Pollution Control in Sao Paulo, Brazil: Costs, Benefits and Effects on Industrial Location

SWP-501

World Bank Staff Working Paper No. 501

November 1981

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WORLD BANK

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With rapid industrialization, environmental pollution has reached alarming proportions in some of the urban centers in Brazil, particularly Sao Paulo. As anti-pollution regulations are now being enacted and implemented to combat this problem, the need to evaluate policy options has surfaced. This paper presents a cost-benefit framework to analyze pollution control policies, and sets out some preliminary order-of-magnitude level estimates.

Available evidence points to large damages from pollution in terms of the detrimental effects on human morbidity and mortality, particularly in the highly contaminated and heavily populated districts of Sao Paulo. In capturing the implied benefits through pollution abatement, however, heavy costs will be incurred, unless a selective approach is adopted. Such an approach would be discriminatory with respect to the group of industries and types of areas targeted for regulation, and the nature of controls imposed on pollution.

Spatial non-uniformity of the desired strategy can lead to induced changes in industrial location. Such a redistribution of output away from the heavily damaged and densely inhabited population centers to areas better capable of absorbing pollution could be welcome. This indirect effect on manufacturing location is generally preferable to policies that directly limit growth in production in certain places as a means to improve environmental quality.

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Preface

Until some years ago, policy makers in Brazil (as in many other countries) felt that a newly industrializing nation was not in a position to afford policies for pollution control. On occasion, polluting activities were even viewed with some degree of approval, on grounds that they possibly reflected growth process. However, environmental degradation associated with rapid industrialization and urbanization soon became a serious concern in highly built-up population centers like Sao Paulo. Consequently, anti-pollution policies on the national level, with support from states and metropolitan areas, began to evolve since the mid 1970s. As pollution control policies are now beginning to be implemented, however, old anxieties about their possible effects on industries´ competitiveness in world markets, on inflation, on energy use efficiency, and on the government budget have reemerged.

The shifts in opinion about environmental regulations and the desirable degree of their stringency call attention to the need for objective analysis and estimates of the effects of policies. A framework of cost-benefit analysis could assist policy formulation, although knowledge may be too limited to permit its application for deriving precise estimates. For analysis of policy options, however, precise estimates of all the various effects may not be necessary. Even rough, order-of-magnitude level measures may be sufficient, and would certainly be better than no estimates at all. Lack of previous estimates for Brazil, nevertheless, is a serious barrier to carrying out a cost-benefit analysis in this area.

Initial work in developing notions of costs and benefits of pollution abatement projects and programs is being carried out at CETESB (Sao Paulo´s environmental protection agency), FIPE (a research institute at the University of Sao Paulo) and the World Bank (in the context of the Bank´s pollution projects). This paper is intended to contribute to this investigation by presenting a framework for analysis, and assembling some of the available information. The estimates presented in this paper are preliminary and obviously inadequate to allow a full application of the framework. Available data and the present analysis, nevertheless, point to some broad policy directions.

This work was carried out with A. E. Comune and Vera Lucia Fava at FIPE, in collaboration with CETESB. The study also benefited from comments and suggestions received from Carlos Celso do Amaral e Silva, Luiz Carlos da Costa, Nilda Fernicola, Rosa Christina de Itapema Cardoso, and Elizabeth Monsowski at CETESB, Carlos A. Longo, Juarez A. B. Rizzieri, and Dennis Sanchez Acuna at FIPE, and Douglas Keare, Homi Kharas and Peter Townroe at the World Bank. Diana Goodman edited the report. Any errors in the paper are, of course my responsibility.

Vinod Thomas

I. Introductory Summary

Sao Paulo is the most industrialized area of Latin America. Next to Mexico City and Shanghai, it is presently the third largest metropolitan center in the world. 1/ Today, Sao Paulo also faces some of the most urgent problems of the urban environment.

Environmental problems in Sao Paulo are not unlike the experiences of other similarly fast-growing urban areas around the world. Environmental degradation is not confined only to Sao Paulo, or to other urban areas within Brazil. Nowhere else in the country, however, has environmental pollution escalated as rapidly as in the Greater Sao Paulo Metropolitan Area (GSPA). 2/

Discussions of the magnitude and the characteristics of airborne emissions in the GSPA as well as descriptions of the area's importance to Brazil are presented in Part I, Section II. The concentration of air effluents in Sao Paulo compares with the levels recorded in some of the most industrialized cities in the world. The severity of pollution, however, is neither uniform within Sao Paulo nor across the country. Spatial variations are striking both in the intensity of pollution and its damage to the population.

The pollution problem is most serious in and around the more industrialized parts of the GSPA. For example, while the municipalities of Santo Andre, Sao Bernardo and Sao Caetano (Map 1) have been described as

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1/ This statement is based on 1975 population and growth rates in Hauser and Gardner [20] and U.N. [41]. Problems arising from conflicting definitions of boundaries make comparisons difficult. Today, Tokyo and New York would also be larger than Sao Paulo if in each case Yokohama and N.E. New Jersey are included respectively.

2/ See Maps 1-4 and Table II.1 for distinctions between Sao Paulo municipality, the GSPA, and the state of Sao Paulo.

"unliveable", over one million people live there. In these areas as well as satellite towns like Cubatao (population 85,000), the air is said to be "unbreathable". Diseases of the respiratory track have been repeatedly observed in these places. In Cubatao, widespread incidence of birth deformities has been reported. 1/

Threat to human health is the most serious aspect of environmental decay, although damages to property, flora and fauna are also often important. Health hazards encountered in a polluted environment have been well documented by medical evidence accumulated worldwide. 2/ In the case of Sao Paulo, the connection between pollution and adverse health effects has been drawing increasing attention. Studies have related high concentrations of pollutants in the ambient air to respiratory and cardiovascular diseases in the GSPA. Similarly, studies have borne out a high interrelationship between deteriorating water quality in the region and the occurrence of transmittable diseases. 3/

If human health is precious, if not priceless, then cleaning up the environment in seriously damaged areas is an urgent matter. However, in most developing countries (LDCs) including Brazil, at least until recently, no concensus on the priority of pollution control has emerged. Reasons for the controversy are varied. First, some maintain that compared to developed

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1/ The relation between pollution and ill-health is considered in studies by Prof. Reinaldo Azoubel at Ribeiro Preto School of Medicine; quoted in "Industrial Pollution Scars Brazil's Valley of Death", Washington Post, May 10, 1981.

2/ For discussions of the relation between pollution and human health, see [2] [27] [30], [35].

3/ A discussion of some of these studies is given in [44].

economies, the problem is not serious in LDCs where the volume of ambiental discharges is lower. This view may be valid in the case of air pollution and solid waste in very poor countries. Airborne effluents are closely related to energy conversion in stationary and mobile sources, while solid waste is roughly proportionate to commodity production [30]. In rapidly industrializing economies like Brazil, however, the magnitude of air pollution is by no means inconsequential. Furthermore, in LDCs in general (including low and middle income countries), the problem of poor water quality, which stems from water discharges, inadequate sewage treatment, and drinking water, are generally far graver than in developed countries.

It should also be noted that damages depend not only on the volume of pollution, but also on the time, form and location of discharges. Even where the quantity of pollution emitted is relatively small, damage can be extensive if the receiving media have a low capacity to innocuously absorb pollutants. In LDCs with high population densities, the media are less capable of harmlessly assimilating ambiental discharges, simply because more people are exposed to them. Thus, in highly built-up and crowded areas like the GSPA, social losses due to heavy pollution are disproportionately high.

Second, it is commonly felt that LDCs cannot afford anti-pollution policies. This is not merely attributed to the fact that less resources are available for environmental action. Underlying this assertion is also an implicit assumption of a trade-off between industrialization and economic growth, on the one hand, and environmental effects on the other. This notion of a trade-off, however, may often be too simplistic. There is no doubt that environmental programs involve a cost. Indeed, one of the purposes of this paper is to evaluate their cost to society. While anti-pollution measures can have effects on the size, nature and location of production, ways and means exist for adopting corrective measures in a rather painless way. There can be substantial pay-offs in terms of the health and the well-being of people associated with such steps. Anti-pollution policies, if conceived rationally, can thus provide net long term benefits.

This paper deals with criteria for choosing anti-pollution policies and programs. The discussion draws on economic analysis of the costs and benefits of improving the environment. Clearly, LDCs differ widely in the size and nature of environmental ills, and the analysis and conclusions should therefore be country-specific. Equally important for countries like Brazil with large spatial differences, the approach needs to be region-specific. The need for a regional strategy based on local costs and benefits is revealed in this paper.

Although the paper uses Sao Paulo as a case study, much of the discussion has general applicability. In order to restrict the scope of policy discussion, the paper is confined to industrial air pollution. As will be clear, however, industrial emission is only one of the principal components of air pollution. In terms of volume, automotive effluents are more important. Furthermore, air pollution is only one principal aspect of the ambiental decay in the GSPA, as water contamination is the other. Discussions of water pollution and non-industrial air pollution in the GSPA are contained in [44].

In Brazil until the early 1970s, there was nearly a tendency for policy makers to opt for environmental damage on grounds that it was inevitable in the pursuit of economic growth and an improved competitive position on international markets. As pollution grew, however, the virtues of accepting such a trade-off, even if it existed in the short run, soon became questionable. Public awareness of the deleterious consequences of pollution increased, and the sacrifice of clean air under rapid industrialization became controversial. In a recent opinion poll in Sao Paulo, about 80% of the people interviewed considered environmental damage in the area as serious a problem as its high living costs and crime in the streets. 1/ This reaction is significant in view of the escalation of the latter problems in recent years.

Under growing pressure from various localities, national anti-pollution policies, with support on state and metropolitan levels, began to evolve in Brazil in the mid 1970s. Because the enactment of laws is of recent origin, actual measures to put them into effect have been limited. Actions taken have focused on the state of Sao Paulo, and the GSPA in particular. These measures are outlined in Part 1, Section III.

Federal legislation has established national air quality standards and broad guidelines for the implementation of anti-pollution policies. While air quality standards are uniform across the country, they do not yet aim toward effective enforcement outside Sao Paulo, thus indicating the policy's regional emphasis. In 1977, the state of Sao Paulo spent US$ 37 million on pollution control, or $ 1.68 in per capita terms.

Even in Sao Paulo, actions to cut down on the existing stock of pollution have been limited, and until very recently, most of the past efforts were concentrated on holding off a deterioration of the existing situation. In so doing, attention has been directed at new potential pollution sources. Means relied upon have been industrial zoning and licensing,tools which indirectly affect pollution through their effects on industrial location.

1/ Revista Veja, Sao Paulo, October 1, 1975, pp. 80.

From the end of 1976 to the end 1979, the state's environmental protection agency, "Companhia de Tecnologia de Saneamento Ambiental" (CETESB), issued over 10,000 installation licenses for new plants, expansion projects and residential developments, upon taking pollution criteria into account.

While the current strategy of influencing industrial location to affect pollution differentiates between old and new sources, a US$ 187 million project is now underway to treat the already existing air and water pollution in Sao Paulo more directly. A World Bank loan of $58 million has been made for this project. The approach under the project is to help meet air quality standards by focussing on the relatively few producers who contribute the bulk of the discharges. An average of 80-90% abatement of particulates from industrial sources is deemed necessary, with the brunt of the effort taking place in the highly polluted areas. Industries are required to apply "best available control technology", which is enforced through a system of fines and penalties. Recent evidence indicates that CETESB has stepped up the enforcement of its system of fines and penalties on polluters. According to a newspaper account, 1/ recent increases in the fines and improvements in implementation have led to a noticeable reduction in pollution levels in Sao Paulo.

Thus, national environmental policy is in its early stages of evolution in Brazil. Legislation and implementation of a full-fledged strategy await the results of further studies on the worthiness and cost-effectiveness of alternative approaches. Part 2, Section IV of this paper presents some cost/benefit considerations as guides to policy formulation.

1/ "Actions of CETESB reduces pollution in Sao Paulo", O Estado de Sao Paulo, July 5, 1981, p. 26.

Justification of a certain air quality target should lie in the equalization (roughly speaking) of incremental cost and benefit at the implied abatement (percentage smoke collection) required to meet that target. These marginal costs and benefits have a location specific character: while the costs depend on the ability of industries belonging to a locality to abate highly pollutant levels, the benefits depend on the changes of local environmental, demographic and meteorological conditions. Thus, in principle, different air quality standards may be called for in different places, depending not only on how large cost/benefit differences are, but also on practical considerations.

Some preliminary cost estimates for Sao Paulo's particulate polluters have been made by CETESB and the World Bank. These are estimates based on capital and installation costs projected by some industries, a majority of which are yet to actually adopt control techniques (Section IV.C). One estimate of the investment cost for industries contributing 90% of industrial particulate effluents is 30 million 1977 US$ to collect 94% of smoke or about 124,000 tons annually. Abatement of about 85% of all industrial particulate discharges and about 55% of all particulates in the GSPA is implied. Assuming a 10 year life of the equipment and a 10% interest rate, the annualized investment cost is US$ 4.75 million. Upon adding a liberal 25% for annual labor and maintenance cost, an overall annual cost of about US$ 6 million is obtained. If it is assumed that 25%-50% of the GSPA's 11 million population is directly affected by the pollution, 1/ a per capita annual cost of about

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1/ The Sao Paulo municipality, parts of which are heavily polluted, constitutes over 65% of the GSPA's population. The heavily industrialized areas of Santo Andre, Sao Caetano, Sao Bernardo, Osasco, Mogi das Cruzes, Guarulhos and Diadema constitute another 20%.

