foreign pollution taxes, and aggregation bias. Unobserved heterogeneity is a well-recognized pitfall, and is typically solved by including industry or country fixed effects, depending on the unit of analysis.[16] Given our panel, we include time and industry fixed effects to soak up unobserved industry-specific or time-specific excluded variables. Many of the unobservable industry characteristics are very slow moving,

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[16] Of course, that implies that researchers have access to a panel of data over many years, something that is not always true. Several researchers have taken this approach, and the results often do support a modest pollution haven effect. See, for example, Ederington and Minier (2003), Ederington *et al.* (2004).

including sources of comparative advantage that attract pollution-intensive industries: geographic proximity to markets, sources of raw materials, etc. By looking at *changes* in net imports as a function of *changes* in pollution abatement costs, we can difference out the unobservable effects of industry characteristics that remain constant.

To address the other two problems, we adopt an instrumental variables approach.[17] It is clear that our instrument must have both time and industry variation; it must be correlated with sector-wide pollution abatement cost measures; and it must be uncorrelated with the industry-specific time varying elements left in e_{it}. Using (3.6) and (2.7) we can write sector-wide pollution abatement costs more generally as:

$$\theta_{it} = \Omega\left(c_{it}^{F}, c_{it}^{F*}, \tau_{it}, \tau_{it}^{*}\right)$$

Since domestic cost, foreign costs, and foreign taxes are unobserved, any time and industry-specific component of these is left in our error. Therefore, our instrument must create independent variation in abatement costs by altering the home country's pollution regulation.

To find instruments we proceed in several steps. First, we note that standard theories of regulation relate the stringency of regulation to the income levels of affected parties, the current level of pollution, and tastes. Hence, variation in income levels, pollutant emissions or tastes are possible candidates.[18] However, these characteristics are not industry-specific. The second step then is to transform these aggregate characteristics into useful instruments with time and industry variation. To do so we employ two facts and make one assumption. The first fact is that much of U.S. environmental policy is set by states. As a result, variation in state-level regulation will affect pollution abatement costs. The second fact is that the distribution of industries across states is not uniform: different industries are concentrated in different parts of the country. A consequence of these two facts is that some industries are predominantly located in stringent states and face high pollution abatement costs; other industries are located in lax states and face low abatement costs.

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[17] Ederington and Minier (2003) also instrument for environmental regulatory stringency in a paper that focuses on environmental regulations as a strategic substitute for trade restrictions.

[18] See for example, Copeland and Taylor (2003, chapter 2).

To construct our instruments, for each industry we take a weighted average of state characteristics (q_s), where the weights are the industry's value added in the various states (v_{is}) at the beginning of the sample period. By using beginning-of-period weights, all variation over time comes from changes in state characteristics. More concretely, for the 48 contiguous U.S. states, our instrument for the pollution costs faced by industry i based on characteristic q, is

$$I_{it} = \sum_{s=1}^{48} q_{st} v_{is,77} \big/ v_{i,77} \tag{4.1}$$

where q_{st} is the characteristic of state s in year t, $v_{is,77}$ is the value added by industry i in state s in 1977, and $v_{i,77} = \sum_{s=1}^{48} v_{is,77}$ is the sum of the value added of industry i across all 48 contiguous states in 1977.

To be a good instrument I_i must be correlated with the pollution abatement costs facing the x_i sector, while simultaneously being uncorrelated with the error e_{it} in (3.5). Take as given that the state characteristic q_{st} is strongly related to state-level regulations and hence pollution abatement costs. And now recall that the error term in (3.5) contains measurement and approximation errors reported in (3.4), time varying sources of comparative advantage $c^{F}*_{\text{it}}/c^{F}_{\text{it}}$, foreign pollution taxes τ_{it}, and measurement error introduced by employing θ_{it} rather than τ_{it}. Since we have included both time and industry dummies, only the time-varying and industry-specific elements of these unobserved variables remain in our error term. Therefore, whether our instruments are valid relies on there being zero covariance between the remaining industry-specific and time varying elements of e_{it} and I_{it}. Since I_{it} is just a (fixed) linear function of state characteristics, this simplifies to requiring that at each t we have $\text{cov}(e_{it}, q_{st}) = 0$ for all s. In turn this requires an assumption:

> Assumption 1. Industry-specific shocks to costs, tariffs, foreign pollution taxes etc. that alter home industry production are not large enough to induce a change in the stringency of environmental policy in the states in which this industry resides.

Assumption 1 is basically a small industry assumption. If it holds, then industry-specific and time-varying shocks in each industry alter net imports in that industry, but do not affect environmental stringency. We assume that states set the stringency of their regulations weighing the marginal benefits and costs of tighter regulation. A beneficial shock to industry *i* will raise the demand for its output and its derived demand for pollution; but if this industry's share of emissions is small in this state then the aggregate demand for pollution is virtually unchanged. Industry-specific shocks then have no effect on pollution demand.

If this industry is also small in providing income to state residents, then the shock will have a negligible effect on state incomes as well and hence no impact on marginal damage. Pollution supply is then unaffected by industry-specific shocks. If the industry is small in both of these senses, then environmental stringency can be thought of as being independent of industry-specific shocks.

