

Title: Voluntary Compliance, Pollution Levels, and Infant Mortality in Mexico.

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Voluntary Compliance, Pollution Levels, and Infant Mortality in Mexico

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The increasing body of evidence from high-income countries linking pollution to health outcomes (Ken Chay and Michael Greenstone, 2003; Janet Currie and Mathew Neidell, 2004), has raised concerns about the health impact of adverse air quality in developing countries, where, in general, environmental regulation is less stringent and health monitoring and treatment are less accessible. These concerns have, in turn, encouraged consideration of the effectiveness of alternative mechanisms for improving air quality while limiting the adverse impact on economic growth. However, the analysis of both the effects of pollution on health and the effectiveness of pollution abatement policies faces particular empirical challenges in low and middle-income contexts, given the scarcity of reliable measures of pollution concentrations. The primary source of good quality data on air quality, ground monitoring, tends to be limited to larger metropolitan areas with monitors being placed at sentinel sites that may or may not yield a representative picture of population exposure.

This paper calls attention to, and makes use of, newly available procedures for extracting measures of air quality from satellite imagery. In particular, satellite-based measures of aerosol optical depth (AOD) are used to obtain estimates of air quality for the whole Mexican territory at a detailed geographic scale, and these estimates are related to measures of participation in the certification program at the level of the county. The resulting estimates are then combined with estimates of the relationship between participation in the certification program and infant mortality due to respiratory causes to obtain a rough estimate of the relationship between air quality and infant health in Mexico.

II. Voluntary Certification.

The Mexican Clean Industry Program (Programa de Industria Limpia), introduced in 1997, is the main voluntary pollution reduction program in Mexico. Plants participating in this program have to pay for an audit by an independent agency on a list maintained by the Mexican Environmental Protection Agency (PROFEPA) that determines the actions that need to be taken in order to make the plant compliant with the pollution emissions standards. 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 is exempt from inspections for two years. Between 1997 until 2007, 2,568 firms received this certification.

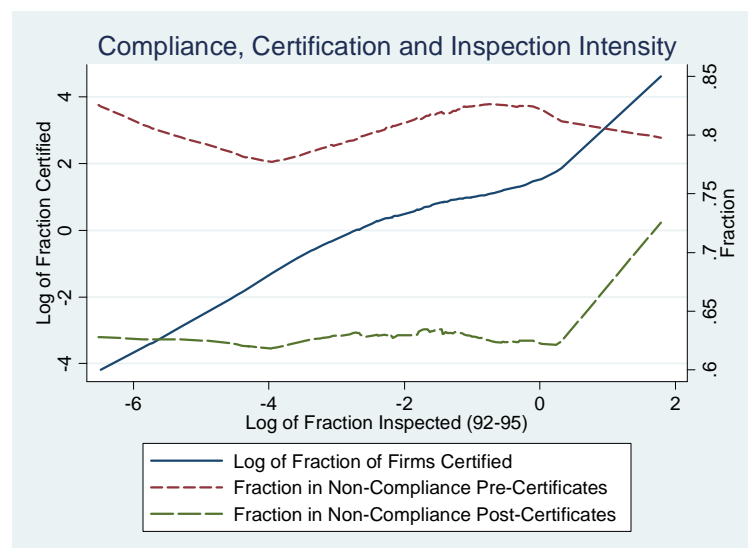
Voluntary pollution reduction programs are increasingly being used to encourage firms to reduce their emissions levels in both the developed and developing worlds. Their emergence has been followed by a growing body of literature trying to evaluate their effectiveness, which has primarily focused on industrialized countries (Martina Vidovic and Neha Khanna, 2007). The US Environmental Protection Agency 33/50 program has received most of the attention in the literature (Abdoul G Sam and Robert Innes. 2006). The only study, to our knowledge, that looks directly at the Mexican Clean Industry Program (Allen Blackman et al., 2007), which is the focus of the present paper, claims that the program is contributing to reductions in pollution emissions by firms, but lacks of a concrete measure of air quality.

This paper examines the effects of the certification program in the Clean Industry Program in Mexico on air quality and infant health. The identification and interpretation of these effects is, of course, dependent on the development of an appropriate framework that characterizes both the certification process and the process governing government environmental audits that interacts

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importantly with certification. Andrew Foster and Emilio Gutierrez (2008) develops and tests a model of these processes in which firms choose certification, compliance without certification, or non-compliance and regulators choose inspection probabilities by sector given firm behavior and variation across sectors in the cost of compliance. The model in that paper captures three important features of the data on certification and compliance for Mexico over the relevant time period that is illustrated in Figure 1. In particular, there is substantial variation across sectors in Mexico in the fraction of firms that are inspected and this fraction predicts well the probability of certification but is not significantly related to the probability that an inspected firm is found to be compliant either before or after the introduction of certification.

