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Transboundary pollution and the selective enforcement of environmental policy

Abstract

The paper investigates the potential for selective enforcement of a federal emissions standard in the context of a transboundary pollution problem. The theoretical results show that selective enforcement arises in the equilibrium of a game between state agencies responsible for the enforcement of the federal standard. In particular, facilities close to state borders are shown greater leniency in response to non-compliance. This leads to an outcome where near-border facilities have a higher incidence of non-compliance. The paper, then, tests for this selective enforcement effect using data on compliance rates under the US Clean Air Act. The results indicate the presence of a significant border effect: *ceteris paribus*, non-compliance rates are higher for facilities located closer to state borders. These results suggest that states are indeed more lenient towards facilities whose emissions are likely to flow into neighboring states.

Keywords: environmental policy, enforcement, transboundary pollution, Clean Air Act.
JEL Classification: Q35.

Introduction

The regulation of transboundary pollution is one of the most difficult issues in environmental policy design. If pollution from one jurisdiction flows into a neighboring jurisdiction then the source jurisdiction has a diminished incentive to control that pollution relative to when the pollutant is purely local. Even if a regional authority is able to set regulations that fully internalize the transboundary costs of pollution within a region as a whole, those regulations are effective only to the extent that *enforcement* is not selective. In particular, if each jurisdiction within the region is more lenient on sources whose pollution flows beyond its borders then a transboundary externality can still arise, and pollution levels will be higher than they should be from a social perspective.

This problem can arise in any setting where there is a separation of powers between the authority that sets the regulations and the authority responsible for the enforcement of those regulations. Such a separation of powers (formally or informally) is common in many federations, including the United States, Canada, and Australia. The same issue arises in looser federations like the European Union, where regulations are increasingly harmonized across countries within the Union but where enforcement remains under the control of national governments.

A similar problem can also arise in a transnational context when an international agreement on a wind-borne transboundary pollutant (like sulfur dioxide or particulates) is selectively enforced by national authorities based on the location of the polluting source relative to national borders.

Our paper makes two contributions to an understanding of this selective enforcement problem. First, we present a theoretical framework to examine the implications of the separation of regulation-setting and enforcement in a multi-jurisdictional context. Second, we test our selective enforcement hypothesis using data on compliance with the US Clean Air Act (CAA).

Our theoretical model involves a game between a collection of state-level governments responsible for enforcement of a federal standard. Some pollution sources within a state are located close to the border with another state, while other sources are located well within the interior of a state. We show that when pollution from a border source flows across the state boundary, each state-level regulator has an incentive to be more lenient on those border sources with respect to enforcement of the federal standard. Our empirical results using CAA data indicate that this selective enforcement does occur in practice, and that the effect is sufficiently large to be of concern to policy-makers.

There is a small existing empirical literature on enforcement behavior in the presence of transboundary pollution. Gray and Shadbegian (2004) analyze emissions (both airborne and waterborne) from US pulp and paper plants and find evidence that plants located within 50 miles of a state border discharge more pollution, on average, than other plants. They also test specifically for a near-border effect on the number of official enforcement actions against plants, but find no evidence of this effect. In contrast, our empirical analysis attempts to capture the effects of both official and *unofficial* enforcement actions; the latter are not reported to federal authorities but are in fact more commonly used in practice. We approach the problem indirectly by looking at compliance rates, and we do find evidence of a near-border effect.

A number of other papers in the literature also find evidence of near-border effects on measured pollution discharges, but without necessarily linking that effect to enforcement behavior. For example, Sigman (2005) uncovers evidence of a transboundary distortion in state-level implementation of the US Clean Water Act (CWA). She finds that a state's control of its CWA program – as determined by its "authorization" status – is associated with lower water quality in downstream states. She argues that this finding likely reflects the fact that authorized states have considerable discretion over both standards and enforcement in implementing the CWA. Sigman (2002) also finds evidence of a near-border effect on pollution in international rivers. In a study of data from the US toxics release inventory, Helland and Whitford (2003) find that toxic pollutant releases are higher in US counties that border other states than in those that do not. Our empirical results add to this existing indirect evidence of a transboundary effect on enforcement via a framework designed to test for it specifically.

There is also an existing theoretical literature on environmental policy design in a federal setting with transboundary pollution. For example, Silva and Caplan (1997) examine a regulatory setting with one federal government and two subordinate regional governments. They derive a neutrality result under which the efforts of a federal regulator to reduce emissions via a tax are undermined by the actions of states via a reduction in the abatement measures that are under their control. While their model does not include selective enforcement, the key transboundary externality that drives selective enforcement in our model also underlies the distortion of policy in their paper.

The paper on which our theoretical framework draws most heavily is Hutchinson and Kennedy (2008). That paper examines the game between a federal regulator and its subordinate states when pollution is transboundary. Its primary focus is on the optimal design of the federal standard when states do not enforce the standard optimally, due to the transboundary externality. In this paper we take the federal standard as given and focus exclusively on the selective enforcement issue. We then test the selective enforcement hypothesis empirically.