What are good candidates for the exogenous variation we need to alter pollution abatement costs? We exploit two basic sources of exogenous variation. The first arises when a set of industries (other than the *i*-th) experiences a shock. For example, suppose foreign costs rise in some set of industries we denote by J, and this stimulates output in those sectors. This shock raises the competitive margin in the set of J industries, shifts pollution demand to the right and raises pollution taxes for the *i*-th sector. Abatement costs in the *i*-th industry rise because of the shock in the *j*-th.

To construct this instrument we need to construct measures of pollutants emitted in each state by all industries. The World Bank has estimated the pollution emissions per dollar of value added for each SIC code in the U.S. manufacturing sector, for 14 different air, water, and solid waste pollutants (Hettige *et al*., 1994). We use these figures to estimate the total emissions of each of the 14 pollutants in each state, based on each industry's value added in each state in each year. This gives us 14 instruments, where we are careful to exclude industry *i*'s contribution in its own instrument. Industries with a high value of this instrument for a given pollutant are located in states with a large amount of that pollutant being generated by *other* 3-digit industries.

Formally, the instrument works as follows. For a given pollutant *E*, say airborne particulates, we take the total amount predicted to be emitted in state *s* by all industries except industry *i*. That gives us the amount of pollution in state *s* at time *t* due to other industries. (This is the term in brackets in (4.2) below.) Then we take a weighted average of all 48 contiguous states, where the weights are industry *i*'s value added in each state in 1977. That gives us our instrument, a measure of the amount of pollutant *E* contributed by other industries in the states in which industry *i* tends to locate.

$$I_{it}^{E} = \frac{\sum_{s=1}^{48}\left(\sum_{j\neq i} E_{jst}\right)\times\left(V_{is,77}\right)}{V_{i,77}} \tag{4.2}$$

Industries that locate in states with lots of pollution caused by other industries will have high values of this instrument, and vice versa. Since the World Bank cover 14 pollutants, we calculate a version of (4.2) for each.

Our second instrument is based on pollution supply rather than pollution demand. State incomes vary over time because of ongoing technological progress and factor accumulation which we take as exogenous to developments in industry *i*. These gains may occur in services, real estate, transportation, mining, agriculture or in other manufacturing industries. To the extent that these changes raise state incomes they will affect the demand for a clean environment (pollution supply). Formally, we take a weighted average of the incomes per capita in the states, where the weights are industry *i*'s value added in each state in 1977.

$$I_{it}^{2} = \frac{\sum_{s=1}^{50}\left(Income\ per\ capita_{st}\right)\times\left(V_{is,77}\right)}{V_{i,77}} \tag{4.3}$$

Industries located in states whose incomes are growing faster will have values of this instrument that increase over time.

4.1 When might the instruments fail?

This discussion suggests our instruments can fail in a couple of ways. First, our "small industry" assumption may be untrue if any single industry can have a significant effect on the aggregate demand or supply of pollution. If changes in the industry's size affect state environmental policy, then the instrument fails. To investigate this possibility, as a robustness test of our instruments we identify those industries that represent more than 3 percent of gross state product in any state, and eliminate those states from the construction of the instruments for those industries.

Second, the geographic dispersion of industries among U.S. states may not be exogenous with respect to trade. Trade agreements and falling transportation costs may make locations closer to borders more attractive over time, and industries may move to border states in order to trade with Mexico and Canada. If dirty and clean industries differ in their mobility, then there may be a dirty-industry specific but time-varying element to our error term. Since the instruments are constructed using 1977 weights, the movement of industry to take advantage of proximity is not in itself a problem for our instruments. The problem arises if the movement of industries is large so that states respond by changing environmental policies. In that case, the increase in stringency in border states would be correlated with the improved competitiveness of industries located there.

To lessen this concern, when studying trade with Mexico, we calculate the instrument using states that do not border Mexico. Similarly, when studying trade with Canada, we calculate the instrument using only states that do not border Canada.

5. Data

Data on imports and exports to and from the U.S. come from the Center for International Data (CID) maintained by Feenstra (1996, 1997) at UC Davis.[19] These data are collected by the U.S. Bureau of the Census, and are organized by industry according to the international Harmonized Commodity and Coding System. The CID has matched these data with the appropriate SIC codes. Thus for each industry and for each country with which the U.S. trades we know the value of exports, the customs value of imports, and the total duties paid.

Data on pollution abatement costs come from the U.S. Census Bureau's Pollution Abatement Costs and Expenditures survey (PACE). The PACE data report the annual pollution abatement operating costs, including payments to governments, by industry. These data are published in Current Industrial Reports: Pollution Abatement Costs and Expenditures, MA-200.

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[19] The CID can be found at http://data.econ.ucdavis.edu/international/.

In constructing the data set for this analysis, we confronted two significant obstacles. The first involves the breakdown of published pollution abatement costs into capital costs and operating costs. The Census Bureau published both, but the capital cost data pose numerous problems. The PACE capital data are for new investment, not annualized costs. Puzzlingly, abatement capital expenditures declined significantly as a share of value added, from around 0.8 percent in 1975 to 0.2 percent in 1984. There are several potential explanations. One is, of course, the aggregation bias discussed above. If environmental regulations cause polluting industries to relocate overseas, then investment in pollution control equipment could easily decline in the U.S. A second explanation involves the type of capital. In the early years of pollution laws, most abatement capital consisted of "end-of-pipe" technologies. Over time, however, abatement investment becomes increasingly difficult to disentangle from production process changes that have little to do with pollution abatement. Finally, many environmental regulations grandfather existing sources of pollution, and this has the effect of stifling new abatement expenditures in exactly those industries most strictly regulated. For all these reasons, we focus on PACE operating costs, while noting that this is only an imperfect proxy for the full costs of regulation.

