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Plant size, industrial air pollution, and local incomes: evidence from Mexico and Brazil

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ABSTRACT. Analysis of a new Mexican database reveals that air-borne, suspended particulate emissions per employee by plants with 20 or less employees are significantly greater than by larger plants within the same manufacturing sector. From a second, new data set on manufacturing plants in Brazil, it is shown that industry in lower-income areas displays a higher concentration of the dirtiest industrial sectors and of smaller plants (which are dirtier). However, harm to humans from industrial air pollution in Brazil is found to be greater in higher-income areas and most of this harm derives from larger plants. This is not simply a reflection of the greater prevalence of manufacturing in urban areas, for the rising projections of human mortality among higher wage municipalities hold, even controlling for population density. Resolution of this apparent paradox hinges on the distinction between emission intensities and total emissions, the latter determining the level of harm, a distinction that has not always been made clear in the course of debate.

1. Introduction

In *Small is Beautiful*, Schumacher (1989, p. 37) asserts that, 'Small-scale operations, no matter how numerous, are always less likely to be harmful to the natural environment than large-scale ones, simply because their individual force is small in relation to the recuperative forces of nature.' In fact very little evidence has appeared on pollution by small plants. Small

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plants are more prevalent in the developing countries (Little, Mazumdar, and Page, 1987), but most of the data on pollution by plant size in lower-income countries cover only medium and large plants. This paper examines, in section 2, a new data set on air emissions from 5,797 manufacturing plants in Mexico, including very tiny enterprises. These data indicate that small plants are more pollution intensive than larger plants.

In *Small is Stupid*, Beckerman (1995, p. 171) concludes that, 'economic growth is a necessary condition for proper protection of the environment. In the longer run it is also probably a sufficient condition.' This position would seem to be consistent with small plants being both dirtier and more prevalent in lower-income areas. Fresh evidence on air pollution from plants of various sizes in relation to local incomes is presented in section 3 of this paper, based upon a new data base of some 156,000 factories in Brazil, again incorporating very tiny plants. The Brazilian data do not report emissions, but these emissions are simulated here by applying the emission intensity measures available from the Mexican data, given employment size and sector of production. Inasmuch as Brazilian manufacturing has technologies and relative input prices similar to those in Mexico, this approach is not unreasonable. The nature of the results on air pollution in relation to local incomes proves very sensitive to the precise manner in which a hypothesis is formulated. Industry in lower-income areas displays a higher concentration of the dirtiest industrial sectors and of smaller plants (which are dirtier). However, harm to humans from industrial air pollution in Brazil is found to be greater in higher-income areas and most of this harm derives from larger plants. Resolution of this apparent paradox hinges in large part on a critical distinction between emission intensities and total emissions, the latter determining the level of harm, a distinction that has not always been made clear in the course of debate.

2. Are small plants dirtier? Evidence from Mexico

It is not self-evident whether small or large plants are likely to be more emission intensive. Production of some commodities is more pollution intensive than is production of others. If these dirtier industries exhibit scale (dis)economies then plant size and pollution intensity will be correlated. Yet even across plants producing identical commodities, there are at least two reasons to anticipate lower pollution intensities among larger plants.[1]

First, environmental regulators generally focus their limited inspection resources on large plants.[2] Inspection-related activities (travel time, effluent sampling, interactions with managers, etc.) are similar across fac-

[1] Other contributing factors, such as the choice of production technique and age of technology, may well also differ with plant size though the direction of association to be anticipated is not obvious.

[2] Wheeler *et al*., (1999), though there is mounting evidence that informal community pressure may provide an important alternative regulatory mechanism which may be better suited to monitoring small plants. Pargal and Wheeler (1996), Hettige, Huq, Pargal, and Wheeler (1996).

tories, regardless of their size. Since inspection's impact on pollution is proportional to plant size,[3] focusing on large facilities is a cost-effective strategy for regulators.

Second, more frequent inspections would reduce the relative pollution intensity of large plants, even if their marginal abatement costs were identical to those of small plants. However, this is far from the case. Controlling for sectoral variation, recent studies of water polluters in developing countries have shown that large factories have significantly lower marginal pollution abatement costs.[4] Since large plants face greater regulatory pressure and lower marginal abatement costs, we would expect them to have significantly lower pollution per unit of output. For water polluters, at least, the econometric evidence is consistent with this expectation.[5] However, most of these results refer to industrial water pollution by medium- and large-scale plants and little previous work has been done on air pollution in general, and on emissions by small plants in particular, in large part because of data scarcity.[6]

The Mexican data, adopted in this section, refer to air pollution and are unusually rich in covering very small manufacturing plants, as well as medium and large plants. In particular, the *Sistema Nacional de Informacion de Fuentes Fijas* (SNIFF) database records emissions of conventional air pollutants, sector of production (coded to the three digit International Standard Industrial Classification) and number of employees for 5,797 plants.[7] The air emissions in the SNIFF database are measured directly from stacks using methods essentially equivalent to those adopted by the US Environmental Protection Agency, with the data being reported by each facility. To this there are some exceptions in the case of low-capacity boilers for which estimates are drawn from emission factors. SNIFF then converts the concentrations at the stacks to annual emission figures in the database. For present purposes three categories of plant size, according to level of employment, are distinguished

	Range of employment	*Number of plants in sample*
Small	1−20	2,345
Medium	21−100	2,142
Large	101+	1,310

[3] Magat and Viscusi (1990).