US$ 1.1-2.2 is implied for the 55% abatement of particulate pollution in the area.

A higher per capita figure results from cost calculations by Kowalczyk [26] for the small but heavily industrialized Medio Paraiba area. The investment cost at 98% control efficiency for four industrial sources that contribute 72% of the 42,466 tons of annual particulates formed by all industries, is about 16.6 million 1979 US$. The annualized investment plus labor cost figure (assuming 25%) is $3.25 million to abate 30,759 tons annually, or 71% of all industrial particulates. Assuming that only 75% of the one million people who live in the area's industrialized parts are directly hurt, an annual per capita cost figure of 1979 US$ 4.33 is obtained.

While the above type of cost estimates are highly preliminary and do not fully indicate welfare cost (as discussed in Section IV.A of this paper), 1/ they give, nevertheless, a range against which one can reflect what the likely benefits are. One may ask, for example, if a greater than 50% improvement in the particulate pollution constitutes annual per capita benefits of more than the order of $1.1-2.2 (1977) in the GSPA or over $4 (1979) in the Medio Paraiba Area. The discussion of benefits in this paper does not actually provide quantitative benefit estimates. The relationship between this paper and previous studies of particulate pollution and mortality, however, as well as other benefit estimates, strongly suggests

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1/ Welfare cost is usually lower than cost estimates based on the investment cost for control equipment since the former allows for full substitution between polluting fuels, non-polluting fuels and control equipment, and also changes in output.

benefits in ranges that amply justify the above types of costs in improving the air in highly polluted/populated areas.

A discussion of the likely benefits from pollution control is contained in Section IV.B. Although the effect of air pollution on human health, and mortality in particular, is focused upon, the effects on human morbidity, plants, animals and structures are also important. Lave and Seskin [27] have suggested that halving the ambiental concentrations of sulfur oxides and suspended particulates over a typical US metropolitan area from their 1960 levels may decrease the death rate by 4.7% or add about one year to life expectancy. Anderson and Crocker [3] have estimated that in Chicago an additional microgram of particulates/m^3 detracts about $48 from the sale price of a residential house and lot, thus implying a yearly equivalent value of $2.40 - $4.80 per property. If such relationships reflect pollution damages for Sao Paulo, large gains, well above the kind of costs indicated above, would be implied. 1/

We analyze the total mortality rate across the 37 municipalities in the GSPA in 1977 as well as 7 selected sub-districts within the Sao Paulo municipality between 1973-78. While the effect of air pollution is measured by suspended particulates, sulfur dioxide and carbon monoxide are estimated through the use of a simple linear model. Socioeconomic variables are used

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1/ These kinds of benefits accrue in places where marginal benefits from pollution control are high at high existing levels of pollution and population concentration (Section IV.D and VII.A). Marginal benefits in Sao Paulo should be comparable to some US cities, given its already high pollution level and population concentration (Section II A and B).

to control for age distribution, population density, income level and other welfare indicators. A number of difficulties in this estimation procedure are discussed in Section IV.B. Subject to these caveats, it is concluded that the measures of air pollution are significant factors in explaining variations in the total death rate. One result is that a 50% reduction in industrial particulates alone, from their 1977 levels, is associated with a 1.2% reduction in the mortality rate in the GSPA. We place less emphasis on this particular finding than on a consistent and significant effect found between particulates (the only pollution variable for which good data are available) and the mortality rate in the municipalities and the sub-districts.

Proper choice of the means of control can reduce the cost of abatement, thereby jusifying more stringent air quality standards than otherwise. Part 2 Section V discusses five alternative means often considered, which include pollution standards, pollution tax, requirements to use control equipment, fuel restriction and output restriction. Pollution standards are usually of two types which are described as emission standard, meaning maximum allowable emissions, and abatement standard, meaning a certain percentage collection requirement. Based on previous studies, the relative merits of pollution standards and taxes over other means are pointed out. Standards and taxes leave complete flexibility to the producer in adjusting to regulation in the least costly way. Producers may be expected to cut back on pollutant fuels as well as adopt control equipment. A fuel restriction policy, in contrast, provides no incentive for the use of control equipment. Similarly, a requirement to use abatement equipment gives no inducement to restrict or to modify fuels. Least effective, however, is a policy restricting industrial output, since it does not lead to the exploration of either of the aforesaid avenues of smoke reduction.

A principal merit of a pollution tax is that a single unit tax will distribute the burden of control most cost-efficiently across sources in an area. The tax, however, is also an approach with little appeal to policy makers. A pollution standard is more popular, as it provides the proper incentives to a particular producer. To minimize cost in principle, however, the pollution standard must be separately determined for each source. If, however, a broad differentiation between low cost and high cost industries (in terms of control cost) can be made within a given area, a single abatement standard (i.e. a certain percentage collection requirement) can be cost-effectively applied to the relatively low cost producers. The same abatement standard, in all likelihood, will not apply to a different area. If the same air quality standard is justified throughout all locations, the more polluted areas would face more stringent abatement standards. Even if (as is more likely) some differences in air quality standards are justified (Section IV.D), differences in abatement requirements under an optimal approach, would probably still persist as long as existing air quality varies widely throughout areas.

The above type of spatial considerations are dealt with in greater detail in Part 3. Systematic differences in the cost of production, the cost of pollution control, and demand schedules faced by industries, give rise to variations in the social cost of abating pollution through the regulation of one producer as opposed to another. Such differences in welfare cost (discussed in Section IV.A) under an optimal strategy, can be the basis for differentiating among groups of producers in an area or across areas, as brought out in Section VI.

Available data for Sao Paulo point to significant control cost differences, depending upon the size and type of producer. Per ton abatement cost generally increases from the large to small producers, and from non-metallic to chemical industries, metallurgic industries, and other industries. To what extent this consideration can and should lead to non-uniformity in policy for producers, depends upon both the level of overall abatement to be achieved and practical considerations. For example, in meeting a 55% overall particulate abatement for the GSPA, it is sufficient and cost-effective to regulate 90% of the top polluters (assuming 94% collection efficency) within industrial activities which contribute 65% of the smoke. The top 90% include the large low-cost producers of the non-metallic type, as well as the large and relatively higher cost producers of the chemical and metallurgic types. At higher abatement targets, smaller producers belonging to these types and/or larger producers of other categories of industry would be included. It may not be always practical, however, to distinguish between industries under law within the same jurisdiction. But cost differences for the major industry types across locations should clearly influence target controls for quite different jurisdictions (states, municipalities, even districts).

The above cost considerations should be viewed in conjunction with the benefit differences examined in Section VII. It is postulated that incremental benefits depend upon existing pollution levels, population density and geographical and meteorological factors, all of which vary widely within Brazil. Furthermore, the concentration of pollution and population, in a majority of cases, varies with multiplying damages. Also, the particularly unfavorable natural factors in the GSPA augment the problem. A clear reason for locational selection in regulating pollution is thus provided. At the same time, since the incremental cost of control increases with the degree of abatement, it is unlikely that an optimal approach would require sufficient differences in abatement across areas in order to bring about equalization of air quality everywhere.

The net effect of considering the above factors for air quality targets across regions cannot be ascertained without a better quantitative notion of costs and benefits. An example is provided in Section VII where higher costs and benefits from pollution control in the GSPA relative to Rio de Janeiro are observed. The evidence is not sufficient, however, to conclude that it is socially optimal to treat pollution sources equally in these two areas.

Unless areas are treated uniformly, anti-pollution policy may be expected to indirectly cause a degree of redistribution of industrial output. This is the subject of Section VIII. If locations are treated differently on the grounds of cost/benefit , such induced dislocation of production is socially beneficial as it cuts down the social cost of pollution control. Often, direct regulations are placed on industrial production in order to indirectly lower pollution. Generally, however, the social cost from such an approach would not be justified on the grounds of pollution.

Any of the measured short term effects on industrial location are likely to be small. More significant effects may be expected over a longer term, unless a policy of spatially uniform controls is expected to evolve.

At the other extreme, if spatially uniform air quality is targeted, (i.e. very different degree of controls) large locational changes may be expected to be induced. An optimal strategy would seem to lie between these extremes in the forseeable future. Some non-uniformity in the degree of controls (but probably not sufficient to equate air quality) would be expected, thereby inducing some of the production (presumably existing and potential) away from the heavily damaged areas.

A recent paper [40] relates the existing anti-pollution policies in the GSPA to industrial location decisions. Drawing on the results of industrial location surveys, it is pointed out that "the Sao Paulo experience demonstrates that the introduction of a fairly strict and comprehensive industrial pollution policy may be expected to have fairly immediate spatial consequences on the geographic pattern of industrial growth....." The overall output of industrial pollutants is dominated by very few sectors and plants, thus calling for a discriminatory policy on theoretical and administrative grounds. Such discrimination by area may then be expected to disperse heavy polluters.

To summarize the scheme of the paper, Part 1 expands upon the nature of the industrial air pollution problem in Sao Paulo (Section II) and summarizes major policy actions carried out or envisaged to combat it (Section III). Part 2 presents basic cost/benefit considerations relevant for formulation of anti-pollution policies in any country. Section IV deals with the determination of air quality targets (and the implied degree of smoke abatement) on cost/benefit grounds, using Sao Paulo as a case study. In Section V the choice of the means of control available to achieve any given air quality target is analyzed. Part 3 elaborates on the spatial implications of policies. In Section VI we explore to what extent differences in the cost of production and pollution control justify differentiating between producers. On grounds of benefit differences, Section VII brings out the advantages of differentiating among locations, while the GSPA is used as a case study. Anti-pollution policies, particularly when they are spatially non-uniform, tend to affect the distribution of industrial output across locations. Such an effect is the subject of Section VIII.

Part I. Air Pollution Problem and Policies in Sao Paulo

II. Industrial Air Pollution

A. The Greater Sao Paulo Metropolitan Area (GSPA)

Sao Paulo's pollution problems assume greater significance when we take into account the area's population and its contribution to the nation's life. Therefore, before we turn to the problems and policies associated with pollution in the area, a description of the size and importance of the GSPA in relation to the rest of the country is presented. 1/.

The following table shows the high degree of population agglomeration in the region. This population concentration has resulted from a 5-6% annual growth level during the 1960s and 70s, compared to a national average of 2-3%.

Table II.1 Brazil and Sao Paulo: Area and Population, 1978

	Area (million km^2)	Population (million hab)	Density (hab/km^2)
Brazil	8.5	113	13
Sao Paulo State	0.25	22	88
Greater Sao Paulo (GSPA)	0.008	11	1375
Sao Paulo Municipality	0.0015	7.6	5067

Source: H. Hirschfeld [21].

1/ See [45] for details.

The GSPA shows tremendous polarization of economic activity. In 1970, it accounted for 70% of the state's domestic product, thus implying a 25% share in Brazil's production. Per capita product for the GSPA therefore remained nearly 2.5 times higher than the national average. The exceptional industrialization that characterized Brazilian growth in the recent past (13% annual growth in industrial value added between 1967-73) has been heavily concentrated in the GSPA. About 70% of the State's industrial value-added originated in this area in 1975, which amounts to over a 40% share in the nation's industrial value-added. In 1975, 68% of the State's industrial labor force, or nearly 35% of the nation's industrial employees worked in the GSPA. Within the area, the Sao Paulo municipality dominates industrial and other economic activities. It is noteworthy that 65% of the GSPA's industrial value-added, and 71% of its industrial manpower were accounted for by the Sao Paulo municipality alone.

B. Amount of Air Pollution 1/

One consequence of the rapid urbanization and industrialization has been a deterioration of the environment in the GSPA, particularly in its densely populated areas. According to the CETESB, air pollutant discharges in the area currently amount to 7,203 tons/day. Carbon monoxide makes up 4,704 tons of total emissions (65%), while sulfur dioxides, hydrocarbons, particulates and nitrogen oxides contribute, respectively, 924 tons (13%), 737 (10%) 493 (7%) and 345 (5%) tons/day (Table II.3).

1/ Detailed discussions can be found in [22], [31], [45].

In some of the GSPA's most crowded areas, the concentration of these emissions in the air far exceeds established maximally "acceptable" levels. In 1978, daily air quality standards, 1/ were exceeded 299 times for carbon monoxide, 121 times for particulate matter, and 17 times for sulfur dioxide in the GSPA. Highest concentration of these substances in the same year were respectively, 282%, 190% and 219% more than their standards. The average annual concentration of carbon monoxide in the more polluted areas of the GSPA during 1976-78 was 12-13.5 p.p.m., while that of particulates was 115-126 $\mu g/m^3$.

These average annual concentrations in the GSPA are comparable with the pollutant levels recorded in some of largest cities in the US during the early 1970s. In New York City and Chicago, for instance, sulfur dioxide concentration averaged 150-160 $\mu g/m^3$ and suspended particulates 180-190 $\mu g/m^3$ in 1972 [6]. Average carbon monoxide concentration recorded in a representative area in New York City in 1975 was 4.0 p.p.m. 2/.

