Direct and Indirect Effects of Voluntary Certification:

Evidence from the Mexican Clean Industry Program

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Abstract

We develop and test a model of environmental regulation that integrates firm and regulator behavior to evaluate a voluntary certification program: the Mexican Clean Industry Program. Imposing structure on the costs of participation and compliance we first establish that plants with lower compliance costs are more likely to certify. Then, we show that because authorities seem to use certification as a screening device, the program leads to higher levels and more efficient targeting of inspections. Using remotely sensed estimates of local air quality we find evidence that is consistent with the model and suggests that the Clean Industry Program had little impact on emissions of firms that certified but reduced emissions overall as a result of the regulatory response that certification made possible.

JEL codes: Q52, Q56.

The process of designing effective policy in the face of limited regulatory capacity presents a major challenge for policy makers in the developing world. As noted by Laffont in his book, 2005, *Regulations and Development*, key implications for regulatory policy that can be derived from models of optimal regulation focused on the developed world cannot be applied with impunity in the developing world given differences in terms of the nature and strength of local institutions.[1] Moreover, while testing of regulatory theories in the developed world is itself difficult, the empirical analysis of regulatory effects in the developing world are even more challenging; capacity and resources are generally inadequate to collect the kind of detailed data necessary to examine the consequences of a particular regulation.

While much of the work to date on regulation and development has focused on the management of utilities, the problems are equally salient in the context of environmental management. Market based interventions that are typically advocated by economists as a mechanism for accommodating unobservable differences in the cost of reducing emissions may not be well suited to a situation in which monitoring costs relative to the value of output are high and in which legal institutions for enforcement of contracts are weak. Similar concerns arise with respect to attempts to cap emissions through direct regulation of firms or plants— the government agency in question may have limited capacity to monitor firm behavior and/or problems of accountability may argue for the use of relatively simple and transparent policies rather than more nuanced policies that allow for regulatory discretion (Estache and Wren-Lewis 2008).

[1]Estache and Wren-Lewis (2008) provide a useful summary of Laffont's arguments in the context of the broader literature on the subject.

An interesting policy tool that may address some of these concerns is that of voluntary certification. In particular, like a market-based system, an appropriately designed voluntary program may have the effect of concentrating emissions reductions on plants with low compliance costs and/or in those plants that are most likely to benefit from being able to demonstrate compliance with environmental regulation. Indeed, voluntary pollution reduction programs are increasingly being used to encourage plants to reduce their emissions levels in both the developed and developing world (OECD, 1999, 2003). Their effectiveness, especially in low and middle-income countries, however, is unclear and may, among other things, depend on the interaction between the information revealed by these programs and other regulatory and non-regulatory pressures for improved environmental performance (Blackman, 2009; Anton, Deltas and Khanna, 2004).

While the theoretical literature has explored how the revelation of information through instruments such as the one studied in this paper may have an impact on other agents' behavior and, indirectly, on compliance (see for example Decker and Maxwell, 2006; Gilpatric et al, 2011; Dranove and Jin, 2010; Heyes, 2000; Garvie and Keeler, 1994), the existing empirical literature (see for example Morgenstern and Pizer, 2007; Khanna, 2001) examines primarily two main questions: (1) which plants participate/what drives participation? and (2) what is the direct impact in terms of pollution emissions of the existence of these programs? Given the relative scarcity of emissions data, most studies in the context of developing countries have focused on the first of these questions. In terms of the program analyzed in this paper, Blackman et al. (2007) show that plants that have been inspected or fined for not complying with pollution emissions standards in the past are more likely to participate. Muñoz-Pina et. al. (2006) find that larger plants, exporting plants and those who sell their goods to the government are more likely to participate, while the average income of the community where plants are located, plant's age, fuel and water use intensity, and the amount of past fines have no predictive power on certification.

There has been some empirical literature for developed countries that considers the question of the impact of voluntary certification on emissions, much of which considers the US Environmental Protection Agency 33/50 program.[2] A central focus of this literature has been on the selection problem: that those firms that meet the 33/50 criteria are not a random sample of firms, leading to potentially misleading inferences about the effects of the program on emissions in cross-sectional data. Results have been inconclusive. The differences in the findings seem to come from differences in the sample used, the mechanisms used to correct for sample selection bias, or the variable used to measure environmental compliance (Alberini and Segerson, 2002). For example, Arora and Carson (1996), Gamper-Rabindran (2006) and Sam and Innes (2006) find that firms that certified experienced a differential reduction in emissions relative to other similar firms that did not certify. Vidovic and Khanna (2007), however, find that a very small percentage of the change in total emissions by participating plants can be attributed to the program.

While, as noted, empirical attempts to date to examine voluntary certification have given considerable attention to the problem of selection as a matter of inference for the econometrician, little consideration to how selection, in the context of voluntary certification, influences the behavior of economic agents such as regulators, consumers, or financiers. But this approach arguably misses a key rationale for voluntary certification and is inattentive to the problems of limited capacity in low- and middle-income countries as highlighted above. In the presence of

[2] See Montero (1999) for an empirical analysis of the drivers of compliance in the context of the US Acid Rain Program.

perfectly observable environmental behavior there would seem to be little point to a program that provides some kind of public acknowledgement in the form of a "certificate". The presence of voluntary certification suggests that problems of unobservability may also affect the choices made by plants and those economic agents with which they interact. Moreover, if the process of certification reveals information about plants that certify, it also reveals information firms that do not certify.

If, for example, regulators presume that those who do not certify are not in compliance, they may be more likely to inspect those plants. This response may, in turn, alter the behavior of plants that do not choose to certify. Under such circumstances, among other implications, a comparison of emissions of certified and uncertified plants would yield a biased estimate of the effect of certification on emissions, even if appropriate adjustments were made for the selection of plants into the certification group.

The role of certification in the revelation of information also may have implications for the pattern of selection. It is generally assumed, for example, that plants that certify would be relatively "green" in the absence of a certification program so that cross-sectional estimates of the effects of certification on emissions are negatively biased. But if certification is used primarily to reveal information, then it may be of little use to plants that are expected to be "green"; instead it will be attractive to plants that are expected to be dirty based on observable criteria but perceive a benefit to signaling their green status. Preliminary evidence on this point is available in Table 1. This table contrasts high and low certification sectors in the context of the Mexican program that will be the focus of the more detailed analysis below. While there is not a clean division between these two groups, a rough cut would suggest that the high certification group includes sectors in which there is a high degree of chemical processing such as cement, pharmaceuticals, synthetic materials, and explosives. The low-certification sectors are ones in which agricultural products play a key role such as natural fibers, coffee/tea and chocolates, and wood products. While systematically collected measures of abatement costs are not available for Mexico, sector-specific data on abatement costs in the US, as discussed below, suggest, as one might expect, that abatement costs are higher in the former industries.

Note further that if revelation of information is an important component of the effect of a voluntary certification program then experimentally induced variation in emissions monitoring is not likely to provide a clear picture of the consequences of such a program. For example, the experimental audits used in the case of Duflo, Greenstone, Pande and Ryan (2012) show that auditor and plant behavior, at least in India, can be importantly influenced by tying incentives to the results of random accurate back-checks. But random variation in the quality of audits for certifying plants when such audits are mandated as in India, or even in the cost to the plant of certification under a voluntary program like the one studied below, may lead to a different process of sorting and thus information revelation than would be the case absent such an experiment. To effectively evaluate voluntary certification on an experimental basis would require intervention at a much larger scale such as all plants in a particular sector. Absent such a study, it seems critical to have at one's disposal an empirically validated theoretical structure that illustrates how the process of selection into certification on firms works and how this process of selection is incorporated into the behavior of key economic agents.

In this paper, we provide such a structure. In particular, we develop a model of environmental regulation that integrates plant and regulator behavior and incorporates a combination of voluntary and mandatory controls. The model is based on and applied to Mexico's Clean Industry Program, in which plants are provided a Clean Industry Certificate if they are willing to establish via a privately financed audit that they meet the legal emissions standards. The model generates a series of implications for patterns of pre- and post-certification inspection rates by sector, the pattern of failed inspections and certification across sectors, and overall emissions under alternative regimes of selection within sector. We then test the implications of the model using a combination of information on certification, inspection, and inspection failures. The only regime that is broadly consistent with observed data is one in which certified plants have the lowest cost of compliance within sector and compliant firms have intermediate costs of compliance within sector.

We then incorporate newly developed satellite based measures of suspended particulates and a plant-level data set with geographical identifiers to examine the consequences of voluntary certification for emissions. Consistent with the model and the observe selection regime, we find that net of increases in the inspection probability at the level of the zip code, there was little or no effect of certification on emissions change. In combination with the model, however, these results suggest that the certification program had a substantial effect on emissions by facilitating more effective targeting of regulatory effort.

II. Environmental Regulation in Mexico

The primary responsibility for environmental control in Mexico lies with the Mexican Federal Environmental Protection Agency (Procuraduría Federal de Protección al Ambiente, PROFEPA). As might be expected of any government agency during a period of rapid economic and political change, the focus, strategy and resources of PROFEPA changed substantially over the study period. Nonetheless, the basic regulatory approach can be distilled into two distinct prongs. First, the agency is responsible for inspecting plants in order to determine if they comply with the current legal pollution emission standards, which are set in terms of emissions per unit of capacity. Inspections are performed at random, assigning a higher probability of inspection to sectors with higher perceived risk of polluting and to larger firms. If a plant is found not to be compliance, a substantial fine is imposed.

Second, in 1994 (the program was originally offered to government-owned plants, but only around 1997 were some private firms offered participation into the program), PROFEPA introduced the Mexican Clean Industry Program (Programa de Industria Limpia). Plants participating in this program have to pay for an audit by an independent agency on a list maintained by PROFEPA. Auditors evaluate emissions as well as the physical plant and determine the actions that need to be taken in order to make the plant compliant with the pollution emissions standards.

Formally, the requirements for getting this certification are only that the plant be in compliance with existing standards in terms of emissions per unit of capacity. However, in practice, since auditors examine the technologies in place rather than just current emissions in making their recommendations, certification may involve a greater degree of capital investment than would be the case for a plant that chooses to meet emissions standards simply, for example, through lower utilization of plant capacity. After it has been established that the plant meets the pollution standards, it is granted a Clean Industry Certificate, which can be used for marketing purposes and to demonstrate to financial institutions, for example, that it is not subject to a potential adverse shock arising from a failed emissions inspection. If certified, plants are then further exempted from inspections for a given period of time (at least two years). Certification rose rapidly between 2000 and 2007. By 2000, only 228 plants were certified and many of these were government-owned, primarily those belonging to PEMEX, the Mexican Oil Company. By 2007, 2,568 had been certified.

III. Model

The first stage in our analysis is to develop a theoretical structure that is modeled on the PROFEPA program and integrates the behavior of plants[3] with and without the possibility of certification and the behavior of regulators. We presume in particular that plants choose the lowest cost option among the available alternatives in the light of regulator behavior and that regulators then optimize a simple objective function in light of firms' responses. We first consider the case in which certification is not available and then augment the model to incorporate the program.