[4] Dasgupta *et al*. (2000), Goldar, Misra, and Mukherji (1999).

[5] Pargal and Wheeler (1996), Hartman, Huq, and Wheeler (1996), Dasgupta, Hettige, and Wheeler (1998), Hettige *et al*. (1996).

[6] Industrial water pollution has traditionally been the focus of regulation in developing countries and water pollution is also easier to measure than air pollution with the result that data are much more plentiful for water polluters.

[7] The data are maintained by the *Instituto Nacional de Ecologia* (INE) in Mexico's Environment Ministry—*Secrataria del Medio Ambiente, Recursos Naturales y Pesca* (SEMARNAP). The authors are most grateful for the generous support of colleagues at INE for their help and assistance in accessing these data. It should be noted that plants in Mexico city may be over-represented in the sample, but it is unclear what direction of bias, if any, this introduces.

Air pollution from fine particles (those with diameters less than 10 microns) probably has the greatest impact on human morbidity and mortality. Fine particulate emissions are not yet commonly measured in developing countries, but they are known to be highly correlated with total particulate emissions and the present study therefore focuses on airborne suspended particulates from the Mexico data base. Table 1 reports the mean of particulate intensities per employee within each industry-size category.[8]

Table 1. *Mean annual particulate emission intensities (tons/employee)*

	Small	*Medium*	*Large*
Basic foods	0.0256	0.0647	0.2072
Other foods	0.1567	0.1792	0.0087
Beverages	0.4086	0.0264	0.0964
Tobacco products			0.0056
Textiles	0.0494	0.0143	0.0233
Apparel	0.0063	0.0015	0.0005
Leather products	0.0279	0.0111	0.0105
Footwear		0.0005	0.0003
Wood products	0.8924	0.0817	0.0919
Furniture	0.0078	0.0012	0.0009
Paper	0.0545	0.0475	0.0498
Printing	0.0009	0.0016	0.0004
Industrial chemicals	0.0978	0.0652	0.2709
Other chemicals	0.0180	0.0215	0.0170
Petroleum refining	0.2099	0.0495	0.0561
Petroleum products	0.2041	0.1111	0.2895
Rubber	0.1201	0.0128	0.0101
China and pottery	0.0172	0.0109	0.0029
Glass	0.0076	0.0225	0.0343
Other non-metallic	0.0565	0.1213	0.0046
Iron and steel	0.2112	0.2350	0.0782
Non-ferrous	0.0433	0.0404	0.0972
Metal products	0.0437	0.0165	0.0158
Machinery	0.1319	0.0208	0.2850
Electrical apparatus	0.0138	0.0088	0.0501
Transport equipment	0.0093	0.0046	0.0116
Professional equipment	0.0309	0.0019	0.0006
Other manufacturing	0.0145	0.0026	0.0018

[8] Intensities are computed as particulate emissions per unit of labor, because comparable output data are not available. If small enterprises are more labor intensive (per unit of output) than large facilities, then a negative relationship between plant size an the pollution/labor ration implies that pollution/output declines more rapidly than labor/output. Supporting data on the Mexican industrial air pollution intensities are available at the website, 'New Ideas in Pollution Regulation' (NIPR), www.worldbank.org/nipr. The intensities reported in table 1 differ slightly from those available at this website: table 1 refers to the mean of the emissions/employment ratios across plants, whereas the website reports mean emissions relative to mean employment.

In 19 of the 26 industries where comparisons are possible in table 1,[9] the emission intensity is greater among small plants than among medium-size plants within the same sector, and in 18 industries the intensity is greater among the small plants than among the large plants. More formally, the intensities reported in table 1 are greater for small plants than for the medium plants, based on unweighted summation across the 26 industries, with a t-statistic of 2.50 (p-value 0.012); the difference between the intensities for small plants and large plants has a t-statistic of 1.53 (p-value 0.126).[10] On a Wald test for the hypothesis that the small plant coefficients are larger than for both the medium and large plants, the resultant chi-squared statistic is 6.98 with a p-value of 0.031. Thus, although there are clearly exceptions in several sectors, on average the small plants indeed emit more particulates per employee.

