Unmasking the Pollution Haven Effect

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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 for 133 manufacturing industries from 1974 to 1986. Our results indicate that those industries where abatement costs have increased most have seen the largest increases in net imports. For the 25 industries hardest hit by regulation, the change in net imports we ascribe to the increase in regulatory costs amounts to about 25 percent of the total increase in trade volume over the period.

JEL codes: F18, Q38, H73
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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 so far been rejected by a large number of empirical economic analyses. For example, in a widely cited review Jaffe, *et al.* (1995), notes, "there is relatively little evidence to support the hypothesis that environmental regulations have had a large adverse effect on competitiveness." The purpose of this paper is to employ both theoretical and empirical methods to uncover and estimate the magnitude of the pollution haven effect while simultaneously arguing that previous failures arise from both improper accounting for unobserved heterogeneity and the endogeneity of pollution abatement cost measures.

Previous attempts to explain 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 firm's 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 findings. Some researchers find larger and more significant pollution haven effects for less pollution-intensive industries. A few even find that industries with relatively high pollution abatement costs are leading exporters.[1] In these cases, the Porter hypothesis – that regulation brings cost-reducing innovation – is often invoked as the explanation for finding a positive link between regulatory stringency and exports.

The current state of empirical work leaves important policy questions unanswered. Many trade policy analysts are concerned that countries may undercut international tariff negotiations by weakening environmental policy to placate domestic protectionist interests. If this is true, international trade agreements 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.

1 See for example Kalt (1988) or Osang et al. (2000).

In this paper we re-examine the link between abatement costs and trade flows using both theory and empirics. Our goal is to provide a more theoretically based examination of the pollution abatement cost and trade flow link in the hope of identifying and accounting for several important econometric and data issues. We believe that these data and econometric issues – and not the relatively small costs of pollution abatement nor the Porter hypothesis – are responsible for the results produced thus far.

To do so we develop a simple many-sector partial-equilibrium model where each manufacturing sector (i.e. a 3-digit SIC industry) is comprised 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 land 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 econometrician's observed measure of sector-wide pollution abatement costs and net imports. This correlation is of course opposite to the direct effect we would expect to find between higher pollution abatement costs and higher net imports, and presents a suggestive explanation for the difficulties encountered by earlier studies.

Second, we use the model to derive an estimating equation linking industry net imports to home 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 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. This use of geography as a source of exogenous variation has of course been used before (see Frankel and Romer (1999) in particular), but here it poses some new challenges because of the mobility of industry within the U.S.

We then estimate the effect of regulations on trade flows using data on U.S. imports in 133, 3-digit manufacturing industries from Mexico, Canada, and the rest of the world over the 1974-1986 period. We are limited in coverage by changes in SIC codes after 1987 and by the discontinuation of the pollution abatement cost data. Throughout we focus on Canada and Mexico since these are the largest, and most proximate, trading partners of the U.S.

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 Canada, Mexico and various aggregations of the rest of the world. In our fixed-effects estimations we find that a 10 percentage point increase in the share of pollution abatement costs leads to a 0.5 percentage point increase in net imports from Mexico, and a 2.7 percentage point increase in net imports from Canada. Since imports from Canada are 7 times imports from Mexico, the coefficient for Canada represents a slightly smaller relative effect. Our theoretical model suggests several reasons why these fixed-effects estimates understate the pollution haven effect, and in our instrumental variable estimation we find larger effects. The same 10 percentage point increase in pollution abatement costs produces an 11 percentage point increase in net imports from Mexico and a 44 percentage point increase from Canada. Similar results are found for other country groupings.

These are not small effects, but we need to acknowledge the fact that the share of pollution abatement costs have increased nowhere near 10 percentage points over the 1974 to 1986 period. In fact, the 25 industries where pollution abatement costs increased the most experienced an average increase of only 2 percentage points. Using this as a guide, we find net imports from Mexico would only rise 15 million dollars according to our fixed-effects estimates and by 34 million dollars according to our instrumental variable estimates. Meanwhile, two-way trade with Mexico in these same hardest-hit industries rose by $139 million over the period. For Canada, these same calculations imply an increase in net imports of 83 million and 134 million dollars respectively, while two-way trade increased by 614 million dollars.

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. In the next section, we detail our model assumptions and generate the within-sector trade pattern predictions. Section 3 then derives the estimating equation, and section 4 describes our instruments. We discuss the data in section 5 and present both fixed-effects and instrumental variable results in section 6. A short conclusion follows.

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 we make no attempt at market clearing, and 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 industrial sectors, indexed by i, with each sector composed of many industries. Empirically, sectors correspond to 3-digit SIC codes and industries correspond to 4-digit SIC codes.[2] 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 in the i-th sector 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 the x_i- sector goods, with expenditures across all industries within the x_i sector being uniform.

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 $\theta(\eta)$. When firms allocate this fraction of inputs to

2 Technically, 3-digit SIC codes are called "industry groups."

abatement, production for sale in a typical industry in the x_i-industry group is (dropping the *i* subscripts for clarity)

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

where F is increasing, concave, and CRS, and $\eta \in [0,1]$ labels industries within the x industry-group. 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.

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 pollution emitted is proportional to output : $z = x = F(K,L)$. When abatement is active, $\theta > 0$ and pollution is reduced.[3]

Following Copeland and Taylor (2003) we adopt a specific formulation for $\phi(\cdot)$ letting $\phi(\theta) = (1-\theta)^{1/\alpha}$, 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.[4]

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

3 See Copeland and Taylor (2003, chapter 2) for more details.
4 This relies on the assumption that pollution taxes are high relative to the costs of abatement inputs. A sufficient condition for firms to abate actively is given by $\tau / c^F > (\alpha(1)/(1-\alpha(1)) \exp[1/(1-\alpha(1))]$. This condition also ensures that our ranking of industries by pollution intensity, [α(η) is increasing in η] matches the ranking of industries by pollution abatement costs as a fraction of value added [θ(η) is increasing in η].