The rest of the paper is organized as follows. In section 1 we present our theoretical model of selective enforcement and its predictions for the link between the location of a source and its compliance with a federal regulation. Section 2 outlines some key elements of the CAA that inform our empirical strategy. Section 3 describes our data set and presents some key summary statistics. Section 4 presents our logit regression results. The final section provides some summary remarks.

1. The theoretical model

We examine a region that comprises a federation of identical states. For simplicity, we assume that these states are distributed around a latitudinal circle such that each state occupies an arc of length one. A continuum of identical polluting facilities is distributed uniformly along the length of each state, and the mass of facilities in each state is normalized to one. The prevailing wind blows from west to east, giving rise to an asymmetric distribution of emissions exposure around each facility.

The downwind transfer coefficient for emissions is given by

$$f(y) = \frac{2(r-y)}{r^2}, \tag{1}$$

where $f(y)$ is the concentration of emissions at a point y miles downwind of a polluting facility that discharges one unit of emissions, and $r \in (0,1]$ is the maximum range of pollutant transportation. Let x denote the distance between a facility and the downwind border of its home state. A facility for whom $x \geq r$ is called an "inside facility", while a facility for whom $x < r$ is called a "transboundary facility". The fraction of a transboundary facility's emissions that remain within-state is given by

$$\theta(x) = \int_0^x f(y)dy = \frac{x(2r-x)}{r^2}. \tag{2}$$

The residual $1-\theta(x)$ creates a transboundary exposure for the downwind neighboring state.

Environmental damage to a state is a function of the aggregate emissions to which it is exposed (emanating from its own facilities and those of its upwind neighbor). Specifically, damage to state j is given by

$$D(E_j) = \delta E_j^2, \tag{3}$$

where E_j is the emissions to which state j is exposed, and $\delta > 0$ is a damage parameter.

The regulatory structure is a hierarchical one: the federal regulator sets an emissions standard, and states are responsible for enforcement of that standard. The federal standard s specifies the allowed level of emissions from each facility. Facilities adopt a technology consistent with the standard, and must undertake maintenance of that technology to ensure ongoing compliance with the standard. The cost of maintaining the technology is

$$c(m) = \gamma m^2, \tag{4}$$

where $m \in [0,1]$ is maintenance effort (henceforth referred to as *compliance effort*) and $\gamma > 0$ is a parameter. Non-compliance is a stochastic event associated with the failure of abatement equipment, where the probability of failure is equal to $1-m$. Equipment failure results in a discharge of emissions in excess of the standard by some amount $k>0$. Thus, the expected volume of emissions discharged by a facility which undertakes compliance effort *m* is

$$g(s,m) = s + (1-m)k\ , \tag{5}$$

where we use *g* to denote expected emissions *discharged* to avoid confusion with emissions exposure.

States are responsible for enforcement of the federally specified standard and the federal authority cannot monitor that enforcement perfectly. Thus, a state enforcement agency can exercise discretion with respect to how *vigorously* it pursues enforcement. We capture this discretionary action by allowing the state agency to levy a lower effective penalty (or a less onerous sanction) against transboundary facilities relative to inside firms. In particular, we assume the following specification for the effective penalty a facility faces for non-compliance with the standard:

$P = F - \varphi(r-x)$ if $x<r$ and $P=F$ otherwise, (6)

where F is a base-level fine or sanction, and ϕ is a discretionary policy parameter reflecting the extent to which enforcement is pursued less stringently against near-border firms. If $\varphi>0$ then the state pursues a selective enforcement policy.

1.1. Equilibrium enforcement. Suppose the state regulator uses the enforcement policy described in (6) above. Faced with this penalty function, each (risk-neutral) facility solves the following problem:

$$\min_m \ \gamma m^2 + (1-m)[F - \phi(r-x)i], \tag{7}$$

where $i=1$ if the firm is transboundary and $i=0$ otherwise. The choice of *m* by a facility of type *i* is therefore given by

$$m_i(F,\phi) = \frac{F - \phi(r-x)i}{2\gamma}. \tag{8}$$

The enforcement problem for each state is to choose a penalty function (parameterized by F and ϕ) to minimize within-state costs, taking as given the federally mandated standard *s*, and anticipating that facilities will respond to its enforcement policy according to (8) above. Thus, a representative state solves

$$\min_{F,\phi} \ \delta\left(\int_0^r \theta(x) g_1(s,F,\varphi)dx + \int_r^1 g_0(s,F,\varphi)dx + E_T\right)^2 +$$

$$+\int_0^r \gamma m_1(F,\varphi)^2 dx + \int_r^1 \gamma m_0(F,\varphi)^2 dx, \tag{9}$$

where $g_i(s,F,\varphi) = s + [1 - m_i(F,\varphi)]k$ is expected emissions discharged by a facility of type *i*, such that $i=1$ if the facility is transboundary and $i=0$ otherwise.

The first term in (9) represents damage to the state; the second and third terms represent maintenance costs for transboundary and inside firms respectively. Damage is a function of the emissions to which the state is exposed, and there are three components to this, corresponding to the three terms inside the damage function in (9). The first term measures exposure to emissions discharged by the state's own transboundary firms. The second term measures exposure to emissions from the state's own inside firms. The third term (E_T) measures emissions from out-of-state to which the state is exposed but over which it has no control.