Figure 1



The model also yields implications for identification. In particular, it establishes that the fraction of all firms in a particular sector that are compliant with Mexican air quality regulations, inclusive of those undertaking voluntary certification, depends only on the shape of the distribution of unobserved costs of compliance within sector, the regulator's perceived benefit of having compliant firms and cost of inspection, and the fraction of firms certified in that sector. Moreover

the distribution shape, perceived costs, and perceived benefits of inspection do not vary systematically with the sector-level average cost of compliance. Thus under a plausible set of conditions the underlying costs of conducting a private audit predict certification but do not predict compliance net of certification. This theoretical argument justifies 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.

III. Data.

As stated, this paper puts together a newly available dataset that includes measures of air quality for the whole Mexican territory, meteorological conditions, information from the 2000 and 2005 Mexican Industrial Censuses at the municipality level, a list of firms that have been granted a Clean Industry Certificate (including the municipality where they are located) provided by PROFEPA, a list of certified auditors (with their address) provided as well by PROFEPA, and infant mortality records by cause of death at the municipality level, provided by the Mexican Statistics Institute (INEGI). Our final panel includes monthly information (from March through December) on AOD levels, respiratory mortality, economics conditions (yearly), births, temperature and dew point for 1,706 municipalities for 2000 and 2006.

The air-quality data come from satellite-based sensors that record electromagnetic radiation that is reflected from the earth surface. Because this radiation interacts with the aerosols (fine solid and liquid particles) present in the atmosphere between the earth and the sensor, the resulting data can be converted into a measure of aerosol optical depth (AOD) with the aid of radiative transfer models (Lorraine Remer et al., 2006). The resulting estimates have been shown to be good predictors of particulate matter of different sizes (sizes ($<2.5\mu\text{m}$ and $10\mu\text{m}$, $\text{PM}_{2.5}$ and PM_{10} , respectively) (D Allen Chu et al., 2002; Pawan Gupta et al., 2006; Naresh Kumar et al.,

2007). The AOD estimates used in this paper were constructed at a spatial resolution of 5km using data from the MODerate-resolution Imaging Spectroradiometer (MODIS) onboard the Terra Satellite (NASA 2007). The images are available on a global basis since February 2000, when the satellite became operational.

An estimated measure of average AOD monthly levels for each zip code was constructed from the 5km pixel-level images to match the spatial resolution of other datasets. Using GIS, the observed measures of AOD from the satellite images were overlapped with the area around each of the municipality's capitals. Daily measures of AOD were first calculated for each of the areas (an unweighted average of all AOD measures in the area in each given day), and then the estimated AOD daily value for each municipality was averaged for each month in the sample.

The relationship between AOD and PM is likely to vary with meteorological conditions and other site specific variables such as surface cover. Our empirical strategy addresses these issues by focusing on changes in AOD levels within municipalities, and adding monthly measures of the temperature and dew point in each municipality to the regressions. The meteorological data were obtained from the US National Climatic Data Center, which publishes the Global Surface Summary of Day Data. This dataset provides daily information for the 2000-2006 period for over one hundred weather stations spread around the Mexican territory. The average monthly values of the temperature and dew point calculated for each weather station were interpolated using an inverse distance weight for the whole Mexican territory. The mean monthly temperature and dew point for each municipality were then estimated by averaging over the interpolated data within each municipality's boundaries.

The infant mortality data is published by the Mexican statistics office, INEGI. The dataset is constructed from death certificate records and includes all registered monthly deaths of children

aged less than 12 months at the time of death, by cause of death and mother’s municipality of residence, until December 2006. We use the information on total infant deaths due to respiratory diseases in each month in each municipality as our dependent variable. The regression results also consider the total number of deaths due to external causes as a dependent variable as a kind of falsification test. We also obtained information on the total number of registered births in 2000 and 2006 by mother’s municipality residence.

From the Mexican Industrial Census of 2000 and 2005, we obtained the total number of establishments and total number of employees in each municipality in each year. Finally, PROFEPA provided a list of all firms that were granted a Clean Industry Certificate from 1997 until 2006, indicating the municipality in which they are located. Our primary explanatory variable of interest is the fraction of the total firms in the 2000 Mexican Census that received a Clean Industry Certificate (total number of certified firms in each municipality, divided by the total number of plants in each municipality in the 2000 census).

