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Evaluating Pollution Control: The Case of São Paulo

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São Paulo is the most industrialized area of Latin America, and after Mexico City and Shanghai it is the third largest metropolitan center in the world.[1] Today some of the most urgent problems of the urban environment are found here, particularly in the highly industrialized sections of the Greater São Paulo Metropolitan Area (GSP).

Pollution: Problems and Policies

Until the early 1970s Brazilian policymakers tended to opt for environmental damage in the pursuit of economic growth and competitiveness in international markets. As pollution grew, however, the virtues of accepting such a tradeoff—even if it existed—became questionable. Under growing pressure from localities national antipollution policies, supported on the state and metropolitan levels, began to evolve in the mid-1970s. The enactment of laws is of more recent origin, and actual measures have been mostly limited to the GSP. As policies are now beginning to be implemented, however, old anxieties have re-emerged about their possible effects on competitiveness in world markets, on inflation, on efficient use of energy, and on the government budget. The shifts in opinion about environmental regulations call attention to the need for objective analysis and estimates of the effects of policies. This chapter uses a *cost-benefit framework* to analyze the welfare effects of industrial location and pollution control, with the focus on industrial air emissions.

The Extent and Sources of Pollution

Pollution in São Paulo has been studied by, among others, Esteves and Gianneschi (1980); Gianneschi, Junior, and Salvador (1979); Licco, Oda, and Galvão Filho (1979); Pazzaglini and Greco (1981); and the World Bank.

Air pollutant discharges in the GSP currently amount to 8,000 tons daily. Carbon monoxide constitutes 65 percent of the emissions, sulfur dioxides 13 percent, hydrocarbons 10 percent, particulates 7 percent, and nitrogen oxides 5 percent. In 1978 daily air quality standards were exceeded 299 times for carbon monoxide, 121 times for particulate matter, and 17 times for sulfur dioxide. The highest concentrations of these substances in the same year were, respectively, 282 percent, 190 percent, and 219 percent more than their standards. During 1976–78 the average annual concentration of carbon monoxide in the more polluted areas was 12–13.5 parts per million (ppm), while that of particulates was 115–126 micrograms per cubic meter. These levels are comparable with those recorded in some of the largest cities in the United States during the early 1970s.[2]

The damage is compounded by São Paulo's climate and topography. Light winds, air stagnation, and frequent temperature inversions hold polluted air close to the ground. In the winter months of June, July, and August the concentration at ground level rises as much as 50–75 percent over the annual mean in some places, which aggravates respiratory illnesses.

Spatial variations in damages are sharp within the thirty-seven municipalities in the GSP. Nine municipalities contribute about 95 percent of total air emissions.

Note: This chapter has been published in a somewhat different form as "Evaluating Pollution Control," *Journal of Development Economics*, vol. 19 (1985), pp. 133–46.

An analysis of the lead content in the blood of humans compared three neighboring areas: Embu-Gauçu, which is mildly polluted; São Paulo municipality, which is more polluted; and São Bernardo, which is heavily polluted (Fernicola and Azevedo 1979). The average lead concentrations in blood among representative groups of people are shown below.

	Average lead in blood (micrograms per cubic meter)	*Standard deviation*
Embu-Guaçu	11.2	5.6
São Paulo municipality	12.4	4.8
São Bernardo	20.5	5.7

In the GSP, about 94 percent of carbon monoxide, 73 percent of nitrogen oxides, and 72 percent of hydrocarbons are discharged by some 2 million vehicles. Industrial processes and stationary fuel combustion by approximately 30,000 establishments are responsible for about 80 percent of particulate matter, over 90 percent of sulfur dioxide emissions, 19 percent of hydrocarbons, and 25 percent of nitrogen oxides. Automotive traffic is clearly the largest source of total pollution, while industrial processes and stationary fuel combustion are the principal sources of particulates and sulfur dioxide. Roughly 65 percent of the industrial emissions are released by a relatively few industries in the nonmetallic, chemical, and metallurgic categories. According to Gianneschi, Junior, and Salvador (1979), about 90 percent of particulates and 74 percent of sulfur dioxide are discharged, respectively, by only 5 percent and 10 percent of the sources; at the other extreme, 3 percent of the particulates and 10 percent of the sulfur dioxide come from 75 percent and 73 percent, respectively, of the least polluting industries.