The solution to (9) yields best response functions of the form $F(E_T)$ and $\phi(E_T)$ for a representative state. From these best response functions we can derive the (symmetric) equilibrium value of E_T and the corresponding interior solutions for F and ϕ. The key property of this equilibrium is described in Proposition 1.

Proposition 1. Let $\{\hat{F}(s), \hat{\phi}(s)\}$ denote the interior equilibrium enforcement policy for any given value of *s*. Then $\hat{\phi}(s) > 0$.

Proof. See the Appendix.

This result tells us that equilibrium enforcement policy is selective: facilities located closer to a downwind border are subject to lower effective penalties for non-compliance. The result reflects the fundamental externality associated with a transboundary pollutant: each state is less concerned with pollution that falls beyond its border than with pollution that remains inside its borders. That asymmetry motivates selective enforcement.

1.2. Equilibrium compliance. A significant component of enforcement activity in practice involves actions that are not of the official type recorded in visitation and punishment reports. Enforcement often involves unofficial phone calls, one-on-one conversations with facility managers, and subtle threats of official action if a problem is not remedied. Much of this activity goes unrecorded (we discuss this further with respect to US enforcement practice in the section 3 below).

This has two important implications. First selective enforcement by states may be very difficult to monitor via federal oversight even if such provisions exist in the federal regulatory framework. Moreover, states may be inclined to rely more heavily on unofficial actions precisely because they are more difficult for the federal agency to monitor for selective enforcement.

Second, for the purposes of testing Proposition 1 empirically, the selective enforcement effect may not show up in official enforcement data even if the effect is present in practice, via the impact on unofficial enforcement measures. For this reason we test a link between geographic location and *compliance* with the regulation, since selective compliance should be an observable consequence of selective enforcement. That link arises in our theoretical model as a corollary to Proposition 1, which we state here as Proposition 2.

Propostion 2. Let $\hat{m}_0(s) \equiv m_0(\hat{F}(s), \hat{\phi}(s))$ and $\hat{m}_1(s,x) \equiv m_1(\hat{F}(s), \hat{\phi}(s))$ denote the compliance effort by an inside facility and transboundary facility respectively in response to the enforcement policy described in Proposition 1. Then $\hat{m}_1(s,x) < \hat{m}_0(s)$ and $\hat{m}_1'(x) > 0$, for $x < r$.

Proposition 2 tells us that a selective enforcement policy will induce variation across facilities in terms of compliance behavior. In particular, facilities located closest to a downwind state border will undertake less compliance effort than facilities located further from the border, and this will manifest itself as a higher noncompliance rate among those near-border facilities. If our selective enforcement hypothesis is correct then this systematic variation in compliance behavior should be observable in the data.

2. Testing for selective enforcement of the Clean Air Act (CAA)

Our analysis focuses on the regulation of stationary sources under the US CAA. The CAA is enacted at the federal level but responsibility for implementation is left largely to the states. In principal, this state-level action is subject to federal oversight to ensure that states do not ignore transboundary pollution flows[1]. However, as noted in the context of Proposition 2 above, much enforcement action in practice is unofficial in nature and therefore difficult for federal authorities to monitor.

The most comprehensive analysis of enforcement practice in the US is provided by Brown and Green (2001). They find that unofficial state actions are far more common than official actions (around 90% of all administrative enforcement actions are unofficial), and that these unofficial actions are surprisingly effective. For example, about three-quarters of the time, a simple oral warning is sufficient to bring a violating facility back into compliance. If this first line of action fails to achieve a return to compliance, increasingly legalistic actions are undertaken.

Other studies have also found that unofficial actions are used widely by regulatory agencies as part of their enforcement mix. For example, Hamilton (1994 & 1996) examines enforcement policy of the US Environmental Protection Agency (EPA) and finds that informal rule-making – such as a clarifying memo – is often preferred to more formal approaches which require a time-consuming administrative review. He argues that this revealed preference is motivated by political and budgetary considerations. Similarly, Helland (1998) looks at the choice of inspection type by state environmental agencies in the enforcement of the US Clean Water Act (CWA) and also finds that extensive use is made of unofficial actions.

In view of the importance of these unofficial actions – which for the most part go unrecorded in data collected and monitored by the EPA – we test our selective enforcement hypothesis indirectly by examining the link between the physical location of a polluting facility and its compliance behavior as induced by selective enforcement (as described in Proposition 2).

3. Data and summary statistics

We collected facility-level information from the EPA's AIRS database for over 42,000 regulated stationary-source facilities that are subject to a federal reporting requirement under the CAA. The dataset includes the compliance history of each facility and its location. We also have data on a variety of other factors that are likely to affect compliance behavior in practice but are absent from the theoretical model. That data includes information on *official* enforcement actions (as reported to the EPA), facility characteristics (including pollutants emitted), specific programs under which each facility is regulated, the industry in which the facility operates, and location-specific variables (including socioeconomic conditions for the region where the facility operates). We are, therefore, able to control for a large number of factors that might otherwise obscure the key relationship of interest. The following presents a summary of our data.