III.1. A model of optimal profiling in the absence of certificates

III.1.1The Plants' Problem

We first consider plant behavior. In the absence of certificates, plants have a choice between two different options: complying with pollution emissions standards and non compliance. Each of the options has a different cost for each plant, depending on the types of goods they produce (industrial sector), plant specific characteristics, and the probability of being found in non-compliance by the authorities if inspected. Authorities, because they do not observe the plant specific cost of compliance, can manipulate the sector-level probability of inspection but cannot

[3]In the model we will assume for simplicity that each firm has one plant so that the term firm and plant may be used interchangeably. In practice, as noted, inspection and certification happens at the level of the plant. For sector-level analysis this makes little difference as long as plants for a given firm are in the same broad sector. For measurement of emissions using remote sensing data it is critical that we have data at the level of the plant.

target specific firms within sector based on the plant-specific cost.[4] Each plant chooses the option that has the lowest expect cost.

In particular, we assume that the cost of compliance with pollution emissions standards without certification for plant *i* in sector *j* is:

$$C_{ij}^{c1} = C_j + d_{ij} \tag{1}$$

where C_j is the sector *j* level cost and d_{ij} is the plant specific cost with a distribution *F*(*d*), which we assume to be differentiable, strictly increasing, and concave. The density function for *d* is denoted *f*(*d*), with concavity implying that $f'(d) < 0$. The cost of non-compliance is assumed to be given by:

$$C_{ij}^{nc} = P_j \times M \tag{2}$$

where P_j is the probability that the authorities will inspect a plant in sector *j* and *M* is the fine imposed if the inspected plant is found to be non-compliant. *M* is assumed to be fixed and exogenous and P_j is set at the sector level, given, as noted, that authorities are unable to observe (or unable to use) the plants' specific d_{ij} .Given this setup, in the absence of certificates, it is clear from equation (1) and (2) that only plants with low d_{ij} will comply with pollution emissions standards.

III.1.2The Regulator's Problem

We now turn to the problem faced by the regulator in the pre-certification case.

[4]The setup of the model is equivalent to a situation in which inspectors observe more than the sector specific cost of compliance, but are constrained to set their inspection policy only with respect to the industrial sector. As noted above in the presence of limited accountability it may be desirable to have regulatory policies that are relatively transparent. If the inspectors had discretion they might be able to target their effort more efficiently but it would be harder to detect deviations from the proscribed behavior such as avoiding inspection of non-compliant firms.

For this, we define as (L_j^0) the compliant fraction in sector *j* (the fraction of plants in that sector for which the expected cost of fines exceeds the cost of being in compliance):

$$L^0(P_j, C_j) = F(b_j) = F(MP_j - C_j) \tag{3}$$

The regulator is assumed to receive a benefit *A* for every compliant plant and to pay a cost of *B* for every inspection. As it knows both the average cost of compliance at the sector level, C_j and the distribution of d_{ij}, the regulator maximizes benefits minus costs through the choice of inspection probabilities by sector[5]. Denoting by N_j the total number of plants in sector *j*, we can formally write the total net benefits obtained from the regulator with the following function, *S*:

$$S = A\sum_j N_j L^0(P_j, C_j) - B\sum_j N_j P_j \tag{4}$$

III.1.3. The basic prediction of the model pre-certificates.

If plants react to the inspection probabilities imposed by the authorities, and authorities take this into account when designing their inspection strategy, the regulators will then maximize their objective function (4) with respect to P_j. Differentiating equation (4) with respecting to P_j and solving yields:

$$AN_j F'(P_j M - C_j)M - BN_j = 0 \, . \tag{5}$$

This expression implies, since *F()* is increasing, that $F(P_j M - C_j) = L^0(P_j M - C_j)$ is constant across sectors. Thus higher cost sectors, given the assumed regulator and plant objective functions, will have higher inspection probabilities and the same fraction of firms will be compliant in each sector.[6]

[5]The implications derived from this setup are the same as if we assumed the authorities maximized compliance given a total budget to perform inspections.

[6]This result mirrors an insight from the literature on racial profiling (Antonovics and Knight, 2008; Knowles, Persico and Todd, 2001). In particular that literature provides conditions under which conviction rates of motorists

III.2. A model of optimal profiling with certification

As for sub-section III.1, the model when certification is available assumes the same basic structure of the regulator's objective function but gives the firms an additional option—to undertake an audit at its own expense that can then be used to obtain a certificate. We impose minimal structure, however, in terms of how the cost (net of any marketing or other benefits) of certification varies with sector and firm specific costs. Instead, we use the model to generate predictions about key observables in our data and then use the data to draw inferences about the underlying cost structure, given the model.

III.2.1 The Plants' problem when certification is possible

In the presence of certificates, plants have a choice between three different options: complying with pollution emissions standards without getting certified; compliance with emissions standards and obtaining a "Clean Industry Certificate"; and non compliance. In this case, the cost of compliance with pollution emissions standards without certification for plant i in sector j, and the cost of non-compliance are still be described by equations (1) and (2), respectively. The only modification that we make to our basic setup is introducing an equation to characterize the cost of certification.

Net costs of compliance for those plants that certify may differ from costs associated with compliance without certification for a variety of reasons including (a) possible marketing benefits (b) reductions in liability and thus improved credit terms[7] (c) the costs of an audit (d) the

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who are stopped by police should not differ by race because inspection probabilities by race adjust optimally to differences by race in the propensity to be in violation of the law.

[7] Foster and Gutierrez (2013) provide evidence that capital markets respond positively to the announcement of certification of a particular firm.

grace period provided and (e) a need to upgrade capital in order to meet the terms of an audit. These costs may affect differentially the observable and unobservable components of compliance costs so we assume that the cost of certification (net of the benefits) can be approximated by a linear function of these cost components:

$$C_{ij}^{c2} = \mu + \alpha C_j + \beta d_{ij} \tag{6}$$

where $\alpha, \beta,$ and μ are constants that are common to all plants. As can be seen, α multiplies the industrial sector level cost of compliance and β multiplies the plant specific cost of compliance.[8]

In the presence of certification, the values of α and β will determine who chooses to get certified. While theoretically we do not impose restrictions on the values of these parameters, we restrict attention to cases in which there is an interior solution in each sector.[9] We see that three such general scenarios are possible. For this purpose, we define a_j as the intersection between equation (1) and (6), b_j as the intersection between equations (1) and (2), and c_j as the intersection between equations (2) and (6).

Figure 1 plots the cost of compliance, noncompliance and compliance with certification for different values of d_{ij}, when $\gamma + \alpha C_i < C_i$ and $\beta > 1$, given an interior solution. The first condition implies that the net benefits of certification are positive for plants with the lowest d_{ij} within sector j. The assumption $\beta > 1$ implies that the cost of participating in the program is

[8]Appendix 1, given possible concerns about the level of corruption and influence peddling in low and middle income countries in general and evidence in particular of corruption on the part of environmental auditors from India (Duflo, Greenstone, Pande, and Ryan 2012), discusses how the setup presented this far can incorporate the possibility for corruption on the part of auditors. The basic conclusion is that corruption may affect the way that compliance costs translate into certification costs, but given that we incorporate flexibility in the specification of certification costs, should not affect inference about patterns of selection within sectors. The fact that inspections themselves have bite is evident in the measured effect of inspection probabilities on remote-sensed emissions as shown in Tables 8 and 9. Finally, most of the auditors that are certified by PROFEPA for the Clean Industry program are large auditing firms that would have general reputational concerns; there is thus not likely to be a *particular* problem with environmental audits in Mexico.

[9]This assumption is supported empirically given that in most sectors all three choices are evident.

higher for plants with relatively high compliance costs within sector[10]. Plants will get certified if $d_{ij}<a_j$. Plants for which $a_j<d_{ij}<b_j$ will be in compliance and not certified, and plants with $d_{ij}>b_j$ will be in non-compliance. Because certification is infra-marginal to compliance, it is evident that in the absence of certification all plants to the left of b_j will be compliant and thus, for a given inspection probability, certification will have no effect on overall compliance.

Figures 2 and 3 plot the same three hypothetical cost schedules for $\gamma + \alpha C_i > C_i$, which implies that the costs of certification outweigh the benefits for plants with the lowest plant-specific cost of compliance. In Figure 2, β is set to be lower than one but higher than zero, so that plants with intermediate levels of d_{ij} get certified. Figure 3 shows the extreme case, in which β is negative, implying that the plants that get certified are those with the highest levels of d_{ij}. In both of these latter cases, some of the plants getting certified, for given inspection probability, are plants that, given inspection rates, would not be compliant in the absence of the program. However, the conditioning on inspection rates is critical here. As with the pre-certification case we will assume that inspection rates are chosen by the regulator based on a specific objective function, and the choice of this inspection rate will in general depend on the level and composition of certified firms.

Having characterized the three possible regimes in the presence of certification, we can then find the expressions for the fraction certified D_j^k the fraction compliant L_j^k, and the fraction of non-certified plants that is compliant, R_j^k, in sector j, given Regime k (based, respectively, on Figures 1-3). For Regime 1,

[10]Appendix 2 provides an illustration of why certification costs may rise more rapidly with d than compliance costs without certification. The premise of the model is that given that standards are set in terms of emissions per unit of capacity a plant can be in compliance through either capital upgrading or output reduction but certification can only be obtained through capital upgrading. Output reduction turns out to be particularly advantageous for firms with high shares of “dirty” capital.

$$D_j^1 = D^1(P_j, C_j) = F(a_j^1) = F\left(\frac{(1-\alpha)C_j - \gamma}{(\beta - 1)}\right), \tag{7}$$

$$L_j^1 = L^1(P_j, C_j) = F(b_j^1) = F(MP_j - C_j) \tag{8}$$

and

$$R_j^1 = \frac{L_j^1 - D_j^1}{1 - D_j^1} = \frac{F(b_j^1) - F(a_j^1)}{1 - F(a_j^1)} \tag{9}$$

Note that the fraction certified in this regime depends on the inspection cost but does not depend on the inspection probability. As is evident in Figure 1, under this regime the fraction certified depends only on the intersection between the certified and compliant cost curves, with compliance being determined as in the non-certification case.

Because in the second regime the certification group is in the middle, the relevant cut points of the certification group are the intersections of the certification line and the other two lines. Compliance is determined by the intersection of the certified and non-compliant curves, so that:

$$D_j^2 = D^2(P_j, C_j) = F(c_j^2) - F(a_j^2) = F\left(\frac{MP_j - \alpha C_j - \gamma}{\beta}\right) - F\left(\frac{(1-\alpha)C_j - \gamma}{(\beta - 1)}\right) \tag{10}$$

$$L_j^2 = L^2(P_j, C_j) = F(c_j^2) = F\left(\frac{MP_j - \alpha C_j - \gamma}{\beta}\right). \tag{11}$$

$$R_j^2 = \frac{L_j^2 - D_j^2}{1 - D_j^2} = \frac{F(a_j^2)}{1 - F(c_j^2) + F(a_j^2)}. \tag{12}$$

In this case, in contrast to Regime 1, both the probability of certification and the probability of overall compliance depend on the inspection probability as well as the cost of compliance in the sector.