The Policy Focus

Federal legislation has established uniform national air quality standards and broad guidelines for their achievement (Companhia Estadual de Technologia de Saneamento Ambiental [CETESB] 1979a, b; Empresa Metropolitana de Planejamento de São Paulo [EMPLASA] 1979; Pazzaglini and Greco 1981). By and large, uniform abatement by polluting industries has also been sought but thus far has been enforced unevenly in different areas. Enforcement of abatement has been effected through the CETESB, the state's pollution control agency, with a system of fines and penalties which has been more effective in the GSP than elsewhere. Thus, at the moment there is considerable spatial differentiation in pollution abatement.

One approach adopted to contain pollution has been to indirectly influence environmental quality by manipulating the growth of industrial output. This policy has resulted partly from the current strategy of trying to prevent a worsening of the problem rather than reduce existing emissions. Toward this goal, the locational decisions of new producers have been influenced through licensing and zoning procedures. The CETESB now licenses all new industrial investment in the state of São Paulo.

In the future, options other than those that directly affect output may be expected to increase. Already there is a $187 million project for air and water pollution abatement which regulates a small number of industrial plants that account for a very high percentage of total pollution. The air pollution control is aimed primarily at particulates, and the water pollution control focuses on toxic wastes. Loans are offered to enable plants to meet state and federal quality standards. It is chiefly plants in the GSP that qualify for the loans. In operation the project is expected to stress whatever turns out to be the least-cost control strategy for reducing smoke and meeting air quality standards. Since air quality is measured in the area near a factory (rather than in the smokestack), greater efforts and higher control costs are to be expected in the more polluted areas.

The Costs of Pollution Control

Estimates of the capital and operating costs of pollution control equipment and spare parts for 285 industries that contribute 97 percent of industrial particulate pollution in the GSP have been compiled. (These estimates are CETESB projections that used information for industries without control equipment.) For the fifty-three industries that account for 90 percent of particulate effluents, a 94 percent abatement—that is, 85 percent of industrial particulates and 55 percent of all particulates—might be achieved in 1977 at a total cost of about 418 million cruzeiros (about $30 million) or about 3,200 cruzeiros ($225) a ton of emissions.[3] If a ten-year life of the equipment and a 10 percent interest rate are assumed, the annualized investment cost is $4.75 million. Addition of a (liberal) 25 percent for annual labor and maintenance costs yields an overall annual cost of about $6 million. If 25–50 percent of the GSP's 11 million people are assumed to be directly affected by pollution,[4] a per capita annual cost of about $1.1–$2.2 is implied. Elimination of an additional 7 percent of smoke from 232 more industries (or, the collection of about 91 percent of industrial particulates and about 70 percent of all particulate effluents) more than doubles the total cost, to about 964 million cruzeiros ($68 million in 1977), and the cost a ton to 6,800 cruzeiros ($480).

The Medio Paraiba area, which has a population of over 1 million, is a small but heavily industrialized and heavily polluted area in the state of São Paulo.[5] Approximate total particulate emissions from point sources are over 42,466 tons a year. According to Kowalczyk (1980) the cost of the best control technology, which achieves about 98 percent abatement, is $16.6 million (in 1979 dollars), or about $550 a ton if the technology is applied to the four sources which account for 72 percent (30,759 tons) of all industrial pollution in the area. If 25 percent annual labor costs are assumed, an annualized investment plus labor cost figure is $3.25 million to abate 30,759 tons annually. If only 75 percent of the people are directly injured by the airborne discharges, this means an annual cost of $4.33 (1979 dollars) for each person affected.

Licco, Oda, and Galvão Filho (1979) estimate that in many Brazilian industries effluent per unit of output (the emission factor e) is constant. In other industries it declines somewhat with the volume of production, X, as shown in the following examples.

Industry	*e, in kilograms per ton of output* X
Steel: basic oxygen process	$6X$
Iron	$9X$
Cement: calcination furnace	$6X$
Ceramics	$9.5X^{0.8}$
Ammonium phosphate	$10X^{0.8}$

If the emission factor declines significantly with output, it would be advantageous to require less than proportionate abatement from larger producers and thereby allow those who pollute less per unit of output to produce more.