[1] For example, section 110 of the CAA contains provisions specifically designed to limit interstate pollution, and these provisions were supplemented by the introduction of the Clean Air Interstate Rule in 2005, the purpose of which is to gain greater federal control over interstate pollution in the eastern US.

3.1. Compliance history. Our data includes information on the historical monthly compliance status for all facilities. Specifically, we know whether or not each facility was deemed to be a "high priority violator" (HPV) in a given month. The HPV category does not record all non-compliance behavior; it identifies only those violations that the EPA believes to be most important environmentally. The HPV category was introduced in 1999, so our analysis covers the period 1999 through 2008 (the latest year for which a complete dataset is available).

Table 1 (see Appendix) presents summary statistics for total HPV violations over the sample period. Approximately 23% of facilities were categorized as HPVs at least once during the sample period. The mode number of months in violation was just one but there are a few cases of persistent violation: 25 facilities were HPVs in all 120 months in the sample period. These facilities and any other facility that was in violation for more than 90% of the period were excluded from our empirical analysis since there seem to be special circumstances surrounding these facilities.

3.2. Location. We are able to match each facility to the county in which it is located, and determine whether that county is adjacent to a state border. We also have specific information on location, as measured by latitude and longitude (to the second), for around 75% of facilities[1]. We use this data to construct a measure of straight-line distance in miles to the nearest state border. Thus, we have two different measures of border-proximity, and we test the selective enforcement hypothesis using each one separately.

Table 2 (see Appendix) presents some summary statistics on facility location according to facility category (whether in violation during the sample period or not). There is some evidence of a correlation between proximity to a state border and violations even in the raw data. In particular, around 60% of violating facilities and 56% of non-violating facilities are located in border counties. This difference is small in size but it is statistically significant.

3.3. Official regulatory activity. We have argued that *unofficial* enforcement activity is most common in practice but official activity is obviously important too, and we need to control for its impact on observed compliance rates in order to isolate that part of compliance behavior that is motivated by the unofficial enforcement activity that we cannot observe (and is most likely to be selective in its application). We have information on three types of official regulatory activity carried out by enforcement authorities, as reported to the EPA: enforcement actions; fines levied; and compliance monitoring.

Enforcement actions are classified by the EPA as either "formal" or "informal" actions. The most frequent informal enforcement action is an official notice of violation. Formal enforcement actions include state-agency administrative orders ("cease and desist" orders authorized under the CAA) and court-ordered decrees (whereby regulatory authorities and violating facilities enter into a court-sanctioned agreement to ensure compliance). In our regression analysis we include variables for these official enforcement actions with a lag, reflecting the fact that these actions occur only *after* a violation has occurred. Similarly, we include the effect of fines with a lag.

Compliance monitoring activities are classified by the EPA as either "Full Compliance Evaluations" (FCEs) or "Partial Compliance Evaluations" (PCEs). An FCE includes activities such as a comprehensive paperwork review or an on-site inspection. A PCE involves compliance monitoring activities that fall short of those that would meet the definition of an FCE (and are somewhat more vague in nature). Our regression analysis includes both lagged and contemporaneous variables for FCEs and PCEs because these activities are not necessarily triggered by non-compliance; some are scheduled as a matter of course. Thus, there is no natural sequencing of events for these activities.

Table 3 (see Appendix) summarizes the incidence of these three types of regulatory activity, for three different categories of facility: all facilities; facilities that have at least one violation in the sample period; and facilities that do not violate at all. As is clear from the table, official regulatory activities are infrequent. The median number of enforcement actions (formal or informal) is zero, and fines are imposed rarely (though they can be large when imposed). The average facility received fewer than two compliance evaluations (partial or full) in the ten year period for which we have data.

One might conclude from this data that environmental agencies are simply not very active when it comes to enforcement effort. However, we know that much of what regulatory agencies actually do to ensure compliance does not qualify as official intervention, and does not show up in enforcement data. It is for precisely this reason that we test for the effect of border proximity on *compliance* behavior rather than on official regulatory activity.

3.4. Permitted pollutants. Different types of pollutants require different types of abatement technolo-

[1] We tested for the possibility that there are systematic differences between facilities for whom latitude and longitude information is available, and those for whom it is not. There is no evidence for such differences.

gy, and so pollutant-type could be an important factor in determining compliance behavior. Moreover, different pollutants have different dispersion patterns and create different transboundary exposures. This should affect the selectivity of enforcement.

There are over 250 different types of permitted pollutants emitted by the facilities in our sample. Table 4 lists the number and frequency of facilities that emit a given pollutant, for the 26 most commonly emitted pollutants. Each facility typically emits more than one pollutant. The median, mean, and standard deviation of the number of pollutants emitted per facility are 4, 4.72, and 4.11 respectively.

3.5. Air programs. Facilities regulated under the CAA are subject to specific regulations under a variety of "Air Programs" that target particular regions, particular pollutants, and particular types of facility. These impose a variety of regulatory requirements on facilities that likely affect the cost of compliance, and hence the incidence of non-compliance.