Finally, in the third regime, certification is determined by the intersection of the certified and non-compliant lines, while compliance is determined by the intersection of the non-compliant curve with that of the two other groups:

$$D_j^3 = D^3(P_j, C_j) = 1 - F(c_j^3) = 1 - F\left(\frac{MP_j - \alpha C_j - \gamma}{\beta}\right) \tag{13}$$

$$L_j^3 = L^3(P_j, C_j) = 1 - F(c_j^3) + F(b_j^3) = 1 - F\left(\frac{MP_j - \alpha C_j - \gamma}{\beta}\right) + F(MP_j - C_j) \tag{14}$$

$$R_j^3 = \frac{L_j^3 - D_j^3}{1 - D_j^3} = \frac{F(b_j^3)}{F(c_j^3)} \tag{15}$$

Here, as in Regime 2, both certification and compliance depend on the inspection probability and the sector-specific cost. As we establish below, this distinction between Regime 1, on the one hand, and Regimes 2 and 3 on the other, is useful in sorting out the underlying pattern of selection on unobservables from the data.

III.2.2 The regulator's problem when certification is possible

The regulator's objective function given certification reflects the fact that inspections need not, for some period of time, be carried out on certified plants because they have already established compliance through a privately financed audit:[11]

$$S^k = \sum_j N_j A L^k(P_j, C_j) - \sum_j B N_j P_j (1 - D^k(P_j, C_j)) \tag{16}$$

The existence of the program effectively alters the sector-specific return to inspections from the perspective of the regulator. In particular, it affects the composition within sectors of the

[11]This assumption matches well with the policy implemented by PROFEPA at least over a two-year window. More generally one might have a regulator choose a lower rates of inspection on certified firms as a means to monitor auditor behavior and/or to ensure that certified plants remain in compliance. As discussed in Appendix 2 because certification involves upgrading capital such as investment in scrubbers, certified firms have, in effect, lower costs of compliance (e.g., the variable cost of using scrubbers) after certification then before as long as that capital remains functional.

unobservable compliance costs of the firms that are inspected and thus the potential benefit of inspection in terms of increased compliance. For example, in Regime 1, since low cost firms opt out of inspection through certification, the average unobservable cost of compliance among those who are inspected would be higher than it would be absent certification.

Of course, what matters in practice is the marginal return to inspection to the regulators. Formally, maximizing the authorities objective function with respect to P_j, yields:

$$A\frac{\partial L_j^k}{\partial P_j} - B(1-D_j^k) - BP_j\frac{\partial D_j^k}{\partial P_j} = 0\,. \tag{17}$$

Given equations (2)-(16) it is clear that inspection probabilities will respond differently to the presence of certification in the different regimes. For example, as is evident in Figures 1-3, an increase in inspection probability (movement up in the horizontal P_jM line) increases certification under Regimes 2 and 3, but not in Regime 1. Understanding the regulator's problem requires an identification of what regime is in place, something on which the theory alone provides little guidance absent additional assumptions about the parameters $\mu, \alpha,$ and β.

IV. Empirical evidence at the sector level

Before turning to the empirical evidence, it is perhaps useful to provide a brief summary of the theoretical predictions presented this far.

a) In the absence of the certification program, the fraction of compliant plants should be independent of the sector-specific cost of compliance, C_j and,the fraction compliant should be increasing in C_j .

b) After the certification program is introduced, only if the cost of certification is such that plants with the lowest cost of compliance within sectors certify, compliance rates should not depend on inspection probabilities, and inspection probabilities should increase more in sectors with high certification rates.

In other words, the model described in section III characterizes formally what we are able to observe in the data: the fraction of certified plants in each sector, the fraction in compliance before certification, and the fraction of plants in compliance (among uncertified plants) after the introduction of the certification program. Moreover, given equation (5), the probability of inspection before the introduction of certificates may be used as a proxy for the sector-level cost of compliance, C_j. Thus, we can up to a positive scalar (*M*), estimate the relationship between the sector level cost of compliance and: (1) compliance after certification, $\frac{dR_j^k}{dC_j}$; and (2) the certification fraction, $\frac{dD_j^k}{dC_j}$; and pre-certification compliance $\frac{dL_j^0}{dC_j}$. By comparing estimates of these relationships to corresponding theoretical regimes we can identify the selection regime and, surprisingly, the approximate shape of the distribution of unobservables, *F()*. By incorporation of this information we can draw further implications for how inspection probabilities should change by sector and how certification and inspection probabilities should be related to emissions that themselves may be tested.

IV.1. Sector-level data

For the first part of the analysis (inclusive of Table 1) we combined three data sets. First, we obtained the total number of plants, employees and the value of production for each four digit NAICS (North American Industrial Classification System) sector from the 1999 Mexican Industrial Census. Second, we obtained from PROFEPA a list of all plants that were granted a Clean Industry Certificate since its introduction until 2006, as well as a yearly list of the total number of inspections performed from 1992 until 2007, by NAICS industrial sector. We also know how many of these inspections found the plants to be out of compliance in each year. We restrict the sample to 160 manufacturing sectors where at least one inspection took place in the period analyzed, excluding utilities (run by the government) and services.

We define the probability of inspection before the introduction of certificates as the total number of inspections between 1992 and 1995 in each industrial sector divided by the total number of plants in each sector in the 1999 Industrial Census. The probability of inspection after the introduction of certificates is defined as the total number of inspections between 2003 and 2006 divided also by the total number of plants in each sector in the 1999 Industrial Census. The fraction of plants certified in each sector is simply the total number of certified plants divided by the total number of plants in each sector.[12]

We also incorporated a data set on inspections and compliance in the US. In particular, the US Environmental Protection Agency (EPA) publishes the Enforcement and Compliance History Online (ECHO). ECHO is a Web-based tool that provides public access to compliance and enforcement information for approximately 800,000 EPA-regulated facilities. ECHO gives access to permit, inspection, violation, enforcement action, and penalty information covering the past five years in the United States. The site includes facilities regulated as Clean Air Act stationary sources, Clean Water Act direct dischargers, and Resource Conservation and Recovery Act hazardous waste generators/handlers. From this system, we obtained the number of pollution emissions inspections conducted in each industrial sector in the US, from 2002 through 2007. The probability of inspection in the United States is then defined as the total

[12] Alternative measures incorporated the total number of plants in the 2005 Mexican industrial census as denominator, with little change in the main results. In addition, it is worth mentioning that the growth in the number of plants per sector between 2000 and 2005 is uncorrelated with the certification intensity, or inspection probabilities.

number of inspections reported in ECHO, divided by the total number of establishments in the US Industrial Census, for each 4 digit NAICS industrial sector. Descriptive statistics for the sector level variables are presented in Appendix Table 1.

IV.2. Relationship between inspections, certification and compliance.

We now turn to the empirical analysis at the sector level. In particular, we first test for the relationship between the probability of inspection before the introduction of the certification program and non-compliance. Table 2 shows the results of sector level regressions, with the log of one plus the fraction of non-compliant plants as the dependent variable and the log of one plus the fraction of plants inspected in each sector during the 1992-1995 period as the explanatory variable.[13] As our model predicts that inspections and non-compliance are uncorrelated, we need to take into consideration the possibility of measurement error on our inspections measure in our regressions, which is likely to bias the relationship between these variables towards zero.

We thus use the inspection probabilities in the US as an instrument for inspections in Mexico. Column 1 in Table 2 shows the OLS regression result. Columns 2, 3 and 4 present instrumental variable estimates of this relationship. Column 2 includes no controls. Column 3 controls for the percentage of the production in each sector that is exported and scale (employees divided by total plants). Column 4 also includes 2-digit sector fixed effects.[14] As can be seen, across specifications, inspections are uncorrelated with non-compliance at the sector level. This result is consistent with our hypothesis that authorities are assigning a higher inspection

[13]The ln(1+x) transformation is used to reduce the influence of outliers; the raw data on compliance and inspections by sector are somewhat skewed.

[14] The first-stage regression results for the regressions presented in Columns 2, 3 and 4 are shown in Columns 1, 2 and 3 of Appendix Table 2, respectively.

probability to sectors that face high compliance costs, thus imposing on them a higher incentive to invest in reducing pollution emissions.

The second set of regressions (Table 3) tests for the relationship between inspection intensity pre-certificates and certification rates at the sector level. Column 1 shows the OLS result, while the next three columns present instrumental variable estimates, with the same controls as in the corresponding columns in Table 2.[15] The relationship between the probability of inspection before the introduction of certificates (our proxy for the observed cost of compliance at the sector level) and certification is always positive and significant. Interestingly, we find that net of inspection probabilities, exports are uncorrelated with certification.

The third set of regressions (Table 4) tests the relationship between *ex ante* inspection intensity pre-certificates and *ex post* non-compliance. Each column presents the results for the specification in the corresponding columns in Tables 2 and 3. As for non-compliance in the pre-certification period, the coefficient for the log of the probability of inspection is close to zero and insignificant for all specifications. We also see no evidence that the other sector-level observables predict the non-compliance rate after the introduction of certificates.

IV.3. Identification of Regime

Given the empirical relationships observed in the sector level data, we can characterize the necessary conditions for regime *k:*

a) The invariance of the compliance fraction with respect to sector-level cost of compliance among non-certified firms $\frac{dR_j^k}{dC_j} = 0$;

[15] The first-stage regression results for the regressions presented in Columns 2, 3 and 4 are shown in Columns 1, 2 and 3 of Appendix Table 2, respectively.

b) The certification fraction is increasing in the cost of compliance $\frac{dD_j^k}{dC_j} > 0$;

c) The invariance of the compliance fraction absent certification $\frac{dL_j^0}{dC_j} = 0$;

The first order condition from our model further constrains the relationship among these variables and thus is included as a fourth condition

d) Equation (14).

We consider the regimes in reverse order. Assume that Regime 3 is in place ($\mu + \alpha C > C, \beta < 0$),

$$R_j^3 = \frac{L_j^3 - D_j^3}{1 - D_j^3} = \frac{F(b_j^3)}{F(c_j^3)} \tag{2}$$

Where conditions (b) and (a) above imply $\frac{db_j^3}{dC_j} < 0$ and $\frac{dc_j^3}{dC_j} < 0$. Differentiating the left hand side of condition (d) with respect to C_j yields

$$\begin{array}{c} (+) \bullet (-) \bullet (-) \; - \; (-) \bullet (+) \bullet (-) \bullet (-) \; - \; (+)((-) + (-) \bullet (+)) \bullet (+)) \\ AM \frac{db_j^3}{dC_j} F''(b_j^3) - \frac{M}{\beta}(A + P_j B) \frac{dc_j^3}{dC_j} F''(c_j^3) - B(\frac{dc_j^3}{dC_j} + \frac{M}{\beta} \frac{dP_j^3}{dC_j}) F'(c_j^3) \end{array} \tag{18}$$

where the signs indicate the signs of the component part. As the three additive terms are all positive, the first order condition must be rising in C_j. Thus given the patterns of certification, inspection and compliance in the data, if the first order condition is satisfied for a given C_j, it will be positive for $C_k > C_j$ and negative for $C_k < C_j$. To satisfy the first order conditions the inspection probability and thus compliance must rise faster with sector-specific cost than it does in the data.