Damages from high pollutant concentrations are compounded by the GSPA's particular climatic and topographic character. Light winds, air stagnation and frequent temperature inversions hold polluted air near to the ground, thus aggravating the ill-effects of the discharges. The problem is worse in the winter months of June, July and August, when the concentration at the ground rises as much as 50-75% over the annual mean in some places. (See Tables II.4 and II.5). A CETESB study [9] has shown a strong association between the aggravation of respiratory illnesses and deaths as well as a correlation between pollution levels and the winter months.

1/ See Table III.1.

2/ Station Laboratory 121, the oldest station in the city located at 121 St.

C. Sources of Air Pollution

In the GSPA, today's air pollution results mainly from automobiles, which number about 2 million, and industrial processes constituted by some 30,000 establishments. Table II.3 gives an estimated break-down of pollutant sources. About 94% of carbon monoxide is discharged by vehicles. In addition, vehicles contribute 73% of nitrogen oxides and 72% of hydrocarbons. Industrial processes are responsible for about 65% of particulate matter and 18% of hydrocarbon emissions. Stationary fuel combustion causes 88% of sulfur oxide discharges and 24% of nitrogen oxides.

Automotive traffic is clearly the single largest (74%) source of air pollution. A significant dent in the pollution problem, particularly in the carbon monoxide component, cannot be made without curbing this source. Industrial air pollution, however, is the subject of this paper. It accounts for 22% of total air pollution in the GSPA. Industrial processes and stationary fuel combustion are the principal sources of particulates and sulfur dioxide (Table II.3). In studying industrial air pollution, therefore, these two pollutants are our main concern.

The bulk of the industrial emissions of particulates and sulfur dioxide, as well as other pollutants, is released by relatively few industries as respectively categorized. Table II.6 reveals that non-metallic, chemical, and metallurgic industries account for a major part of the damage. They give rise to 26%, 22% and 16% of total air discharges respectively. Together, they are responsible for 65% of industrial air pollution in the GSPA. These industrial classes should be of major concern in the formulation of anti-pollution policy.

Within industries as a whole, there exists a considerable concentration of pollutant activity from relatively few sources. In a recent study [19], industries were classified into three polluting classes: A corresponding to high, B to medium, and C to low. About 90% of particulates and 74% of sulfur dioxides are discharged respectively by only 5% and 10% of different industrial sources. At the other extreme, only 3% of the particulates and 10% of the sulfur dioxide come from 75% and 73% of the least polluting industries respectively (See Table II.7) 1/.

D. Spatial Differences

Not only are emissions highly concentrated according to the type of sources, but even more so due to location. As noted earler, the pollution problem is far graver in Sao Paulo than elsewhere in the country, and the overall interregional differences are bound to be striking. Later in the paper we shall compare the neighboring states of Sao Paulo, Minas Gerais and Parana to reveal striking urban/rural and regional differences (Table VII.1 and Map 1). Within the GSPA itself, sharp differences exist, as discussed later in this text (Table VII.2). Of the 37 municipalities in the GSPA (see Map 2), 9 contribute about 95% of total air emission. Map 2 displays the sharp spatial variation in the dirtiness of air within the GSPA. In the Sao Paulo municipality alone, industrial activities emit 170 tons of particulates daily (45% of GSPA's industrial air pollution), 431 tons of sulfur oxides (52%), and 101 tons of hydrocarbons (72%).

1/ These estimates refer to 1978 data. In a 1980 update [13], greater concentration is shown. In the case of particulates 3.3% contribute 90%, while 87% contribute only 2.5%.

Air quality within the Sao Paulo municipality is by no means uniform. Dirtiness of the air measured by 13 stations in the GSPA alone reached "attention" levels 34 times in the winter of 1978. In parts of the central city, this occurrence was far more frequent (12 times in Tatuape, 9 in Aclimacao, 4 in Campos Eliseos and twice in Moema and Praca da Republica) than in others 1/. Attention levels were also recorded outside the municipality in the industrial centers of Guarulhos (twice) and Santo Andre (once) 2/.

In addition, health effects on populations located in various parts of the GSPA and outside the area, obviously vary widely. To provide one indication of possible health effect differences, a recent study [14] is considered in which an analysis was carried out of the lead content in the blood in three neighboring areas in the GSPA. Embu-Guacu, where the population faces moderate amounts of air effluents from stationary and mobile sources, is mildly polluted. Sao Paulo municipality is more polluted, with a heavy concentration of discharges from mobile sources. Sao Bernardo, the third municipality studied, is heavily polluted, primarily by the smoke from stationary industrial sources. In these three areas, representative people numbering 56,100, and 54, respectively, were examined. Various types of test results are reported. Below the average lead concentrations in blood are given.

1/ See Map 3.

2/ See Tables II.3 and II.4 for differences in air quality recorded at various monitoring stations in and outside the municipality.

Table II.2 Lead Concentration in the Blood in Three Distinct Areas in the GSPA

	Average Lead in the blood (μg/100)	Standard Deviation
Embu-Guacu	11.2	5.6
Sao Paulo Municipality	12.4	4.8
Sao Bernardo	20.5	5.7

Source: Fernicola and Azevedo [14].

The above study and others [9], [15] show that damages from pollution vary drastically among locations within the GSPA. Given dramatic differences in industrial activity and population concentration between the GSPA and other outlying areas, even wider differences in damages may be expected to exist across these areas. These differences ought to constitute the basis for strategies, thus allowing for a spatially selective approach in pollution control 1/.

1/ On decentralization of pollution control in Sao Paulo see Alves, Junior and Genda [1].

Table II.3 GSPA: Estimated Levels of Air Pollution by Sources - 1977/1978*

Air Pollutants

Sources	Particulate Matter Tons/day	Particulate Matter % Total	Sulfur Dioxide Tons/day	Sulfur Dioxide %Total	Carbon Monoxide Tons/day	Carbon Monoxide % Total	Nitrogen Oxide Tons/day	Nitrogen Oxide % Total	Hydrocarbon Tons/day	Hydrocarbon % Total
Industrial Processes	319 (399)	65	25 (18)	3	101 (86)	2	—	—	132 (27)	18
Stationary Fuel	57 (28)	12	810 (514)	88	52 (19)	1	85 (62)	25	8 (9)	1
Combustion	57 (28)	12	810 (514)	88	52 (19)	1	85 (62)	25	8 (9)	1
Diesel Vehicles	10	2	57	6	163	3	111	32	27	4
Gasoline Vehicles	23	5	31	3	4268	91	142	41	504	68
Solid Waste Incinerations	32	5	1	—	120	3	7	2	39	5
Others	51	10	—	—	—	—	—	—	27	4
Total	493	100	924	100	4704	100	345	100	737	100

*The figures in the table are for 1977. Further verified estimates for some of the pollutants from industrial processes and stationary fuel combustion for 1978 are given within brackets.

— negligible

Source: Gianneschi, Junior and Salvador [19].

Table XI.4 Particulates Concentration in the GSPA: 1973-1980
($\mu g/m^3$)

	1973 year average	1973 winter average /1	1974 year average	1974 winter average /1	1975 year average	1975 winter average /1	1976 year average	1976 winter average /1	1977 year average	1977 winter average /1	1978 year average	1978 winter average /1	1979 year average	1979 winter average /1	1980 /2 year average
Aclimação	105	124	88	94	75	122	98	150	89	119	81	122	85	134	83
Campos Elíseos	100	118	100	121	98	137	122	165	111	138	110	142	159	190	140
Cerqeira Cesar	80	92	69	93	77	116	83	122	79	103	74	110	72	107	65
Moema	59	78	64	90	67	106	78	122	72	108	68	107	66	111	59
P. da República	n.a.	n.a.	n.a.	111/3	91	128	107	148	96	125	83	113	90	135	76
Tatuapé	117	135	135	162	130	179	147	192	134	190	136	183	130	178	129
Vila Anastácio	71	86	78	100	78	127	77	129	72	109	68	114	62	103	53
Cap. Residencial n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	44	62	47	65	42	60	43	57	43
Cap. Industrial	43	52	44	65	49	77	55	88	55	72	55	90	61	102	47
Guarulhos	90	105	94	116	105	152	105	140	95	109	101	144	112	146	96
Osasco	52	61	57	75	66	105	71	110	66	101	61	97	60	92	63
Sao C. do Sul	56	76	63	87	65	105	83	132	71	102	69	108	70	113	61
Santo André	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	128/4	69	92	66	94	60	99	56
Pinheiros	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	60	91	65	107	52	93	50
GSPA	77	93	79	100	81	123	92	135	84	115	82	122	88	127	80

/1 i.e. average for June, July and August.
/2 Average for the first five months. Excluding June, July and August that shows the highest pollution levels.
/3 August only.
/4 Average for July and August.

n.a. = not available.

Source: CETESB.

Table II.5 SO_2 Concentration in the GSPA 1973-1980
($\mu g/m^3$)

	1973 year average	1973 winter average/1	1974 year average	1974 winter average/1	1975 year average	1975 winter average/1	1976 year average	1976 winter average/1	1977 year average	1977 winter average/1	1978 year average	1978 winter average/1	1979 year average	1979 winter average/1	1980 year average/2
Aclimação	109	144	110	140	112	163	106	134	127	155	131	156	153	190	157
Campos Elíseos	107	130	119	148	120	170	121	401	147	176	143	167	169	201	161
Cerqueira Cesar	80	95	76	92	82	112	72	86	84	95	94	112	111	137	118
Moema	61	70	64	82	64	81	64	69	79	90	89	108	94	120	111
P. República	n.a.	n.a.	n.a.	138/3	115	162	103	125	111	128	118	140	139	178	142
Tatuapé	130	165	131	170	135	198	115	142	127	153	134	152	145	171	138
Vila Anastácio	103	104	101	123	97	135	82	98	92	104	98	109	105	124	111
Cap. Residencial	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	117	158	126	106	122	120	181	155	203
Cap. Industrial	246	254	276	242	189	234	193	161	170	147	131	145	169	179	182
Guarulhos	104	107	105	128	129	161	107	121	121	129	132	147	142	173	136
Osasco	78	77	83	84	83	101	72	75	73	75	83	95	99	115	112
Sao Caetano do Sul	115	139	120	150	129	155	122	136	115	115	113	94	135	154	133
Santo André	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	140/4	107	115	100	104	123	122	125
Pinheiros	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	68	80	72	89	75	101	83
GSPA	114	164	119	136	115	151	105	115	113	124	115	132	133	157	136

/1 i.e. average for June, July and Sugust.
/2 Average for the first five months. Excluding June, July and August that show the highest pollution levels.
/3 August only.
/4 Average only for July and August.

n.a. = not available

Source: CETESB.

Table II.6 GSPA: Distribution of Air Pollution from Industry - 1977

	Particulates		Sulfur Dioxide		Carbon Monoxide		Nitrogen Oxide		Hydrocarbon	
	Tons/day	%	Tons/day	%	Tons/day	%	Tons/day	%	Tons/day	%
Metallurgical	65	17	187	22	116	76	19	23	23	16
Non-Metallic Minerals	181	48	152	18	2	1	17	20	3	2
Chemicals	66	18	159	19	2	1	10	12	21	15
Textiles	5	1	137	17	1	1	12	14	13	19
Food Products	18	5	53	6	1	1	7	8	1	1
Transport Equipment	5	1	46	6	6	4	9	11	13	9
Pulp and Paper	1	-	34	4	-	-	2	2	1	1
Others	35	10	67	15	25	16	9	10	65	47
Total	376	100	835	100	153	100	85	100	140	100

- negligible

Source: CETESB.

Table II.7 GSPA: Concentration of Pollution Within Industries - 1978

	Polluting Class			
	High	Medium	Low	Total
Particulates				
Number Industries	53	231	869	1153
%	5	20	75	100
Emission (Ton.day)	358	30	11	399
%	90	7	3	100
Sulfur Dioxide				
Number Industries	134	231	972	1137
%	10	17	73	100
Emission (Ton/day)	406	88	54	548 1/
%	74	16	10	100

1/ The divergence from the estimate in Table II.2 is due to the exclusion in this table of bakeries.

Source: A. Gianneschi, A.P. Junior and N.N.B. Salvador, [19].

III. Anti-Pollution Policies

Enactment of anti-pollution policies is a recent phenomenom in Brazil, as in most other countries. In fact, some evidence suggests that as recently as 1972, pollutant activities were viewed with some degree of approval on grounds that they are indicative of a growth process. "The Brazilian policy of economic growth - seeking industries that cause it until it becomes a problem - is only one part of a nation wide drive for economic growth that has made Brazil a boom country ..." wrote Novitski in 1972 1/. The implicit trade-off between pollution abatement and economic growth (and welfare), however, soon became questionable. Thus barely a year after environmental legislation was rejected as an impediment to growth in 1972, a dramatic change in policy appeared to have taken place. In 1973, Howe wrote: "Pollution entered the Brazilian vocabulary about two years ago. Since then not a day has passed without alarming reports about the country's diminishing resources, the contamination of the beaches, the devastation of the Amazon forests, and the dangers of air polluted by filth and noise" 2/. In subsequent years, severe pressure for a national anti-pollution policy began to be expected by municipalities.