It is helpful to rank the industries in terms of their pollution intensity, α(η), so that high-η industries are the most pollution-intensive: $\alpha'(\eta) > 0$.

2.2 Within-Sector Trade Patterns

Since every sector has its own specific factor K_i we can be assured that both countries will produce at least some subset of industries within every sector. To determine which set of industries is produced at home and abroad, we compare their unit costs. From equation (2.3), it is straightforward to show 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 two factors of production (K_i, L) sell at prices (w,r_i). 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

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

Home produces and exports all industries η such that $c(\eta) \leq c^*(\eta)$. Thus, Home produces those industries η for which

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

Note by construction the left side of (2.6) is independent of η and only varies across sectors of the economy. The right side is falling in η because we have assumed $\tau > \tau^*$ and ordered the industries such that α(η) is increasing in η.[5]

5 To see this, take the log of the right side and differentiate.

Figure 1 depicts the situation for the x_i industry-group when it faces given factor costs and pollution taxes. The ratio of Home to Foreign costs of production determine (c^F/c^{F*}) , while relative pollution taxes together with Γ determine a threshold industry index $\bar{\eta}$. The threshold industry is defined by taking (2.6) with equality and solving to find:

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

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

Industry sectors differ in two dimensions. First, every sector uses a different specific factor and thus the ratio of costs (c^F/c^{F*}) differs across sectors. This implies that differences across countries in their abundance of primary factors, capital, land or skilled human capital, will be reflected in trade patterns. Second, sectors may also differ in their pollution intensity so that a very dirty sector, J, may exhibit $\Gamma_J > \Gamma_I$ for all η, even if firms in both sectors I and J face the same pollution taxes.

Having solved for the marginal industry, $\bar{\eta}_i$, we can now simply write Home net imports (imports minus exports) in the x_i sector. Let b_i denote the fraction of income spend 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 spend on imported foreign goods. Foreign 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 given by the difference between imports and exports:

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

Equations (2.7) and (2.8) give us a relationship between trade flows and pollution regulations by industry sector. Domestic pollution taxes decrease Γ() and move $\bar{\eta}_i$ to the left in figure 1, increasing net imports. To examine this relationship empirically, we need to derive an estimating equation and discuss potential data-related problems.

3. From Theory to Estimation

Since sectors differ greatly in size, empirical work typically scales net imports by domestic production or value shipped.[6] In our model these are the same, and noting the value of domestic production must be $b_i \eta_i(I+I^*)$ we obtain net imports in the x_i industrial sector, scaled by domestic production, as simply:

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

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 $s > \bar{\eta}_i$; i.e. home is a net importer if Home's share of world income exceeds its share of world production in i.

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

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

where $\beta_0 = -1$ and $\beta_1 = 1$. Then we can use (2.7) to rewrite (3.2) as

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

6 This is to ensure that any excluded right hand side variable that is correlated with industry size does not automatically contaminate the error.

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

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

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 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, industry dummies (D_i) are added to control for industry 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, it is well known that U.S. environmental regulation 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*_{it}/c^F_{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.

Unobserved Environmental Regulation

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 industry-group are given by $p(1-\alpha_i)x_i$. Total pollution abatement costs (PACs) are just a fraction of this given by $p(1-\alpha_i)x_i\theta$. To find the sector wide measure integrate over all the industries in the x_i sector that are actively producing in Home, to find the sector PACs given by:

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

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

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

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, θ_i 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 industry group x_i that is spent on pollution abatement when Home produces goods in the range $[0, \bar{\eta}_i]$.

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 1974 to 1996 it is also the measure of regulatory stringency used by numerous studies examining the effect of pollution regulation. One immediate implication of (3.6) is that since θ_{it} is function of the threshold $\bar{\eta}_i$ while the threshold is a function of unobserved foreign pollution taxes, τ_{it}*, (recall (2.7)) the error e_{it} in (3.5) is almost surely correlated with the right hand variable θ_{it} making estimation by OLS biased and inconsistent.

Moreover, unobserved foreign pollution taxes can introduce a spurious negative correlation between measured pollution abatement costs and net imports suggesting that when pollution abatement costs rise, net imports should fall – contrary to a pollution haven effect. To see why note that if foreign pollution taxes rise then from (2.6) $\bar{\eta}_i$ rises. Differentiating (3.6) then shows that that when Home takes over a larger share of the x_i sector, measured pollution abatement costs rise provided $\theta(\eta)$ increases with η.[7] Measured pollution abatement costs rise because when $\bar{\eta}_i$ rises Home is taking over industries which, at the margin, are more polluting than the set of industries it already produces. It also implies, from (3.1), that when $\bar{\eta}_i$ rises net imports (scaled) fall at the same time that measured Home pollution abatement costs rise, introducing the negative correlation mentioned earlier.

Unobserved Heterogeneity

Another problem confronting empirical work in this literature is the likelihood of unobserved 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.

To demonstrate suppose we compare two industrial sectors: x_1 and x_2 . 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_1 in

7 A sufficient condition for $\theta(\eta)$ to increase with η is given in footnote 4.

Foreign is relatively cheaper than x_2. That is, $c_1^{F*} < c_2^{F*}$. Then Foreign has a comparative advantage in x_2 relative to x_1, and we find $\bar{\eta}_1 < \bar{\eta}_2$. Differentiating (3.6) will show that measured pollution abatement costs are now larger in sector 2 than in sector 1. Since foreign costs are unknown, we only observe that industry x_1 has lower pollution abatement costs and higher net imports than x_2 -- a seeming contradiction of a negative link between environmental control costs and competitiveness. Sector 2 in comparison has lower net imports but higher pollution abatement costs.