Economies of scale in pollution control are implied in Kowalczyk (1980). As table 13-1 shows, the control costs per ton of emissions for the largest polluters, who contribute 90 percent of the particulates in the GSP, are

Table 13-1. *Control Costs for Industries That Contribute 97 Percent of Particulate Emissions in the GSP*
(thousands of cruzeiros, except where otherwise specified)

				Control costs (1977 estimates)						
				Capital costs		*Installation costs*		*Total cost*		
Industry	*Number of industries*[a]	*Emissions (tons per year)*	*Control efficiency (percent)*	*Total*	*Per ton*	*Total*	*Per ton*	*Total*	*Per ton*	*Total cost (1980–81 estimate)*
Nonmetallic	110	107,015	n.a.	n.a.	n.a.	n.a.	n.a.	443,870	4.15	1,194,600
Average		973	n.a.	n.a.	n.a.	n.a.	n.a.	4,035	4.15	10,860
Top 90 percent	36	103,770	95	110,810	1.07	101,620	0.98	212,430	2.05	660,340
Average		2,882	95	3,078	1.07	2,822	0.98	5,900	2.05	18,340
High[b]		9,600	n.a.	10,000	1.04	10,000	1.04	20,000	2.08	54,000
Low[b]		400	n.a.	2,600	6.50	1,600	4.00	4,200	10.50	11,300
Chemicals	20	16,030	n.a.	n.a.	n.a.	n.a.	n.a.	122,190	7.62	328,900
Average		802	n.a.	n.a.	n.a.	n.a.	n.a.	6,110	7.62	16,455
Top 90 percent	6	15,360	80	n.a.	2.81	31,900	2.08	75,100	4.90	202,000
Average		2,560	80	7,200	2.81	5,317	2.08	12,517	4.90	33,670
High[b]		3,300	n.a.	6,550	1.98	5,200	1.59	11,800	3.57	31,760
Low[b]		980	n.a.	6,550	6.68	3,950	4.03	10,500	10.71	28,300
Metallurgic	115	17,110	n.a.	n.a.	n.a.	n.a.	n.a.	397,270	23.22	1,069,170
Average		110	n.a.	n.a.	n.a.	n.a.	n.a.	2,563	23.22	6,898
Top 90 percent	11	12,560	98	68,000	5.41	62,000	4.94	130,000	10.35	350,110
Average		1,142	98	6,182	5.41	5,636	4.94	11,818	10.35	31,800
High[b]		2,200	n.a.	10,700	4.86	10,700	4.86	21,400	9.72	57,590
Low[b]		430	n.a.	3,000	6.98	2,000	4.65	5,000	11.63	13,460
All industries	285	140,155	n.a.	n.a.	n.a.	n.a.	n.a.	964,330	6.88	2,592,670
Average		492	n.a.	n.a.	n.a.	n.a.	n.a.	3,384	6.88	9,097
Top 90 percent	53	101,690	98	220,401	1.68	195,520	1.48	417,530	3.16	1,212,450
Average		3,485	94	4,190	1.68	3,690	1.48	7,878	3.16	22,800

n.a. Not available.

a. Particulates involve a total of about 1,150 enterprises.

b. Excluding extremes.

Source: CETESB estimates; Kowalczyk (1980).

significantly lower than for the other polluters. Thus, it may be advantageous to focus control policies on the largest polluters. If an 85 percent overall abatement were achieved, the effort to control the remaining 10 percent—the smaller polluters—would raise overall costs, compared with a strategy of relying only on the top 90 percent of the polluters (assuming a control efficiency of 94 percent).[6]

The efficiency of control equipment and the abatement cost for each unit also vary among industries (see table 13-1). Nonmetallic industries, which contribute the bulk of particulate emissions (76 percent excluding fuel combustion), face significantly lower control costs than do chemical and metallurgic industries. (Industries excluded from the table experience still higher control costs.)

The range in cost differences is apparent when a low control cost industry, cement, is compared with iron, a high control cost industry (see table 13-2). As a greater variety of equipment becomes available in the market and experience accumulates, however, these cost differences are likely to diminish. The existing interindustry cost variation nevertheless implies potential savings from differentiation between producers on cost grounds.

The Benefits of Pollution Control: Health Effects

The health effects of pollution are discussed in Lave and Seskin (1977) and in Smith (1976).

Air Pollution and Human Health

Fernicola and Lima (1979) have evaluated the degree of exposure of the population of São Paulo to carbon monoxide. To determine the carboxihemoglobin (COHb) content by the spectrophotometric method, 327 blood samples were collected from adults. Thirty samples for each control group were taken from residents of Embu-Gauçu, an area considered to have a low carbon monoxide concentration. The following significant results were obtained.