Regime 2 can be ruled out in a different way. Assume Regime 2

($\mu+\alpha C>C,\beta>0$) is in place so that

$$R_j^2=\frac{L_j^2-D_j^2}{1-D_j^2}=\frac{F(a_j^2)}{1-F(c_j^2)+F(a_j^2)}. \tag{12}$$

Condition (d) is thus $\frac{M}{\beta}(A+P_jB)F'(c_j^2)-BF(a_j^2)+1-F(c_j)=0$. Substituting for $F(c_j^2)$ from R_j^2 equation yields

$$\frac{M}{\beta}A+\frac{1}{\beta}(b_j^2\beta+\mu+\alpha C_j)BF'(b_j^2)-\frac{B}{1-R_j^2}(1-F(b_j^2)), \tag{19}$$

which is an ordinary differential equation in b_j^2. Solving with F(0)=0 yields

$$F(z)=1-(1+\nu_j z)^{-\theta} \tag{20}$$

Where $\theta=1/(1-R_j^2)$ and $\nu_j=B\beta/(AM+B(\mu+\alpha C_j))$. Note, however, that $F()$ depends on the cost of compliance, C_j. This result implies that the fraction compliant absent certification is $L_j^0=\left(\frac{B}{M\theta\nu_j}\right)^{\theta/(1+\theta)}$ and thus $\frac{dL_j^0}{dC_j}\neq 0$ if $\alpha\neq 0$. This condition violates (c) except in the special case that there is no sector-specific variation in the cost of certification.

Finally we assume that Regime 1 is in place, in which case,

$$R_j^1=\frac{L_j^1-D_j^1}{1-D_j^1}=\frac{F(b_j^1)-F(a_j^1)}{1-F(a_j^1)} \tag{21}$$

and condition (d) reduces to $f(b_j^1)=\frac{B}{AM}(1-F\left(a_j^1\right))$. Solving (9) for $F(a_j^1)$ and substituting yields

$$Af(b_j^1)M-B(\frac{1-F(b_j^1)}{1-R_j^1}) \tag{22}$$

which is again an ordinary differential equation. Solving, as in Regime 2, for the boundary condition $F(0) = 0$, yields $F(z) = 1 - \exp(-\theta z)$ where $\theta = B / ((1 - R_j^1) AM)$. For this distribution function,

$$P_j = \frac{1}{M}(C_j + \frac{\ln(A\theta M / B)}{\theta}) \tag{23}$$

In contrast to Regime 2, this distribution function does not depend on C_j, and thus the fraction compliant prior to certification,

$$L_j^0 = 1 - \frac{B}{A\theta M}, \tag{24}$$

is also invariant with respect to C_j (condition (c)). The fraction certified is

$$D_j^1 = 1 - \exp(-\frac{\theta(C_j(1-\alpha) - \mu)}{\beta - 1}), \tag{25}$$

which is increasing in C_j (condition (b)) for $\beta > 1$ and $\alpha < 1$. Thus, all four conditions are met. Given the relationships found in the data, according to our model, for the Mexican Clean Industry Program context, it is the plants with the lowest cost of compliance within each industrial sector that chooses to certify.

The fact that together the model and empirical analysis imply that the distribution of unobservables must be exponential is both striking and perhaps a bit unnerving given that there is no particular reason, otherwise, to believe that an exponential distribution characterizes within-sector variation in the cost of compliance. This result might be taken instead as evidence that the model imposes too much structure. For example, it may be that the assumption that the distribution function is the same across sectors is unrealistic. Or alternatively, it may be the case that one of the empirical results is being taken too literally. In this regard an obvious candidate is the result that compliance among non-certified firms does not vary with respect to the cost of compliance. As illustrated in Table 5, which categorizes sector-level non-compliance by pre-certification inspection probability, the pre-certification fraction non-compliant is literally flat with respect to probability of inspection as predicted by the model. However, while we cannot overall reject the hypothesis that the post-certification non-compliance fraction among non-certified firms does not vary with pre-certification inspection cost, from a non-parametric perspective the post-certification non-compliance fraction initially rises with respect to the inspection cost before leveling off. From this perspective the exponential distribution may be thought of as a reasonable approximation to the extent that the non-compliance fraction is flat with respect to pre-certification inspection probabilities at the sector level.

These caveats considered, a key advantage of being able to isolate the distribution is that it is possible to obtain closed form solutions for relationships of interest. In particular, the post-certification inspection probability is:

$$P_j = \frac{1}{M}\left(\frac{(\beta-\alpha)C_j-\mu}{\beta-1}+\frac{\ln(A\theta M/B)}{\theta}\right), \tag{26}$$

The compliance among non-certified firms is:

$$R_j^1 = 1-\frac{B}{\theta AM}, \tag{27}$$

And the total fraction compliant under certification:

$$L_j^1 = 1-\frac{B\exp\left(-\frac{\theta(C_j(1-\alpha)-\mu)}{\beta-1}\right)}{\theta MA}. \tag{28}$$

A number of conclusions may be drawn from these expressions. First, (23) and (26) are the same. Thus absent any change in model parameters (θ, A, M or B) the *ex ante* (*ex ante* relative to the introduction of certification) non-compliance fraction should equal the *ex post* non-compliance fraction among non-certified firms. Table 5 indicates that the latter is greater than the former suggesting, for example, an increase in the perceived benefit of compliance or a decreased cost of inspection pre and post certification. Second, for fixed parameters, the certification program increases overall compliance: the *ex post* total fraction compliant (28) exceeds the *ex ante* fraction (24). Third, it is not clear whether all certifying firms would be compliant in the absence of certification. Indeed for certain parameters[16] the certification probability will be lower than *ex ante* compliance in low cost sectors but higher than *ex ante* compliance in high cost sectors. Fourth, differencing (23) and (26) and allowing for changes over time in the cost and benefit parameters of the regulators yields

$$P_j^1 - P_j^0 = \frac{1}{M}\frac{(1-\alpha)C_j - \mu}{\beta - 1} + \frac{\ln(A^1\theta M / B^1)}{\theta M} - \frac{\ln(A^0\theta M / B^0)}{\theta M} \tag{29}$$

Thus given the necessary conditions for Regime 1 to be an equilibrium, the inspection probability rises more following certification in high cost than in low cost sectors.[17]

The formal expressions also permit some assessment of the welfare effects of certification. Clearly, for given parameters, and ignoring the costs to the government of the certification program, the regulator's objective function improves in the presence of certification. For given inspection rates and constant parameters, the regulator's costs of inspection are lower because it applies to fewer firms and benefits are at least as high; the regulator chooses a higher inspection level than that, which can only improve its objective function. Among firms, those that choose compliance *ex ante* and certification *ex post* are clearly better off. Firms that choose compliance *ex ante* and *ex post* but do not certify have the same costs. Those that were non-compliant *ex ante* are worse off, the compliant ones because they incur the cost of compliance

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[16] A=1, B=9/10, M=1, $\theta = 1$, $\mu = 0$, $\alpha = 1/2$ and $\beta = 2$.

[17] If M changes with the introduction of certification, this prediction may not obtain. For example, as *ex post* M gets very large the inspection probability in both high and cost sectors falls to zero, predicting a greater decline in inspection in high cost sectors.

and the non-compliant ones because they face a higher inspection probability. In this sense the certification program works like a tax on high cost firms within a sector and a subsidy for low cost firms, but does not require the regulator to know information on firm costs within sector.[18]

IV.4. Change in inspection probabilities

As noted, our model predicts that regulator's inspection probabilities should change systematically in the presence of certification (equation (28)). In particular, the derivative of the probability of inspection with respect to the sector level fixed cost of compliance should be higher in a context in which certificates are available. In our industrial sector level data, we have information about the number of inspections performed since 1992 until 2007. Given that certificates in our sample were not granted until around 1997, we can compare the calculated inspection probabilities before and after the introduction of the program (1992-1995 and 2003-2006).

We define the probability of inspection after the introduction of the certificates as the total number of inspections performed in the sector divided by the total number of plants in the census for that sector. This is an overestimate of the total number of plants subject to inspection because in practice certified plants are not inspected for at least two years. We see this as a conservative approach given that taking certified plants out of the denominator for the calculation of inspection probabilities post certificates in principle biases our measure of change in inspections upwards in sectors with higher certification rates.

Also, for this section, it is worth stressing that, because we cannot directly observe the sector-level cost of compliance, we are in effect using the probability of inspection as a proxy for

[18]Total cost across all firms in a sector can be either positive or negative and the sum or regulator and firm welfare depends in addition on the value put on compliance.

the fixed cost of compliance in each sector. If the probability of inspection is a noisy measure of the sector level fixed cost of compliance, as one would generally expect it is, correlating the probability of inspection in the 1992-1995 period against the change in the probability of inspection before and after the introduction of the certificates will produce a downward biased estimate of the derivative of the inspection probability with respect to the fixed cost of compliance. We thus instrument inspection probabilities before certification, as in Tables 2-4, with inspection probabilities in the US.

Finally, we see the differential increase in inspection probabilities as an important test of the model that has power against the alternative that, for example, improved compliance in high cost sectors rose over this period due to differential technological change that resulted in a lower cost of compliance in those sectors. A potential concern with this approach is that PROFEPA may have changed its enforcement and monitoring activities over the period in which certification was introduced (see, e.g., Alvarez-Larrauri and Fogel, 2008) in ways that mimic the predictions of the model. We partially address this concern in two ways: a) showing that the change in inspection probabilities around the introduction of the certification program is positively correlated with inspections pre-certificates, even when controlling for potentially confounding factors that might otherwise have influenced PROFEPA's allocations of inspection effort, and b) showing that the changes over time in relative inspection intensity before the introduction of the certification program across sectors is uncorrelated with inspections pre-certificates.

The first four columns in Table 6 show the results for the same specification as Tables 2, 3 and 4, this time using the change in inspection probabilities as the dependent variable. The fifth column includes the log of one plus the fraction of firms fined in each sector before the introduction of certificates as a control variable.[19] Column 6 shows the results of the same specification as in Column 5, this time using the change in inspections between 1992-1995 and 1995-1996 as the dependent variable.

Given the possibility of measurement error, the regression of the change in probability of inspection on the initial probability of inspection yields a negative coefficient. Once we instrument for pre-certification inspection probabilities, all regressions show a positive relationship between pre-certificates inspection rates and the change in inspections around the introduction of the program, regardless of the controls included. As can be seen in the last column, this positive relationship is only present around the introduction of the certification program, and not before. These results are consistent with the idea that higher certification rates within a sector resulted in higher inspection rates, as predicted by the model.