The second significant data problem involves the definition of an industry. In 1987 the SIC codes were substantially changed, making time-series comparisons difficult. Six of the 3-digit codes defined as of 1972 were eliminated, and 3 new codes added. The total number of 3-digit SIC codes declined from 143 to 140. Of the 3-digit codes that remained, 37 were altered by changing the definition of manufacturing industries within them.

Some papers attempt to span the change in SIC codes in 1987 by applying published concordances, so that the pre-1987 data are listed according to post-1987 SIC codes, or vice versa.[20] These are typically based on total output as of 1987, when the Census Bureau collected the data using both SIC categorizations. Two major problems arise under this methodology. First, while one may be able to attribute *x* percent of the output of industry *i* to industry *j* using such a concordance, that percentage will not likely apply to pollution abatement expenditures. So converting the post-1987 pollution abatement data to the pre-1987 SIC codes will inevitably

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[20] For example, Bartelsman, Becker, and Gray (1996) maintain such a concordance at *www.nber.org/nberces*.

attribute some pollution expenditures to the wrong industries. Second, the 1987 concordance becomes increasingly irrelevant as industries change over time. So while *x* percent of industry *i*'s output may be attributable to industry *j* in 1987, that will not likely be true by 1994. Consequently, we have limited our study to the 1977-1986 period. This is the period of fastest growth in pollution abatement operating costs.

6. Empirical Results

The first, and simplest, implication of our discussion so far is that cross-section regressions of net imports on pollution abatement costs may be biased by unobserved heterogeneity. Fixed effects easily solve this.

6.1 Fixed Effects

In table 3 we present versions of equation (3.5), the regression analog to the differences of means at the top of table 1. In column (1) the dependent variable is net imports from Mexico divided by valued shipped in the U.S. The pollution costs coefficient is large and statistically significant, suggesting that those industries in which pollution abatement costs increased also saw increased imports from Mexico. Column (2) of table 4 presents the same specification except that the dependent variable is net imports from Canada. In both cases we find a positive relationship between pollution abatement costs and net imports. In addition, import tariffs lower net imports, although the coefficients are not statistically significant.

Overall these results are sensible – increases in abatement costs raise net imports and tariffs reduce them. This is a departure from much of the literature that uses cross-sections of data and finds no evidence of a pollution haven effect.[21]

To get a feel for the magnitudes involved note that a one percentage-point increase in the share of pollution abatement costs in an industry leads to a 0.064 percentage-point increase in net imports from Mexico and a 0.53 percentage-point increase from Canada. Although the Canada coefficient is eight times as large as that for Mexico, imports from Canada were seven times

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[21] We have also run cross-section versions of table 3 without industry fixed effects and reproduced the lack of evidence for a pollution haven effect. Coefficients on pollution costs are either small and statistically insignificant, or are negative.

imports from Mexico during this period, so the Canada coefficient represents an effect of comparable magnitude.

The average 3-digit industry in the U.S. imported from Mexico 0.32 percent of the total value of U.S. shipments, and exported to Mexico 0.49 percent (resulting in the net import share of -0.1 percent reported in table 2.B). If the change in net imports measured by the pollution cost coefficient of 0.064 in table 3 comes entirely from changing gross imports, the relevant elasticity is 0.22. (This corresponds to ξ_1 in equation A.2. See the appendix for details of these elasticity calculations.) On the other hand, if the change comes entirely from gross exports, the relevant elasticity is about 0.17 (ξ_2 in equation (A.3)).

For imports from Canada, the fixed-effects coefficient in column (2) of table 4 corresponds to an elasticity 0.45 if the change in trade comes entirely from imports, and 0.32 if the change comes from exports. Note that for Mexico, the elasticity based on imports is larger than that based on exports ($\xi_1 > \xi_2$), while for Canada the reverse is true. This is because the U.S. is a net exporter to Mexico, and a net importer from Canada.

We should note that for most industries, the share of pollution abatement costs did not increase even one percentage point from 1977 to 1986. In fact, table 1 shows that the 20 industries where pollution abatement costs increased the most experienced an average increase of only 2.7 percentage points. Only 9 industries experienced increases larger than 2 percentage points.[22] As a useful upper bound we can calculate the change in net imports predicted for the 20 industries where costs rose most. Using the coefficients from table 3, the 2.7 percentage-point increase in costs translates into an average increase in net imports from Mexico of approximately \$38 million per year in these worst-hit industries.[23] The same calculation for Canada predicts an increase in net imports of \$312 million per year.

These adjustments are not small, but they only occur in the hardest-hit industries. We should also recall that trade in these industries can be very large. In these same 20 hardest-hit

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[22] The 9 industries are SIC codes 214 (tobacco stemming and redrying), 266 (building paper and board mills), 286 (industrial organic chemicals), 287 (agricultural chemicals), 291 (petroleum refining), 311 (leather tanning and finishing), 331 (blast furnace, basic steel prod.), 333 (primary nonferrous metals), and 334 (secondary nonferrous metals).