Group	*Concentration of COHb in blood (percent)*
Traffic policemen	
Smokers	6.3 ± 2.07
Nonsmokers	2.1 ± 0.68
Bus drivers	
Smokers	4.6 ± 1.94
Nonsmokers	1.6 ± 0.48
Control	
Smokers	3.8 ± 1.74
Nonsmokers	0.8 ± 0.21

Thus, if the national air quality standard of 9 ppm for carbon monoxide were met, COHb would be kept to about 2 percent for nonsmokers. The relation between increasing cardiovascular disease and COHb content of over 2 percent has been cited in Fernicola and Lima (1979).

Mendes (1976) has examined the effect of air pollution on mortality in an epidemiological study that correlated deaths for each day in the GSP in 1973 with meteorological conditions and air pollution levels. Five peaks in deaths were observed; at least one, on August 1, was clearly related to a dramatic worsening of air pollution. Particulate and sulfur dioxide concentrations rose after July 25 and reached very high levels by July 30. On August 1 sulfur dioxide reached a peak in Capuava of 452 micrograms per cubic meter, in Aclimação of 371, in Tatauape of 292, and in Cerqueira Cesar of 288. On the same day deaths reached a high for the year of 299, compared with an annual average of 228. Deaths of people over 65 or less than 1 year old and deaths attributed to respiratory diseases also peaked on the same day. In all, a close correlation between concentration of sulfur dioxide, total deaths, and deaths resulting from respiratory diseases (particularly for people over 65 or less than 1 year old) was observed statistically between July 25 and August 8. If the same study were carried out for 1974 and 1975, when air pollution was worse, more conclusive evidence on the relation of pollution to the deterioration of human health might have been found.

Air Pollution and Mortality

A regression technique, after Lave and Seskin (1977), has been used to try to isolate a pollution-mortality relation (see Thomas 1980 for details). It should be emphasized at the outset that the purpose is to explore the existence of any significant association between the two phenomena in São Paulo rather than to derive the exact effect of pollution on mortality. As will be clear, the absence of an adequate data base limits the explanatory power of the equations. More generally, one should not expect to adequately capture relatively short-term pollution-mortality relations, which must be based on long-term exposure to the effluents. Furthermore, these regressions measure the marginal effects of pollution on mortality with other variables held constant, but in reality a simultaneous explanation of the changes in other variables as well as in pollution and mortality might be required.

Annual cross-sectional data for 1977 for the thirty-seven municipalities in the GSP were analyzed with the use of linear multivariate regression analysis. The mortality rate (deaths per 10,000 population) is the dependent variable. Death is recorded at the place of domicile

Table 13-2. *Pollution Control Costs for Some High-Pollution Industries: São Paulo and Rio de Janeiro, 1980*
(1979 U.S. dollars)

		Metropolitan São Paulo			*Metropolitan Rio de Janeiro*			
		Particulate emissions			*Particulate emissions*			
Industry	*Average collection efficiency*	*Tons per year*	*Percent*	*Capital cost per ton*	*Tons per year*	*Percent*	*Capital cost per ton*	*Cost-benefit ratio*
Nonmetallic								
Cement	98	38,917	28.39	67	25,500	20.69	69	1.0
Quarrying	95	31,467	22.95	222	64,300	52.17	124	13.6
Ceramic								
Clay	90	19,900	14.52	292	9,930	8.06	94	n.a.
Gypsum lime	90	2,419	1.76	952	...	...	...	n.a.
Asphalt	98	10,745	7.84	358	21,588	17.52	169	17.9
Concrete	66	3,370	2.46	490	316	0.26	563	62.1
Glass	80*	785	0.57	8,577	...	...	n.a.	n.a.
Chemicals	80*	12,252	8.94	625	...	...	n.a.	n.a.
Metallurgic								
Steel	98	6,863	5.01	1,058	1,268	1.03	1,879	13.6
Iron foundries	98	10,364	7.56	1,860	343	0.28	6,467	45.6
Total or average	94	137,082	100.00	468	123,245	100.00	151	n.a.

... Zero or negligible.
n.a. Not available.
* Approximation.
Note: Ratio of particulate emission, São Paulo/Rio, 1.11. Ratio of control cost, São Paulo/Rio, 3.10.
Source: Based on Kowalczyk (1980).

rather than of death, although it is not known how long the person had lived there. Data on total mortality are used first. Then, on the assumption that the pollution effect is longer term, children less than 1 year old and less than 10 years old are excluded alternatively.