To show that this is a real concern in the data, consider Canada and Mexico (since it is clear that 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 1974-86. The 25 industry groups (3-digit SIC codes) with the lowest pollution abatement operating costs (PAOC) spent 0.13 percent of their value added on abatement. By contrast, the 25 industries with the highest PAOC spent 3.7 percent of their value added on PAOC. Now note that 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. The U.S. imports from Canada significantly more goods with high pollution abatement costs.[8]

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. In truth these data may 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.[9] But this trade pattern prediction is not inconsistent with the result that increases in U.S. pollution abatement costs raise net imports from both countries at the margin: that is there is a pollution haven effect.

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8 This pattern is not an artifact of the particular set of countries: The U.S. imports more from OECD countries in the industries that spend more on pollution abatement, and less from non-OECD countries.
9 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 see this, in the bottom panel of table 2 we present the *change* in net imports for the 25 industry groups whose pollution abatement costs *increased least* from 1974 to 1986, contrasted with those whose pollution costs *increased most*. In contrast to the top panel, the industry groups whose pollution costs increased most saw the largest increase in net imports from both Canada and Mexico. Though not statistically significant, these results suggest a link between higher environmental control costs and increased net imports whereas the top panel of table 1 suggested the opposite.

Aggregation bias

A third problem with estimating (3.5) arises from the fact that the unit of observation (3-digit industry groups) is a heterogeneous mix of 4-digit industries. This heterogeneity means that when pollution taxes rise at home, the composition of the remaining industry may change. 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, differentiate (3.6) with respect to τ, and rearrange to find:

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

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 industry-group *x*. These cost increases then drive up prices which in turn will lower the quantity demanded by foreigners. This is the first element in (3.7) and it raises θ_i in equation (3.6). In effect this first (positive) element tells us the change in pollution abatement costs holding constant the composition of industries.

There is, however, a second effect. 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 active in Foreign and their goods will now be imported rather than being produced domestically. Since these industries were the dirtiest produced in the x_i sector, this second effect *lowers* θ_i in equation (3.6).

This second effect is essentially a form of selection bias. Studies seeking to measure the effect of pollution costs on trade inadvertently also capture the effect of trade on measured pollution costs. The direction of this bias is however 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.[10]

To investigate we plot in figure 2 pollution abatement operating costs per dollar of value added in the U.S. manufacturing sector. The bottom line 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.[11] To see this, the second line in figure 1 plots pollution abatement operating costs, 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.

Figure 2 contains evidence that there is a pollution haven effect, and an explanation for why it is so difficult to observe. The figure shows that aggregate measures of pollution abatement costs per dollar of value added understate the rise in regulatory stringency in the U.S.

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10 For example, some very dirty natural resource industries may have little or no international mobility whereas relatively clean assembling operations may move quite easily.

11 In other words, the first line plots $\sum_i P_{it} \Big/ \sum_i V_{it}$, where P is pollution abatement costs and V is value added for industry i at time t. The second line plots $\left[\sum_i \frac{P_{it}}{V_{it}} V_{i,74}\right] \Big/ \left[\sum_i V_{i,74}\right]$

because the composition of output has become relatively cleaner over time. This poses a major problem for research on the effect of environmental costs on trade: industries whose regulations increased greatly are most likely to be imported, but this then lowers measured pollution costs by industry. Researchers trying to estimate the effect of costs on trade can be misled by the effect of trade on costs.

Endogeneity of Regulation

A fourth problem confronting estimation of (3.5) is that pollution regulations are not randomly assigned to industries, but instead are placed and adjusted in accord with the demands of citizens and the political economy of policymaking. Standard theories of pollution regulation identify income levels and industry size as two likely determinants. Relevant political economy determinants may be the size of net imports into an industry and the level of foreign pollution taxes. Both industry size and incomes may in turn affect trade flows by altering either the scale of production or the demand for domestic products. In (3.5) industry attributes are captured by industry fixed effects, and changes in country level income by time fixed effects. Nevertheless, unmeasured industry specific and time-varying attributes may be relevant to both pollution regulation and net imports. In addition, the size of net imports may a direct determinant of pollution regulation, while foreign regulation is also an unmeasured variable.

Requirement for the Instruments

The preceding has detailed the econometric problems involved in estimating (3.5): unobserved heterogeneity, aggregation bias, and endogenous regulation. Unobserved heterogeneity is a well-recognized pitfall, and is typically solved by including industry or country fixed effects, depending on the unit of analysis. 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.[12] Given our panel, we include time and industry fixed effects to soak up unobserved

12 See, for example, Ederington and Minier (2001), Ederington *et al.* (2003).

industry-specific or time-specific excluded variables. Many of the unobservable industry characteristics are very slow moving, 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 exports 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 variable approach. 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 elements of e_{it}. In the next section we describe how we exploit geographic variation in the location of dirty industries in the U.S. to construct our instruments.

4. Geography as an Instrument

Our instrument relies on two facts and one assumption. The first fact is simply that much of U.S. environmental policy is set at the state and local levels, and hence varies by state. The second 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 located predominantly in stringent states and face high pollution abatement costs, other industries are located in lax states and face low abatement costs. Our assumption is that the geographic location of manufacture is unrelated to whether it is more or less likely to be imported. If this is true, then the geographic distribution of industries will produce variation in pollution abatement costs faced by U.S. industries that is unrelated to trade, and it will serve as a good instrumental variable.

To see how we construct the instruments consider the four states pictured in figure 3, labeled *A* through *D*. Each state has a characteristic q_s. Think of q as local environmental stringency. There are two industries (X and Y), and v_{is} refers to the value added by industry i in state s. In the figure, we have placed a capital "Q" in states A and D, to indicate that those states have large values of characteristic q, and a lowercase "q" in states B and C to indicate small values of the characteristic. Similarly, capital V_{is} indicates large value added by industry i in state s, and lowercase v_{is} indicates small value added by industry i in state s.