[23] To calculate this figure we used the average value shipped in these industries over the whole time period to convert the change in net imports/value shipped to the change in net imports. Multiply .064 (from table 3) with .027 (the change over the whole sample, from table 1) times 21 billion dollars (the average value shipped over the sample) to get the figure in the text.

industries, average two-way trade grew by \$143 million per year between Mexico and the U.S., and by \$595 million between Canada and the U.S. All of these calculations are summarized in appendix table A1.

While the fixed-effects estimates in table 3 appear more reasonable to us than the cross-section or pooled estimates in the earlier literature, there are still reasons to believe the coefficients misstate the true effect of pollution costs on imports. First, the statistical endogeneity of the pollution cost variable, due to its aggregation across different industries, means that even the fixed-effects regressions in table 3 are likely biased against finding a pollution haven effect. Second, the fixed-effects regressions assume implicitly that unobserved industry characteristics that simultaneously affect tariffs, pollution abatement, and imports are fixed over time. While it is reasonable to imagine that this is true for some industry characteristics (location, geography, natural resource abundance), for others it is surely false. For these reasons, we turn to instrumental variables estimates of the pollution haven effect.

6.2 Instrumental Variables

Table 4 presents first-stage regressions in which pollution abatement operating costs as a share of value added (the right-hand side variable in table 3) is regressed on tariffs, a year trend, 130 industry fixed effects, and the instruments. The first column excludes states that border Mexico, the second column excludes states that border Canada, and for comparison the third column includes all 48 contiguous U.S. states.

Note that because the first stage includes industry and year fixed effects, the coefficients in table 4 can be interpreted as the result of changes in the underlying variables. Industries facing higher tariffs tend to have increasing abatement costs. Industries concentrated in states whose incomes grew fastest tend to have pollution abatement costs that grew less fast. (This could be due, for example, to national pollution regulations forcing less stringent states to catch up with the leaders.) And for the most part, industries located in states with growing concentrations of other polluting industries tend to have declining relative pollution abatement costs, though some of the pollution coefficients are positive.[24]

The final two columns of table 3 contain two-stage least-squares (2SLS) versions of the fixed-effects regressions in columns (1) and (2), where the first stage constitutes estimates of θ_{it} as a function of the exogenous variables, from table 4. For Mexico, instrumenting for pollution costs increases the coefficient from 0.064 to 0.144. For Canada the coefficient increases from 0.529 to 0.792.

To interpret these coefficients we again need to discuss their magnitudes. We can use our previous example and examine the 20 industries where costs rose most -- by 2.7 percentage points. Using the Mexico coefficient in column (3) of 0.144, these industries are predicted to average an $82 million increase in net imports.[25] During the period, trade volume with Mexico in these 20 industries increased by an average of $143 million. The same calculation for Canada predicts an increase in net imports of $453 million, while trade volume grew by $595 million. For Mexico, the predicted increase in net imports due to increased pollution costs is 58 percent of the increase in trade volume in these 20 industries over the period; for Canada it is 76 percent.

Again, it is important to remember that these effects, while large, occur only among the industries with the largest environmental cost increases. The average U.S. manufacturing industry saw its pollution costs increase only 0.64 percentage points, leading to predicted increases in net imports of $14 million from Mexico, and $79 million from Canada. These figures amount to about 10 percent of the change in trade volume over this period. (See appendix table A1.)

6.3 Robustness checks

To test the robustness of these estimates, particularly with respect to the instruments, we ran a series of standard tests. First, note that in table 4, F-tests of the joint significance of all of the instruments are high. Second, in table 5 we estimate the 2SLS models with alternate sets of

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[24] The instruments in table 3 are highly collinear. Note, for example that criterion air pollutants (SO2, NO2, CO and VOCs) all have correlations greater than 0.9.

[25] The calculation is (0.144)(0.027)($21 billion).

instruments. The original coefficients are reproduced in the top row. Row (2) drops the state incomes from the first-stage, relying only on state pollution levels as instruments. The pollution abatement cost coefficient for Mexico shrinks, but remains much larger than the fixed effects estimate. The Canada coefficient is unaffected by dropping incomes.

We have also tried dropping all of the 14 measures of state pollution levels, one-by-one. These results are reported in appendix table A2. The pollution abatement cost coefficients are all similar to those in the base specification in table 4, statistically significant, and much larger than the analogous fixed-effects coefficients.

In each case where we have dropped instruments from the first stage, we have also tried including those dropped variables as regressors in the second stage. None of them (income nor any of the 14 pollutants) were statistically significant predictors of trade.

Another concern might be that our "small industry" assumption is violated, and that our instrumental variables results are driven by the few industries that are highly concentrated in a few states. In that case, the instrumented pollution costs might be endogenous. In row (3) we drop from the instrument stage those state-industry combinations where the industry comprises more than 3 percent of gross state product.[26] If anything, this change renders the pollution coefficients larger than when all industries are included.

In row (4) we include the Mexico border states in the calculation of the instruments in column (1), and the Canada border states in the calculation in column (2). (Recall that the border states were dropped to alleviate concerns that industries may move to border states in order to trade with Mexico or Canada.) The Mexico coefficient shrinks, but remains large, statistically significant, and larger than its fixed-effects counterpart. The Canada coefficient becomes even larger once the border states are included.