The independent variables that represent environmental, physical, and socioeconomic characteristics are pollution level, population density, average income level, hospital beds per person, and the percentage of the population 65 years and older.[7] Since air quality data are not available at the municipal level, annual emission data were used instead. The emission data for particulates, sulfur dioxide, and carbon monoxide are available for the six municipalities which account for about 80 percent of industrial pollution. For the other municipalities levels of particulates and sulfur dioxide had to be approximated with the use of estimated emission factors (emissions for a quantity of industrial output), and the level of carbon monoxide had to be estimated from an emission factor based on the number of vehicles. All the emission variables are expressed as a fraction of the area in square kilometers, to better reflect their concentration. Since estimates of particulates are far more reliable than estimates of sulfur dioxide and carbon monoxide, the latter two pollutants are excluded in one set of calculations.

Population density is an important determinant of the incremental damages from a given amount of pollution. The age of the population clearly increases the mortality rate. Average personal income is expected to affect mortality inversely; estimated per capita value added by municipalities, which is admittedly a crude proxy for the income of people living in those locations, had to be relied on. For the municipalities the availability of medical service was approximated with data on hospital beds per person, as a socioeconomic variable.

Equation 13-1 regresses the total mortality rate (deaths per 10,000 population) for the thirty-seven municipalities on total pollution (tons a square kilometer) and the socioeconomic variables for 1977.

$$
\begin{aligned}
(13\text{-}1)\quad TM = 76.214 &+ \underset{(1.51)}{0.120\,PM} - \underset{(-1.03)}{0.068\,SO_2} \\
&- \underset{(-0.67)}{0.020\,CO} + \underset{(1.25)}{4.357\,P{\geqslant}65} \\
&- \underset{(-0.43)}{67.893\,VA} - \underset{(-1.46)}{0.248\,HB} \\
&- \underset{(-1.43)}{0.002\,P/km^2} + e \\
&\qquad\qquad\qquad R^2 = 0.341
\end{aligned}
$$

where TM is the total mortality rate for the municipality, PM is mean particulate matter, SO_2 is mean sulfur dioxide, CO is mean carbon monoxide, $P \geqslant 65$ is the percentage of the population aged 65 and older, VA is per capita value added, HB is hospital beds per 1,000 people, and P/km^2 is population density. The units of the variables are given in table 13-3. The numbers in parentheses are t-statistics.

Only 34 percent of the variation in the total mortality rate is explained by the seven independent variables ($R^2 = 0.341$).[8] The exclusion of important socioeconomic variables in the equation may partly account for its low explanatory power. The noteworthy result is the positive and significant coefficient for particulates. Because particulate data are the most reliable, this result is encouraging. The other pollution variables, mean sulfur dioxide and mean carbon dioxide, have no significant effect in the regressions, but the poor quality of the data may account for this result. As expected, the percentage of the population over 65 is consistently and significantly related positively to the death rate. The variable for per capita hospital beds also has a significant and negative effect on the mortality rate. Population density has a negative effect, which is contrary to expectation.[9] That income is not a significant factor in any of the equations is probably explained by the weakness of the data.

According to equation 13-1, an annual increase of 1 ton of particulates per square kilometer in the GSP over 1977 particulate levels is associated with an increase in the mortality rate of 12 deaths per million people. On the basis of a mean particulate concentration of about 17 tons per square kilometer[10] and a mean mortality rate of 8,830 per million, a 50 percent reduction in industrial particulates alone[11] would be associated with a 1.2 percent reduction in the mortality rate. Inclusion of better estimates of mean sulfur dioxide and carbon monoxide levels may be expected to raise this effect significantly.[12]

Table 13-3. *Total Mortality per 10,000 Population, Thirty-seven Municipalities, GSP, 1977*

	Particulates			*Particulates, SO_2, CO*		
Value	*TMT*	TM_1	TM_9	*TMT*	TM_1	TM_9
R^2	0.175	0.343	0.366	0.341	0.451	0.470
Constant	69.079	22.290	25.618	76.214	27.913	30.759
Air pollution variables (tons a square kilometer a year)						
PM	0.006*	0.002	0.002	0.120*	0.075*	0.075*
	(1.423)	(0.629)	(0.584)	(1.509)	(1.630)	(1.460)
SO_2	—	—	—	−0.068	−0.032	−0.030
				(−1.031)	(−0.843)	(−0.694)
CO	—	—	—	−0.020	−0.127	−0.017
				(−0.667)	(0.715)	(−0.848)
Socioeconomic variables						
$P \geqslant 65$ (percent of total)	5.331*	7.449**	8.723**	4.357	6.633**	8.015**
	(1.606)	(3.984)	(4.140)	(1.245)	(3.290)	(3.525)
VA (cruzeiros per capita)	−189.581	14.330	52.335	−67.893	61.350	112.000
	(−1.251)	(0.168)	(0.543)	(−0.430)	(0.674)	(1.091)
HB (per 1,000 population)	−0.251*	−0.166*	−0.228*	−0.248*	−0.162*	−0.225**
	(−1.393)	(−1.640)	(−1.996)	(−1.458)	(−1.547)	(−2.037)
P/km^2	—	—	—	−0.002*	−0.119*	−0.001*
				(−1.431)	(−1.599)	(−1.432)