To construct the instrument, we need to transform characteristics of states into characteristics of industries. For each industry we take a weighted average of the state characteristics (q), where the weights are the industry's value added in the various states (v). The value of the instrument for industry X, based on state characteristic q is

$$
\begin{aligned}
I_X &= \sum_{s=A}^{D} q_s v_{Xs} \Big/ \sum_{s=A}^{D} v_{Xs} \\
&= Q\left(\frac{V}{V+v+V+v}\right) + q\left(\frac{v}{V+v+V+v}\right) + q\left(\frac{v}{V+v+V+v}\right) + Q\left(\frac{V}{V+v+V+v}\right) \qquad (4.1) \\
&= Q\left(\frac{V}{V+v}\right) + q\left(\frac{v}{V+v}\right)
\end{aligned}
$$

Similarly, the value of the instrument for industry 2 is

$$I_Y = Q\left(\frac{v}{V+v}\right) + q\left(\frac{V}{V+v}\right). \qquad (4.2)$$

It follows that $I_X > I_Y$ because relatively more of industry X is located in states with large values of characteristic q.

For the 48 contiguous U.S. states our instrument for the pollution costs faced by industry i is thus

$$I_i = \sum_{s=1}^{48} q_s v_{is} / v_i \qquad (4.3)$$

where $v_i = \sum_{s=1}^{48} v_{is}$ is the sum of the value added of industry i across all 48 states. 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). Each industry i faces the same set of state characteristics, q_s. So the q's are not endogenous with respect to different industries' levels of imports. Industries differ only in their geographic distribution, the v's. As long as the distribution of industries throughout the U.S. is not a function of international trade, the instrumental variable can be considered exogenous.

This condition, that the geographic distribution of industries be uncorrelated with trade, raises an immediate concern: some industries may locate in border states to facilitate exporting. In our stylized example, suppose state *B* borders Canada, and state *D* borders Mexico. If industry *X* has a high value added in state *D* because manufacturers of *X* locate in *D* in order to export product to Mexico, and state *D* responds to the pollution generated by *X* by levying high pollution taxes, then pollution abatement costs and net imports will be negatively correlated. This is just another example of an unobserved source of comparative advantage (proximity to Mexico in this case), yielding a bias against finding a pollution haven effect.

To mitigate this problem, we take several approaches. First, 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.[13] Finally, when studying trade with other groups of countries (OECD countries, non-OECD countries, etc.), we exclude trade with Canada and Mexico. In that case, the instruments are calculated using all 48 contiguous states, but the dependent variable, net imports, does not include trade flows with bordering countries.

The instruments

We use three types of instruments. These are essentially characteristics of states that we believe are correlated with the environmental regulatory stringency of those states: q_s in the above example and in equation (4.3). The first state characteristic is an index of state-level pollution abatement costs, controlling for the states' industrial compositions. The index is described in Levinson (2001), and in appendix A of this paper. Briefly, the index is greater than 1 for a given state if pollution abatement costs in that state are higher than would be predicted based on its industrial composition, and less than 1 otherwise.[14] Consequently, industries largely

13 Mexico border states excluded are CA, AZ, NM, and TX. Canada border states excluded are WA, ID, MT, ND, MN, WI, MI, NY, NH, VT, and ME.
14 Note that the index is a *relative* measure of regulatory costs among states, not an absolute measure. This is important because an absolute measure would be endogenous for all the reasons outlined in section 2.

concentrated in states with high values of this index will face higher pollution abatement costs than industries concentrated in states with low values of this index.

The second instrument uses the idea that environmental quality is a normal good, and that wealthier states will have higher pollution taxes. We use a weighted average of the incomes per capita of U.S. states, where the weights are each industry's value added in each state. Industries concentrated in wealthier states will face higher pollution abatement costs, ceteris paribus.

The final instrument we employ is based on the amount of pollution in each state. If marginal disutility is increasing in pollution, more polluted jurisdictions will levy more stringent pollution taxes. Industries concentrated in more polluted states will face more stringent regulations. Hettige *et al*. (1994) have 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. We use these ratios to estimate the total potential amount of each of the 14 pollutants in each state, based on each industry's value added in each state in each year, excluding the contributions of the industry for which the instrument is being calculated. 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.

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) at UC Davis.[15] 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

15 The CID can be found at http://data.econ.ucdavis.edu/international/.

published in Current Industrial Reports: Pollution Abatement Costs and Expenditures, MA-200, various years. Descriptive statistics for these data are in table 2.

Data issues

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 here 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.[16] These are typically based on total output as of 1987, when the Census Bureau collected

16 For example, Bartelsman, Becker, and Gray (1996) maintain such a concordance at

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 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 1974-1986 period. This is the period of largest 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.

Fixed Effects

In table 3 we present four 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. Columns (3) and (4) present the analogous regressions for imports from all other OECD countries (besides Mexico and Canada) and for all non-OECD countries. In all four columns we find a positive relationship between pollution abatement costs and net imports although this result is not significant in

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http://www.nber.org/nberces.

column (3). In addition, imports tariffs lower net imports as expected although the coefficient for Canada is not significant at conventional levels.

Overall these results are very encouraging – 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.[17]

To get a feel for the magnitudes involved note that a 10 percentage point increase in the share of pollution abatement costs in an industry leads to a 0.5 percentage point increase in net imports from Mexico and a 2.7 percentage point increase from Canada. Although the Canada coefficient is more than five times as large as that for Mexico, imports from Canada were almost seven times imports from Mexico during this period, so the Canada coefficient represents a slightly smaller pollution haven effect. Similarly, the OECD and non-OECD coefficients represent significantly smaller effects, because those groups of countries comprise a much larger share of U.S. trade volume.