Yet another concern involves the fact that the 1970s and early 1980s saw rising energy prices. Since the U.S. is an oil importer, and Mexico and Canada are exporters, one might be concerned that polluting industries are also energy-intensive industries, and that changes in trade patterns we are attributing to pollution abatement costs really arise from oil prices. Our 2SLS specification should eliminate this concern, unless state characteristics are affected by oil prices and in turn affect state pollution stringency. To be sure, however, in row (5) of table 5 we have

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[26] Of the 133 industries in 48 states, there were 451 cases where the industry was this large, or 7 percent of the sample.

included interactions between average annual crude oil prices and the industry fixed effects. The results hardly differ from the basic specification in row (1).

In every alternative specification, the 2SLS pollution coefficients are large, statistically significant, and larger than the fixed-effects coefficients. We conclude from this that the fixed-effects coefficients typically understate the actual effect of pollution abatement costs on imports

In addition to the alternate instrument sets, we performed a test of the overidentifying restrictions (Davidson and MacKinnon, 1993). This consists of regressing the residuals from the second stage regression on the set of instruments, and examining the test statistic (nR^2). Under the null hypothesis that the specification is correct and the instruments are uncorrelated with the error term e_{it} in equation (3.5), this test statistic is distributed Chi-squared. This is the test that all of these sets of instruments fail. The results are reported at the bottom of table 3. Although we cannot assert that we have precisely estimated the structural effect of pollution costs on imports, we feel that the fixed-effects and instrumental variables regressions in table 3 demonstrate the bias associated with cross-section regressions of trade on pollution costs, and demonstrate that even the fixed effects will in general understate the true effect of pollution costs on trade.

7. Conclusion

Recent research on the effects of pollution regulations on trade has generated mixed results. Most studies using cross-sections of data are unable to disentangle the simultaneous effects of industry characteristics on both trade and abatement costs. As a result, pollution abatement costs are often found to have no effect on trade flows; in some cases costs appear to promote exports. This uncertainty is unfortunate because without firm evidence linking environmental control costs to trade flows, it is difficult to know whether governments have the ability – let alone the motivation – to substitute environmental policy for trade policy.

In this paper, we use a simple theoretical model to examine the statistical and theoretical sources of endogeneity that confront attempts to measure the effect of environmental regulations on trade flows. We show that for very simple reasons unrelated to pollution havens, pollution abatement costs and net imports may be negatively correlated in panels of industry-level data. This negative correlation can easily bias estimates against finding a pollution haven effect.

In the empirical work, we first estimate a fixed-effects model and show that those industries whose abatement costs increased most have seen the largest relative increases in net imports. We then use our model to demonstrate several reasons why the fixed-effects estimates are likely to understate the pollution haven effect. We develop a set of instruments based on the geographic dispersion of industries across U.S. states, and estimate 2SLS versions of the same estimating equation. The 2SLS estimates are consistently and robustly larger than the fixed-effects estimates.

Not only are the estimated effects of pollution costs on net imports positive and statistically significant, they are economically significant. For each country group studied, for the industries whose pollution abatement costs increased most, the increase in net imports due to increased pollution costs represents a considerable fraction of the increase in total trade volumes over the period.

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Appendix: Magnitudes as elasticities.

The fixed-effect pollution abatement cost coefficient in column (1) of table 3 suggests that a one percentage-point increase in the share of value added going to pollution costs is associated with a 0.064 percentage point increase in net imports as a share of U.S. value shipped. Is this large? It is somewhat difficult to think about elasticity calculations for *net* imports. Consider two hypothetical industries: Industry A has gross imports of $2 million and gross exports of $1 million; Industry B has gross imports of $1 billion and gross exports of $999 million. Each has net imports of $1 million. An increase in pollution costs that causes net imports in both industries to increase to $2 million represents a large effect on industry A, and a small effect on industry B. Hence the elasticity of net imports is not a useful tool for comparing these coefficients.[27] We need a unit-free measure of the responsiveness of trade to pollution costs that is not sensitive to the initial size of *net* imports, but is comparable across industries with very different levels of *gross* imports and exports.

The main analysis here, in equation (3.5), regresses net imports divided by value shipped (N) on pollution abatement divided by value added and other covariates.

$$N_{it} \equiv M_{it} - X_{it} = \ldots + a\theta_{it} + \ldots + e_{it}$$

To interpret $\hat{\alpha}$, divide it into two terms:

$$\hat{\alpha} = \frac{\partial N}{\partial \theta} = \frac{\partial M}{\partial \theta} - \frac{\partial X}{\partial \theta} \qquad \text{(A.1)}$$

If we multiply both sides by the average value of θ and divide by the average value of gross imports ($\bar{M}$) we get

$$\xi_1 \equiv \hat{\alpha}\frac{\bar{\theta}}{\bar{M}} = \left(\frac{\partial M}{\partial \theta}\frac{\bar{\theta}}{\bar{M}}\right) - \left(\frac{\partial X}{\partial \theta}\frac{\bar{\theta}}{\bar{M}}\right) = \xi_{M\theta} - \xi_{X\theta}\left(\frac{\bar{X}}{\bar{M}}\right) \qquad \text{(A.2)}$$

where $\xi_{M\theta}$ is the elasticity of gross imports with respect to pollution costs, and $\xi_{X\theta}$ is the elasticity of gross exports with respect to pollution costs. Note our prior is that $\xi_{M\theta}$ is positive and $\xi_{X\theta}$ is negative, so the whole expression is positive.