Growing environmental degradation and an awareness of its ill-effects have resulted in the formulation of public policies and programs in recent years. These actions have taken place at the federal, state and

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1/ Joseph Novitski, " Brazil Shunning Pollution Curbs", New York Times, February 13, 1972, p. 11 quoted in Baumol and Oates [6],

2/ Marvin Howe, "Brazil Enacting Pollution Curbs - Development at Any Price no Longer the Rule", New York Times, March 11, 1973, quoted in Baumol and Oates [6].

metropolitan levels. These are discussed, in turn, in subsequent sub-sections. It may be noted that legislation in the use of natural resources can be enacted solely by the Federal government in Brazil. Individual states have authority, however, to take "complementary" actions. For instance, in the case of water and air protection, specific legislations have been enacted by the state of Sao Paulo in keeping with the spirit of federal laws. In turn, municipalities can take additional steps, as has been the case of the Sao Paulo municipality with solid waste, visual and noise pollution and, most importantly, land use.

Considering that the enactment of laws is of recent origin, actual measures to put them into effect have been limited thus far. In actions actually taken, the State of Sao Paulo, and the GSPA in particular, have clearly taken the lead. This will be clear from the following discussion of environmental policies at the federal, state and metropolitan levels.

A. Federal Legislation 1/

The first federal act of consequence occurred in 1973 when the Special Secretariat of the Environment (SEMA) was created in the Ministry of Interior to handle environmental policy (Decree no. 73,000: October 30). 2/ Subsequently, a number of regulations and decrees were issued. In 1975, a legislation provided means such as restriction on fiscal incentives and the

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1/ For details, see [7].

2/ Prior to 1973, general laws such as the National Health Code (Codigo Nacional da Saude - Lei Federal no. 2,132) of September 3, 1954 and regulation approved by Decreto no. 49,974-A of January 21, 1961) had to be resorted to by local authorities.

suspension of production activities to enforce industrial pollution control policies (Law no 1413, August 14 and Decree no 76,389, October 3). Under these acts, the responsibility to set norms for the operation of industries rests with the states and municipalities, while the federal authorities reserve the right to shut down industries on pollution grounds.

In 1976, minimum air quality standards that were to be met by the states were established by the Federal government, (Regulation no. 13, January). In the case of air pollution, standards were issued for four substances: particulate matter, sulfur dioxide, carbon monoxide and photochemical oxides. For other pollutants, the determination of target concentration is awaiting the results of further studies.

The national air quality standards established for the main four pollutants are discussed below. In the cases of particulates and sulfur dioxide, a maximally allowable annual average concentration and a daily standard not to be exceeded more than once a year are issued. For carbon monoxide, and photochemical oxides, the standards refer to hourly maximums not to be exceeded more than once a year. These standards take into account "the ill-effects of exceeding them on human health, safety and well being of the population, as well as loss to flora and fauna, materials and the environment in general." Where the damages from pollution are particularly severe, the states are allowed to issue stricter air quality standards than those given below. Referring to the following table, it is clear that in large parts of the country, little anti-pollution efforts will be called for. At the same time, in certain areas such as the GSPA, great efforts will be needed to cut back on emissions (see previous chapter).

Table III.1 Brazil: National Air Quality Standards 1/

($\mu g/m^3$)

	Annual Mean	At Most One Day in a Year
Particulates	80, 2/	240
Sulfur Dioxide	80, 3/	365
	In 8 Hrs At Most Once a Year	In One Hour At Most Once a Year
Carbon Monoxide	10,000	40,000
Photochemical Oxides	—	160

1/ Maximum allowable concentration of the discharges.

2/ Geometric Average.

3/ Arithmetic Average.

Source: CETESB [7].

Federal legislation has also sought to influence industrial location . Resolution 14 was issued in 1978 to specifically ban federal incentives for new industrial projects in the GSPA, except in "special cases" involving light industries. Such industries may be located in the GSPA only if they are non-polluting, require an urban location, and are proposed by small and medium-sized Brazilian enterprises. On the other hand, an earlier decree (no. 81,107, December 1977) determined industrial activities

1/ This policy was reinforced in November 1980 by a federal decision to limit payments for technological upgrading to only those companies in the GSPA which export at least 50% of their output or have a low net foreign exchange requirement.

considered of high interest for national development and security. Such industries are excluded from any rigorous anti-pollution laws. Although the intention of Resolution 14 was to promote decentralization of industrial activity, considerable ambiguity has been left as to who should be exempt from the policy, thus resulting in ample room for making exemptions.

In the design of national environmental policy, major responsibility for further legislation and implementation is entrusted with the state governments. This is evidenced by the experience with environmental programs in the state of Sao Paulo.

B. State Action 1/

In 1975, the redefinition of an existing state organ in 1975 as the State Environmental Protection Agency (CETESB) was the first serious anti-pollution measure in the state of Sao Paulo (Decree no. 6,371, July 3). State Law 997 (May 31, 1976) and its complementary Decree no. 8,648 (September 8, 1976) were important in providing a clear legal framework for controlling air pollution and other forms of pollution. Specific sanctions against violators were provided. CETESB was given authority to apply Law no. 997. A licensing and registration system became mandatory for all productive enterprises. State air and water quality standards were defined and regulations for pollution control and sanctions were approved.

To carry out an air pollution control program, the state of Sao Paulo has been divided into "air quality control areas" (RCQA) corresponding

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1/ See [7] for details.

to 11 administrative divisions 1/, 2/. Some RCQAs are further divided according to topographic and meteorological characteristics. Each RCQA is classified as saturated or not, depending on whether pollutant concentrations exceed state standards. In saturated RCQAs, the installation of new sources, or the expansion of existing ones will be allowed only if they do not raise pollution appreciably. The relocation of high polluters is generally encouraged for all saturated RCQAs. The GSPA (RCQA-1) clearly faces the most detailed programs as will be shown later.

For main pollutants, air quality standards in the State are the same as those for the nation (see previous sub-section). CETESB's strategy is to determine the amount of collection of smoke necessary in various RCQAs to meet these standards. Based on these required abatements for RCQAs, emission standards are to be issued for sources, taking available technology into account. Emphasis has currently been placed on issuing standards for stationary combustion units to control sulfur dioxide, industrial activities to reduce particulates, and gasoline powered vehicles to lower carbon monoxide. For others, the best practical technology available is urged to be adopted.

1/ The regions corresponding to the 11 RCQAs are given below (see Map 2).

GSPA - RCQA1	Bauru - RCQA7
Litoral - RCQA2	Sao Jose do Rio Preto - RCQA8
Vale do Paraiba - RCQA3	Aracatuba - RCQA9
Sorocaba - RCQA4	Presidente Prudente - RCQA10
Campinas - RCQA5	Marilia - RCQA11
Ribeirao Preto - RCQA6	

2/ Federal legislation in July 1980 permits states and municipalities to zone land uses on pollution grounds.

Actual emission standards applied for existing sources have been limited. In the case of industries, enforcement would focus on the few largest polluters who are responsible for most of the damage (see Table 11.6). The smallest ones would be required to comply only where inexpensive control devices are available. To meet the state's air quality standard for particulates, at least 80-90% abatement by industries is deemed necessary. Where enforced, these collection requirements are likely to be uniform in percentage terms and in the form of mandatory use of control equipment of that efficiency. Stricter abatements of new sources, however, may be required.

Industries face a number of other actual and possible restrictions. For example, the open air combustion of solid waste, liquids or other fuels is prohibited, at least without CETESB's approval. Chimneys are mandatory. The options for requiring "high stacks" to allow an adequate dispersion of effluents in the atmosphere, and mandatory use of low sulfur fuels are being explored. New sources must already satisfy several requirements such as the use of only certain types of fuels in some areas and the installation of pollution control equipment in others.

There also exists an emergency plan to react to critical episodes of air pollution, thus preventing serious risks to people's health. The following table sets out concentration levels considered dangerously injurious to health. When these levels are surpassed, restrictions may be issued for the use of vehicles and for certain industrial activities in critical areas.

Table III.2 GSPA: Air Pollution Levels Considered Critical for Short Time Periods

	Attention	Alert	Emergency
Particulates ($\mu g/m^3$-24 hrs)	375	625	873
Sulfur dioxide ($\mu g/m^3$-24 hrs)	800	1600	2100
Carbon Monoxide (parts per million-8 hrs)	15	30	40
Photochemical oxides ($\mu g/m^3$-1 hr)	200	800	1200

Source: CETESB [7].

To help enforce anti-pollution policies, a scheme of penalties ranging from warnings and fines to a temporary or permanent closing down of industrial activity has been set up through state legislation. The most potent means of enforcement existing is perhaps terms relating to pollution control that must be adhered to in obtaining licensing for industrial installations. 1/ These, of course, are relevant only for new sources. It reflects, however, the emphasis that has been placed on controlling potential new pollution. This becomes more evident in the subsequent discussion of policies for the GSPA.

1/ Two licenses -- one before investment is installed and a second after -- are to be bought at a fee.

C. Metropolitan Regulations 1/

Within the state of Sao Paulo, relatively more progress in pollution control has been made in the GSPA. In this area, the most concrete means of affecting the environment has been land use policy. Today, a state law is in effect to establish objectives of metropolitan industrial development and to determine industrial zoning, location, classification and licensing in the GSPA (Law no 1,817, 27 October, 1978). 2/ Under this law, any industry seeking location or an expansion of activities in the area must obtain a license from the Secretary for Metropolitan Affairs. In the provision of an industrial license for location, the nature of areas and of industries from the environmental point of view are taken into account. The terms of the license sets limits on the type and extent of polluting activities allowed.

To facilitate land use policy, the GSPA is divided into three industrial zones: ZEI, ZUPI and ZUD (see Table III.3). These divisions take into account, among other factors, ambiental aspects, the relation to the regional economy, and the urban infrastructure of particular areas. The first, ZEI, is reserved strictly for industrial use away from urban centers. The highest polluters are confined to this zone. A limit of a minimum of 500 meters is placed between industrial structures and property boundaries on the one hand, and between the pollution source and the zonal boundaries on the other. Such a zone as ZEI, solely utilized for industrial use, has yet to be created. $ZUPI_1$ and $ZUPI_2$ are designed predominantly for industrial use within

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1/ See [8] for details.

2/ Land use controls operated at the municipal level have been extended to the Paraiba Valley (see Section VII). Similar controls have also been introduced in Curitiba (Map 1).

urban areas, but away from schools, hospitals, homes, etc. $ZUPI_2$ has somewhat stricter criteria than $ZUPI_1$ for the type of polluting industries that can locate in it. Stricter limits are also placed on the maximum size of industrial establishments. ZUD is a zone meant for diverse use. Therefore, none but mild polluters, who do not pose an environmental threat to urban activities, can locate there. Restriction on the maximum construction area is also strictest (Table III.3).

In establishing criteria for the eligibility to locate in the above zones, industries are divided into 5 classes - IN, IA, IB, IC and ID. This classification is based on (i) industrial size, taking into account area of construction in relation to the urban area, and (ii) type of activity, taking into account, among other factors, environmental aspects, and the effects on regional economy and urban life. Table III.3 shows how different industry types are distributed among zones under the law. It should be noted that the law applies to new industries -- i. e. ones not yet approved at the time the law was passed or approved but not executed until a year after approval.

Industries belonging to IN are considered as posing the most serious threat to the environment. Production of iron, asphalt, natural sugar and cellulose are examples. New industries in this class are prohibited in any of the zones described earlier. Type IA industries are high polluters who may be located in ZEI. But as noted earlier, ZEI has yet to be created. Examples of industries belonging to IA are cement, lime and firearm production. For IN and IA, the size of area occupied is not an important criteria; it is the type of activity that is the overriding consideration. IB and IC, on the other hand, are very similar in their types of activities, but differ according to the size and intensity of activities. IB is allowed in $ZUPI_1$ (or ZEI), allowing a built area of more than 10,000 m^2. In addition, IC can be in $ZUPI_2$ as well, allowing a built area of no more than 10,000 m^2. Production of fertilizers, coffee, mechanical pulp and wines belong to category IB/IC. Establishments of type ID can locate in any of the zones including ZUD, or outside the industrial areas. Maximum built area for ID industries is 2,500 m^2. Production of ceramics, glass and crystals, detergents and a host of other items belong to the ID category.

The following table summarizes the main features of industrial zoning in the GSPA.

Table III.3 GSPA: Industrial Zones

Types of Zones		Allowed Industry Types	Minimum Distance of Emission Source from Zonal Boundary	Maximum Construction Area
Zones	Characteristics			
ZEI	Strictly Industrial	IA, IB, IC, ID	500m	-
$ZUPI_1$	Predominantly Industrial	IB, IC, ID	200m	$\geq 10,000m^2$
$ZUPI_2$	Predominantly Industrial	IC, ID	200m	$\leq 10,000m^2$
ZUD	Diverse Use	ID	-	$\leq$ 2,500m^2
Non-Industrial		ID	-	$\leq$

Source: EMPLASA [12].

D. Conclusion

National environmental policy is in its early stages of evolution in Brazil. Federal legislation has established national air quality standards and broad guidelines for the implementation of anti-pollution policies. The state of Sao Paulo, and the GSPA in particular, have made relatively more progress in the initiation of programs to fight pollution. In 1977, the state spent 37 million US dollars on pollution control, which was $1.68 in per capita terms. As a fraction of the State's GDP, this amounted to 0.065% 1/.

Federal legislation has set uniform air quality standards across the country. If these were implemented, large spatial differences in the required abatement (smoke collection) would result. How much spatial variation in efforts is desirable, in principle, cannot be answered without some notion of the costs and benefits of pollution control (Section IV).