3. Local income levels and industrial air pollution: evidence from Brazil

In this section, three inter-related questions are posed sequentially. (a) Are small plants more common in lower-income areas of Brazil? (b) Do the inherently dirtier industries congregate in the lower-income areas? (c) How is human exposure to airborne particulates associated with income levels in Brazil (and what is the role of plant size in this exposure)?

The database used to address these questions is made available by the *Instituto Brasileiro de Geografia e Estatistica* (IBGE) and covers 156,000 factories in 4,972 Brazilian municipalities (*municipios*). The factories in this database are categorized by 266 4-digit *Classificacao Nacional de Atividades Economicas* (CNAE) codes, employment size, and municipality of location. Particulate emissions for the Brazilian plants are imputed here according to pollutants per employee, within a specific sector, for plants in a given size category, from the Mexican data base. To achieve this matching, both the Mexican and Brazilian data are first aggregated to the 3-digit level of International Standard Industrial Classification (ISIC). The 1991 demographic census of Brazil reports the median wage of household heads, as well as population, for 4,319 of the 4,972 municipalities in the data set and the wage measures are used here to divide municipalities into deciles of higher or lower wage areas. For three of the 4,319 municipalities, data are missing on particulate emissions, and the remaining 4,316 municipalities contain approximately 91 per cent of Brazil's population and some 85 per cent of the land mass.[11]

Income levels and the role of small enterprises

Although small plants may remain important in niche markets in advanced economies, there are several reasons to anticipate that smaller

[9] In the three industry-size categories left blank in table 1 no plant appears in the Mexican database.

[10] The standard errors used to compute these t-statistics are heteroskedasticitly robust.

[11] The mean area of the municipalities in the working data base is thus 1,683 square kilometers.

plants will be more competitive in lower-income settings: market size may expand with income levels permitting exploitation of scale economies, though this association may be broken where external trade is important; to the extent that labour intensity and small scale are positively correlated, smaller plants may be more competitive at lower wage levels; the governance of firms commonly shifts out of family-held operations as financial markets and managerial skills evolve at higher-income levels; and either policy decisions or limited regulatory capacity frequently leave smaller enterprises exempt from a broad range of regulations and taxation in lower-income settings.[12]

The international evidence supports the anticipated pattern. For instance, Little, Mazumdar, and Page (1987) conclude that there has been a decline in the relative role of both tiny and small to medium enterprises among the developing countries as industrialization has proceeded, and that the decline of small to medium enterprises has a long history among the industrialized countries.[13]

Table 2 reports some results of examining the pattern of small plant incidence across municipalities of Brazil according to the median wage measures available for each municipality. In each regression in table 2, the dependent variable is the fraction of manufacturing employment that is in small-scale plants. Since this fraction is censored to lie on the 0–1 interval, with a substantial fraction of observations being either zero or one, a two-limit tobit estimator is adopted.[14] The regression in the first column of table 2, showing t-statistics for a zero null-hypothesis, serves to establish a strong negative association; areas with lower wages have a significantly higher incidence of small-scale plants.

The regression reported in the last two columns of table 2 elaborates on this finding by adopting a spline specification of the median-wage variable, to permit flexibility in exploring whether the estimated negative association is monotonic over the entire range of wage classes. Breakpoints for this specification are chosen at the minimum wage observed, plus the upper bound of each decile of municipalities, ranked according to median wage, with each decile containing approximately 10 per cent of the population. The breakpoint for the first decile is omitted as the reference point. The second column in table 2 reports the resultant, estimated coefficients; the t-statistics reported in parentheses beneath each coefficient in this column refer to the null-hypothesis that relative employment in small

[12] We are grateful to an anonymous referee for drawing our attention to an argument which may operate in the opposite direction. Public provision of infrastructure and education is generally more intense in higher-income locations. Given that the cost of providing these inputs privately ae subject to scale economies, small firms may tend to be more competitive in higher-income areas.

[13] Little, Mazumdar, and Page (1987) refer to household manufacturing with less than five employees and small enterprises with 5–50 and medium with 50–100 employees.

[14] In fact the nature of the estimates is hardly affected by whether ordinary least squares or a tobit is adopted, or by whether the censored model is assumed to have a normal or Weibull distribution.