Table 1

Descriptive Statistics Municipality Level Variables		
	Mean	Std. Dev.
Infant mortality due to respiratory diseases	0.157	0.649
Infant mortality due to external causes	0.070	0.299
AOD	0.222	0.111
Fraction of Firms certified	0.005	0.019
Births	850.8	2405.0
Temperature (F)	70.6	5.6
Dew Point (F)	55.4	10.9
Employees	7502	32911
Establishments	1534	4875

Table 1 shows descriptive statistics for our sample. There are approximately 2,400 municipalities in Mexico. However, the sample is restricted to 1,706 municipalities, for which The Mexican Census provides information on the number of firms and employees. On average, in 2000, there were 0.16 infant deaths due to respiratory diseases and 0.07 deaths due to external causes in each Mexican municipality. 851 births are reported in average in each municipality in

each year. Municipalities have, in average, 1534 establishments and 7502 employees, while slightly more than 0.5 percent of establishments in each municipality have received a Clean Industry Certificate. It is worth noting, however, that the percentage of firms certified is likely to be an underestimate of the actual certification intensity. While we do not directly observe the size of certified firms or the size of each of the firms in the Industrial Censuses, it is known that large firms are more likely to receive a certificate than smaller ones. Thus we control for municipality level economic variables, such as total number of establishments and employees (and their log), this fact will be relevant when interpreting the empirical results.

As stated before, our empirical strategy uses variation in local competition between auditors as an instrument for certification. 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 municipality's capital and each of the five closest environmental auditing firms.

IV. Empirical Strategy.

Our analysis measures differences in changes in the outcomes of interest in municipalities where a higher number of firms received a Clean Industry Certificate relative to those where no firms received such certification. Specifically, the empirical specification is:

$$Y_{it} = \alpha_i + \beta_1 TC_i + \beta_2 T + \sum_k \delta_k X_{itk}^1 + \sum_k \gamma_k X_{itk}^2 T + \varepsilon_{it}$$

where Y_{it} is the outcome of interest in municipality i in period (month) t (the measured level of AOD, the infant mortality level due to respiratory diseases, and the infant mortality level due to external causes); the α_i are municipality fixed effects; T is a dummy variable equal to one for all observations in the year 2006; C_i is a variable indicating the fraction of firms in each municipality that received a Clean Industry Certificate; X_{itk}^1 are a set of control variables for each

municipality i in each period t , including the total number of establishments (and its log), the total number of employees (and its log), as well as the measures of temperature and dew point calculated for each of them (the 2005 industrial census information was assigned to the 2006 observations); the X_{ik}^2 are a set of municipality level variables, including, depending on the specification, the levels of respiratory mortality and AOD in 2000, the number of employees (and its log), number of plants (and its log) in the 2000 census in each municipality; and. ε_{it} is an error term. The coefficient of interest is β_1 , which captures the change in the outcome between 2000 and 2006 for municipalities with a fraction C of certified firms relative to that in areas with no certified firms.

V. Results.

The first stage regression results are excluded from this version of the paper due to space constraints. Distance variables strongly predict certification with the joint F on these variables being 12.0. Interestingly, we find that increased distance to the nearest auditor results in *higher* certification while distance to other auditors results, for the most part, in *lower* certification. Given a simple model of Cournot competition in which distance increases the marginal cost of serving a particular area, the positive coefficient on distance to the nearest firm is a bit surprising. The pattern can, however, be easily generated by model in which there are fixed costs of entry and entry is endogenous. In particular, when the close firm has a sufficiently large cost advantage due to its relative proximity, the other firms do not enter the market, thus allowing the close firm to obtain monopoly rents by curtailing supply.