The relevant air programs include New Source Review (NSR) and New Source Performance Standards (NSPS) Air Programs, which apply stricter standards to newer facilities; the Prevention of Serious Deterioration (PSD) Program, for facilities located in regions designated as environmentally sensitive; the National Emissions Standards for Hazardous Air Pollutants (NESHAP) program and Maximum Achievable Control Technology MACT program (for facilities designated as major sources of hazardous pollutants); the Acid Rain Program (for facilities subject to Title IV regulation of sulfur-dioxide emissions); and the CFC Program. We include dummy variables in our regression analysis for each of these air programs. The breakdown of facilities regulated under each program is summarized in Table 5 (see Appendix).

3.6. Regional attainment status. The CAA sets harm-based National Ambient Air Quality Standards (NAAQS) for each of the regulated "criteria" pollutants. The exact nature of the regulatory standard applied to a facility depends on whether or not that facility is operating in a region that is in attainment of the NAAQS. In particular, a stricter technology standard is applied to facilities operating in a *non-attainment region*. This difference in standard could affect compliance behavior and so we control for it.

Our data on NAAQS-attainment status for facility locations (at the county level) were obtained from the EPA's Green Book, which reports attainment status by year for each of the criteria pollutants subject to the NAAQS. We have coded a county as a "non-attainment county" if its ambient air quality failed to meet the NAAQS for at least one of the criteria pollutants during the sample period. Of the facilities in our sample, approximately 38% are located in non-attainment counties.

3.7. Socio-economic data. The socio-economic conditions of a region likely affect the vigor with which state agencies enforce compliance. Concern over employment impacts in a depressed region, different degrees of community pressure – as determined by wealth and education levels – and a variety of other socio-economic factors affect enforcement action in practice.

Our socio-economic data on the communities in which facilities are located is taken from the 2000 Census of Population and Housing. We construct two sets of socio-economic controls. The first set uses the data for the county in which the facility is located. We use these controls when our facility location measure is county-based. The second set uses facility-level latitude and longitude information to match each facility to all census tracts whose centroids lie within two miles of the facility[1]. We use these controls when our facility location measure is based on miles to the nearest border.

Table 6 (see Appendix) summarizes our socio-economic variables at the county level, based on whether a community has a violating or non-violating facility located nearby, and for the sample as a whole. On balance, violating facilities tend to be located in communities which are poorer, less well-educated, more densely populated, and more urbanized than are non-violating facilities. These differences are small in size but statistically significant.

4. Logit regression results

We estimate a series of random-effects logit models in which the dependent variable takes a value of one if the facility is in violation of its standard during that year, and zero if it is not. Each estimated model is distinguished by which controls are included and how proximity to the border is defined.

Table 7 (see Appendix) reports the coefficient estimates for these models. In each of the first five columns we measure border proximity as a dummy variable which takes the value one if the facility is located in a border county, and zero if it is not. Column (1) includes only border proximity as a control; each successive column represents the results as we include more controls, using county-level data for

[1] We also matched each facility to all census tracts whose centroids lie within one and three miles respectively of the facility. Using these different definitions for "community" has no substantive effect on our regression results.

the socio-economic controls. Column (6) reports the regression results when border-proximity is measured as distance in miles to the border (instead of the border-county dummy). For consistency, socio-economic controls in that model are measured using the two-mile-radius census tract data (instead of the county-level data)[1].

The results in column (1) tell us that border-proximity – as measured by the county-dummy – is positively correlated with a facility's probability of non-compliance when no other explanatory variables are included. Columns (2) through (5) tell us that this result is robust to the inclusion of our other control variables. The results in Column (6) tell us that the border-effect also appears when proximity is measured in miles to the border. In all cases the effect is highly significant, providing strong and consistent evidence of a selective enforcement effect on compliance.

How large is this effect in practical terms? The marginal effects calculated from the coefficient estimates in column (5) imply that the violation probability of the mean facility located in a non-border county is 12.6% lower than that of an otherwise identical facility located in a border county (that is, about 6.7% likelihood of violation versus 7.5%). Similarly, the marginal effects from the coefficient estimate in column (6) imply that moving the mean facility ten miles away from its nearest state border would result in a 1.2% reduction in the probability of violation. To put this in perspective, if we were to take the mean facility and move it one standard deviation further away from the nearest state border, then the probability of a violation would fall by 8.4% (that is, from about 7.5% to 6.9%).

Conclusion

We have investigated the potential for selective enforcement of a federal emissions standard in the context of a transboundary pollution problem. Our theoretical results show that selective enforcement arises in the equilibrium of a game between state agencies responsible for the enforcement of the federal standard. In particular, facilities close to state borders are shown greater leniency in response to non-compliance. This leads to an outcome where near-border facilities have a higher incidence of non-compliance.

We tested for this selective enforcement effect using data on compliance rates under the US CAA. Our results indicate the presence of a significant border effect: *ceteris paribus*, non-compliance rates are higher for facilities located closer to state borders. These results suggest that states are indeed more lenient towards facilities whose emissions are likely to flow into neighboring states.