We should note that the share of pollution abatement costs increased nowhere near 10 percentage points from 1974 to 1986. In fact, table 1 shows that the 25 industries where pollution abatement costs increased the most experienced an average increase of only 2 percentage points. Only 7 industries experienced increases larger than 2 percent.[18] As a useful upper bound we can calculate the change in net imports predicted for the 25 industries where costs rose most. Using the coefficients from table 3, the 2 percentage point increase in costs translates into an increase in net imports from Mexico of approximately \$15 million per year in these worst-hit industries.[19] The same calculation for Canada predicts an increase in net imports of \$83 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 25 hardest-hit

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17 We have also run cross-section versions and reproduced the lack of evidence for a pollution haven effect. Coefficients on pollution costs are either small and statistically insignificant, or are negative.

18 The 7 industries are SIC codes 331 (blast furnace, basic steel prod.), 286 (industrial organic chemicals), 261 (pulp mills), 266 (building paper and board mills), 334 (secondary nonferrous metals), 291 (petroleum refining), and 333 (primary nonferrous metals).

19 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 .049 (from table 3) with .02051 (the change over the whole sample, from table 1) times 15 billion dollars (the average value shipped over the sample) to get the figure in the text.

industries, average two-way trade grew by $139 million per year between Mexico and the U.S., and by $614 million between Canada and the U.S.

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 understate 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.

Instrumental Variables

Table 4 presents a first-stage regression 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.[20] Note that the regression in table A1 is representative of the first stages. Each regression will have a different first stage, depending on the countries from which trade is being modeled. (E.g. we drop the northern border states from the estimate of trade with Canada.) Industries facing higher tariffs tend to have larger abatement costs, but the coefficient is small and statistically insignificant. Industries located in states with higher indices of abatement costs face higher abatement costs. After controlling for state stringency, industries located in wealthier states do not appear to have higher abatement costs.[21]

Table 5 contains two-stage least-squares versions of the fixed-effects regressions in table 3, where the first stage constitutes estimates of θ_{it} as a function of the exogenous variables, as in

20 We are restricted to 1977-86 because the index behind instrument 1 only goes back as far as 1977, and to 130 SIC codes because the pollution data behind instrument 4 only cover those industries.

21 The instruments in table 3 are highly collinear. Note, for example that criterion air pollutants (SO_2, NO_2, CO and VOCs) all have correlations greater than 0.9. Moreover, the first-stage regression includes both a state-level abatement cost index, and measures that may be predictors of that index, such as income levels and pollution levels.

table 4. In each case, the coefficient on instrumented pollution cost shares is larger than the un-instrumented cost shares in table 3. For Mexico, instrumenting for pollution costs increases the coefficient from 0.049 in table 3 to 0.112 in table 5. For Canada the coefficient increases from 0.271 to 0.435. The OECD pollution cost coefficient increases from 0.053 to 1.95, and the Non-OECD coefficient increases from 0.685 to 5.05.

To interpret these coefficients we again need to discuss their magnitudes. We can use our previous example and examine the adjustment that needs to be made in the 25 industries where costs rose most. The Mexico coefficient in table 5 is 0.112. The 25 industries with the biggest cost increase saw pollution costs rise by 2 percentage points, and the average value shipped in these industries was $15 billion. The prediction is thus a $34 million increase in net imports.[22] During the period, trade volume with Mexico in these industries increased by an average of $139 million. The same calculation for Canada predicts an increase in net imports of $134 million, while trade volume grew by $614 million. For the OECD, for the 25 hardest-hit industries the coefficient predicts an increase in net imports of $600 million, while trade volume grew by $1.05 billion, and for non OECD countries, the prediction is an increase in net imports of $1.5 billion, while trade volume grew by $4.4 billion. For Mexico, the predicted increase in net imports is less than 20 percent of the increase in trade volume in these 25 industries over the period. For Canada, it is 22 percent; the OECD 45 percent; and the non-OECD countries 27 percent.

Robustness checks

Of the two standard tests of the identifying restrictions in 2SLS models, the instruments we have devised pass one easily, and fail the other. First, in table 6, we estimate the models in table 5 with alternate sets of instruments. The original coefficients are reproduced in the top row. Row (2) drops the state indices of abatement cost from the first-stage, relying only on state incomes and on state pollution levels as instruments. The pollution abatement cost coefficients remain large, statistically significant, and of approximately the same magnitude as in the table 5. Row (3) drops the state incomes from the calculation. All of the coefficients remain larger than in the fixed-effects model in table 4, but the coefficient for Mexico is now statistically insignificant.

22 The calculation is (0.112)(0.02)($15 billion).

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. With a few exceptions, these coefficients are all similar to those in the base specification in table 5. The exceptions are that for Mexico, for a few of the pollutants, the coefficient is statistically insignificant, and for one (VOCs), it is smaller than the fixed-effects coefficient.

In table 6 we also explore some other robustness checks. One might be concerned that our instrumental variables results are driven by the few industries that are highly concentrated in a few states. In those cases, environmental policy might be endogenous. In row (4) we drop from the instrument stage those state-industry combinations where the industry comprises more than 3 percent of gross state product.[23] If anything, this change renders the pollution coefficient larger than when all industries are included.

Our basic results suggest that those industries whose environmental costs increased most over the 1970s and 1980s experienced the largest increases in net imports. This time period also saw a dramatic rise in 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 address this concern, in row (5) of table 6 we have 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 just about every alternative specification, the 2SLS pollution coefficient is large, statistically significant, and significantly larger than the fixed-effects coefficient in table 3. We conclude from this that the fixed-effects coefficients understate the actual effect of pollution costs on imports, and that the 2SLS coefficients are not driven by any one particular instrument.

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

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

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 tables 3 and 5. 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 tables 3 and5 demonstrate the bias associated with cross section regressions of trade on pollution costs, and demonstrate that even the fixed effects understate the true effect of pollution costs on trade.

One final concern we had was that due to data limitations, the 2SLS estimates were run for 1977-1986, while the fixed-effects estimates go back to 1974. To make sure that the different results are not merely due to the different time periods, in row (6) of table 6 we recreate the fixed-effects estimates, using the same years as the 2SLS estimates. With the exception of Canada, in column (2), each of the pollution coefficients is closer to the value in table 3, and considerably smaller than the 2SLS estimates.