V. Zip-code level analysis

The results presented in section IV are key to the setup for the empirical analysis that follows. On one hand, according to the sector-level evidence, plants with the lowest cost of compliance within a sector are the most likely to certify. As many if not all of these plants were previously compliant the effects of certification for a given plant are expected to be modest. On the other, given that high-cost sectors saw a higher increase in the probability of inspection following the introduction of certification than did low-cost sectors, non-certified plants in high certification sectors had higher incentives to comply with environmental regulations as a result of the introduction of the certification program. Thus one would expect greater reduction in emissions in high cost than low-cost sectors even among non-certifying firms.

[19] The first-stage regression results for the regressions presented in Columns 2 through 4 are shown in Columns 1-3 of Appendix Table 2, respectively. The first-stage regression results for the regressions presented in Columns 5 and 6 are shown in Column 4 of Appendix Table 2.

V.1. Data

To test these predictions, we incorporate three additional sources of data. In particular, given the difficulty of accessing geographically identified plant-level data from the census, our plant-level and zip-code level analysis uses data from the SIEM (Sistema de Información Empresarial Mexicano), administered by the Mexican Ministry of Economics. These data contain information on 32,332 plants in the industrial sector. It includes each plant's exact address (including zip code), NAICS industrial sector, number of employees, and dummy variables indicating whether the plant exports or imports. SIEM does not include government-owned plants.

We then assigned, to each plant in the SIEM dataset, the percentage of plants certified in their declared NAICS sector, the fraction of plants inspected before the introduction of certificates in their NAICS sector, and the fraction of plants inspected after the introduction of certificates in their NAICS sector, as defined in section IV.1. The geographic coordinates of each of the plant's zip code were obtained from Postal Code World©, which provides geographic coordinates for the 2,737 zip codes in SIEM.

In order to assign a measure of certification at the zip-code level, we exploit the fact that the list of certificates indicates the municipality where certified plants are located. We then define certification at the zip code level as the total number of plants in each zip code's municipality that received a certificate, divided by the total number of plants in each zip code's municipality.

Air quality at the level of the zip codes was constructed using remote sensing sources. In particular, spectral data on reflectance from the Moderate Resolution Imaging Spectroradiometer (MODIS onboard the Terra Satellite) were acquired from the NASA's Goddard Space Flight

Center Earth Sciences Distributed Active Archive Center (DAAC). These data were used to construct daily measures of Aerosol Optical Depth (AOD) at a 5km spatial resolution for cloud-free areas over the whole of Mexican territory for the period between March 1st 2000 and December 31st 2006. AOD has been shown to be a very good predictor of levels of suspended particles in the atmosphere (Chu et al., 2002; Gupta et al., 2006; Kumar et al., 2007)[20]. An estimated measure of average AOD monthly (from March through December 2000 and 2006) levels for each zip code was constructed from the 5km pixel-level images. Using GIS technology, the observed measures of AOD from the satellite images were overlapped with the area around each of the zip codes. Daily measures of AOD were first calculated for each of the areas, and then the estimated AOD daily value for each zip code was averaged for each month in the sample, only considering those days for which we had an AOD measure. We then assigned ten measures of AOD for each year to each zip code, one for each month between March and December. Excluding months in which AOD could not be measured due to clouds, there were 20,445 observations of a possible 27,737 in 2,737 zip codes in which there were at least two observations for both pre and post years for the same calendar month.

Figure 4 shows a map of the calculated levels of AOD for the whole Mexican territory, in October, 2006. While AOD levels seem higher around metropolitan areas (Mexico City, Guadalajara and Monterrey), other regions of the country seem to show comparable levels of AOD. Location of polluting industries, or geographic conditions that could facilitate the accumulation of particulate matter in specific areas could explain this.

[20]These data have already made it possible to evaluate the effects of particulate matter concentrations on infant mortality for the whole Mexican territory (Gutierrez, 2010), as well as how the effects of the voluntary certification program studied in this paper have translated into reductions in infant mortality (Foster, Gutierrez and Kumar, 2009).

It is also known that weather conditions -particularly dew point and temperature- can influence satellite based measurement of AOD and its relationship with suspended particles and that the empirical relationship between the ground measurements of suspended particles and AOD can vary regionally, given that the composition of aerosols is different in each geographic region. We address these issues by focusing on changes in AOD levels within zip codes, and by adding monthly measures of the temperature and dew point in each zip code in the regressions. A map of the change in the logarithm of AOD between October 2000 and 2006 (the dependent variable in our empirical analysis of emissions) is presented in Figure 5.

The weather data were obtained from the US National Climatic Data Center, which publishes the Global Surface Summary of Day Data providing daily information for the 2000-2006 period for over one hundred weather stations spread around the Mexican territory. Average monthly values of the temperature and dew point were calculated for each weather station. A weighted average of a variable for each pixel in the map was assigned using weights that are an inverse function of the distance between that point and each of the points for which a measure of the variable exists (in this case, each of the weather stations). The mean monthly temperature and dew point for each zip code were then estimated by averaging over the interpolated data within each zip code's boundaries. Descriptive statistics for the zip code level variables are presented in Appendix Table 3.

V.2. The relationship between inspections, certification, and air quality.

In this section, we provide evidence at the zip-code level on : (1) whether certified firms have fewer emissions than otherwise compliant firms (2) whether regulator behavior in fact has an impact on air quality. To address these issues as well as to quantify the effect of certification on emissions we now turn to a direct assessment of changes in air quality. Note first that we do not observe compliance or d_{ij} at the plant level, and that we measure certification and air quality at the level of the zip code. This suggests the estimation of an equation of the following form using first differences

$$\overline{A}_{zt} = \kappa_t + \kappa_z + \kappa_D \overline{D}_{zt} + \kappa_P \overline{P}_{zt} + \kappa_c \overline{X}_{zt} + \kappa_W W_{zt} + e_{zt} \tag{30}$$

Where t={0,1} denotes pre and post certification, respectively, $\overline{A}_{zt}$ is a measure of air quality, κ_t and κ_z are time and zip code specific constants, $\kappa_D, \kappa_P, \kappa_C$ and κ_W are other constants, $\overline{D}_{zt}$, $\overline{P}_{zt}$ and $\overline{X}_{zt}$ denotes average certification, inspection, and firm characteristics, respectively, in zip code z and time t, and W_{zt} denotes weather. Note that $D_{z0} = 0$ because time 0 denotes pre-certification.

Interpretation of this specification is aided through the imposition of some simplifying assumptions: (1) that emissions among compliant firms are at the minimal compliant level (in terms of emissions per unit size), which is normalized to zero; (2) that emissions per unit size among non-compliant firms is related to the underlying cost structure according to $\phi_0 x_{zjt} e^{\phi_1 (C_j + d_{ij})}$ where x_{ztj} denotes firm size and assumes all firms in the same sector within a particular zip code are of the same size; and (3) that the composition of firms and idiosyncratic costs by sector and zip code are fixed over time. Under these conditions the change in the ln of expected emissions by sector, place and time, $\ln(E(A_{jzt}))$,

$$\Delta \ln(E(A_{jzt})) = -M(\theta - \phi_1)\Delta P_{zt} + \Delta \ln(x_{jzt}) + \Delta \kappa_t \tag{31}$$

Constructing the weighted (by the number of firms per sector) average of this expression across sectors within zip codes yields a restricted version of (30), with $\kappa_D = 0$, $\kappa_P = -M(\theta - \phi_1)$.

To implement (30) a weighted average of each of the variables in equation (30) is calculated for each zip code, using the total number of employees reported by each plant divided by the total number of employees in each zip code (the sum of the employees of all plants in the SIEM database in each zip code) as the weight for each of the observations. The dependent variable is the change in the log of AOD between 2000 (the first point in time for which we have information on the pollution concentration) and 2006. The regressions are then run at the zip code level. Given that we constructed a measure of monthly AOD in each zip code from our data, we pool all calendar months (from March through December), and run the regression including calendar month fixed effects and cluster the standard errors of the coefficients at the zip code level. Controls for the differences in the temperature and dew point in each zip code between 2000 and 2006 are also included.

V.2.1. Results

The results of the OLS regressions are presented in Table 7. Column 1 is the regression output for the change in AOD at the zip code level against the fraction of plants certified in each zip code's municipality and the weighted change in inspection probabilities given the sector composition of each zip code, controlling for size dummies (more than ten and more than 100 employees); Column 2 adds dummies indicating the weighted fraction of importing and exporting plants in each zip code; Column 3 additionally controls for weather conditions, and Column 4 includes an additional control for a weighted measure of plant size in each zip code.

As can be seen, the coefficient on certification is close to zero and insignificant for all specifications, regardless of the controls included, suggesting that certification is uncorrelated with changes in pollution concentration levels measured by AOD at the zip code level. This first result suggests that certification, as predicted by the restricted model (31), does not have an effect on plants' emissions. The coefficient on the change in inspection probabilities is negative, significantly different from zero, and consistent through all specifications. Changes in inspections in a particular zip code, which our model suggests are driven by local sectoral composition and differential rates of certification by sector are then correlated with reductions in emissions, again consistent with the predictions of the restricted model.

We now address potential problems with our estimates in Table 7. As certification at the zip code level is likely measured with error, the coefficient on the certification variable is likely to be biased towards zero. In addition, simply correlating certification with changes in pollution would not necessarily capture a causal relationship between these variables. For example, a plant experiencing an exogenous downward shock in its cost of compliance (d_{ij}) during the time period analyzed might have lower emissions and choose to certify. In this case, in an OLS regression, the certification coefficient in the emissions change regression would be negative, but the relationship would not be causal. This selection problem is of course common to all studies evaluating the direct effectiveness of voluntary programs.

In order to address these issues empirically, we augment the theory by assuming that the underlying cost of conducting a private audit varies across firms according to the degree of competition among nearby auditors and influences only the certification cost (e.g., it does not affect the cost of compliance without certification) and it does not affect emissions net of certification and/or compliance. This theoretical argument, along with the assumption that auditor´s location is exogenous with respect to *changes* in the cost of compliance, suggests the use of regional variation in the market supply of auditors available for certification as an instrument for certification in an assessment of the effects of certification on compliance.

In particular, from a data set including all 94 auditors accredited by PROFEPA, with information on their geographic location, we constructed estimates of the distance (in km) between each zip code and each of the three closest environmental auditing plants. The average distance to the first auditor is 56 kilometers, while that to the second is 81 kilometers and, to the third, 134 kilometers. Table 8 shows the OLS output of a regression of the fraction certified in each zip code against distance to the three closest auditors (and their squares). Only the coefficients for the instruments are reported, but each regression includes the same controls as the corresponding Columns in Tables 7 and 9. Although no clear economic intuition can be derived from the coefficients on each of the instruments, throughout specifications, the instruments are strong predictors of certification levels.

The instrumental variables regression results are presented in Table 9. The coefficient for certification at each zip code's municipality is in all cases positive. However, it varies greatly in magnitude across specifications and is never significantly different from zero. The coefficient on the change in inspection probabilities is still negative, significantly different from zero, and consistent through all specifications. The interpretation of the results shown in Table 7 is then robust to this instrumental variable analysis.