Table 2. *Relative employment in small plants (dependent variable: fraction of manufacturing employment in small enterprises)*

	Two limit tobit		
		Spline	
	Linear	*Coeffic.*	*Margin*
Intercept	1.150	1.128	
	(37.10)	(23.50)	
Median wage	−6.167		
	(−18.31)		
Wage breakpoint		−0.055	
Lowest value		(0.22)	
First decile			0.055
			(0.21)
Second decile		−0.271	−0.271
		(3.87)	(3.87)
Third decile		−0.361	−0.090
		(6.22)	(1.43)
Fourth decile		−0.607	−0.246
		(9.79)	(4.05)
Fifth decile		−0.739	−0.132
		(11.55)	(2.02)
Sixth decile		−0.778	−0.039
		(10.81)	(0.52)
Seventh decile		−0.967	−0.189
		(10.40)	(1.71)
Eighth decile		−0.919	0.048
		(8.35)	(0.35)
Ninth decile		−1.082	−0.163
		(7.21)	(0.84)
Top decile		−0.098	0.984
		(0.16)	(1.49)
Log likelihood	−2,971		−2,905
No. observations		3,134	
Censored at 0		115	
Censored at 1		1,260	

plants at this wage level differs from that at the omitted, first decile breakpoint. In the third column of table 2, the marginal change is reported between the estimated coefficient at each decile an the coefficient at the next lower decile, with t-statistics for the null-hypothesis that this marginal difference in the spline is zero. The simple negative association with median wage already observed is estimated to be almost monotonic over the entire range of wages, with only a weak upturn in the lowest and eighth deciles and a more significant increase in the relative importance of small plants in the highest decile. The last exception hints at a u-shape relationship, but the reversal appears sensitive to a few outliers in the upper tail.

Since the principal concern here is whether the population in lower wage deciles is more exposed to pollution from small plants, population

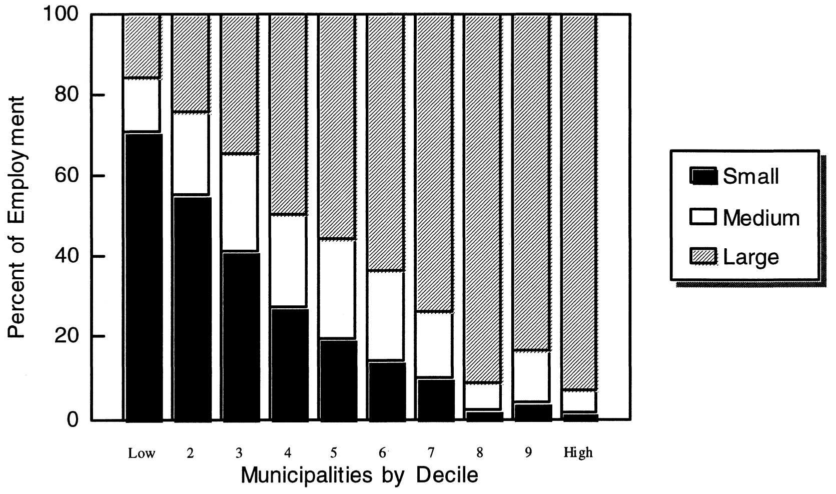

Figure 1. *Weighted fraction of manufacturing employment by plant size: municipalities of Brazil by decile of median wage*

weighted measures are of particular interest. Figures 1 serves to reinforce the regressions in table 2, showing the fraction of employment in small, medium, and large plants weighted by the population in the relevant municipality.[15] Evidently the relative incidence of small plants declines sharply with median wage and that of large enterprises expands.

Income levels and the concentration of dirty industries

The sectoral composition of industry is a key determinant of environmental quality. Whether this composition shifts toward greater emphasis on cleaner or dirtier industries as local incomes rise is, however, subject to opposing forces. On the one hand, demand for a cleaner environment rises with income, resulting in increased pressure to regulate dirty industries, as well as relocation of residence to avoid dirty industries. Higher-income communities and countries also tend to possess greater ability to regulate pollution effectively. moreover, to the extent that pollution and labor are complements in production, as suggested by recent research, dirty industries will have a tendency to locate in low-wage regions.[16] On the other

[15] Each wage decile contains approximately 10 per cent of the population, though in constructing figure 1 municipalities with no reported industrial employment are excluded. The database provided by IBGE is more comprehensive than any comparable information source we have seen. Nevertheless, it is entirely possible that small enterprises are undercounted in the database. For this exercise, what matters is the effect of income level on the propensity to undercount. Data-gathering is probably less efficient in poor regions, so undercounting of small plants should be more serious there. Thus, the results in the text probably *underestimate* the decline in small enterprise share as income increases.