Finally, we do have data for 1989-1994, the years after the SIC codes were redefined and before the abatement cost data were discontinued. This much shorter panel yields largely insignificant coefficients, reported in column (7) of table 6.

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, increases in pollution abatement costs are often found to have no effect on trade flows; in some cases increases in 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 lax environmental policy for trade policy. If environmental regulation has little effect on international competition it seems unlikely that government's will engage in fruitless attempts to attract industry on the basis of weak regulation.

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. In each case, the 2SLS estimates are 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 25 industries whose pollution abatement costs increased most, the increase in net imports due to increased pollution costs represents 20 percent or more of the increase in total trade volumes over the period.

Appendix A: Index of State Abatement Costs

This discussion is taken from Levinson (2001). The state pollution cost index compares the *actual* pollution abatement costs in each state, unadjusted for state industrial composition, to the *predicted* abatement costs in each state, where the predictions are based solely on nationwide abatement expenditures by industry and each state's industrial composition. Let the actual costs per dollar of output be denoted

$$S_{st} = P_{st} / Y_{st} \tag{A.1}$$

where P_{st} is pollution abatement costs in state s in year t, and Y_{st} is the manufacturing sector's contribution to the gross state product (GSP) of state s in year t. By failing to adjust for the industrial composition of each state, equation (A.1) likely overstates the compliance costs of states with more pollution-intensive industries and understates the costs in states with relatively clean industries.

To adjust for industrial composition, compare (A.1) to the *predicted* pollution abatement costs per dollar of GSP in state s:

$$\hat{S}_{st} = \frac{1}{Y_{st}} \sum_{i=20}^{39} \frac{Y_{ist} P_{it}}{Y_{it}} \tag{A.2}$$

where industries are indexed from 20 through 39 following the 2-digit manufacturing SIC codes, Y_{ist} is industry i's contribution to the GSP of state s at time t, Y_{it} is the nationwide contribution of industry i to national GDP, and P_{it} is the nationwide pollution abatement operating costs of industry i. In other words, $\hat{S}_{st}$ is the weighted average pollution abatement costs (per dollar of GSP), where the weights are the relative shares of each industry in state s at time t.

To construct the industry-adjusted index of relative state stringency, S_{st}*, divide actual expenditures in (A.1) by predicted expenditures in (A.2).

$$S_{st}^{*} = S_{st} / \hat{S}_{st} \tag{A.3}$$

When S_{st}* is greater than 1, that indicates that industries in state s at time t spent more on pollution abatement than those same industries in other states. When S_{st}* is less than 1, industries in state s at time t spent less on pollution abatement. By implication, states with large values of S_{st}* have relatively more stringent regulations than states with small values of S_{st}*.

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Table 1.
Comparisons of pollution abatement operating costs (PAOC) and net imports: 1974-1986.

	PAOC/ value added	Average net imports divided by value shipped in the U.S.	
		Mexico	Canada
Cross-section comparison of levels. Averages for 1974-1986.	(1)	(2)	(3)
25 3-digit SIC codes with the lowest average PAOC per dollar of value added.	0.0013* (0.0005)	0.00010 (0.00717)	-0.0065* (0.0094)
25 3-digit SIC codes with the highest PAOC per dollar of value added.	0.0369 (0.0245)	-0.00188 (0.00762)	0.0351 (0.1041)
Time-series comparison of changes. Averages for 1982-86 minus average for 1974-78.			
25 3-digit SIC codes for which PAOC share increased least.	-0.00062* (0.00116)	-0.00030 (0.00368)	0.0046 (0.0125)
25 3-digit SIC codes for which PAOC share increased most.	0.02051 (0.02184)	0.00102 (0.00455)	0.0075 (0.0438)

The top panel contains average values over the entire 1974-86 period. The bottom pane reports the changes, the difference between the average values from 1982-86 and the average values from 1974-78.
*Indicates that the relevant figures for clean and dirty industries are statistically different from each other at 5 percent.

Table 2.
Descriptive statistics 1974-1986.

	Mean and std. deviation.
Manufacturing imports from Mexico to U.S. (1982 $M)	38.3 (120.8)
Manufacturing exports from U.S. to Mexico (1982 $M)	60.2 (129.1)
Manufacturing imports from Canada to U.S. (1982 $M)	262.5 (1280.9)
Manufacturing exports from U.S. to Canada (1982 $M)	210.8 (808.8)
Value shipped by U.S. industries (millions $ 1982)	12,504 (20,012)
Net imports from Mexico divided by US value shipped.	-0.00097 (0.00698)
Net imports from Canada divided by US value shipped.	0.0038 (0.0543)
PAOC by U.S. industries (millions $ 1982)	60.0 (174.7)
Value added by U.S. industries (millions $ 1982)	5356 (6532)
Pollution abatement cost as fraction of U.S. industry value added	0.0108 (0.0191)
Tariff rate	0.056 (0.041)
Sample size (133 industries per year)	1412

Std. errors in parentheses.

Table 3.
U.S. trade with other countries.

	With Industry Fixed Effects			
	From Mexico	From Canada	From OECD (less Mexico and Canada)	From non-OECD
	(1)	(2)	(3)	(4)
Pollution abatement operating costs per dollar of value added.	0.049*	0.271*	0.053	0.685†
	(0.014)	(0.046)	(0.152)	(0.391)
Tariffs by two-digit SIC code	-0.032*	-0.057	-0.643*	-1.48*
	(0.011)	(0.036)	(0.119)	(0.31)
n	1412	1412	1412	1412
R^2	.734	0.951	0.879	0.832

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

Table 4.
Predicted pollution abatement costs 1977 ! 1986.