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[27] Worse still, if an industry imports and exports the same amount, net imports are zero, and any measured elasticity will be infinite. Moreover, if the increase in pollution costs at home causes net imports to increase from a large negative number to a small negative number, the measured elasticity of net imports will be negative.

On the other hand, if we divide by the average value of gross exports ($\bar{X}$ rather than $\bar{M}$) we get

$$\xi_2 \equiv \hat{\alpha}\frac{\bar{\theta}}{\bar{X}} = \left(\frac{\partial M}{\partial \theta}\frac{\bar{\theta}}{\bar{X}}\right) - \left(\frac{\partial X}{\partial \theta}\frac{\bar{\theta}}{\bar{X}}\right) = \xi_{M\theta}\left(\frac{\bar{M}}{\bar{X}}\right) - \xi_{X\theta} \qquad \text{(A.3)}$$

Both ξ_1 and ξ_2 approximate the sum of the absolute values of the elasticities of imports and exports with respect to pollution costs. If net imports are positive ($\bar{M} > \bar{X}$), then $\xi_1<\xi_2$, ξ_1 understates this sum of elasticities, and ξ_2 overstates the sum. If net imports are negative, then $\xi_1>\xi_2$, ξ_1 overstates the sum of elasticities, and ξ_2 understates it.

The statistics ξ_1 and ξ_2 have several nice properties. They provide bounds for a sensible magnitude with which to interpret the coefficient $\hat{\alpha}$. They are comparable across sets of countries. And, if $\bar{M} = \bar{X}$, the two statistics are identical and equal to the sum of the import and export elasticities: $\xi_1=\xi_2=\xi_{M\theta}+\xi_{X\theta}$.

Table 1. Comparisons of pollution abatement operating costs (PAOC) and net imports: 1977-1986.

Cross-section comparison of levels. Averages for 1977-1986.	PAOC/ value added (1)	Average net imports divided by value shipped in the U.S. Mexico (2)	Canada (3)
20 3-digit SIC codes with the lowest average PAOC per dollar of value added.	0.0012* (0.0005)	-0.00021 (0.00545)	-0.00535* (0.00741)
20 3-digit SIC codes with the highest PAOC per dollar of value added.	0.0482 (0.0284)	-0.00159 (0.00845)	0.04693 (0.10742)

Time-series comparison of changes. Average for 1986 minus average for 1977.	Change in PAOC/value added	Change in average net imports divided by value shipped	
20 3-digit SIC codes for which PAOC share increased least.	-0.00054* (0.00114)	-0.00017 (0.00524)	-0.00345[†] (0.04236)
20 3-digit SIC codes for which PAOC share increased most.	0.02726 (0.02651)	0.00103 (0.00529)	0.02662 (0.05582)

The top panel contains average values over the entire 1977-86 period. The bottom panel reports the changes, the difference between the average values from 1986 and the average values from 1977.

*Indicates that the relevant figures for clean and dirty industries are statistically different from each other at 5 percent. ([†]Statistically significant at 10 percent.)

Table 2. Descriptive statistics 1977-1986.

	Mean and std. deviation
A. Industry characteristics	
PAOC by U.S. industries (millions $ 1982)	77.0 (201.8)
Value added by U.S. industries (millions $ 1982)	6683 (7172)
Value shipped by U.S. industries (millions $ 1982)	15617 (22521)
Pollution abatement cost as fraction of U.S. industry value added	0.0122 (0.0215)
Tariff rate	0.052 (0.038)

B. Trade	Mexico	Canada
Manufacturing imports to the U.S. (1982 $M)	50.0 (140.2)	335.8 (1488.8)
Manufacturing exports from U.S. (1982 $M)	77.0 (147.4)	261.2 (925.1)
Net imports divided by U.S. value shipped. (1982 $M)	-0.0010 (0.0073)	0.0056 (0.0527)

Notes:
The sample is 1015 observations on 133 industries over 10 years. (1979 is omitted because the PACE data are not available for that year.)
Trade data for the OECD in column (3) excludes imports and exports from Canada and Mexico. Column (4) comprises of non-OECD countries that are GATT signatories.

Table 3. U.S. trade with Mexico and Canada.

	Fixed effects		2SLS with fixed effects	
	From Mexico (1)	From Canada (2)	From Mexico (3)	From Canada (4)
Pollution abatement operating costs per dollar of value added.	0.064* (0.018)	0.529* (0.045)	0.144* (0.063)	0.792* (0.102)
Tariffs by two-digit SIC code	-0.017 (0.017)	-0.061 (0.043)	-0.031† (0.016)	-0.083† (0.046)
n	1015	1015	991	1000
R^2	.76	0.97	0.78	0.97
Sargan overidentification test.			49	180
F test of the joint significance of the instruments.			7.6	14.4
Elasticity of net imports with respect to changes in pollution costs. (Derivation in appendix.)				
-- based on exports (ξ_2):	0.17	0.45	0.38	0.67
-- based on imports (ξ_1):	0.22	0.32	0.49	0.49

*Statistically significant at 5 percent.
†Statistically significant at 10 percent.
Heteroskedastic-consistent std. errors in parentheses.
All columns contain year and industry fixed effects.