[16] Lucas (1996), Hettige, Mani, and Wheeler (1998).

hand, higher-income workers may be concerned to reduce their commuting time as the value of time rises. If dirtier industries are intensive in the use of more highly skilled workers, this may result in high wage workers locating close to dirty industries. The combined outcome is ambiguous, though a common postulate is that the pollution intensity of industry may at first rise with incomes then decline at higher incomes.[17]

To examine this issue in the Brazilian context, the share within each municipality of total manufacturing employment derived from six industries, that are often deemed to be especially dirty activities,[18] is adopted as a proxy for the concentration of dirty industry. This share forms the dependent variable in the regressions reported in table 3.[19]

The first, linear regression in table 3 indicates a strong negative association between the local median wage and share of employment in these dirty-six industries. However, the spline specification reveals a somewhat more complex pattern; the relative incidence of the dirty-six industries rises sharply and significantly within the lowest decile of wages then declines fairly steadily across the remaining nine deciles. The statistical confidence in each step of the piece-wise linear regressions is generally weak, as revealed by the t-statistics on the difference in coefficients reported in table 3. However, the overall decline from the breakpoints at the bottom of the second to the bottom of the tenth decile is statistically significant with a t-statistic on the difference in coefficients of −3.2.

Finally, figure 2 displays the fraction of manufacturing employment in the dirty-six industries weighted by the population in the relevant municipality. This figure reinforces the finding of declining relative incidence of the dirty-six industries as median wage rises, though most of the decline occurs within the first three deciles based on this measure, and any initial rise within the first decile is masked.

Health damage and total emissions

The results from the Mexican data indicate greater particulate emission intensities from small plants; the Brazilian data indicate that small plants are relatively more common in lower wage areas and that lower wage

[17] Hettige, Mani, and Wheeler (1998). Note that in addition the pollution intensity of output more generally may at first rise then decline with income, as industrial production rises relative to agriculture at low incomes, then services increase relative to industry at high incomes. Here we refer to the intensity of industrial production, not to output more generally.

[18] The six industries are iron and steel, petroleum and coal products, metal products, pulp and paper, chemicals, and food products. Based on particulate emissions alone, wood products, beverages, machinery and non-ferrous metals might have been other contenders to enter this list, according to the Mexican data. However, the six industries focused upon here are often referred to as the dirty-six activities in terms of overall pollution (see, for instance, Robison, 1988; Tobey, 1990; Mani, 1996; Mani and Wheeler, 1997).

[19] Obviously, many other factors besides local wage/income can affect the mix of industries. However, the analysis here is constrained by very limited information availability. As a result, the estimates in table 3 and elsewhere should clearly be treated as descriptive of patterns, rather than causal in nature.

Table 3. *Relative employment in dirty-six industries (dependent variable: fraction of manufacturing employment in dirtiest six industries)*

	Two limit tobit		
		Spline	
	Linear	*Coeffic.*	*Margin*
Intercept	0.557	0.630	
	(24.53)	(18.53)	
Median wage	−1.608		
	(−6.17)		
Wage breakpoint		−0.667	
Lowest value		(3.55)	
First decile			0.667
			(3.55)
Second decile		−0.131	−0.131
		(2.57)	(2.58)
Third decile		−0.211	−0.080
		(5.02)	(1.69)
Fourth decile		−0.261	−0.050
		(5.67)	(1.11)
Fifth decile		−0.275	−0.014
		(4.44)	(0.57)
Seventh decile		−0.259	−0.019
		(3.65)	(0.22)
Eighth decile		−0.290	−0.031
		(3.41)	(0.29)
Ninth decile		−0.376	−0.086
		(3.24)	(0.57)
Top decile		−0.496	−0.120
		(1.05)	(0.24)
Log likelihood	−2,670		−2,653
No. observations		3,134	
Censored at 0		496	
Censored at 1		482	

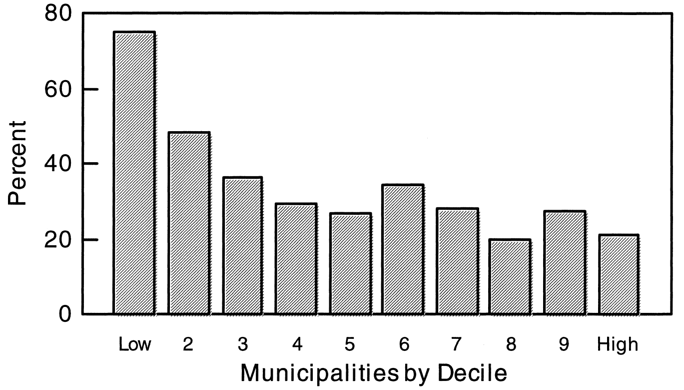

Figure 2. *Weighted fraction of manufacturing employment in dirty-six industries: municipalities of Brazil by decile of median wage*

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areas possess a higher fraction of employment in the dirtiest industries. The question posed in this section is whether these results imply that residents of low wage areas suffer greater exposure to the health and life-threatening effects of particulate emissions.