Our analysis has abstracted from a number of potentially important issues that are worthy of further attention. First, the federal regulator plays only a passive role here; it simply sets the standard and allows states to undertake all enforcement action. In practice, a strategic regulator would recognize the incentive that states have to use selective enforcement, and could infer any actual selectivity by observing the same empirical pattern that we have identified in the compliance data. In principle, the federal regulator could then adjust its standard-setting policy accordingly, but this turns out to be less straightforward than it might appear. In particular, in Hutchinson and Kennedy (2008) we show that a stricter standard can induce less selective enforcement but can also lead to less enforcement overall. A stricter standard can therefore only go part way to addressing the enforcement distortion and the associated interstate pollution problem. Moreover, we also show that *location-based* federal standards (that specifically target interstate pollution) actually exacerbate the selective enforcement problem via state actions to neutralize the location-based variation. Thus, a single standard – as assumed in our analysis here – is in fact an optimal federal response to selective enforcement.

A second issue from which we have abstracted is the question of facility location choice. We have taken facility location as given, and focused only on compliance as a function of that location. Given that near-border facilities face weaker enforcement actions – based on our empirical results – facilities should have an incentive to locate close to borders. That is, location-choice should be endogenous in our model. However, accounting for that endogeneity empirically requires a richer dataset than we have available. In particular, location choices by different facilities are made at different points in time, reflecting heterogeneity in the age of facilities. Thus, controlling for the factors behind location choice requires facility-specific data contemporaneous with the location-choice date. Some of those factors will be time-invariant – such as proximity to a waterway – but others will have changed over time, such as economic conditions, population densities and state tax-subsidy policies. A dataset capable of examining location choice would need to include data on these factors at the time of the location choice. We have not yet been able to compile a dataset with that level of detail.

[1] We also estimated the model in column (5) using this second set of socio-economic controls. The results (not reported here) are consistent with the results reported in column (6).

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Appendix

Proof of Proposition 1. Differentiating (9) with respect to F and ϕ yields best response functions given by

$$F(s,E_T) = \alpha_F[(3-r)(s+k)+3E_T] \tag{A1}$$

and

$$\phi(s,E_T) = \alpha_\phi[(3-r)(s+k)+3E_T], \tag{A2}$$

where

$$\alpha_F = \frac{4\gamma\delta k(24-17r)}{\delta k^2(52r^2-177r+144)+12(12-9r)} > 0 \text{ since } r \le 1 \text{, and} \tag{A3}$$

$$\alpha_\varphi = \frac{24\gamma\delta k(3-2r)}{r[\delta k^2(52r^2-177r+144)+12(12-9r)]} > 0 \text{ since } r \le 1. \tag{A4}$$

Substituting (A1) and (A2) into (8) for $i=0$ and $i=1$ yields

$$m_0(s,E_T) = \frac{F(s,E_T)}{2\gamma} \text{ and} \tag{A5}$$

$$m_1(s,E_T,x) = \frac{F(s,E_T)-\varphi(s,E_T)(r-x)}{2\gamma}, \tag{A6}$$

respectively. The expected emissions discharged by an inside firm and a transboundary firm are then given by (A7) and (A8) respectively:

$$g_0(s,E_T) = s+[1-m_0(s,E_T)]k, \tag{A7}$$

$$g_1(s,E_T,x) = s+[1-m_1(s,E_T,x)]k. \tag{A8}$$

Using (A8) we can derive the total emissions discharged by transboundary firms (in a representative state) that flow across the downwind state border:

$$G_T(s,E_T) = \int_0^r [1-\theta(x)]g_1(s,E_T,x)dx. \tag{A9}$$

In the symmetric Nash equilibrium, $G_T(s,E_T) = E_T$. Making this substitution in (A9) and solving for E_T yields the interior equilibrium value of interstate emissions:

$$\hat{E}_T = \frac{r(s+k)[\delta k^2(3-2r)^2 + 4\gamma(4-3r)]}{4(4-3r)[\delta k^2(3-r)+3\gamma]}. \tag{A10}$$

Substituting (A10) into (A3) then yields

$$\hat{\varphi}(s) = \frac{6\gamma\delta k(s+k)(3-2r)}{r(4-3r)[\delta k^2(3-r)+3\gamma]}, \tag{A11}$$

from which it follows that $\hat{\phi}(s) > 0$ since $r \leq 1$.