A further concern is that the negative effect of the change in the probability of inspection on emissions change may not be reflecting the consequences of increased certification in dirty sectors as posited by the model. For example, there may be a change in the regulator's strategy to allocate inspections to zip codes in which there is a decrease in the cost of emissions control for other reasons. More subtly there may be an exogenous change in inspection probabilities in certain industries that may lead to emissions reductions. It would be useful to know that in fact exogenous increases in inspections reduce emissions but this would have little to do with our model. What we would like to know is whether variation in inspections that arises from differences in certification costs are responsible for the observed negative effect.

We can address this concern by exploiting the arguably exogenous variation in certification costs given by the distance to auditors. Given the results presented in Table 8, we can compute a predicted fraction of plants certified in each zip code given their distances to the three closest auditors. And, given that we know, from the SIEM database, the declared NAICS sector of each of the firms in each zip code, we can use this information to calculate a predicted level of certification at the sector level, simply averaging the predicted certification rate for each firm in the SIEM database (given their zip code) within each sector. This variable will then capture differences in certification rates by sector, given the geographic distribution of auditors and firms across the Mexican territory, and can be used as an instrument for the change in inspections.

Table 10 presents first stage regression results with the change in inspections as the dependent variable, with the (weighted) calculated sector level certification as the explanatory variables. Again, only the coefficients for this instrument are reported, but each column corresponds to the regression including the same controls as the corresponding Columns in Tables 7, 9 and 11 and the distances to auditors included in Table 8. In all columns, the calculated sector-level certification rate has a strong positive predictive power on the change in inspections.

The instrumental variables regression results using both the distances to the three closest auditors and their squares, and the sector level predicted certification rate as instruments for certification and the change in inspections are presented in Table 11. As can be seen, when we instrument for the change in inspections, the negative coefficient becomes higher in absolute value, and remains negative and significantly different from zero, suggesting that increased inspections resulting from certification do lower pollution concentrations around plants. Combining the estimates from Tables 6 and 3, the Wald estimator suggests that a ten percent differential in certification arising from differences in the pre-certification inspection probability results in a 3 percent differential increase in inspection probability. Combining this number with the coefficients found in Table 11, a 10 percent increase in certification would imply a 4.5 percent decrease in AOD. The coefficient on certification, although it shows higher variation across specifications, remains not statistically different from zero.

VI. Conclusions

The specific focus of this paper has been on the effects on air quality of a voluntary pollution reduction program in Mexico. We develop and test a simple model of regulator and plant behavior that incorporates observable (to the regulator) sectoral variation in the cost of compliance with environmental regulations as well as unobserved variation in compliance costs within sectors. Our results suggest that those plants that certify are those with the lowest cost of compliance within sector and that certification provides an informational benefit that increases the efficiency of regulator's monitoring of plant behavior. The model is then used to structure an analysis of the effects of the certification on a measure of suspended particulates using the zip code as the level of analysis. Our analysis suggests that the program primarily had an indirect effect on air quality.

In addition to these conclusions this paper has some more general implications for the analysis of regulatory behavior. First, the results suggest that the voluntary certification programs can be an important tool for reduction of emissions in low and middle income countries. By shifting the cost of auditing to the plants while at the same time providing some sort of tangible benefit to the plants, the regulating agency can more efficiently target its limited resources and thus induce higher levels of compliance. In addition, the results from this paper suggest that a voluntary certification program can be designed in such a way that it is most attractive to those plants with a relatively low cost of compliance thus reducing the overall cost of achieving a given level of compliance.

Second, in examining the effects of particular programs it is important to keep in mind what other programs are in place and how their implementation of these other programs is likely to be affected by other policies. In the absence of a systematic scheme to monitor and fine non-compliant plants, the effects of the Clean Industry Certification program would likely have been quite different. By the same token the experience of Mexico might not readily generalize to other settings. Even in the presence of experimental variation in access to the certification program it would be difficult to interpret measured effects of the program without a clear understanding of the interaction of different types of policy tools. The presence of these indirect effects also has implications for the establishment an appropriate control group for evaluating emissions among those plants that choose to certify. In this particular case, for example, the behavior of uncertified plants in terms of level of compliance is importantly affected by the presence of the certification program as a result of the endogenous response from the regulator.

Third, our results suggest that remotely sensed measures of air quality can provide a useful tool for the evaluation of emissions regulations in developing countries. As noted, few low and middle income countries have systematically collected ground level data on emissions. These countries also in general lack the capacity to monitor emissions of more than a small fraction of plants, particularly given the presence of a large informal and small-scale manufacturing sector. This lack of data, which is an important constraint for those wishing to control plant emissions and/or to implement a system for trading permits, also presents a problem for the evaluation of alternative programs. The technology for the processing of remote images to construct measures of AOD is still in infancy and much needs to be done over time to both evaluate and improve the accuracy of these measures. But the present work adds to a growing body of evidence that suggests that the technology has a great deal of potential.

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VIII. Tables.

Table 1

Select Sectors with Low and High Inspection and Certification Intensity

LowInspection/LowCertification	High Inspection/High Certification
Natural fibers	Syntheticfibers
Wine	Beer
Shoes	Explosives
Printing	InkforPrinting
WoodenFurniture	Paint
Office Supplies	CleaningProducts
Paper	Glue
Coffee/Tea Industry	Pharmaceuticals
Chocolates	EdibleOil
WoodenConstructionSupplies	Cement

Table 2

Determinants of non-Compliance at the Sector Level Dependent variable: Log of the fraction of inspections resulting in non-compliance pre certificates				
	OLS	IV	IV	IV
Log Fraction Inspected (92-95)	-0.0028	-0.01959	-0.01714	-0.00571
	[0.00668]	[0.01605]	[0.01725]	[0.01985]
Percentage of production exported			0.00017	0.00011
			[0.00012]	[0.00012]
Employees per firm			0	-0.00007
			[0.00013]	[0.00013]
Sector Fixed Effects	No	No	No	Yes
Constant	-0.21027	-0.24901	-0.25283	-0.20081
	[0.01941]***	[0.03894]***	[0.04732]***	[0.07014]***
Observations	160	160	160	160

Standard errors in brackets

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 3

Determinants of Certification Dependent variable: Log of 1+ the fraction of firms Certified				
	OLS	IV	IV	IV
Log Fraction Inspected (92-95)	0.29362	0.9707	0.8884	0.94618
	[0.04131]***	[0.15987]***	[0.15849]***	[0.19642]***
Percentage of production exported			-0.0019	-0.00133
			[0.00113]*	[0.00123]
Employees per firm			0.00195	0.00211
			[0.00115]*	[0.00124]*
Sector Fixed Effects	No	No	No	Yes
Constant	1.72074	3.28258	3.04824	3.49088
	[0.11997]***	[0.38773]***	[0.43479]***	[0.69402]***
Observations	160	160	160	160

Standard errors in brackets

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 4

Determinants of non-Compliance (2003-2006) at the Sector Level

Dependent variable: Log of the fraction of inspections resulting in non-compliance post certificates

	OLS	IV	IV	IV
Log Fraction Inspected (92-95)	0.00746	0.0348	0.03359	0.04886
	[0.01125]	[0.02699]	[0.02905]	[0.03493]
Percentage of production exported			-0.00026	-0.00032
			[0.00021]	[0.00022]
Employees per firm			-0.0001	-0.00018
			[0.00021]	[0.00022]
Sector Fixed Effects	No	No	No	Yes
Constant	-0.39606	-0.33299	-0.31443	-0.24022
	[0.03267]***	[0.06545]***	[0.07969]***	[0.12342]*
Observations	160	160	160	160

Standard errors in brackets
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 5

Sector Level variables by Pre Certificates Inspection Probability (quartiles)

Quartile Inspection Intensity pre certificates	Range Fraction Inspected 92-95	Fraction Non Compliance 92-95	Fraction Non Compliance 03-06	Fraction Certified
1	Less than 2%	0.84	0.50	0.04
2	2-10%	0.79	0.65	0.03
3	10-30%	0.81	0.65	0.06
4	More than 30%	0.83	0.67	0.10

Table 6

Change in Log Inspection Probabilities (1992-1995 to 2003-2006)						
	Around the Introduction of Certificates					Pre-certificates (92-95 to 95-96)
	OLS	IV	IV	IV	IV	IV
Log Fraction Inspected (92-95)	-0.2372	0.396	0.3645	0.3865	0.3893	0.017
	[0.0558]***	[0.1770]**	[0.1876]*	[0.2259]*	[0.2269]*	[0.1204]
Percentage of production exported			-0.0015	-0.0013	-0.0014	-0.0009
			[0.0013]	[0.0014]	[0.0014]	[0.0008]
Employees per firm			0.0003	0.0003	0.0004	0.0004
			[0.0014]	[0.0014]	[0.0014]	[0.0008]
Log 1+ Fraction Fined (92-95)					0.5002	1.3512
					[0.9224]	[0.4895]***
Sector Fixed Effects	No	No	No	Yes	Yes	Yes
Constant	-1.0713	0.3893	0.3751	0.5355	0.6359	-0.2978
	[0.1620]***	[0.4293]	[0.5147]	[0.7980]	[0.8242]	[0.4374]
Observations	160	160	160	160	160	160

Standard errors in brackets

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 7

OLS Regression Results				
Dependent Variable: Change in Log AOD between 2000 and 2006				
Fraction Certified	-0.093	-0.04	-0.116	-0.138
	[0.282]	[0.287]	[0.285]	[0.286]
Change in Inspections	-0.044	-0.048	-0.046	-0.046
	[0.026]*	[0.026]*	[0.026]*	[0.026]*
More than 10 Employees	0.008	0.014	0.016	-0.013
	[0.018]	[0.017]	[0.018]	[0.023]
More than 100 Employees	-0.023	-0.007	-0.004	-0.037
	[0.018]	[0.019]	[0.020]	[0.026]
Importing		-0.045	-0.052	-0.056
		[0.019]**	[0.019]***	[0.019]***
Exporting		-0.002	0	-0.005
		[0.019]	[0.019]	[0.019]
Difference in Temperature			0.019	0.019
			[0.002]***	[0.002]***
Difference in Dew Point			-0.005	-0.005
			[0.001]***	[0.001]***
Size				0.015
				[0.007]**
Constant	-0.259	-0.255	-0.235	-0.247
	[0.011]***	[0.011]***	[0.012]***	[0.013]***
Observations	20445	20445	20445	20445
R-squared	0.07	0.07	0.07	0.07

Robust standard errors clustered at the zip code level in brackets

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 8

First Stage Regression Results

Dependent Variable: Fraction Certified

Distance to First Auditor	0.002	0.002	0.002	0.002
	[0.002]	[0.002]	[0.002]	[0.002]
Distance to Second Auditor	-0.008	-0.008	-0.008	-0.008
	[0.002]***	[0.002]***	[0.002]***	[0.002]***
Distance to the Third Auditor	0.008	0.008	0.007	0.007
	[0.001]***	[0.001]***	[0.001]***	[0.001]***
Distance to First Auditor Squared	0	0	0	0
	[0.001]	[0.001]	[0.001]	[0.001]
Distance to Second Auditor Squared	0.002	0.002	0.002	0.002
	[0.000]***	[0.000]***	[0.000]***	[0.000]***
Distance to the Third Auditor Squared	-0.002	-0.002	-0.002	-0.002
	[0.000]***	[0.000]***	[0.000]***	[0.000]***
Observations	20445	20445	20445	20445
R-squared	0.04	0.05	0.05	0.05