In particular, three steps are taken with the Brazilian data set to permit examination of the implications of particulate emissions for human mortality. First, total particulate emissions from plants of a given size category are calculated within each municipality, given the emission intensities per employee for the relevant (three-digit) industrial sector and total employment in that industry. Second, emissions are converted to an average rate of air concentration of particulates, using a simple dispersion model. Third, an expected number of deaths per person, in each municipality, is calculated based on a specific 'dose-response' function. Before proceeding, some amplification of the last two steps is necessary in order to highlight some of the underlying assumptions and hence limitations.

The dispersion model, developed by the World Health Organization (1989), used to estimate the impact of industrial emissions on air quality in each municipality, represents average particulate concentration in the air, from plants within a particular size category, as given by

$$c = p\Sigma_i \alpha_i \, e^{\beta_i - \gamma_i r - \delta_i r^2}$$

where p refers to total particulate emissions from plants in that size category

$$r \quad \ln \sqrt{\left(\frac{a}{\pi}\right)}$$

and a stands for the area of the municipality. The parameters α_i, β_i, γ_i, and δ_i are set according to smoke stack height for the plant size and according to seven categories (i) of atmospheric stability and wind speed.[20]

Finally, the concentration rates from the dispersion model are converted into mortality probabilities for the population of each municipality using the linear particulate 'dose-response' function developed by Ostro (1994) from a number of prior studies.[21] In particular, a 0.1 $\mu g/m^3$ reduction in concentration induces a fall of 0.067 per 100,000 in the mortality rate.

This three-step procedure obviously embodies several simplifying assumptions and these should be emphasized before proceeding. First, it is assumed that the mortality effects of suspended particulates are confined to the municipality in which they are emitted. In fact, the main impact of particulate emissions is fairly concentrated, as may be seen from figure 3. At 20 kilometers from a large plant the concentration of air pollution has fallen to less than one tenth of the level at one kilometer from

[20] For details see the Decision Support System for Integrated Pollution Control, which is available on the website: http://www-esd.worldbank.org/pollution/dss

[21] More recent evidence raises doubts about whether the dose-response function for air pollutants is appropriately specified as linear and suggests, in particular, that responses may be particularly sensitive to extreme events (see, for example, Cropper *et al.*, 1997; Butterworth and Bogdanffy, 1999; and Millimet and Slottje, 1999. Given the data available on Brazil, such potential non-linearities cannot be adequately represented here.

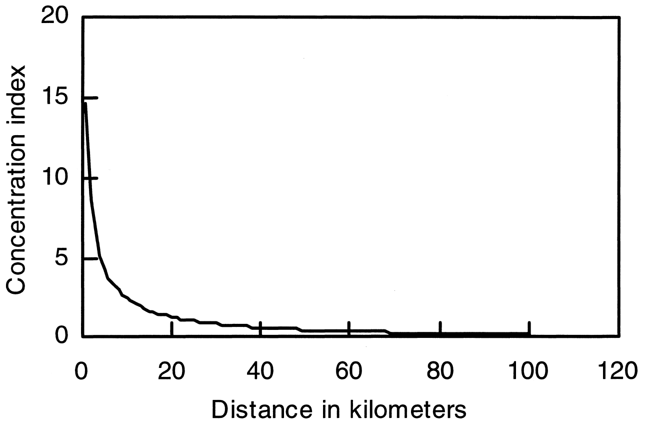

Figure 3. *Concentration of air pollution and distance from small plants*

that plant, according to the parameters of the adopted model. Since the mean radius of a municipality in the sample is just over 23 kilometers, this suggests more than a 90 per cent drop in concentration of air pollution at the municipality's boundary, from a large plant located at the center of the average municipality, which favors the assumption that air pollution effects are predominantly local. Second, it must be remarked that we are unable to deal with cross-municipality pollution which may arise especially from plants located near to the boundaries of a municipality. Third, the adopted concentration model is unable to deal with the specific geographic shapes, implicitly treating each area as circular with plants located at the center. Fourth, no information is available about the distribution of population within each municipality; adopting the average concentration essentially assumes a uniform distribution and neglects the potential that people vote with their feet with respect to air pollution. Finally, air pollution concentration from small plants is considerably greater than from large plants. For instance, at 23 kilometers from a plant, the dispersion model assumes that concentration from a small plant is approximately 14 times greater than from a large plant.

The outcome of projecting expected mortalities is examined in relation to municipality median wage in the regressions reported in table 4. Despite the foregoing findings—that small plants have greater emission intensities, result in much larger air concentrations and are relatively more common in low wage areas, and that the portion of employment in the dirtiest industries is higher in low wage areas—projected mortality per capita is strongly, positively associated with median wage across municipalities. As the results in table 4 show, this positive association holds both across all municipalities and among those municipalities which report positive levels of manufacturing employment.[22]

[22] If emissions are more correctly depicted as fixed in relation to output, rather than employment, then any decline in labor intensity in higher wage areas would suggest that the estimates in relation to wage are downward biased here.