— Not applicable.
Notes: The numbers in parentheses are t-statistics.
* Significant at 10 percent level.
** Significant at 5 percent level.
Variables:
TMT = total mortality rate
TM_1 = mortality rate excluding children 1 year old and younger
TM_9 = mortality rate excluding children 9 years old and younger
PM = particulate matter
SO_2 = sulfur dioxide
CO = carbon monoxide
$P \geqslant 65$ = population 65 years and older
VA = value added
HB = hospital beds
P/km^2 = population per square kilometer

With child mortality excluded, an increase of 1 ton of particulates per square kilometer may be associated with an increase of about 8 deaths per million. Given a mean mortality rate of about 5,690 per million for the population over a year old, the implication is that a 50 percent reduction in particulates alone is associated with an approximate 1.2 percent decrease in the mortality rate of noninfants.

As a further check on the above results, data for seven highly polluted subdistricts within the São Paulo municipality over the six-year period 1973–78 were analyzed.[13] Data on total mortality for all age groups were available from Secretaria de Economia e Planejamento (SEPLAN). Mean monthly pollution readings by the CETESB, in micrograms per cubic meter for particulates, sulfur dioxide, and carbon monoxide, were averaged for 1973–78.[14] The weakest link in the data is income; per capita income was estimated rather roughly by EMPLASA for various zones which were aggregated to correspond to the subdistricts.

Equation 13-2 regresses the total mortality rate (deaths per 10,000 population) for the seven subdistricts during 1973–78 on mean and maximum particulate and sulfur dioxide concentrations in micrograms per cubic meter. It is assumed that family income grew by 3 percent in real terms between 1973 and 1978. (Other results are in table 13-4.)

$$\begin{aligned} (13\text{-}2)\qquad TM' = {}& -134.99 + \underset{(5.72)}{0.888}\ PM\ mean \\ & + \underset{(1.27)}{0.153}\ SO_2 + \underset{(4.28)}{10.655}\ P \geqslant 60 \\ & + \underset{(2.83)5}{0.009}\ I \\ & - \underset{(4.76)}{0.003}\ P/km^2 + e \qquad\qquad R^2 = 0.579 \end{aligned}$$

where TM' is the subdistrict mortality rate, PM *mean* and SO_2 *mean* are the average particulate and sulfur dioxide concentrations, respectively, $P \geqslant 60$ is the percentage of the population aged 60 or older, I is per capita income, and P/km^2 is population density. In table 13-4 *PM max* and SO_2 *max* are annual averages of monthly maximum values of particulate and sulfur dioxide concentrations.

About 60 percent of the variation in mortality among the subdistricts is explained in equation 13-2. Inclusion of *PM max* and SO_2 *max* raises the explanatory power to 66 percent.[15] A change in the assumption of constant income to a 3 percent growth in income has little effect. Similarly, the deletion of the variables *PM max*, SO_2 *max*, and P/km^2 does not affect principal results appreciably.

Equation 13-2 implies a high and significant association—an improvement by 1 microgram per cubic meter is associated with a decrease in mortality of 8 deaths per 100,000—which may be explained by several factors. The seven subdistricts face about the worst pollution problem, and marginal benefits from control at existing pollution levels are high. The pollution variable may also be a proxy for excluded socioeconomic variables. The relatively low level of public services in some of the more polluted areas may contribute to higher mortality rates. Thus, the strong marginal mortality effect found should not be fully attributed to pollution, but the consistently significant coefficient of particulate concentration may be additional evidence of a significant incremental pollution-mortality effect in areas that are already heavily polluted.