Robust standard errors clustered at the zip code level in brackets

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 9

IV (LIML) Regression Results Endogenous variable: Fraction Certified Instruments: Distance (and square distance) to closest three auditors Dependent Variable: Change in Log AOD between 2000 and 2006				
Fraction Certified	0.546	0.164	0.856	0.477
	[2.039]	[2.007]	[2.187]	[2.174]
Change in Inspections	-0.044	-0.049	-0.047	-0.046
	[0.026]*	[0.026]*	[0.026]*	[0.026]*
More than 10 Employees	0.008	0.014	0.016	-0.012
	[0.018]	[0.017]	[0.018]	[0.023]
More than 100 Employees	-0.026	-0.008	-0.007	-0.038
	[0.020]	[0.020]	[0.021]	[0.026]
Importing		-0.046	-0.052	-0.057
		[0.019]**	[0.019]***	[0.019]***
Exporting		-0.003	-0.003	-0.006
		[0.020]	[0.020]	[0.020]
Difference in Temperature			0.019	0.019
			[0.002]***	[0.002]***
Difference in Dew Point			-0.005	-0.005
			[0.001]***	[0.001]***
Size				0.015
				[0.007]**
Constant	-0.264	-0.256	-0.243	-0.252
	[0.019]***	[0.019]***	[0.022]***	[0.022]***
Observations	20445	20445	20445	20445
Kleibergen-Paap rk LM statistic:	84.658	82.969	87.625	82.386
Kleibergen-Paap rk Wald F statistic:	10.436	10.27	11.109	10.607
Stock-Yogo weak ID test critical values:				
10% maximal LIML size	4.45	4.45	4.45	4.45
15% maximal LIML size	3.34	3.34	3.34	3.34
20% maximal LIML size	2.87	2.87	2.87	2.87
25% maximal LIML size	2.61	2.61	2.61	2.61
Hansen J statistic:	43.517	47.053	50.138	48.777

Robust standard errors clustered at the zip code level in brackets

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 10

First Stage Regression Results

Dependent Variable: Change in Inspections

Predicted Sector-Level Certification	14.257	14.049	13.94	13.961
	[4.138]***	[4.169]***	[4.176]***	[4.216]***
Observations	20445	20445	20445	20445
R-squared	0.03	0.03	0.03	0.03

Robust standard errors clustered at the zip code level in brackets

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 11

IV (LIML) Regression Results Endogenous variables: Fraction Certified and Change in Inspections Instruments: Distance (and square distance) to closest three auditors and predicted certification at the sector level Dependent Variable: Change in Log AOD between 2000 and 2006				
Fraction Certified	3.568	3.294	3.49	3.284
	[2.729]	[2.766]	[2.950]	[2.942]
Change in Inspections	-1.347	-1.435	-1.597	-1.576
	[0.321]***	[0.340]***	[0.358]***	[0.355]***
More than 10 Employees	-0.013	-0.003	-0.002	-0.019
	[0.024]	[0.024]	[0.025]	[0.034]
More than 100 Employees	-0.051	-0.024	-0.024	-0.043
	[0.028]*	[0.029]	[0.030]	[0.038]
Importing		-0.098	-0.11	-0.111
		[0.033]***	[0.035]***	[0.035]***
Exporting		0.02	0.024	0.022
		[0.030]	[0.033]	[0.032]
Difference in Temperature			0.017	0.017
			[0.003]***	[0.003]***
Difference in Dew Point			-0.007	-0.007
			[0.002]***	[0.002]***
Size				0.009
				[0.012]
Constant	-0.332	-0.325	-0.31	-0.315
	[0.030]***	[0.030]***	[0.033]***	[0.032]***
Observations	20445	20445	20445	20445
Kleibergen-Paap rk LM statistic:	53.009	48.449	49.072	49.459
Kleibergen-Paap rk Wald F statistic:	4.869	4.5	4.731	4.705
Stock-Yogo weak ID test critical values:				
10% maximal LIML size	3.9	3.9	3.9	3.9
15% maximal LIML size	2.83	2.83	2.83	2.83
20% maximal LIML size	2.52	2.52	2.52	2.52
25% maximal LIML size	2.35	2.35	2.35	2.35
Hansen J statistic:	10.327	10.171	9.287	9.145

Robust standard errors clustered at the zip code level in brackets

* significant at 10%; ** significant at 5%; *** significant at 1%

Figure 1

Regime 1. $\mu + \alpha C < C$, $\beta > 1$.

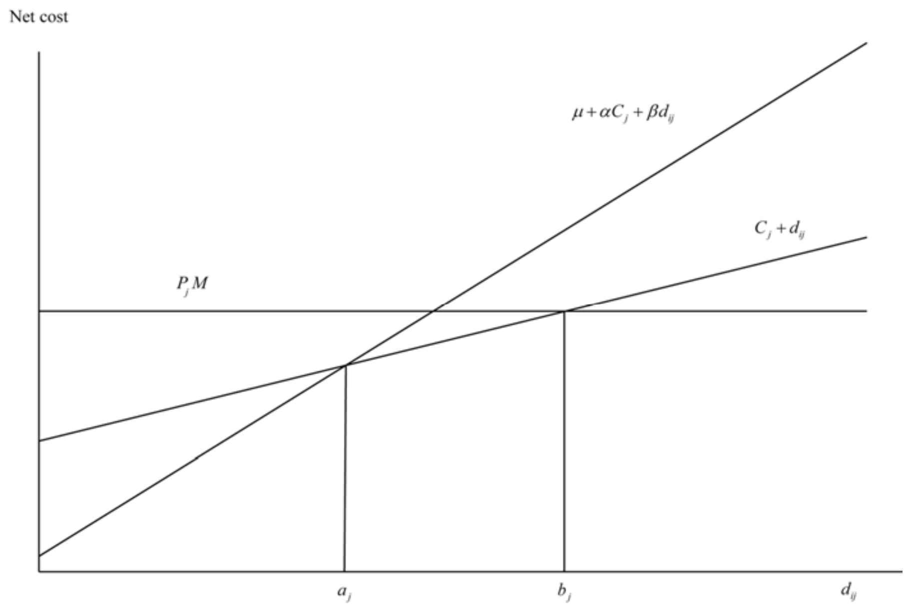


Figure 2

Regime 2: $\mu + \alpha C > C$, $\beta < 1$.

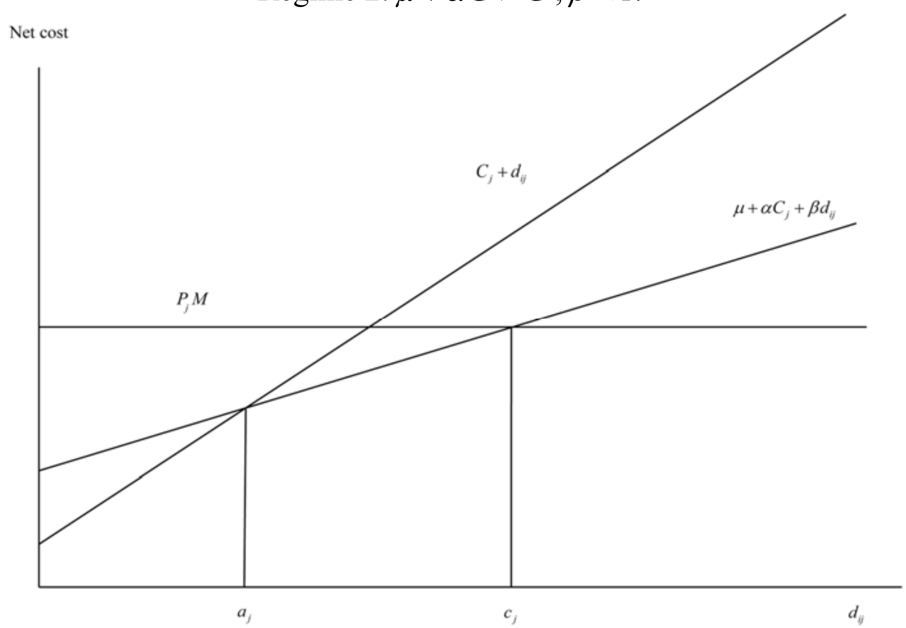


Figure 3

Regime3. $\mu + \alpha C > C$, $\beta < 0$.