Table 1. Total violations

Number of months as HPV	Number of facilities	Percent
0	31.240	76.67%
1 to 10	2.955	7.25%
11 to 20	2.306	5.66%
21-30	1.328	3.26%
31-40	828	2.03%
41-50	546	1.34%
51-60	344	0.84%
61-70	295	0.72%
71-80	197	0.48%
Mote than 80	706	1.73%
Total	40.745	100%

Table 2. Facility proximity to state border

	Mean	Std. dev.	Median	Min	Max
All facilities (40,424)					
Border county	57.19%				
Distance to border (in tens of miles)	6.60	6.72	4.30	0.00	47.3
Facilities with at least one violation (9,184)					
Border county	60.25%				
Distance to border (in tens of miles)	6.68	7.10	4.10	0.00	47.0
Facilities with no violations (31,240)					
Border county	56.25%	0.50			
Distance to border (in tens of miles)	6.57	6.60	4.37	0.00	47.3

Table 3. Total regulatory actions

	Mean	Std. dev.	Median	75th%-ile	90th%-ile	Min	Max
All facilities (40,424)							
FCE	0.53	0.57	1	1	1	0	17
PCE	0.99	2.59	1	1	2	0	292
Formal enforcement actions	0.07	0.31	0	0	0	0	12
Informal enforcement action	0.08	0.40	0	0	0	0	40
Total penalties	$1,685	$46,474	$0	$0	$0	$0	$5,340,000
Percent of facilities receiving any penalty	5.13%						
Facilities with at least one violation (9,184)							
FCE	0.51	0.61	0	1	1	0.00	17.00
PCE	1.67	4.71	1	2	4	0.00	292.00
Formal enforcement actions	0.16	0.49	0	0	1	0.00	12.00
Informal enforcement action	0.16	0.66	0	0	1	0.00	40.00
Total penalties	$5,789	$93,218	$0	$0	$1200	$0	$5,340,000
Percent of facilities receiving any penalty	10.93$						
FCE	0.54	0.56	1	1	1	0.00	5.00
PCE	0.79	1.42	0	1	2	0.00	44.00
Formal enforcement actions	0.04	0.22	0	0	0	0.00	9.00
Informal enforcement action	0.06	0.28	0	0	0	0.00	14.00
Total penalties	$478	$15,299	$0	$0	$0	$0	$1,482,700
Percent of facilities receiving any penalty	3.43$						

Table 4. Permitted pollutants emitted by facilities

Permitted pollutants	Number of facilities	Percent of facilities
Volatile organic compounds*	24,610	60.88%
Total particulate matter*	22,119	54.72%
Nitrous oxide*	20,309	50.24%
Carbon monoxide*	17,052	42.18%
Sulfur dioxide*	16,759	41.46%
Particulate matter < 10 um*	12,338	30.52%
Lead	1,944	4.81%
Toluodine	1,442	3.57%
Benzene	1,306	3.23%
Xylene	1,271	3.14%
Particulate matter < 25 um*	1,165	2.88%
Ethylbenzene	847	2.10%
Nitrous oxide*	775	1.92%
Hexane	762	1.89%
Asbestos	679	1.68%
Hydrogen chloride	665	1.65%
Methanol	656	1.62%
Tetrachloroethylene	590	1.46%
Styrene	583	1.44%
Methyl ethyl keton	541	1.34%
Hedrogen sulfide	523	1.29%
Fine particulated, low violation probability*	465	1.15%
Mercury	436	1.08%
Odors	402	0.99%
Fine particulated, high violation probability*	396	0.98%
Fugitive dust*	392	0.97%
Other pollutant	10,357	25.62%

Notes: * Denotes criterion pollutant.

Table 5. Applicable air programs

	Number	%
All facilities (40,424)		
Acid rain	477	1.18%
MACT	8,137	20.13%
CFC tracking	634	1.57%
PSD	3,770	9.33%
NSR	2,195	5.43%
NESHAP	3,749	9.27%
NSPS	12,194	30.17%
Facilities with at least one violation (9,184)		
Acid rain	194	2.11%
MACT	3,194	34.78%
CFC tracking	297	3.23%
PSD	1,841	20.05%
NSR	805	8.77%
NESHAP	1,288	14.02%
NSPS	3,662	39.87%
Facilities with no violations (31,240)		
Acid rain	283	0.91%
MACT	4,943	15.82%
CFC tracking	337	1.08%
PSD	1,929	6.17%
NSR	1,390	4.45%
NESHAP	2,461	7.88%
NSPS	8,532	27.31%

Table 6. County-level socioeconomic variables

	Mean	Std. dev.	Median	Min	Max
All facilities (40,424)					
Median house income	$41,596	$11,064	$39,607	$11,946	$87,068
Population density (thousand of ppl/sq mile)	2.18	8.71	0.22	0.00	66.94
Percent urban	68.4%	29.2%	73.36%	0.00%	100.0%
Percent under the age of 5	25.5%	2.9%	25.53%	9.9%	39.3%
Percent under the age of 55	0.1%	0.0%	12.72%	0.0%	0.3%
Percent with a college degree as highest ed. level	20.2%	6.2%	19.79%	4.9%	45.2%
Percent with a grad. degree as highest ed. level	7.8%	4.3%	6.72%	1.3%	36.0%
Percent living below the poverty line	12.3%	5.5%	11.62%	2.1%	50.9%
Facilities with at least one violation (9,184)					
Median house income	$41,157	$10,593	$39,244	$16,133	$87,068
Population density (thousand of ppl/sq mile)	2.51	9.65	0.21	0.00	66.94
Percent urban	70.2%	28.4%	77.55%	0.0%	100.0%
Percent under the age of 5	25.9%	3.1%	25.88%	12.9%	39.3%
Percent under the age of 55	0.1%	0.0%	12.53%	0.0%	0.3%
Percent with a college degree as highest ed. level	19.5%	5.9%	19.13%	5.0%	43.6%
Percent with a grad. degree as highest ed. level	7.5%	4.1%	6.44%	1.3%	30.6%
Percent living below the poverty line	13.2%	5.4%	12.53%	2.6%	39.9%
Facilities with no violations (31,240)					
Median house income	$	$	$	$	$
Population density (thousand of ppl/sq mile)	2.08	8.42	0.22	0.00	66.94
Percent urban	67.8%	29.5%	75.06%	0.0%	100.0%
Percent under the age of 5	25.4%	2.8%	25.42%	9.9%	39.9%
Percent under the age of 55	0.1%	0.0%	12.76%	0.0%	0.3%
Percent with a college degree as highest ed. level	20.3%	6.3%	20.06%	4.9%	45.2%
Percent with a grad. degree as highest ed. level	7.9%	4.3%	6.79%	1.3%	36.0%
Percent living below the poverty line	12.1%	5.4%	11.26%	2.1%	50.9%