Policy Implications

It was indicated that if 25–50 percent of the GSP's population is assumed to be directly affected by pollution, the per capita costs of a 94 percent abatement by the industries (or of a 55 percent reduction in total particulate emissions in the area) would be \$1.1–\$2.2. A per capita cost figure of about \$4 is implied by Kowalczyk (1980) for the abatement of 71 percent of industrial particulates in the heavily industrialized Medio Paraiba area, on the assumption that only 75 percent of the people are directly hurt. It was also suggested (with caveats) that air pollution is statistically significant in explaining variations in the total death rate in the GSP.

Although no dollar value was placed on the health benefits associated with pollution control, the orders of magnitude of costs of control suggest that net benefits could possibly be obtained from a substantial reduction—say 85–90 percent—in the stock of pollution. In the GSP smoke abatement can be efficiently achieved by focusing on a relatively few large polluters, and this is the current policy. Concentration on the large nonmetallic industrial polluters may also make sense on economic grounds, but such a discriminatory approach may not be practical.

Of the methods of reducing pollution, the strategy of affecting industrial output is relatively inefficient because it does not lead to substitutions in the production processes which could lower the cost of controls. The preferred approach would be to directly control pollution either by an emission tax or by pollution abatement standards, which induce producers to cut back their use of pollutant fuels or find substitutes for them and to adopt control equipment. Direct fuel restrictions provide no incentives for the use of control equipment. Similarly, requirements to use abatement equipment give no inducements to restrict or modify fuel use.

The higher intensity of industrial activity and the

Table 13-4. ***Total Mortality per 10,000 Population for Seven Subdistricts, São Paulo Municipalities, 1973–78***

	Constant real income			*3 percent annual growth in real income*		
Value	*A*	*B*	*C*	*A*	*B*	*C*
R^2	0.317	0.587	0.667	0.314	0.579	0.663
Constant	−38.330	−136.380	−124.025	−37.548	−134.990	−122.236
Air pollution variables (micrograms per cubic meter)						
PM mean	0.472**	0.894**	1.097	0.469**	0.888**	1.119**
	(2.94)	(5.81)	(5.44)	(2.91)	(5.72)	(5.48)
SO_2 *mean*	0.040	0.160*	0.062	0.033	0.153	0.065
	(0.27)	(1.34)	(0.493)	(0.225)	(1.27)	(0.51)
PM max	—	—	−0.220**	—	—	−0.235
			(−2.25)			(−2.38)
SO_2 *max*	—	—	0.147*	—	—	0.134
			(1.33)			(1.21)
Socioeconomic variables						
P≥60 (percent of total)	3.312*	10.55*	9.112**	3.499*	10.655	9.209*
	(1.33)	(4.28)	(3.87)	(1.40)	(4.28)	(3.89)
Per capita income (cruzeiros)	0.003	0.009	0.010**	0.002	0.009**	0.010**
	(0.78)	(2.97)	(3.53)	(0.67)	(2.83)	(3.44)
P/km^2	—	−0.003	−0.003**	—	−0.003**	−0.003**
		(−4.85)	(−5.42)		(−4.76)	(−5.37)

— Not applicable.

Notes: Numbers in parentheses are *t*-statistics. Variables are defined in table 13-3. Columns A: variables *PM max*, SO_2 *max*, and P/km^2 excluded; columns B: variables *PM max* and SO_2 *max* excluded; columns C: all variables included.

* Significant at 10 percent level.

** Significant at 5 percent level.

greater population density in São Paulo, combined with the city's unfavorable geographic and climatic characteristics, imply higher incremental damages there than in Rio. According to the 1970 Industrial Census, the value of production in São Paulo was 8.6 times that in Rio. The difference in particulate effluents indicated in Kowalczyk (1980) for 1979 is only 11 percent, which appears to be the result of a serious underestimation of fugitive dust in São Paulo. When fugitive dust sources from quarries and asphalt plants are excluded, São Paulo's effluents exceed Rio's by 145 percent. Given São Paulo's larger area, however, pollution concentration in the two places would not be of the same order of magnitude. Population density in São Paulo exceeds that in Rio (by about 17 percent in 1970 and more at present), which would lead to a significantly higher marginal benefit of pollution control in São Paulo.

Rio's industries seem to face lower control costs than those in São Paulo (table 13-2). With quarries and asphalt plants included, the difference in cost per ton of pollution control between the two places is 210 percent. Because of the inaccuracy of data on fugitive dust, however, a better comparison is provided by excluding quarries and asphalt plants; then the cost difference is 60 percent. The large difference in the control cost for asphalt plants is primarily attributable to the inclusion of fugitive dust emissions in the Rio inventory. Ceramic plants in Rio, which are small in size, can use water spray systems instead of more expensive bag filters. Rio's higher cost per ton for foundries and steel mills appears to be a result of smaller-size facilities, for which the cost per ton of initial abatement hardware is higher.