Table 4. *Expected deaths per capita (Dependent variable: expected deaths per capita)*

	All municipalities				*Municipalities with industrial employment*			
			Spline				*Spline*	
	Linear		*Coeff.*	*Marg.*	*Linear*		*Coeff.*	*Marg.*
Intercept	−2.349	−1.534			−2.771	−1.671		
	(5.09)	(5.34)			(3.83)	(3.64)		
Median wage	0.563	0.355			0.618	0.379		
	(7.52)	(7.41)			(6.14)	(5.84)		
Population density		0.637	0.596			0.633	0.593	
		(5.51)	(5.11)			(5.47)	(5.10)	
Wage breakpoint			−0.580				−1.011	
Lowest value			(3.69)				(2.26)	
First decile			0.121	0.701			0.508	1.519
			(1.21)	(2.87)			(2.62)	(2.52)
Second decile			0.320	0.199			0.441	−0.067
			(2.92)	(1.35)			(3.00)	(−0.26)
Third decile			0.424	0.104			0.505	0.064
			(4.88)	(0.72)			(4.99)	(0.34)
Fourth decile			0.906	0.482			0.978	0.473
			(6.98)	(3.20)			(7.09)	(2.85)
Fifth decile			1.338	0.432			1.377	0.399
			(5.58)	(1.46)			(5.61)	(1.31)
Sixth decile			2.606	1.268			2.763	1.386
			(6.71)	(2.74)			(6.90)	(2.92)
Seventh decile			4.430	1.824			4.513	1.750
			(4.08)	(1.53)			(4.02)	(1.42)
Eighth decile			7.678	3.248			8.141	3.628
			(2.44)	(0.82)			(2.48)	(0.88)
Ninth decile			15.190	7.512			15.240	7.099
			(3.77)	(1.14)			(3.78)	(1.06)
Top decile			−2.746	−17.94			−2.742	−17.98
			(0.73)	(2.86)			(0.72)	(2.86)
No. observations	4,313	4,313		4,313	3,132	3,132		3,132
R-squared	0.14	0.53		0.57	0.13	0.53		0.56

Since mortality is dictated largely by total emissions, it is feasible that these observed patterns simply reflect the greater concentration of manufacturing in urban areas, which also happen to be high wage zones. Unfortunately, data are not readily available on the extent of urbanization in each municipality. As a proxy for the extent of urbanization, the second regressions reported in table 4 therefore include population density for each municipality.[23] The results indicate that projected mortality rates are indeed higher in more densely populated municipalities, both in general and among municipalities with positive industrial employment. However, the positive association with median wage still holds, albeit with a diminished slope. Some additional specifications were also explored, including the interaction between median wage and population density, but this interaction proved not to be statistically significant and its inclusion did not alter the significant positive association with median wage. Moreover, the spline specifications in table 4 indicate that projected mortality per capita from particulate emissions rises fairly monotonically (either with or without population density included), at least across the first nine deciles, though there is a significant decline in mortality within the highest decile.

The explanation for this apparent paradox is that higher wage municipalities simply contain a far larger volume of manufacturing employment. This is apparent in figure 4 which displays manufacturing employment per capita within each decile of municipalities. Note that in the highest decile, manufacturing employment declines. The result of lower projected mortality at the highest levels, in table 4, may then reflect the declining prevalence of manufacturing in the highest wage municipalities where services may be comparatively more important, though this cannot be tested with the available data.

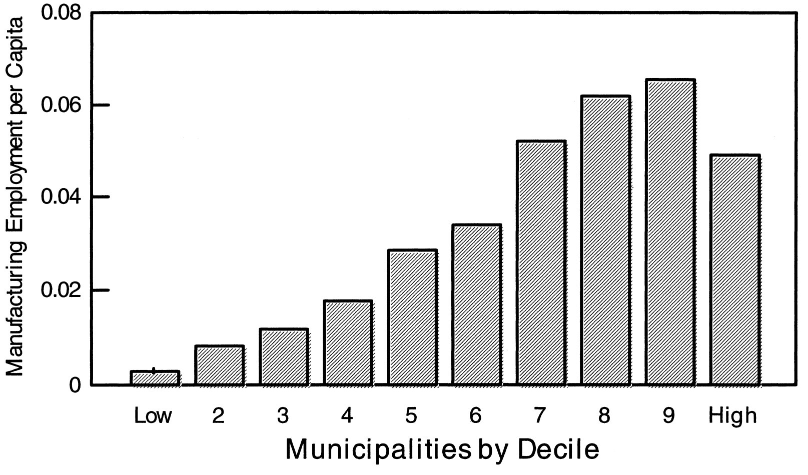

Figure 4. *Manufacturing employment per capita: municipalities of Brazil by decile of median wage*

[23] The authors are particularly grateful to an anonymous referee for this suggestion.