	Pollution abatement operating costs per dollar of value added.
	(1)
Tariffs	0.028 (0.026)
State-level abatement costs.	0.016* (0.006)
State-level income per capita ($millions).	-0.43 (0.16)
State level pollution concentrations (billions).	
Biological oxygen demand (thousands)	-0.165* (0.053)
Total suspended particulates (millions)	-3.65 (53.3)
Air toxics (millions)	0.383 (0.282)
Water toxics (millions)	0.140 (0.671)
Solid waste toxics (millions)	-0.353* (0.107)
Air particulates (millions)	-0.567† (0.305)
Air CO (millions)	-0.129* (0.111)
Air SO2 (millions)	-0.260† (0.137)
Air NO2 (millions)	0.286 (0.227)
Air VOCs (millions)	0.480* (0.164)
Air PM10 (millions)	1.00 (2.84)
Air metals (thousands)	0.033 (0.025)
Solid waste metals (millions)	0.99 (1.14)
Water metals (thousands)	0.114* (0.048)
n	981
R^2 (within industry groups)	0.24

*Statistically significant at 5 percent.
Std. errors in parentheses.
Contains 128 industry fixed effects.

Table 5.
2SLS regressions of U.S. trade with fixed effects. 1977 ! 1986.

	Imports as a fraction of U.S. value shipped			
	From Mexico	From Canada	From OECD (less Mexico and Canada)	From non-OECD
	(1)	(2)	(3)	(4)
Instrumented Pollution Abatement Operating Costs, per dollar of Value Added	0.112* (0.069)	0.435* (0.103)	1.95* (0.68)	5.05* (1.68)
Tariffs by two-digit SIC code	-0.035* (0.017)	! 0.039 (0.033)	-0.61* (0.19)	-1.17* (0.48)
n	972	972	981	981
Sargan overidentification test.	125	86	214	135

*Statistically significant at 5 percent.
Regressions include 130 industry fixed effects.
Limited to 1977-1986 because the abatement cost index instrument starts in 1977.

Table 6.
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	From Canada	OECD	non-OECD
	Change relative to Table 5	(1)	(2)	(3)	(4)
(1)	Table 5 coefficients	0.112* (0.069)	0.435* (0.103)	1.95* (0.68)	5.05* (1.68)
(2)	Without state indices	0.167* (0.075)	0.443* (0.105)	1.69* (0.69)	5.07* (1.73)
(3)	Without state incomes	0.072 (0.072)	0.427* (0.139)	1.89* (0.68)	4.89* (1.68)
(4)	Without industries that are >3% of gross state product	0.306* (0.075)	1.28* (0.18)	3.85* (0.89)	10.13* (2.23)
(5)	With Oil prices interacted with industry dummies	0.108† (0.063)	0.451* (0.092)	1.78* (0.61)	4.18* (1.55)
(6)	Fixed effects as in table 4, for 1977-93.	0.064* (0.018)	0.529* (0.045)	0.251 (0.178)	1.32* (0.46)
(7)	Base specification for 1989-1994	-13.1 (13.9)	35.3 (42.7)	3.26† (1.80)	-0.78 (1.54)

*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 4 and 5.

Appendix table A1.
Robustness checks: Dropping pollutants from the instrument.

	Change in instruments, relative to Table 5.	Coefficients on instrumented PAOC as a fraction of U.S. value added			
		From Mexico	From Canada	OECD	non-OECD
		(1)	(2)	(3)	(4)
(1)	Drop biological oxygen demand	0.146[†] (0.074)	0.447* (0.103)	1.89* (0.70)	4.54* (1.73)
(2)	Drop total suspended solids	0.106* (0.069)	0.375* (0.111)	1.99* (0.66)	4.91* (1.65)
(3)	Drop air toxins	0.098 (0.069)	0.481* (0.107)	2.10* (0.67)	4.90* (1.66)
(4)	Drop water-borne toxins	0.074 (0.070)	0.433* (0.104)	2.00* (0.66)	4.91* (1.65)
(5)	Drop land toxic pollution	0.121[†] (0.071)	0.460* (0.107)	2.70* (0.71)	6.62* (1.77)
(6)	Drop particulates	0.099 (0.069)	0.462* (0.105)	2.30* (0.68)	5.38* (1.68)
(7)	Drop CO	0.108* (0.069)	0.438* (0.103)	1.87* (0.67)	4.91* (1.66)
(8)	Drop SO_2	0.093 (0.070)	0.409* (0.110)	2.30* (0.68)	5.20* (1.68)
(9)	Drop NO_2	0.112 (0.069)	0.317* (0.166)	2.19* (0.67)	5.22* (1.67)
(10)	Drop VOC	0.006 (0.072)	0.512* (0.106)	2.12* (0.69)	5.18* (1.72)
(11)	Drop PM10	0.074 (0.069)	0.499* (0.107)	2.56* (0.72)	5.71* (1.76)
(12)	Drop metals in the air	0.208* (0.073)	0.345* (0.107)	2.42* (0.69)	4.74* (1.66)
(13)	Drop metals in solid waste	0.230* (0.078)	0.463* (0.105)	2.13* (0.67)	4.80* (1.66)
(14)	Drop metals in the water	0.084 (0.070)	0.434* (0.103)	2.42* (0.69)	4.74* (1.66)

*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 4 and 5.

Figure 1. Unit costs determine net imports within industry-group *X*.