Thus, while higher apparent pollution damages in São Paulo call for more stringent abatement than in Rio, the generally higher range of control costs in São Paulo limits the desirability of controls. In the absence of better estimates of benefits and costs, one cannot conclude whether it would be socially beneficial to treat São Paulo and Rio differently under an antipollution strategy. More information would make possible a cost-benefit ranking of the various control options for each area, with implications for differential treatment, to aid in identifying the proper priorities.

Much greater differences in damages from pollution in the São Paulo–Rio comparison may be expected if smaller towns are also considered. The desirable approach would be to set widely different abatement goals for different locations. Two other strategies may be considered: one that requires uniform percentage abatement in all areas and another that sets equal maximum allowable emission standards for all places. In principle Brazil has uniform emission standards; in practice they are enforced only selectively and through more or less uniform percentage abatement requirements. The resulting spatial differentiation, although not necessarily ideal, would be better than that implied by the implementation of identical emission standards.

The least amount of spatial shifts in production would be induced by the uniform abatement (percentage collection) policy. If, in addition, new sources are singled out for regulation, or if they face significantly stricter restrictions, the existing locational patterns would tend to be frozen. In contrast, the desirable policy would normally require more abatement in the more damaged places and thereby encourage some displacement of existing output and induce future entrants away. An extreme but not unrealistic possibility is that an optimal policy would concern itself only with highly built-up urban centers and would set no controls on highly rural situations. As a result industrial plants would be induced to move away from population centers, which would help to cut down on the total cost of antipollution policies.

Notes

1. On the basis of projections in Hauser and Gardner (1982) and United Nations (1980). Problems arising from conflicting definitions of boundaries make comparisons difficult. Today Tokyo and New York would also be larger than São Paulo if Yokohama and northeastern New Jersey were included in the respective metropolitan areas.

2. In New York City and Chicago, for instance, sulfur dioxide concentration averaged 150–160 micrograms per cubic meter and suspended particulates 180–190 micrograms per cubic meter in 1972. The average carbon monoxide concentration recorded in a representative area in New York City in 1975 was 4.0 parts per million.

3. The welfare cost of pollution control, as in Thomas (1980, 1982), would be somewhat lower than these measures.

4. The São Paulo municipality, parts of which are heavily polluted, contains over 65 percent of the GSP's population. The heavily industrialized areas of Santo Andre, São Caetano, São Bernardo, Osasco, Mogi das Cruzes, Guarulhos, and Diadema account for another 20 percent.

5. A 1980 population estimate for the industrialized municipalities that constitute this area is 1.16 million, or a population density of 224 persons per square kilometer.

6. It does not follow, however, that to meet overall abatement standards which are significantly higher than 85 percent it would be desirable to raise the standards for the larger producers above 94 percent. Instead, as the overall standards are raised, it would most likely be desirable to include the smaller polluters in the operation.

7. Data sources are Secretaria de Economia e Planejamento (SEPLAN); Fundação Sistema Estadual de Analises de Dados Estatísticos (SEADE); Secretaria de Estado de Saúde, Centro de Informacoes de Saúde (CIS); and Secretaria de Fazenda.

8. Elimination of infant mortality and child mortality raises the explanatory power to nearly 50 percent. The coefficient on particulates falls, however, presumably because of the vulnerability of babies to pollution.

9. This may suggest that density is endogenous within the model in adjusting for pollution levels (that is, the impact of particulate concentration on density is negative), and thus density has a negative relation to mortality.

10. About 137,000 tons of annual particulate emissions by industries is divided by the GSP's area of 7,951 square kilometers.

11. This means about a 33 percent reduction in total particulate emissions, since industries contribute 65 percent.

12. Lave and Seskin (1977) found that for 117 Standard Metropolitan Statistical Areas (SMSAS) in the United States for 1960 a 50 percent reduction in particulates and sulfates was associated with a 4.7 percent decrease in the mortality rate.

13. The subdistricts are Aclimacão, Cerqueira Cesar, Consolacão, Indianapolis, Lapa, Santa Cecilia, and Tatuape.

14. Other data sources were SEPLAN, SEADE, CIS, and EMPLASA.

15. The negative coefficient of *PM max* is unexpected and is contrary to findings reported earlier by Mendes (1976).

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