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Table 5. *Percent of expected deaths from plants of different sizes*

	Weighted mean ratio				*Ratio of means*			
Decile	*Small*	*Medium*	*Large*		*Small*	*Medium*	*Large*	
1	82.3	9.0	8.7	100.0	28.4	1.6	70.0	100.0
2	76.7	8.7	14.6	100.0	34.1	3.9	62.0	100.0
3	74.8	9.1	16.2	100.0	62.2	5.1	32.7	100.0
4	65.8	8.7	25.5	100.0	56.9	6.3	36.8	100.0
5	61.5	9.5	28.9	100.0	51.2	7.5	41.3	100.0
6	58.3	7.3	34.4	100.0	47.5	5.4	47.1	100.0
7	51.1	6.0	42.9	100.0	34.1	4.9	61.0	100.0
8	17.9	2.8	79.2	100.0	1.6	0.5	97.9	100.0
9	35.1	6.2	58.7	100.0	26.8	4.8	68.4	100.0
10	18.2	3.0	78.8	100.0	12.4	2.1	85.4	100.0

Finally, table 5 addresses the portion of projected deaths from plants of different sizes across deciles. The second panel in that table shows the ratio of mean deaths from a given plant size relative to mean total deaths within each decile. Based on this measure, most projected deaths arise from large plants.[24] Moreover, large plants account for the overwhelming majority of expected deaths, both at the higher wage and lower wage deciles, though small plants are comparatively more important around the third through sixth decile. The finding that most expected deaths are attributable to large plants, even in the bottom two deciles, may seem anomalous in view of the results on relative concentration of small plants in these low wage regions, already noted in figure 1. The explanation resides in the skewed distribution of manufacturing employment among the low wage municipalities. Although small plants predominate among low wage municipalities, weighted by the population of each municipality, as shown in figure 1, total employment in large plants within all municipalities in the lowest decile is far larger than employment in small plants because of the concentration of large plants in a few, low wage municipalities. In consequence, in the first panel of Table 5, the population-weighted, mean ratio of deaths from small plants relative to total deaths is very high in the low wage deciles, even though the ratio of means is not. In other words, within the low wage areas, most projected deaths from particulate emissions are from large plants, but among these same areas most of the population lives in municipalities where projected deaths from small plants are by far the most common.

4. Conclusions

The Mexican data on individual plants indicate that, on average, small manufacturing plants emit significantly larger quantities of airborne

[24] It should be emphasized that this study focuses on particulate air pollution from the manufacturing industry alone. Large power plants are a major source of particulate pollution, and including them would obviously increase estimates of deaths attributable to large plants. Motor vehicles are another major source of particulate pollution. For an estimate of their contribution to overall mortality in Brazilian municipalities, see Von Amsberg (1997).

particulates per employee, than do medium or large plants within the same three-digit industry. Given the typically far shorter smoke-stacks on small plants, this results in considerably greater air-concentrations of particulates arising per employee from small plants.

The location data on Brazilian manufacturing plants, indicate that the population in low wage areas has a higher degree of exposure to air pollution from small plants than from medium or large plants. Does this result imply that the assertion by Schumacher, cited in the introduction, that small operations are always less harmful to the environment than are large ones, is incorrect? Not really, for in both low wage and high wage areas of Brazil, most projected deaths are from large plants. The very high concentration of large plants in just a few low wage areas results in high projected mortalities in these areas, even though most people in low wage areas live in regions where small plants and their high intensity of particulate emissions predominate.

Again within Brazil, our evidence suggests that the concentration of particulates to which people are exposed is significantly greater in high wage areas than in low wage areas. At least within the range of incomes represented by these Brazilian municipalities, this evidence thus seems to contradict Beckerman's position, again cited in the introduction, that development is a necessary and sufficient condition for environmental improvement, though of course our results refer only to manufacturing pollution whereas Beckerman emphasized a wider scenario. Nonetheless, at least for manufacturing, the rise in scale of production in higher income areas, combined with rising urbanization and hence greater population concentration close to that manufacturing, does result in greater air pollution concentrations in high wage areas, at least within Brazil.

The Mexican data on air pollution by large, small, and even tiny plants has presented an unusual opportunity to examine pollution by size categories of plants in a developing country. The large Brazilian data set on municipality of location for small, medium, and large manufacturing plants has enabled some analysis of air pollution exposure according to median local incomes. To pursue these issues further, without resorting to some of the strong simplifying assumptions necessitated and outlined in this paper, will require a different kind of data. In particular, household survey data are probably required to document location of specific household categories in relation to polluting industries. Ideally such data would be combined with health and mortality data on each household, and perhaps community levels of pollution. However, to date such data do not appear to exist.

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