Although national air quality standards are uniform, efforts to meet them have been non-uniform, as noted earlier. Within the state of Sao Paulo, the tendency has been to try to improve air quality by enforcing uniform abatement by sources. If uniform abatement by sources were implemented, air quality would not be equated within the State. But in reality, implementation is very uneven, and uniform abatement by all sources is not enforced across the State. Thus, at the moment, considerable spatial differentiation does exist in the amount of pollution abatement carried out by sources

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1/ In comparison, Japan and the US spent respectively $ 3,106 and $ 40,600 in 1977, implying per capita figures of $ 27.6 and $ 137. As a fraction of GDP, these were 0.6% in Japan and 2.4% in the US.

located in different places within and outside the state. How much of these spatial differences are desirable needs to be analyzed (Sections VI, VII).

In the choice of the means to lower pollution, various alternatives have been considered. One approach has been to affect the growth of industrial output. In this case, the effect on environmental quality is clearly indirect. Quite likely, a consideration of non-environmental effects are also behind the adoption of such a strategy. The efficacy and adequacy of meeting environmental goals by indirectly affecting output needs to be studied (Section V).

The emphasis on influencing industrial production results from the current strategy of primarily preventing a worsening of the pollution problem, rather than reducing the existing stock of emissions. At present, emphasis has been placed on lowering any addition to pollution by influencing the location of new producers. A variety of licensing and zoning procedures are in effect in the GSPA for this purpose. The system of licensing by CETESB of all new industrial investment is now fully operative in the state of Sao Paulo. From the end of 1976 through the end of 1979, over 10,000 installation licenses were issued for new plants, expansion projects, and residential developments.

This present strategy of differentiating between existing and new sources by primarily influencing new industrial location needs to be evaluated (Section VIII). At the same time, it is clear that as efforts are mounted to cut back existing smoke in the future, the importance of options other than those directly affecting output will increase. Already, a $187 million project for air and water pollution abatement running from the present to the end of 1983 is underway. A World Bank loan of $ 58 million has been made for this project.

Under the above project, emphasis is placed on regulating the relatively small number of industrial plants accounting for a very high percentage of pollution (Table II.7). The air pollution control is aimed primarily at particulates, and the water pollution control focuses on toxic wastes. Loans are designed to enable plants to meet state and federal air quality standards. Plants in the GSPA are the chief qualifiers. In operation, the project is expected to stress whichever turns out to be a least-cost control strategy of lowering smoke and meeting air quality standards. Since air quality is measured in the area near a factory (rather than in the smoke stack), greater efforts and control costs will be expected in the more polluted areas. Thus, in the future, a lowering of existing pollution in proportionately greater amounts in the heavily polluted parts of the GSPA may be expected to take place.

Part 2. Benefits and Costs of Policies

IV. Choice of the Degree of Control

A. The Framework

Much of the economic literature on pollution has emphasized the consideration of incremental benefits and costs as a central criterion for determining target levels of emission control. A detailed discussion of the application of this criteria is not presented in this study since various authors have done so [6], [30], [38]. A diagramatic exposition of the main argument, however, is set out.

In Figure IV.1, MC measures the marginal private cost of producing conventional output X in location A 1/. Given the demand for X represented by D_X, output and price are respectively X* and P*. The use of pollutant fuels produces smoke denoted by S_A in Figure IV.2. In the absence of controls, S_A^* is the quantity of emissions (tons/year) corresponding to X*. The release of effluents gives rise to marginal damages represented by MD_A, thus raising the marginal social cost of producing $\bar{X}$ to $(MC_X + MD_A)$. The total cost of pollution to society is the integral of MD over the range of production where emissions result in damages - i.e., the area kdek.

A restriction that smoke not exceed $\bar{S}_A$, 2/ in Figure IV.2 does not affect the producer's decisions, as seen from MC_X up to $\bar{X}$ in Figure IV.2. But

1/ The figure also shows production of another industry Y in location B for comparison in a later section.

2/ Various policy instruments to attain this implied pollution reduction are discussed in the next section. The present discussion deals with cost and benefit under a straight-forward standard, discussed in V.A. later. A tax could have been discussed (V.B) under this same framework.

beyond $\bar{X}$, effort to restrict smoke shifts MC_X to MC'_X. Depending on pollution control costs at various levels of X, new MCs may exceed $(MC_X + MD_X)$. In the case of $\bar{S}_A$, output falls from X* to X′ and price rises from P* to P_X.

Due to the shift in MC_X to MC'_X, a cost called the welfare cost of the policy, is imposed on society. In Figure IV.1, it is measured by bjdc.[1/] The total benefit to society, called the welfare benefit from collecting $S^*_A S_A$, is the saving of MD_X over the range of $\bar{X}$ where smoke is eliminated. In the present example, $(MC_X + MD_X)$ is ka up to X, beyond which it becomes the same as MC'_X. Total benefit is given by ajde, which means that net welfare benefits are abcde. Out of this measure of net benefit, abcl accrues from pollution control, and lcde from a reduction in output. A further reduction of smoke has been associated with additional welfare benefit and additional cost. If $\bar{S}$ is optimal, the net marginal welfare benefit at a more stringent standard will be negative. To achieve the greatest net benefit, the level of pollution control should be such that incremental benefit and incremental cost from changes in control are brought in line with each other.

1/ In the original equilibrium (X*, P*) kOX*dk is the return to the factors of production, while kdP^*_X is the producer surplus and $P^*_X dm$ the consumer surplus. With the control set at S, factor returns change to OX′cbjk, producer surplus to $kjbcP'_X$ and consumer surplus to $P'_X cm$. Loss in consumer surplus is $P^*_X dcP'_X$, a transfer from consumers to producers, of which $P^*_X ocP'_X$ goes as producer surplus and one as a resource cost. Excluding the transfer that goes as producer surplus, jdob is the loss in producer surplus and odc the loss in consumer surplus. Hence, bjde is the welfare loss, which is the measure of the welfare cost. X′X*di is not an additional loss, provided these resources make alternative earnings elsewhere. jicb is a transfer from producers and consumers surplus to factor cost, and cid is a net cost.

B. Making Benefit Estimates

While the literature underlines the importance of considering costs and benefits, it also notes the practical difficulties of this task. Although the cost of control may be relatively easier to estimate, the difficulty of measuring benefits (i.e. damages) can hardly be overstated. Absence of previous estimates, particularly in LDCs, makes the task even more difficult; at the same time, it becomes all the more important that some preliminary calculations are done.

A number of methods have been developed to assist in the measurement of benefits. Surveys of work on benefit estimation are available from the American Lung Association [2], Lave and Seskin [27], Smith [35], and Friedlaender [16]. One approach is to separate out land value differences which arise from pollution across locations, and to regard them as indicators of the value people place on being pollution free [3], [11]. Another method relies on money wage differentials across areas, as indicators of the compensation required to attract people into polluted areas [23]. Discussions and an evaluation of these approaches are given by Daniel L. Rubinfeld in Friedlaender [16]. The effectiveness of the econometric estimations required to separate out the pollution factor in the land value, or the estimation procedures based on money wages is often questioned.

A conceptually straightforward approach is to add up all the direct benefits of pollution abatement [10], [27], [30]. In the case of air emissions, these include improvements in human health, decreased damages to plants and animals, lower cleaning costs, and longer lives for various materials and structures. One can think of various other benefits that improve the quality of life.

Such an approach of adding up various benefit components, while conceptually simple, is extremely difficult to quantify. The difficulty has to do not only with establishing the exact relation of air pollution to various damages such as human illness, but also with quantifying the damages in money terms once the relationship has been proved. In spite of serious difficulties, estimates have been made of the damages due to pollution under the various categories mentioned above (see Lave and Seskin [27] for a review). In most cases, the tendency is to underestimate "true" benefits, because various components simply cannot be quantified. But at least this approach, if well-conceived, can provide a lower bound on damages, which will be valuable in comparing against cost estimates.

In view of the data on Sao Paulo, we believe that benefit estimation of at least some of the major components is both possible and promising. While it is unlikely that an exact estimate of benefits will emerge, extreme precision is unnecssary to develop broad policy directions. Since costs are not negligible, an indication that benefits roughly justify costs is needed. Even crude quantitative estimates of benefits, with the appropriate caveats, would be more useful for public policy than no estimate at all.

The greatest concern regarding air pollution pertains to its effect on human health. In the rest of this section, we therefore consider the possible health effects of air pollution in Sao Paulo. Other categories of damages, such as those to property, materials, farm animals, and crops are also important, but are beyond the scope of our present discussion. Any indication of the damages based on the health effects examined below, would constitute a lower bound on the possible overall damages.

1. Air Pollution and Human Health

While most people would assume that pollution has deleterious effects on health, the establishment of an exact relationship leads to a series of problems. A large number of scientific studies, however, have shown significant relationships. Some of these are discussed with caveats for interpretation in Lave and Seskin [27], Mills [30], and Smith [35]. Several micro studies linking pollution to morbidity have been carried out by CETESB. Section II.D discusses the results of a study by Fernicola and Azevedo [14] in which lead concentration in the blood is positively related to pollution in the GSPA.

In another study, Fernicola and Lima [15] evaluate the degree of exposure of the Sao Paulo population to carbon monoxide. 327 blood samples were collected from adults to thereby determine the carboxihemoglobin (COHb) content by "the spectrophotometric method". Thirty samples per control group, were taken from residents of Embu-Guacu, an area considered to have a low carbon monoxide concentration. The following results (in %) were obtained:

(1)	traffic policemen :	smokers	6.3 ± 2.07,	non-smokers	2.1 ± 0.68
(2)	bus drivers :	smokers	4.6 ± 1.94,	non-smokers	1.6 ± 0.46
(3)	control group :	smokers	3.8 ± 1.74,	non-smokers	0.8 ± 0.21.

The effect of the exposure to carbon monoxide, as revealed in rising COHb content and worsening coronary problems, appears significant. It is indicated that if a national air quality standard of 9 ppm for CO (Section III.A) were met, COHb would be kept to 2% for non-smokers. The above results have been obtained by other authors. The relationship between increasing cardiovascular diseases and an alarming COHb content of over 2% has also been brought out by other studies which are quoted in Fernicola and Lima [15].

Mendes [9] has examined the effect of air pollution on mortality in an epidemiological study correlating daily death in the GSPA with meteorological conditions and air pollution levels in 1973. Five peaks in deaths were observed in which at least one, on August 1, was clearly related to a drastic worsening of air pollution. Since July 25, particulates and sulfur dioxide concentrations were on the rise to reach very high levels by July 30. On August 1, SO_2 reached a climax in Capuava of 452 $\mu g/m^3$, in Aclimacao of 371 $\mu g/m^3$, in Tatauape of 292 $\mu g/m^3$ and in Cerqueira Cesar, of 288 $\mu g/m^3$. On the same day deaths reached a peak of 299, compared to an annual average of 228. Deaths of people over 65 and less than one year old also reached peaks that day. Deaths due to respiratory diseases also reached a peak on the same day. In all, a close correlation between SO_2 concentration, total deaths, and deaths due to respiratory diseases (particularly for people over 65 and less than one year old) was statistically observed between July 25 and August 8. Mendes proposes that if the same study were carried out for 1974 and 1975 when air pollution worsened, more conclusive evidence relating pollution to the deterioration of human health would be found.

In order to obtain a fuller measure of the possible impact of pollution on mortality, we have used a regression technique to isolate and to determine a pollution-mortality relationship. The results of this exercise are given below.

Air Pollution and Mortality

In view of Lave and Seskin [27], we hypothesize that in the long run air pollution causes an increase in the mortality rate 1/. The goal is to separate the pollution factor from other determinants of mortality, such as physical and socioeconomic characteristics of the population. Compared with a time series analysis, a cross-sectional analysis of areas with widely differing pollution levels at a given time offers a greater possibility of isolating the effects of pollution. We analyze annual cross-sectional data for 1977 for the 37 municipalities in the GSPA (Map 1) using linear multivariate regression analysis. Time series data on pollution levels at the municipality level are not available.

The mortality rate is the dependent variable (deaths per 10,000 people). Information on mortality in the municipalities was provided by "Secretaria de Economia e Planejamento" (SEPLAN) in Sao Paulo. Death is recorded at a place where a person has been living rather than died, although one does not know how long the person had lived there. The data are tabulated by cause of death and age groups. First, we use total mortality, then, presuming that the pollution effect is longer term, we alternatively exclude children less than one year old and less than ten years old.

The independent variables representing environmental, physical and socio-economic characteristics are: pollution level, population density,

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1/ For a discussion of the effects of different pollutants on human health and mortality, see also the American Lung Association [2], Baumol and Oates [6], Mills [30] and Smith [35].

average income level, hospital beds per person, and the percentage of people over 65 years of age. No air quality data is available at the municipality level. Instead, we use annual emission data for particulates, which reveals the SO_2 and CO levels recorded by CETESB for the six municipalities that constitute about 80% of industrial pollution. For the other municipalities, levels of particulates and SO_2 are approximated using estimated emission factors (emission ÷ industrial output). In the case of CO, the emission factor is based on the number of vehicles. Admittedly crude, these procedures could have distributed emissions among the low polluting 31 municipalities inaccurately. All the emission variables are expressed per area in km^2 to better reflect their concentration.