Table 4. Predicted pollution abatement costs 1977-1986.

	Pollution abatement operating costs per dollar of value added.		
	Without Mexico border states (1)	Without Canada border states (2)	Using all states (3)
Tariffs	0.025 (0.027)	0.074* (0.033)	0.087* (0.033)
State-level income per capita ($millions).	-2.65* (1.30)	0.76 (1.56)	-2.49† (1.51)
<u>State level pollution concentrations</u>			
Biological oxygen demand (thousands)	-0.021 (0.069)	-0.466* (0.121)	-0.525* (0.091)
Total suspended particulates (thousands)	-0.067* (0.020)	-0.121* (0.023)	-0.049* (0.020)
Air toxics (millions)	-0.498* (0.246)	0.545 (0.382)	0.091* (0.035)
Water toxics (millions)	0.110 (0.422)	-1.87 (1.14)	-2.73* (1.12)
Solid waste toxics (millions)	-0.528* (0.210)	0.039 (0.150)	0.014 (0.15)
Air particulates (millions)	-0.452 (0.333)	-0.830* (0.342)	-1.10* (0.40)
Air CO (millions)	0.118 (0.120)	0.692* (0.176)	0.353* (0.150)
Air SO2 (millions)	-0.139* (0.148)	-0.701* (0.208)	-0.326† (0.182)
Air NO2 (millions)	-0.042 (0.272)	0.342 (0.306)	0.188 (0.286)
Air VOCs (millions)	-0.211 (0.154)	-0.371 (0.281)	-0.260 (0.204)
Air PM10 (millions)	1.87* (0.49)	1.40* (0.43)	1.41* (0.40)
Air metals (thousands)	0.158* (0.055)	0.235* (0.039)	0.117* (0.033)
Solid waste metals (millions)	-3.97* (1.75)	-2.72* (1.09)	-2.38* (1.18)
Water metals (thousands)	0.111† (0.060)	-0.045 (0.059)	0.048 (0.060)
n	991	1000	1000
R^2	0.92	0.93	0.92
F-test of the joint significance of all the instruments	7.56	14.41	13.98

*Statistically significant at 5 percent. †Significant at 10 percent. Std. errors in parentheses.
Contains 130 industry fixed effects and 9 year fixed effects.

Table 5. Robustness checks: Alternative instrumental variables regressions of U.S. trade with fixed effects. 1977-1986.

		Coefficients on instrumented PAOC as a fraction of U.S. value added	
		From Mexico (1)	From Canada (2)
(1)	Table 5 coefficients	0.144* (0.063)	0.792* (0.102)
(2)	Without state incomes	0.103[†] (0.063)	0.798* (0.103)
(3)	Without industries that are >3% of gross state product	0.300* (0.110)	1.28* (0.18)
(4)	With border states included in instruments	0.080* (0.037)	1.02* (0.11)
(5)	With oil prices interacted with industry dummies.	0.146* (0.060)	0.808* (0.102)

*Statistically significant at 5 percent.

[†]Statistically significant at 10 percent.

Heteroskedastic-consistent std. errors in parentheses.

All regressions contain year dummies, industry fixed effects, and tariff levels, as in tables 3 and 4.

Appendix table A1. Magnitudes.

	Predicted change in net imports due to increased pollution abatement costs ($1982 millions)	
	From Mexico (1)	From Canada (2)
Average of the 20 industries whose pollution abatement costs increased most.		
Fixed effects	$37	$302
2SLS	82	453
Average increase in trade volume	143	595
Average industry.		
Fixed effects	6	53
2SLS	14	79
Average increase in trade volume	154	601

Notes: Each predicted change in imports is the coefficient estimate, times the increase in pollution abatement costs for the average industry, times the average value shipped. For example, the fixed effects coefficient for trade with Mexico from table 3 is 0.064. On average, for the 20 industries whose pollution abatement costs increased most, PAC divided by value added increased by 0.028. Those same industries' average value shipped was $21 billion. Multiply the three numbers to get $38 million, the top figure in column (1).

Appendix table A2. Robustness checks: Dropping pollutants from the instrument.

		Coefficients on instrumented PAOC as a fraction of U.S. value added	
		From Mexico (1)	From Canada (2)
(1)	Drop biological oxygen demand	0.147* (0.062)	0.786* (0.106)
(2)	Drop total suspended solids	0.155* (0.066)	0.794* (0.110)
(3)	Drop air toxins	0.134* (0.064)	0.764* (0.103)
(4)	Drop water-borne toxins	0.143* (0.063)	0.785* (0.103)
(5)	Drop land toxic pollution	0.159* (0.065)	0.794* (0.102)
(6)	Drop particulates	0.138* (0.063)	0.692* (0.103)
(7)	Drop CO	0.142* (0.063)	0.759* (0.106)
(8)	Drop SO_2	0.134* (0.063)	0.817* (0.106)
(9)	Drop NO_2	0.144* (0.063)	0.796* (0.106)
(10)	Drop VOC	0.124* (0.063)	0.790* (0.103)
(11)	Drop PM10	0.114† (0.067)	0.751* (0.104)
(12)	Drop metals in the air	0.170* (0.065)	0.794* (0.112)
(13)	Drop metals in solid waste	0.167* (0.064)	0.769* (0.104)
(14)	Drop metals in the water	0.153* (0.064)	0.784* (0.102)

*Statistically significant at 5 percent. †Statistically significant at 10 percent.
Heteroskedastic-consistent std. errors in parentheses.
All regressions contain year dummies, industry fixed effects.