Results using AOD as the dependent variable are presented in Table 2. Column 1 shows the simple difference in differences estimator when only adding municipality and calendar month fixed effects. Column 2 adds the interaction between month and year and the measures of

temperature and dew point as controls. Column 3 includes the total number of establishments and employees (and their logs), as well as the values of these variables in the 2000 census interacted with the year dummy, and Column 4 includes the measure of the outcomes (AOD and respiratory mortality level) in the baseline month interacted with the year dummy as controls. Column 5 shows the IV estimates. As can be seen, the coefficient of the interaction of the fraction of firms certified and the year dummy, for all specifications (except the instrumental variables specification), is negative and significant at the 5% level, ranging from -0.17 to -0.14, depending of the control included in the regression. The IV estimate in Column 5 is around eight times higher than the OLS one. This larger result may be reflective of measurement error—while certification is well measured we suspect, given the nature of the data on firm locations we suspect that the denominator of the certification rate is quite noisy. An alternative explanation is that this result arises from a heterogeneous treatment effect: the model in Foster and Gutierrez (2008) suggests that firms with an intermediate unobserved (to the regulator) cost of compliance will be both more sensitive to variation in auditor cost and more likely to alter emissions after the introduction of certification than are those firms with either low or high costs of compliance. In any case, taking this IV estimate at face value, because the average fraction of firms certified at the level of the zip code is .005, one may estimate that certification lead roughly to a 3.6 percent improvement in AOD.

Table 2

Regression Results. Changes in Pollution and Certification Intensity at the Municipio Level					
Dependent Variable: AOD	1-OLS	2-OLS	3-OLS	4-OLS	5-IV
Fraction Certified*2006	-0.171 [0.071]**	-0.159 [0.070]**	-0.141 [0.070]**	-0.164 [0.073]**	-1.366 [0.408]***
Year	-0.062 [0.001]***				
Other Controls					
Log Births	Y	Y	Y	Y	Y
Municipality FE	Y	Y	Y	Y	Y
Month FE	Y				

Month*Year FE		Y	Y	Y	Y
Weather		Y	Y	Y	Y
Economic			Y	Y	Y
Baseline Economic*2006			Y	Y	Y
Baseline Outcomes*2006				Y	Y
Constant	0.234	26.463	25.299	31.499	29.465
	[0.018]***	[0.678]***	[0.726]***	[0.990]***	[1.142]***
Observations	32973	32973	32973	32973	32973
R-squared	0.65	0.68	0.68	0.69	

Robust standard errors clustered at the municipio level in brackets

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

Table 3 shows the same specification, this time with infant mortality due to respiratory diseases as the dependent variable. Again, as for AOD, the coefficient of the interaction between the fraction of firms certified and the year dummy is consistently negative and significant, ranging from -0.7 to -0.56, depending on the specification, and much higher when using our instrument for certification. Using the IV estimates Table 3 implies that certification has approximately translated into a 16 percent decrease in infant mortality due to respiratory illnesses. As a robustness check, the same specification was run using infant mortality due to external causes as the dependent variable and the coefficients for all specifications were close to zero and not significant (including the instrumental variables estimate). Combining the respiratory mortality result and the AOD result and assuming that the certification program only operates through AOD yields the result that a 1 percent increase in AOD results in a 4.4 percent increase in respiratory mortality.

Table 3

Regression Results. Changes in Infant Mortality due to Respiratory Diseases and Certification Intensity at the Municipio Level					
Dep Var: Resp. Mortality	1-OLS	2-OLS	3-OLS	4-OLS	5-IV
Fraction Certified*2006	-0.563	-0.561	-0.578	-0.707	-5.178
	[0.235]**	[0.235]**	[0.233]**	[0.263]***	[1.976]***
Year	-0.045				
	[0.005]***				
Other Controls					
Log Births	Y	Y	Y	Y	Y
Municipality FE	Y	Y	Y	Y	Y
Month FE	Y				
Month*Year FE		Y	Y	Y	Y
Weather		Y	Y	Y	Y
Economic			Y	Y	Y

Baseline Economic*2006			Y	Y	Y
Baseline Outcomes*2006				Y	Y
Constant	0.156	22.804	13.28	15.198	7.972
	[0.068]**	[5.869]***	[5.944]**	[7.140]**	[7.840]
Observations	32973	32973	32973	32973	32973
R-squared	0.47	0.47	0.47	0.48	

Robust standard errors clustered at the municipio level in brackets

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

VI. Conclusions

Increased recognition of the health costs of exposure to suspended particulates has increased the need to both evaluate existing voluntary and mandatory air-quality regulations and to better understand the processes underlying enforcement of and compliance with these regulations. This need is particularly acute in developing countries where the health consequences of adverse air quality may be particularly severe and regulatory and/or monitoring capacity may be inadequate. The results from this paper as well as the full-length manuscript (Foster and Gutierrez 2008) that provided the motivation for the present document suggest that satellite-based measures of aerosol optical depth can be a valuable component of a broader arsenal for examining such issues.

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