Because there are better inventories for the 6 municipalities as well as better estimates of the emission factors, particulates is the most reliable pollution variable for the municipalities. The CO inventory is very preliminary. The emission factor used for SO_2 was not adequate since it was based on industrial production, rather than on fuel combustion alone, due to lack of data. Therefore, results are presented excluding both SO_2 and CO, with all the three pollution variables.

The density of population is an important determinant of the incremental damages from pollution through observing the number of people each unit of pollutant injures. The total mortality rate may also be positively affected if there exists as much (or more) smoke per person in the more densely populated places as in the less densely populated places. To control for this possible effect, we include the density of population in one set along with all the population variables. The data were obtained from Fundacao Sistema Estadual de Analises de Dados Estatisticos (SEADE).

The percentage of the aged in the population would clearly affect the mortality rate positively. Data provided by the Secretaria de Estado de Saude, Estado de Sao Paulo (Centro de Informacoes de Saude-CIS) are used to determine the % population over 65 for the municipalities. Average personal income is expected to affect mortality inversely. For the municipalities, a proxy is given by per capita value added estimated by the Secretaria da Fazenda do Estado de Sao Paulo (Boletim Tributario). Clearly, any correspondence between the value-added in a location and the income of people living in that same location would be less than exact. Ideally, in addition to income, socio-economic variables such as nutritional status, education and public service availability should also be included to explain mortality. For the municipalities, we have been able to include only the available medical service by using hospital bed per person as a proxy. Data were obtained from the Secretaria de Saude (CIS).

Equation (IV.1) regressed the total mortality rate (per 10,000) for the 37 municipalities on all pollution (tons/km^2/yr) and socio-economic variables for the year 1977.

$$\begin{aligned} TM = {} & 76.214 + \underset{(1.51)}{.120}\, PM - \underset{(-1.03)}{.068}\, SO_2 - \underset{(-.67)}{.020}\, CO \\ & + \underset{(1.25)}{4.357} \geq 65 - \underset{(-.43)}{67.893}\, VA - \underset{(-1.46)}{.248}\, HB - \underset{(-1.43)}{.002}\, P/Km^2 \\ & + e \qquad (R^2 = .341) \qquad\qquad \text{(IV.1)} \end{aligned}$$

where TM is the municipality total mortality rate; PM is the mean particulate matter; SO_2 is the mean sulfur dioxide, and CO is the mean carbon monoxide; $\geq$65 is the percentage population aged 65 and older; VA is the per capita value-added; HB is hospital bed per 1000 people and P/km^2 is the density of population.

All the units of the variables are given in Table IV.3. In parentheses are t statistics.

Only 34% of the variation in the total mortality rate across the 37 municipalities is explained by the seven independent variables ($R^2 = .341$). It is seen in Table IV.3, that eliminating infant mortality and child mortality raises the equation's explanatory power to nearly 50%. 1/ Yet clearly, important socio-economic variables have been excluded in the equation in its present form, thus accounting for its low explanatory power.

The most noteworthy result in equation IV.1 and Table IV.3 is the positive and significant coefficient for particulates. Because particulate data are most reliable, this result is encouraging. The other population variables SO_2 and CO have no significant effect in the regressions but the poor quality of data might account for this result. As one would expect, the % population over 65 is consistently and significantly related positively to the death rate. The only socio-economic variable, per capita hospital beds, also has a consistently significant, and as expected, negative effect on the mortality rate. Population density, on the other hand, also has a significant effect, yet contrary to expectation, it is negative. 2/ Income, which was expected to have an important negative influence on mortality, is not a significant factor in any of the equations. The weakness of the data may explain this.

1/ The coefficient on particulates falls, however, indicating the vulnerability of babies to pollution.

2/ This may suggest that density is endogenous within the model in adjusting for pollution levels (i.e. a negative impact of particulate concentration on density), thus giving its negative relation to mortality.

According to equation IV.1, an annual increase of 1 ton of particulates per km^2 in the GSPA from 1977 levels is associated with an increase in the mortality rate of 12 per million. Based on mean particulate concentration of about 17 tons/km^2 1/ and a mean mortality rate of 8830 per million,it is implied that a 50% reduction in industrial particulates alone 2/ is associated with a 1.2% reduction in the mortality rate. Inclusion of better estimates of SO_2 and CO may be expected to raise this effect significantly. 3/ Excluding child mortality, an increase of 1 ton of particulate/km^2 may be associated with an increase of about 8 per million in the mortality rate. Given a mean mortality rate for the population over one year of about 5690 per million, it is again implied that a 50% reduction in particulates alone is associated with about a 1.2% decrease in the mortality rate of non-infants.

The above interpretation was presented more for illustration than for providing exact implications of the results. The absence of good data on SO_2, CO and income limit the explanatory power of the equations presented in this paper. More generally, one should be careful in deducing a short term pollution-mortality association from a result that must have been based on years of exposure to the effluents. 4/

1/ About 137,000 tons of annual particulate emissions by industries is divided by GSPA's area of 7951 km^2.

2/ This means about a 33% reduction in total particulate emissions, since industries contribute 65%.

3/ Lave and Seskin [27] found that for 117 SMSAs in the US for 1960, a 50% reduction in particulates plus sulfates was associated with a 4.7% decrease in the mortality rate.

4/ For a discussion, see Mills [30], ch. 5.

Our present purpose is really a narrower one than deriving an exact pollution effect on mortality. Our first concern has been to explore whether a significant and sizeable association exists between the two phenomena. As a further check on the results in Table IV.3, therefore, we analyze data for 7 highly polluted sub-districts within the Sao Paulo municipality for the 6 years 1973-78. 1/ Data on total mortality for all age groups were available from SEPLAN. Mean monthly pollution readings made by CETESB in micrograms/m^3 for particulates SO_2 and CO were averaged for the years 1973-78. Density of population was estimated from data from SEADE, while data on the % of population over 60 were obtained from the CIS. The weakest link in the data is income. Per capita income were estimated rather roughly by the "Empresa Metropolitana de Planejamento de Sao Paulo" (EMPLASA) for various zones, which were aggregated to correspond to the sub-districts. No other welfare indicator was available to be included in the regression.

Equation (IV.2) regressed the total mortality rate (per 10,000) for 7 sub-districts during for the 6 years 1973-78, on mean and maximum particulate and SO_2 concentration ($\mu g/m^3$). It is assumed that family income grew 3% in real terms between 1973-78. Other results are in Table IV.4.

$$TM' = \underset{}{-134.99} + \underset{(5.72)}{.888}\ \text{PM mean} + \underset{(1.27)}{.153}\ SO_2 + \underset{(4.28)}{10.655}\ P \geq 60$$

$$+ \underset{(2.83)}{.009}\ \text{Income} - \underset{(4.76)}{.003}\ P/km^2 + e \quad (R^2 = .579) \qquad \text{(IV.2)}$$

1/ These are Aclimacao, Cerqueira Cesar, Consolacao, Indianopolis, Lapa, Santa Cecilia, and Tatuape (Maps 3, 4).

where TM´ is the sub-district mortality rate; the PM mean and SO_2 mean are average particulate and sulfur dioxide concentrations; ≥ 60 is the percentage population aged 60 and more, income is per capita income, and P/km^2 is the density of population. In Table IV.2, PM max and SO_2 max are annual averages of monthly maximum values of particulate and SO_2 concentrations.

About 60% of the variation in mortality across the sub-districts is explained in equation IV.2. Inclusion of the PM max 1/ and the SO_2 max raises the explanatory power to 66%. As Table IV.4 shows, assuming constant income, or a 3% growth rate, affects the results very little. Similarly, the deletion of the PM max, the SO_2 max, and the density of population in Table IV.4 does not affect the major results appreciably.

According to equation (IV.2) Table IV.4, ambiental concentration of particulates is consistently significant among the factors explaining mortality. Equation (IV.2) implies a high and significant association - an improvement by one $\mu g/m^3$ associated with a decrease in mortality of 8 per 100,000. This high association may be explained by a number of factors. The seven sub-districts face about the worst pollution problem, thus implying high marginal benefits from control at existing pollution levels. The pollution variable may be standing as a proxy for excluded socio-economic variables. Some of the more polluted areas also appear to have relatively less public services, the lack of which must be contributing to higher mortality rates. Therefore, one should be careful in attributing the strong mortality effect

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1/ The negative coefficient of PM max is unexpected and contrary to Mendes´ finding reported earlier.

found in Table IV.3 to pollution alone. At the same time, the consistently significant coefficient of particulate concentration may be interpreted as additional evidence that there exists a significant incremental pollution-mortality effect in areas that are already heavily polluted.

Further Work. The foregoing is the only segment in this paper that attempts to quantify the benefits of pollution control. The regression technique measures marginal effects on the mortality of pollution, holding other variables equal. But the variables used to explain mortality may not be held equal, as they require a simultaneous explanation of their changes along with pollution/ mortality. In the course of future work, some tests for the endogenity of the explanatory variables should be carried out. Based on further analysis of independent variables, and better data, the pollution/ mortality relationship should be re-estimated.

C. Some Cost Estimates

Far more estimates are usually available for the cost of pollution control than for benefits. Discussions of cost estimates can be found in Baumol and Oates [6], Mills [30], Thomas [36] and Friedlaender [16].

A shortcoming of many cost estimates is that they are based simply on engineering relationships, without accounting for the full range of flexibility in production relationships. "True" welfare cost (shown in Figure IV.1), on the other hand, should allow for substitutability among polluting fuels, non-polluting and pollution control inputs, and for possible changes in output. Measures that do not allow for such substitution usually overstate the cost of pollution control. Cost estimates are generally overstated also because the effect of cost reducing technical changes is not accounted for.

The accurate calculation of welfare costs requires the modeling of the industrial production of a conventional output with the joint production of pollution, and tracing the effect of controls on cost. Estimates of various production coefficients are required. In this paper, it has not been possible to present welfare cost estimates. Instead estimates of pollution control costs made by a World Bank Mission [45] and CETESB are reported. 1/ These estimates measure the capital and operating costs of control equipment that achieve a certain smoke reduction. Hence they correspond to emcost (n) discussed in Section V.C and VI. Welfare costs would be lower than these under an optimal policy (Section V.A).

Preliminary cost estimates are available for 285 industries that contribute 97% of industrial particulate pollution in the GSPA. These industries can be classified under non-metallic, chemical and metallurgic industry categories. Total cost is comprised of capital and labor costs for design, installation, equipment and spare parts. Total cost estimates for 1977 are updated for 1980/81.

Table IV.1 summarizes the cost estimates for the few biggest polluters contributing 90% of total smoke. Annex Table 1 gives details for these and other factors contributing an additional 7%. For 53 industries constituting 90% of particulate effluents (i.e. about 132,000 tons/year), a 94% abatement - i.e. 85% of industrial smoke and 55% of all particulate emission in the GSPA, could be achieved in 1977 at a total cost of about Cr$418 million, or (equivalently about 30 million 1977 $US) or about Cr$3,200 i.e. US$225 per

1/ Further work is being carried out at CETESB to develop actual cost figures. The present estimates are based on CETESB projections using information of industries who had yet to use control equipment.

ton of emissions. Depending on the life of the equipment and additional yearly labor and maintenance costs, an annualized cost figure can be derived. Elimination of an additional 7% smoke from 232 more industries, i.e. about 91% of industrial and about 70% of all particulate effluents in the GSPA, more than doubles the total cost to about Cr$ 964 million ($ 68 million in 1977) and the per ton figure to Cr$ 6,800 ($ 480) (Annex Table 1).

Kowalczyk [26] reports cost estimates for the control of four major point sources in the Medio Paraiba Area. This is a small but heavily industrialized and polluted area in the state of Sao Paulo, with a population of over one million 1/. Approximate total particulate emission from point sources are over 42,466 tons/year, of which the four sources constitute about 30,759 tons/year, or about 72%. The cost is based on the best control technology achieving about 98% abatement from the four sources, or equivalently 71% from all industrial sources. Total cost is 16.6 million in 1979 $US, or about $ 550/ton. Assuming 25% annual labor costs, an annualized investment plus labor cost figure is $ 3.25 million. Assuming that only 75% of the one million people in the area are directly injured by the airborne discharges, this means an annual per capita cost of 1979 US$4.33 per person affected.

D. Setting Air Quality Targets Across Regions

Ensuring a minimum "acceptable" air quality is an often mentioned objective. While criteria for acceptable air quality vary, its target often

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1/ The 1980 estimate from FIBGE for the industrialized municipalities that constitute this area is 1.16 million. This implies a population density of 224 hab/km2.

takes into account the deleterious effects on human health if such a target is not met. Usually, at the national level, maximum "acceptable" concentrations of various types of pollutants are determined on the basis of scientific studies. Although these target air quality levels should vary from place to place based on geographic, meteorological, demographic and other factors, they are often left uniform for political and administrative reasons. Each state or district is then urged to meet its air quality standard through emission standards 1/ or other policies.

Usually a maximum pollutant concentration with a certain frequency and/or a maximum allowable steady presence of pollutants in the air is stated. It may be said that each place has a right to the above implied minimum level of air purity; thus, there is a certain appeal to setting uniform minimum air quality standards everywhere. Among identically polluted areas, this approach also has the appeal of often requiring the same percentage smoke removals on the part of the sources, thus treating them equally in the fight against pollution.