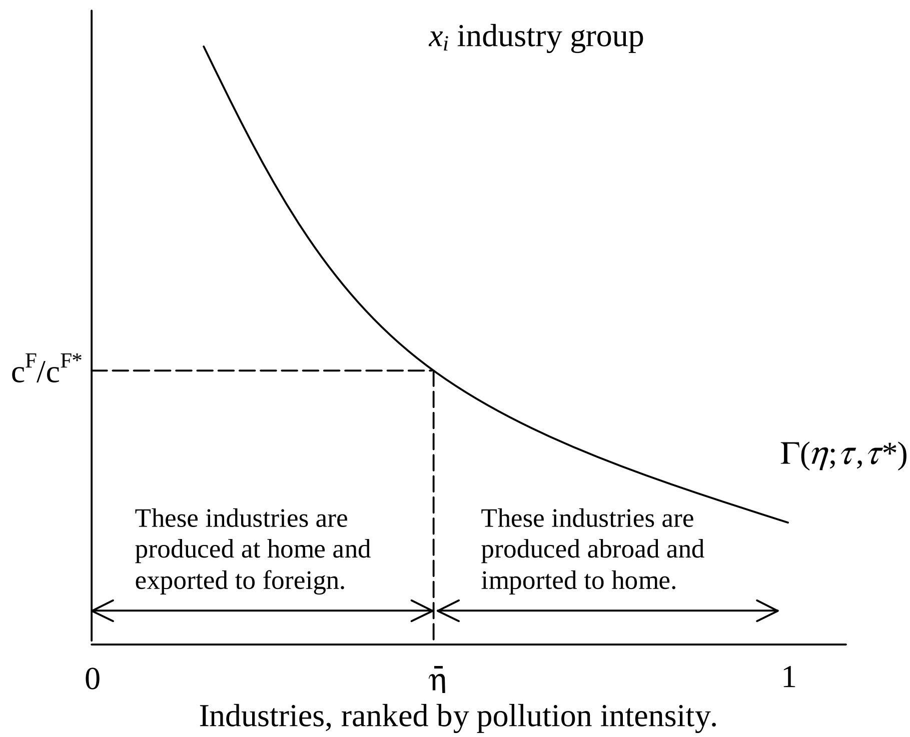

Fig. 2. Pollution abatement costs as a fraction of value added.

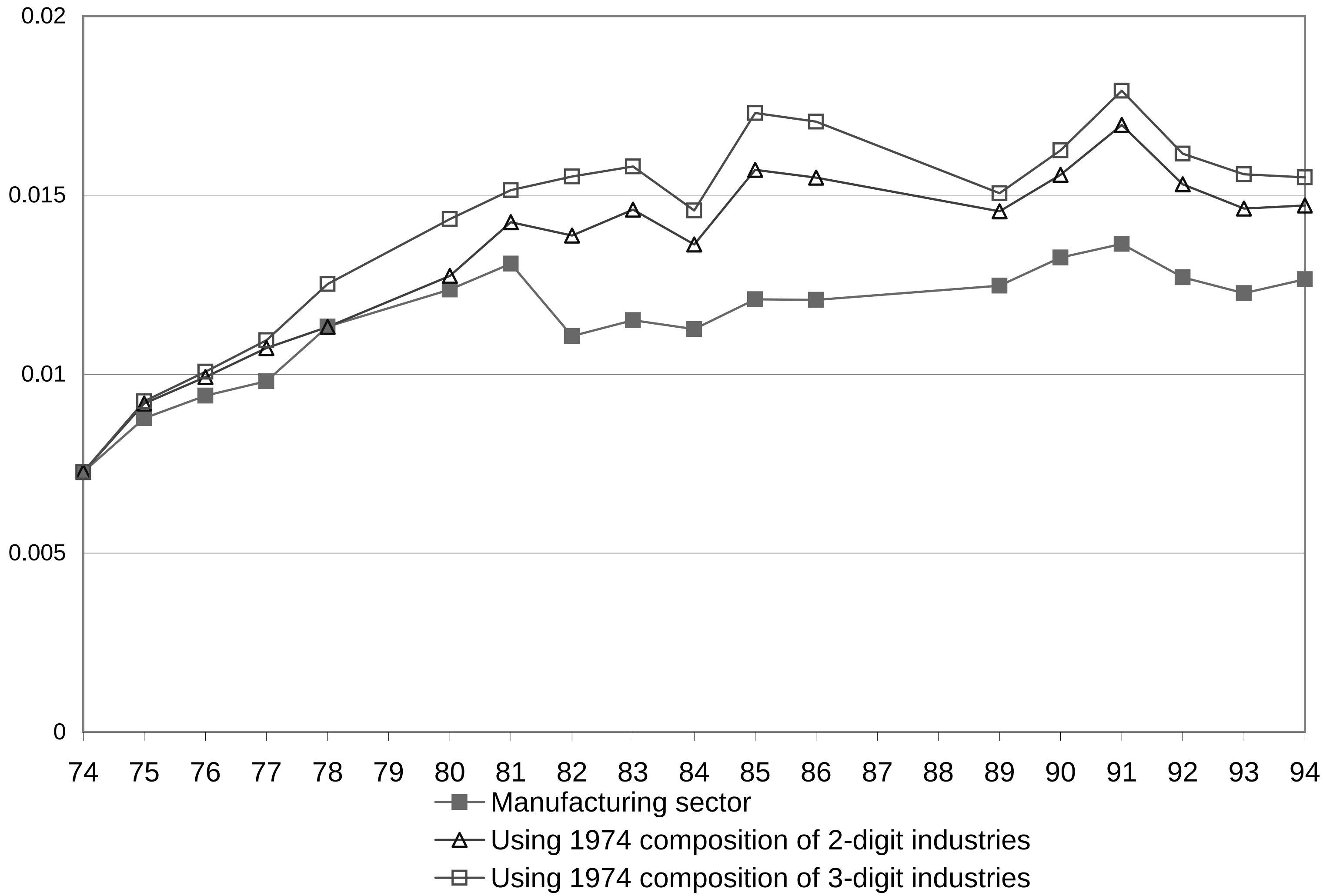

Figure 3. A schematic view of the instruments.

<u>State ***A***</u> Characteristic $q_A = Q$ Industry *X* and *Y* value added: $v_{XA} = V$ $v_{YA} = v$	<u>State ***B***</u> $q_B = q$ $v_{XB} = v$ $v_{YB} = V$
<u>State ***C***</u> $q_C = q$ $v_{XC} = v$ $v_{YC} = V$	<u>State ***D***</u> $q_D = Q$ $v_{XD} = V$ $V_{YD} = v$