Figure 1a. Unit costs determine net imports within an industry group.

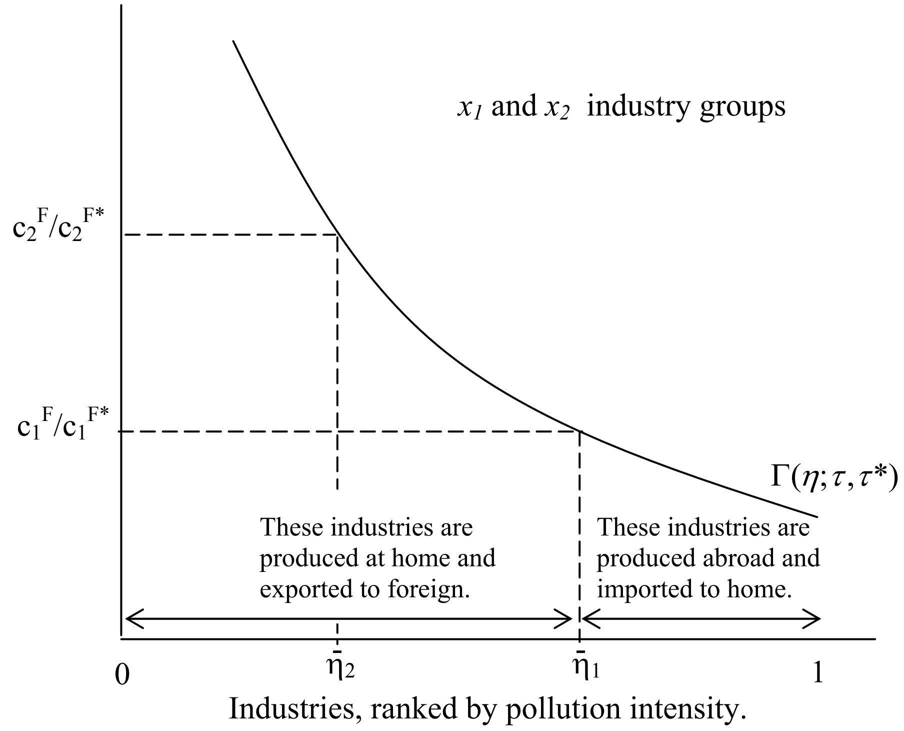

Figure 1b. The effect of an increase in pollution taxes on abatement costs.

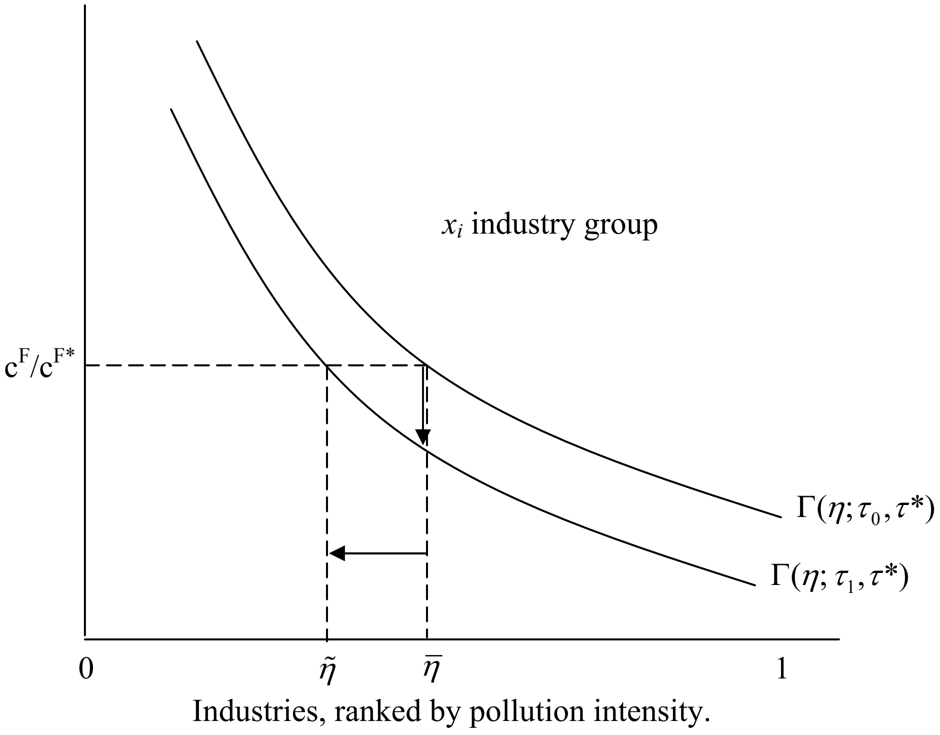

Fig. 2. Pollution abatement costs as a fraction of value added.