Among areas widely differing in air pollution, on the other hand, a uniform air quality standard requires widely differing efforts, with the heavily polluted areas collecting more of its emissions not only absolutely, but also in percentage terms 2/. Such "differential" treatment implicit in

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1/ An air quality standard refers to a region or area, usually defined in terms of maximum dirtiness of air. An emission standard is essentially the same thing, stating maximum allowable emissions, except that it refers to the sources.

2/ The following distinction in terms is important. A uniform standard or target for emission signifies the same maximally allowable smoke the sources have to comply with. Uniform abatement, on the other hand, means the same percentage removal of smoke.

uniform air quality standards may or may not be justified on cost-benefit grounds. Marginal damages (which is the marginal benefit) depend, among other things, on the level of air quality in any region, thus implying the foregone benefits if the target standards were not spatially the same. However, other important factors such as the density of population, geographical and meteorological conditions, determine damages and decide the capacity of an area to absorb pollutants. As these factors may vary widely across regions, a sparsely populated area may be able to tolerate more effluents than a crowded residential area. A spatially indiscriminating air quality standard raises the possibility of a redistribution of pollution from the presently polluted areas to the relatively undamaged places. While redistribution of smoke to places with a better capacity to assimilate it without serious damages could be beneficial, a uniform air quality standard could also involve losses if the presently clean locations potentially involve more damages per effluent than the already polluted ones.

Among other factors, the marginal cost of restricting discharges usually depends on the positive difference between the existing and target smoke levels, i.e. the percentage of smoke that is removed. Consequently, even if the marginal benefit depends only on the level of air quality achieved, uniform air quality standards may not be the best approach if they imply a widely differing percentage in smoke collections. The same air quality standards require a higher percentage abatement and hence higher marginal costs in a heavily polluted area; if marginal benefits were also not equally higher at that standard, its higher cost would not be worthwhile. Of course, cost depends on other factors as well, such as available control technology for the relevant sources in the various regions, which may or may not strengthen the case for non-uniform air quality standards.

Under a policy that evaluates the differences in costs and benefits in Brazil, some spatial non-uniformity in air quality targets is likely to remain. Nevertheless, more percentage abatement is likely to be warranted in cleaning up the more seriously affected areas. This is because the highly polluted areas are also usually heavily populated ones (see Table VII.1). However, non-uniformity in abatement among areas sharply differing in pollution is unlikely to lead to an equalization of air quality spatially under an "optimal" policy. Two reasons may be noted. First, incremental cost rises increasingly with percentage smoke collection (see [5]) which eventually limits correction measures in the highly polluted areas. Second, relative to cost, high benefits could accrue from making some improvements in air quality even in moderately damaged areas (See Section VI).

E. Conclusion

It is evident that the marginal benefits and costs of controls should be considered in policy formulation. The problem, however, is putting this objective into practice. In order to set "optimal" air quality targets, empirical estimates of costs and benefits are needed. The calculation of costs is relatively easier. The difficulty of measuring benefits, however, can hardly be overstated. The absence of any previous benefit estimates in developing countries like Brazil compounds the measurement problem.

Attempts at some initial estimation of the benefits and costs of controls will, nevertheless, be valuable in policy formulation. Rough orders of magnitude alone are likely to provide high pay-offs. These could be the basis for setting the broad direction of policy, for example, whether to treat all regions equally or to be selective. Such spatial content of policy derived from cost/benefit considerations is likely to be important in a country like Brazil with large regional differences. This subject is further discussed in Sections VI and VII.

FIGURE IV.1

WELFARE COST AND BENEFIT OF POLLUTION CONTROL UNDER AN OPTIMAL POLICY

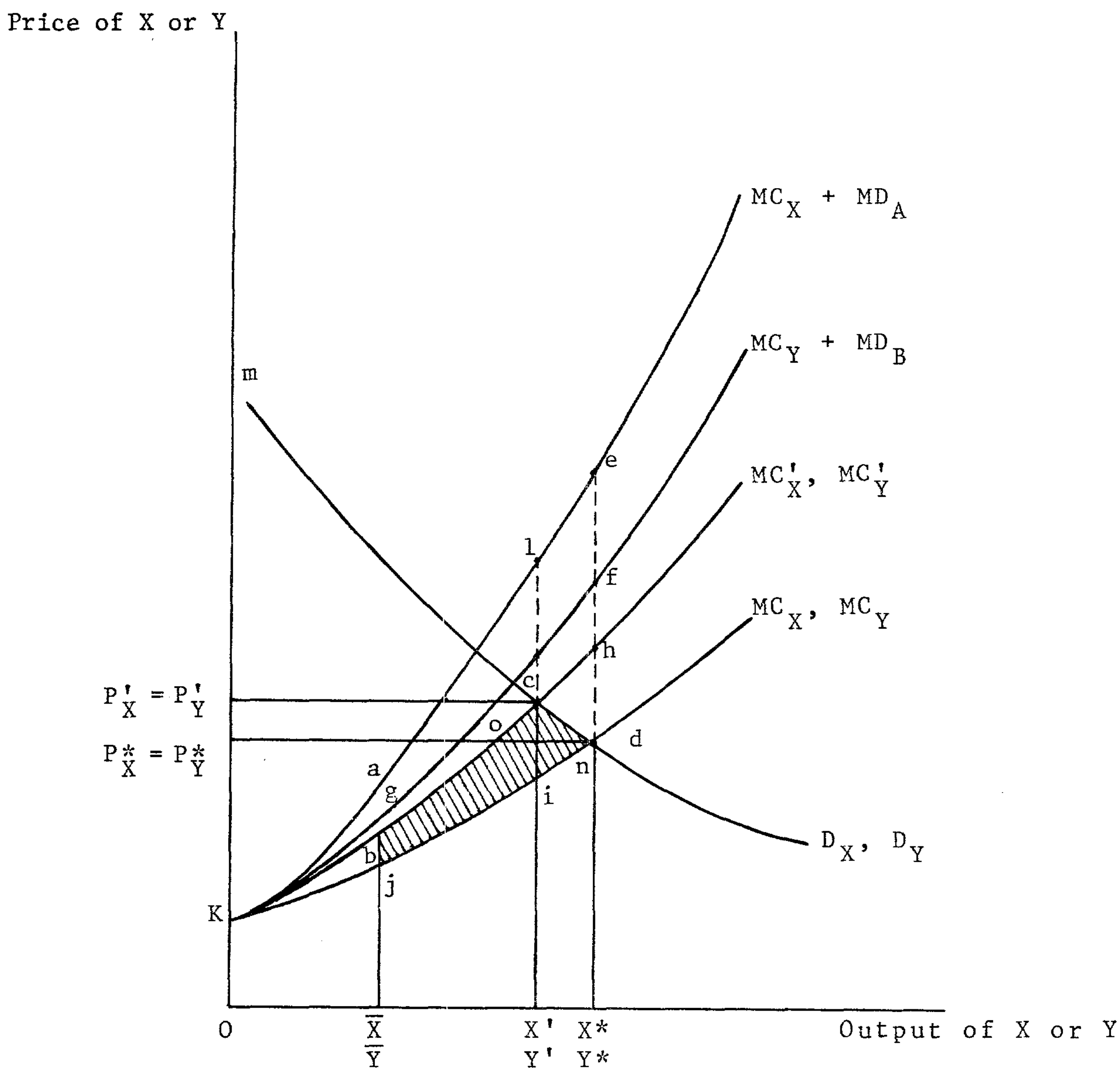

FIGURE IV.2

JOINT-PRODUCTION OF SMOKE

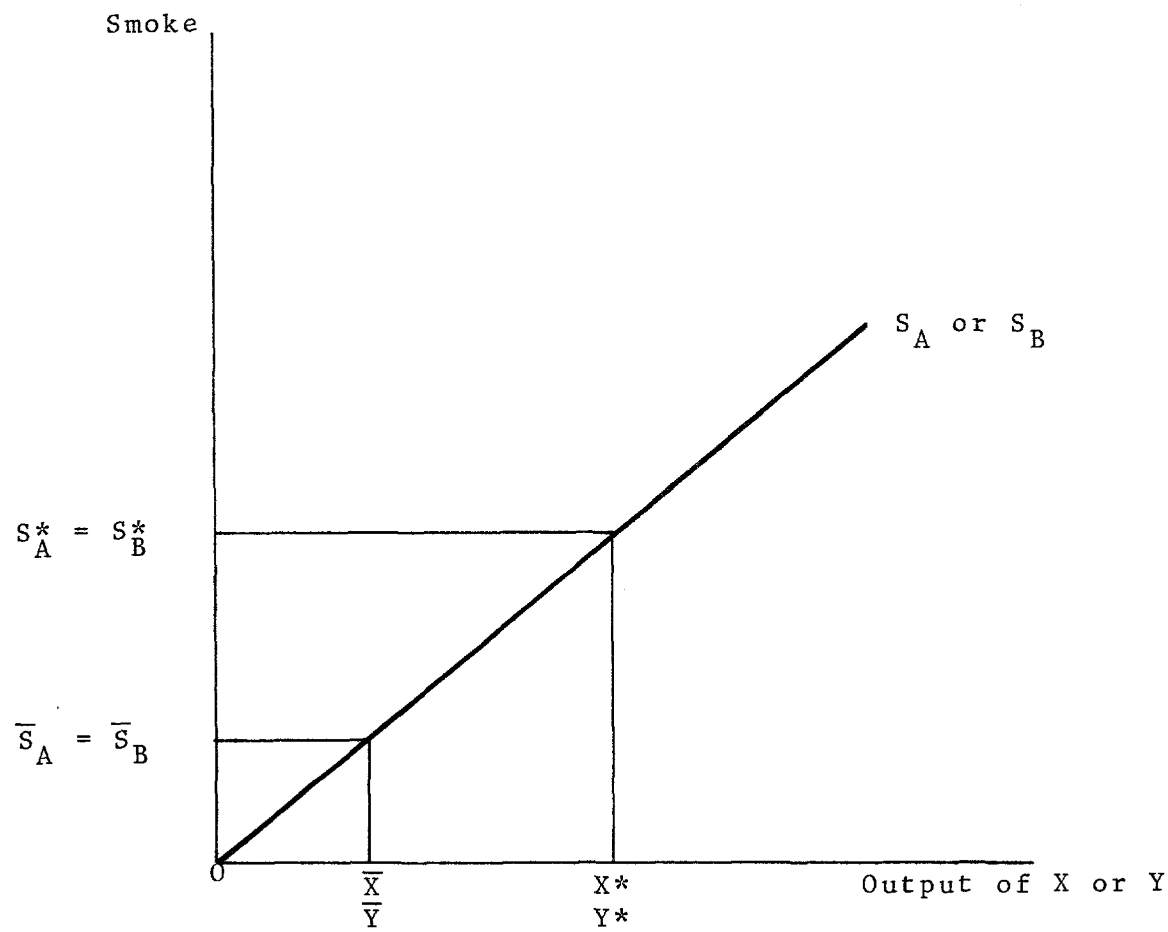

TABLE IV.1

CONTROL COST FOR INDUSTRIES CONTRIBUTING 90% OF GSPA's PARTICULATE EFFLUENTS - 1977 ESTIMATES (CR$ 1977)

	Number of INDUSTRIES	PARTICULATE EMISSIONS (T/Yr)	AVERAGE CONTROL EFFICIENCY	COST /a (1000 CR$)	
				TOTAL	PER TON EMISSION
Non-Metallic	36	103,770	95%	212,430	2.05
Chemical	6	15,360	80%	75,100	4.90
Metallurgic	11	12,560	98%	130,000	10.35
Total/Average	53	131,690	94%	417,530	3.16

/a Capital plus Installation Costs

Source: Annex Table 1

TABLE IV.2

POLLUTION CONTROL COSTS FOR SOME HIGH POLLUTING INDUSTRIES:

SÃO PAULO AND RIO de JANEIRO - 1980

(US$ 1979)

INDUSTRIES	AVERAGE COLLECTION EFFICIENCY	METROPOLITAN SÃO PAULO			METROPOLITAN RIO de JANEIRO			
		PARTICULATE EMISSIONS		CAPITAL COST/TON	PARTICULATE EMISSIONS		CAPITAL COST/TON	COST/ BENEFIT RATIO
		T/Yr	%		T/Yr	%		
I. Non-Metallic								
1. Cement	98	38,917	28.39	67	25,500	20.69	69	1.0
2. Quarrying	95	31,467	22.95	222	64,300	52.17	124	13.6
3. Ceramic								
-Clay	90	19,900	14.52	292	9,930	8.06	94	na
-Gypsum Lime	90	2,419	1.76	952	--	--	--	na
4. Asphalt	98	10,745	7.84	358	21,588	17.52	169	17.9
5. Concrete	66	3,370	2.46	490	316	0.26	563	62.1
6. Glass	80*	785	0.57	8,577	--	--	na	na
II. Chemicals	80*	12,252	8.94	625	--	--	na	na
III. Metallurgic								
1. Steel	98	6,863	5.01	1,058	1,268	1.03	1.879	13.6
2. Foundries	98	10,364	7.56	1,860	343	0.28	6.467	45.8
IV. Total/Average	94	137,082	100.00	468	123,245	100.00	151	na