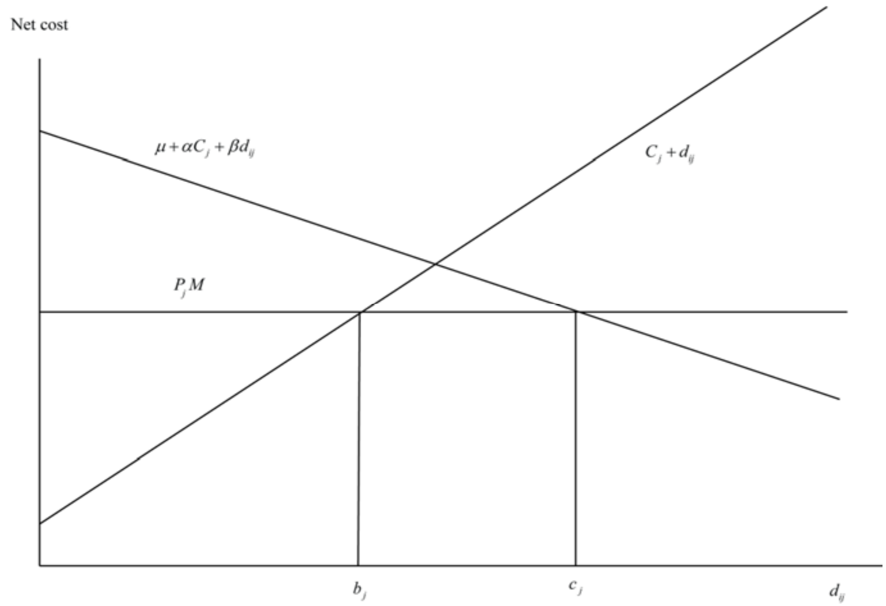


Figure 4

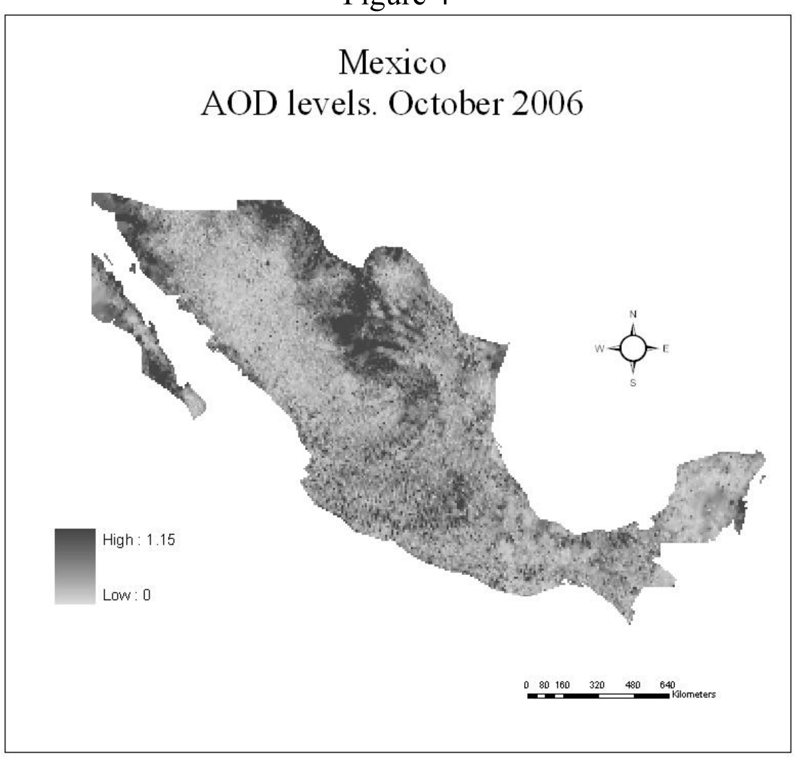
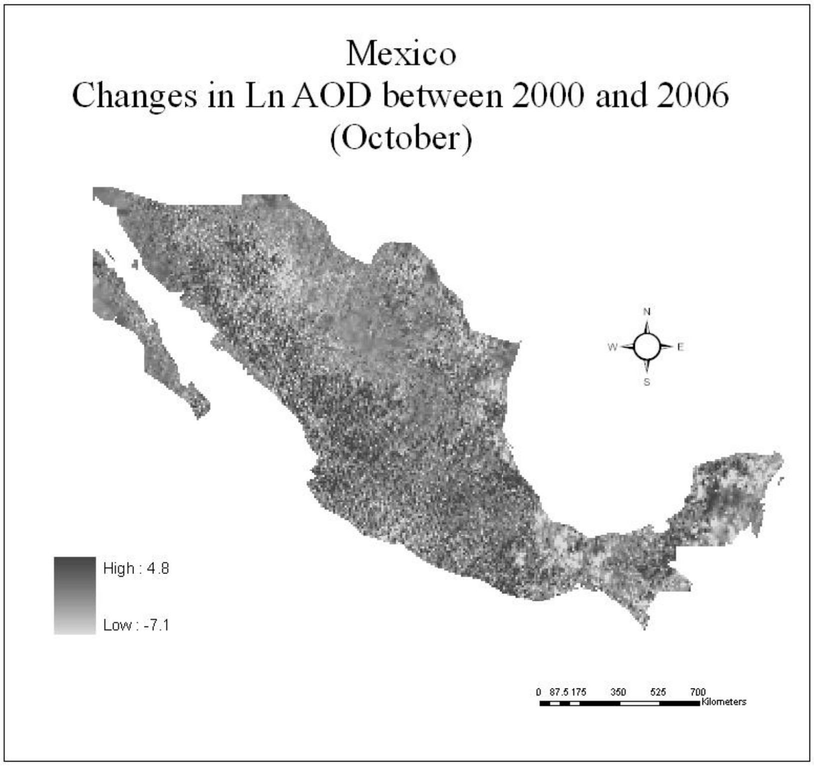


Figure 5


Mexico
Changes in Ln AOD between 2000 and 2006
(October)
N
W
E
S
High : 4.8
Low : -7.1
0 87.5 175 350 525 700
Kilometers

Appendixes (Not for Publication)

Appendix I. Incorporating corruption.

Corruption can take different forms. First, plants can avoid to pay the fine set by the legal system in case they are found to be in non-compliance by paying the inspector some given sum of money (strictly lower than the fine). In the model, however, as long as the probability of corruption is the same for all firms in the economy, this would simply mean that the value of M is strictly lower than the one set by the legal system, and the theoretical predictions of the model would not change substantially. Stronger assumptions have to be made, however, for our empirical analysis to be consistent with a setting in which this type of corruption is possible. As we observe the total fraction of inspections resulting in non-compliance reported by the authorities, inspected plants that avoid being declared as non-compliant by bribing the inspectors, would not be counted in our measure of non-compliance. Our empirical analysis needs then to assume that there is a constant probability that a given plant (regardless on which industrial sector it belongs to), if inspected and found in non-compliance, is unable to corrupt the authorities.

Another possible form of corruption is extortion: inspectors might be able to threaten a compliant plant to declare it as non-compliant every time it is inspected, unless the plant pays some bribe E. In this case, the cost equation for a plant to be in compliance with no certificate would be:

$$C_{ij}^{1b} = C_j + d_{ij} + P_j * E$$

Where E is the amount that the plant has to pay to be declared in compliance when inspected and it is complying, and P_j is the probability of being inspected. It is easy to see that, as E increases, compliance goes down. However, E imposes an extra incentive for plants to get certified, as they are exempt from inspections (in the context analyzed), and thus from paying *E* to inspectors. The conditions for the identification of regime derived in section III.3 are consistent with the conditions derived from a model incorporating this form of corruption.

Finally, there can be corruption in the certification process. Plants might be able to pay some fixed amount *G* in order to be given a certificate when in non-compliance. However, auditors need to be licensed by authorities. Moreover, although plants are exempt from random inspections if certified, they are still subject to inspections in case other agents in the economy file a complaint to the authorities. As a smaller number of auditors is likely to imply higher monopoly power to certified auditors, each auditor has incentives to file complaints about firms that have been certified by their competition, expecting the authorities to take the license away from corrupt auditors. Thus, we believe that a model that ignores this type of corruption is well suited for the specific context analyzed.

Appendix II. A more explicit model for certification costs.

The purpose of this appendix is to suggest why within-sector differences in costs of compliance may lead to larger differences in certification costs ($\beta > 1$), even though certification costs focus on the same emission targets. The premise of this model is that although the certification process generally results in mandated upgrades to capital, compliance in the absence of certification can be achieved through adjustment along other margins and, in particular, through reductions in output. This insight rests on the fact that legal targets are set in terms of emissions per unit of plant capacity.

We model variation in compliance cost within sector (the *d* component) as driven by differences in the share of "green" capital. Suppose, in particular, that a plant that only uses capital in production and has a 1-*f* share of green capital that produce emissions of 1 per unit capital and an *f* share of dirty capital that produces emissions of *e* per unit of capital with *e*>1. Suppose further that the regulations indicate that emissions per total capital must be less than *n* where *n*>1, and that capital and product markets are sufficiently competitive that the marginal revenue product *p* of a unit of capital is equal to the interest rate *r*. Finally, assume that given *e* and *n*, *f* is sufficiently high that the firm is not in compliance with the regulatory standard if it produces at full capacity.

It is now clear that the firm can be in compliance if it uses only a fraction *d1* of its dirty capital where (1-*f*)+*d1***f***e*=*n*. Solving for *d1* this costs it *p**(*f**(1-1/*e*)-(*n*-1)/*e*) in lost value of output per unit of total capital per period. The discounted cost of an infinite stream of lost earnings is this figure divided by *r*. A unit increase in f thus results in an increase of (*e*-1)/*e*<1 in the cost of compliance.

Conversely, the firm can be in compliance if it replace a fraction $d2$ of its dirty capital with clean capital where $(1-f)+d2*f+(1-d2)*f*e=n$ and produces at full capacity. This change costs $f-(n-1)/(e-1)$ in replacement capital per unit of total capital. A unit of increase in f in the capital conversion case thus results in a unit increase in the cost of compliance but a less than unit increase in the cost of compliance for output reduction. Intuition maybe gained from the case of $e=2$ and $n=1$. Note that for capital conversion case all dirty capital must be converted so the cost is f. But because of the way limits are set, with output reduction, one can continue to use half of the dirty capital and still meet the standard so the cost is $f/2$

In general a firm choosing to comply will choose the cheaper of the two avenues of compliance. But the two cost lines cross at zero and thus for the range of f for which the firm is not initially in compliance $f>(n-1)/(e-1)$, reducing output will always be cheaper than converting capital. However if certification leads to a sector specific net reduction in cost ($\alpha < 1$) and must result in the use of the capital upgrading mode of compliance then certification will be the lower cost choice for the lowest cost firms and compliance without certification the lowest cost choices for intermediate cost firms.

Appendix Tables and Figures

Appendix Table 1

Sector Level Descriptive Statistics

	Obs	Mean	Std. Dev.
Percentage Certified	160	5.1	14.5
Percentage Inspected 92-95	160	31.9	67.4
Percentage inspected 95-96	160	16.3	31.5
Percentage inspected 03-06	160	18.0	36.7
Percentage Fined 92-95	160	81.8	12.5
Percentage Fined 03-06	160	61.8	55.2
Number of Establishments	160	2128	6590
Number of Employees	160	24575	44548
Scale	160	74.9	125.8
Percentage of Production Exported	160	31.9	35.3

Appendix Table 2

First Stage Regression Results: Inspection Probabilities pre Certificates

Dependent variable: Log Fraction Inspected (92-95)

	OLS	OLS	OLS	OLS
Log Fraction Inspected USA	2.64508	2.52734	2.30234	2.30184
	[0.44868]***	[0.45024]***	[0.47947]***	[0.48116]***
% production exported		0.00162	0.00096	0.00096
		[0.00129]	[0.00133]	[0.00134]
Employees per firm		0.00253	0.00229	0.00228
		[0.00111]**	[0.00112]**	[0.00113]**
Log non-compliance pre certificates				-0.03809
				[0.84942]
Sector Fixed Effects	No	No	Yes	Yes
Constant	-3.09685	-3.33821	-3.64844	-3.6553
	[0.18470]***	[0.19607]***	[0.25284]***	[0.29616]***
Observations	160	160	160	160

Standard errors in brackets

* significant at 10%; ** significant at 5%; *** significant at 1%

Appendix Table 3

Zip-Code Level Descriptive Statistics

Variable	Obs	Mean	Std. Dev.
Change in Log AOD from 2000-2006	2735	-0.25	0.50
Log AOD in 2000	2735	-1.28	0.71
Fraction Certified	2735	0.01	0.02
Change in Inspections from 92-95 to 03-06	2735	-0.05	0.16
Fraction More than 10 employees	2735	0.47	0.45
Fraction More than 100 employees	2735	0.32	0.43
Fraction Importing	2735	0.27	0.38
Fraction Exporting	2735	0.20	0.35
Average Difference in Temperature	2735	-0.24	1.75
Average Difference in Dew Point	2735	2.26	4.76
Employees per firm	2735	2.62	1.92
Predicted Sector-Level Certification	2735	0.010	0.001
Distance to Closest Auditor (100 km)	2735	0.56	0.78
Distance to Second Closest Auditor (100 km)	2735	0.81	0.96
Distance to Third Closest Auditor (100 km)	2735	1.34	1.48