Table 7. Logit regression results

	(1)		(2)		(3)		(4)		(5)		(6)	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
Border	0.900***	0.026	0.281***	0.043	0.0208***	0.055	0.157***	0.045	0.127***	0.048		
Miles to border											-0.012***	0.004
Air programs												
Acid rain			0.384***	0.126	0.330**	0.135	0.057**	0.145	0.671***	0.152	0.467	0.155
MACT			1.362***	0.044	1.336***	0.061	1.115***	0.050	1.336***	0.061	1.479	0.074
CFC			1.086***	0.146	1.455***	0.147	1.062***	0.124	0.868***	0.120	0.682	0.119
PSD			1.808***	0.062	2.052***	0.077	1.688***	0077	1.585***	0.066	1.698	0.075
NSR			0.396***	0.068	0.491***	0.080	0.384***	0.080	0.378***	0.097	0.741	0.119
NESHAP			0.179***	0.056	0.203***	0.063	0.308***	0.076	0.201***	0.075	0.145	0.076
NSPS			0.630***	0.042	0.550***	0.050	0.274***	0.050	0.371***	0.050	0.311	0.056
Non-attainment region			0.514***	0.031	0.503***	0.037	0.451***	0.036	0.085**	0.043	0.080	0.046
Regulatory actions (count)												
FCE					-0.373***	0.039	-0.351***	0.039	-0.350***	0.039	-0.409***	0.045
FCE, 1 period lag					-0.161***	0.127	-1.560***	0.125	-1.531***	0.125	-1.651***	0.143
FCE, 2 period lag					-2.056***	0.0220	-1.945***	0.215	-1.932***	0.212	-2.138***	0.248
PCE					0.040***	0.008	0.034***	0.008	0.030***	0.008	0.040***	0.010
PCE, 1 period lag					-0.402***	0.073	-0.385***	0.072	- 0.0400***	0.073	-0.386***	0.079
PCE, 2 period lag					-1.236***	0.170	-1.171***	0.169	-1.136***	0.169	-1.146***	0.181
Formal enf. acts, 1 period lag					0.253**	0.123	0.297**	0.121	0.327**	0.124	0.181	0.147

Table 7 (cont.). Logit regression results

	(1)		(2)		(3)		(4)		(5)		(6)	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
Regulatory actions (count)												
Formal enf. acts, 1 period lag					0.253**	0.123	0.297**	0.121	0.327**	0.124	0.181	0.147
Formal enf. acts, 2 period lag					0.359**	0.175	0.410**	0.171	0.400**	0.179	0.300	0.207
Informal enf. acts, 1 period lag					0.999***	0.125	0.965***	0.123	1.027***	0.128	1.046***	0.149
Informal enf. acts, 2 period lag					1.016**	0.191	0.940***	0.198	1.086***	0.198	1.199***	0.236
Penalty amount, 1 period lag ($100.000)					0.191*	0.000	0.000*	0.000	0.150	0.112	0.101	0.155
Penalty amount, 2 period lag ($100.000)					0.393	0.113	0.000	0.000	0.338	0.306	0.402	0.363
Socioeconomic controls												
Median HH income ($1.000)									0.0250***	00056	0.0112*	0.0061
Populations density (thousands sq. m.)									0.0347***	0.0037	0.032***	0.004
Percent urban									-0.0010	0.0013	0.000	0.001
Percent under age 5									-0.0210	0.0135	-0.032**	0.015
Percent over age 55									-0.5734**	1.1125	-2.012*	1.136
Percent with college degree as highest ed.									-0.0158	0.0120	0.008	0.011
Percent with graduate degree as highest ed.									-0.0603***	0.0115	-0.0071***	0.017
Percent living in poverty									0.0367***	0.0097	0.035***	0.011
Pollutant controls	NO		NO		NO		YES		YES		YES	
State controls	NO		NO		NO		NO		YES		YES	
Number of observations	404,240		404,240		363,618		323,392		323,320		262,592	
Number of groups	40,424		40,424		40,424		40,424		40,415		32,824	