-negligible; na=not available

Ratio of Particulate Emission: $\frac{\text{Sao Paulo}}{\text{Rio}} = 1.11$

Ratio of Control Cost: $\frac{\text{Sao Paulo}}{\text{Rio}} = 3.10$

*Approximations

Source: Based on Kowalczyk [26]

TABLE IV.3 TOTAL MORTALITY PER 10,000 FOR 37 MUNICIPALITIES, GSPA 1977

	I. Particulates Only			II. Particulates, SO_2, CO		
	TMT	TM_1	TM_9	TMT	TM_1	TM_9
R^2	.175	.343	.366	.341	.451	.470
Constant	69.079	22.290	25.618	76.214	27.913	30.759
<u>Air Pollution Variables</u> (Ton/km^2/yr)						
PM	.006* (1.423)	.002 (.629)	.002 (.584)	.120* (1.509)	.075* (1.630)	.075* (1.460)
SO_2	..	..	..	-.068 (-1.031)	-.032 (-.843)	-.030 (-.694)
CO	..	..	..	-.020 (-.667)	-.127 (.715)	-.017 (-.848)
<u>Socio-Economic Variables</u>						
P ≥ 65 (% of total)	5.331* (1.606)	7.449** (3.984)	8.723** (4.140)	4.357 (1.245)	6.633** (3.290)	8.015** (3.525)
VA (per capita)	-189.581 (-1.251)	14.330 (.168)	52.335 (.543)	-67.893 (-.430)	61.350 (.674)	112.000 (1.091)
HB (per 1000)	-.251* (-1.393)	-.166* (-1.640)	-.228** (-1.996)	-.248* (1.458)	-.162* (-1.647)	-.225** (-2.037)
P/KM^2	..	..	..	-.002* (-1.431)	-.119* (-1.599)	-.001* (-1.432)

Note: The numbers in parentheses are t statistics; * significant at 10% level, ** at 5%

<u>Variables</u>
TMT - Total Mortality Rate
TM_1 - Mortality Rate Excluding one year olds
TM_9 - Mortality Rate Excluding less than 10 year olds
PM - Particulate Matter

SO_2 - Sulfur dioxide
CO - Carbon monoxide
P ≥ 65 - Population over 65 years
VA - Value added
HB - Hospital beds

P/KM^2 - Population per km^2

TABLE IV.4 TOTAL MORTALITY PER 10,000 FOR 7 SUB-DISTRICTS, SÃO PAULO MUNICIPALITY 1973-78

	I. Constant Real Income			II. 3% Annual Growth in Real Income		
R^2	.587	.317	.667	.579	.314	.663
Constant	-136.38	-38.33	-124.025	-134.99	-37.548	-122.236
Air Pollution Variables						
($\mu g/m^3$)						
PM mean	.894**	472**	1.097**	.888**	.469**	1.119**
	(5.81)	(2.94)	(5.44)	(5.72)	(2.91)	(5.48)
SO_2 Mean	.160*	.040	.062	.153	.033	.065
	(1.34)	(.27)	(.493)	(1.27)	(.225)	(.51)
PM Max	..	..	-.220**	..	..	-.235
			(-2.25)			(-2.38)
SO_2 Max	..	..	.147*	..	..	.134
			(1.33)	..	..	(1.21)
Socio-Economic Variables						
P ≥ 60	10.55*	3.312*	9.112**	10.655**	3.499*	9.209*
(% of total)	(4.28)	(1.33)	(3.87)	(4.28)	(1.40)	(3.89)
Income	.009*	.003	.010**	.009**	.002	.010**
(per capita)	(2.97)	(.78)	(3.53)	(2.83)	(.67)	(3.44)
P/KM^2	-.003**	..	-.003**	-.003**	..	-.003**
	(-4.85)		(-5.42)	(-4.76)		(-5.37)

Note: The numbers in parentheses are t statistics; * significant at 10% level, ** at 5%.

Variables are defined in Table IV.3.

V. Choice of the Means of Control

A variety of policy means to lower pollution have been advocated or adopted in different countries 1/. Those that are more important may be classified under the following five broad categories: (i) issuance of mandatory pollution standards, (ii) provision of market incentives or an inducement to cut back pollution, (iii) inducement or requirement to use pollution control equipment, (iv) modification or restriction of the use of pollutant fuels, and (v) limitation or influencing of the output of products that are accompanied by a discharge of effluents. We shall consider the merits and defects of each of these alternative schemes throughout this section. It should be noted, however, that often, other methods -- not included in the above classification -- have also been seriously considered or adopted. One of these methods involves direct government expenditure to improve the environment.

A. Pollution Standards

Conceptually, the simplest procedure is to require pollution sources to meet a pollution standard. If there is only one source, or various identical sources, the stipulation could be issued either in the form of an abatement standard (meaning a certain percentage smoke collection) or in the form of an emission standard (meaning a maximum allowable level of smoke). If, on the other hand, sources are quite diverse in their size and discharge, an abatement standard and an emission standard would be quite different in their implications. An abatement standard implies smoke collection in proportion to emission. An

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1/ For a discussion see [16], [36], [38].

emission standard, however, requires more than proportionate collection from greater polluters.

The abatement standard and the emission standard both share fundamental advantages. One advantage is their directness: in confronting the pollution problem, they directly restrict smoke itself. Thus the costs from the reallocation of resources are minimized. These standards are general forms of control, which allow producers complete flexibility to adapt to them. Producers are not instructed to reduce emissions in any particular way. Thus, the least costly methods may be expected to be adopted. Normally producers would cut back on their use of highly pollutant fuels and/or modify their use, and in addition, would employ control techniques. Polluters are likely to consider, at least in the long run, both "end-of-pipe" treatment as well as changes in process and technology.

In the case of a single producer, or several identical producers, the cost of a pollution control standard may be estimated by considering a minimizing cost of producing conventional output while simultaneously meeting a pollution target. The diagramatic analysis in the previous section deals with this case. Empirical estimates of production functions of output and of emissions are needed to measure costs. In one study of the case of particulate effluents from the steel industry in the US [36], it was found that the welfare cost of meeting a 90% smoke reduction through a standard is below 1% of the value of output of steel. The cost of attaining the same abatement through alternative instruments was higher. The exception is an equivalent tax, which is discussed in the next sub-section.

In most practical situations, various polluters of different sizes are responsible for environmental degradation within an area. Hence, in this sub-section, it is important to point out how an abatement standard and an emission standard differ.

1. Abatement Standard

Suppose it is deemed desirable that 90% of existing pollution should be cut down in an area (a micro or subregion, district, municipality or a small metropolitan area). If there were only one source or many that were identical, it would be most cost-effective to simply require sources to collect 90% of effluents. Such a uniform standard would not be cost-effective, however, if the cost of control significantly varied non-proportionately in the percentage of smoke collection from different sources. In such cases, one would have to devise differential abatement standards that achieve different percentages of smoke removal from different sources. Cost-effectiveness would depend on whether costs of percentage collection rise or fall with the size of polluter (i.e. as a function of output, or inputs). However, it may not be feasible to do this correctly.

If control costs are roughly proportionate to the percentage abatement and/or if their differences are not sufficient grounds to differentiate between sources within an area, a uniform abatement standard (e.g. 90% abatement by everyone in an area) would be satisfactory. In Section VI, it is suggested that if abatement standards are opted, it may be neither necessary nor worthwhile to set different levels for different sources within an area. Across areas and regions, however, non-uniform abatement is recommended.

Within CETESB´s overall strategy, the option of simply setting abatement standards, a collection requirement of 90%, for example, is increasingly considered. More often, however, the practice has been to require the use of technology with 90% control efficiency. While this policy is to be considered later in this section, most actions, thus far, have been preventive in nature. Thus, although effective abatement standards to cut down on existing smoke have been few [7], [8], they will assume greater importance in the future (Section III.D).

2. Emission Standard

If control costs are approximately proportionate to percentage collection, a single emission standard would clearly be inefficient. If, however, unit control costs fall systematically with percentage abatement, big producers ought to collect proportionately more (See Section VI), despite the consideration that a single emission standard may still not be cost-effective. Implemented in a functional form which varies with the size of the producer, an emission standard could conceivably turn out to be efficient.

Various types of emission standards, which stipulate the maximally allowable emissions as functions of output, inputs or fuels used in processes, have existed in the US. A recent approach has been to set a uniform standard for all existing sources in a functional form which increases at a declining rate with "the process-weight" of producers. In an empirical study [36], this approach was shown to be only slightly more costly than a least cost strategy, which was revealed to be a uniform abatement standard within areas.

B. Pollution Taxes

An approach favored by most economists in the fight against pollution is the use of market incentives and disincentives. Emission taxes are most often advocated. Because they embody the advantages of directness and generality of standards, as discussed in the previous sub-section, emission taxes may seem to cause producers to adopt the least-costly means of abatement. It is argued, in addition, that taxes are administratively simple. In principle, a single unit tax could be devised to achieve the required pollution reduction while minimizing government involvement. This type of unit tax would distribute the burden of smoke collection among sources according to their ability (i.e. cost) to do so [6]. Recall that with the use of standards, either different levels would have to be chosen or a functional form of the standard must be determined if control costs vary widely. This procedure compounds administrative problems. It should be noted, however, that it is equally possible to choose the wrong tax to develop the wrong standards. The relative merit of either approach is therefore debatable [29], [44].

If there are no serious grounds to differentiate between types of polluters in an area, and if control costs rise in proportion to percentage abatement, an emission tax and an abatement standard differ little in their effects on the costs of controls (economic and administrative). Indeed, this is considered to be the case in this study. In addition, taxes and standards equally share the problem of requiring the monitoring of effluents.

In spite of the merits of pollution charges, policy makers seldom resorted to them. A variety of reasons may be noted for their unpopularity. In addition to uncertainty as to the magnitude of their effects, a second difficulty of pollution charges is the relative inflexibility in changing them within political processes. A third problem may be the political obstacles in levying different tax rates across regions. The previous section revealed the costs and benefits of pollution control, assuming that a standard is the means of control. Although it is slightly more complicated, a tax could have been used to illustrate the basic case as well. In further discussions in this paper, we use the example of an abatement standard in order to illustrate the functioning of a least cost policy instrument.

C. Required Pollution Control Equipment

Based upon observed recovery efficiencies of the control techniques available to industries, instructions which require the use of control equipment are often issued. Incentives are sometimes provided to step up the application of control technology through subsidies or tax write-offs. A recent initiative to finance control equipment in Brazil and tax exemptions for pollution control devices in the US are examples. Also considered in Brazil are ways of recovering, recycling or treating residuals either biologically, mechanically or chemically.

A limitation of this policy option is that there is no incentive for producers to lower the use of highly pollutant fuels, which could potentially lower the cost of meeting air quality norms. Confronting a requirement to install a particular control device, the producer does not find it necessary to do anything else -- such as exploring other and possibly cheaper ways to lower environmental damage.

Of course, a pollution control equipment policy could achieve the same abatement as either a tax or a standard. The cost of doing so, however, would normally be higher. The principal reason for higher costs is that pollution reduction is entirely achieved by the use of control inputs, without exploring possibilities of lowering or modifying the use of polluting fuel. On the other hand, this policy would not be more costly if industry does not face realistic alternatives to cut down on polluting fuels. However, in the empirical study mentioned earlier, a degree of substitutability between polluting and non-polluting fuels was allowed and consequently, the additional cost of this policy was found to be 30% more than an emission standard.

The requirement to install control devices of a certain efficiency or "the best available techniques" for new pollution sources is a feature of the CETESB strategy. Whether this approach involves a significantly higher economic cost than standards (or taxes) is an empirical matter, primarily depending upon the degree of substitutability betwen polluting and non-polluting inputs. In the empirical study mentioned earlier, the considerable substitutability that was assumed led to higher costs under this policy than in the case of a standard. It should also be noted that as long as the installment of equipment of specified efficiencies is ensured, the need to meter pollution is minimized under this policy, at least for a period of time.

D. Restrict Polluting Fuels

An approach often relied upon is the regulation of fuels which are prime sources of the problem. While an extreme possibility would entail the establishment of maximum quantities of polluting fuels permissible in a process, this approach is likely to yield greater costs than those of an emission standard. Another option presently being considered in Brazil, is to attempt to increase technical and engineering efficiency in order to reduce the ratio of pollutant input to usable input. Also being examined are the possibilities of substituting highly pollutant fuels for low polluting ones. Restrictions on the quality of fuels, such as regulating the maximally allowable sulfur content, is another option.

A drawback of this approach is that no inducements are provided for the use of control devices, which could greatly simplify the task of cleaning up the environment. Faced with a requirement to change fuel usage, the producer finds no need to install control equipment. Thus, in order to meet a certain air quality standard, more modification of fuel use will be needed than if control inputs were also induced, thereby raising the cost of the program. In an extreme situation where no control technology exists, a policy of concentrating efforts on fuels may be the best attainable. In most practical situations, however, some control devices are available, and this is therefore likely to be a costly approach. Indeed, this was the conclusion of the empirical study mentioned earlier.

E. Limit Output

Given relationships between conventional output and emission, one indirect policy would be to influence output as means of restricting pollution. Lowering the stock of output to achieve any meaningful reduction in the stock of effluents would involve prohibitive costs in terms of lost output and employment. A more moderate strategy which is often resorted to, is to influence additions to output as a means to limit further deterioration of the environment. A case in point is the existing industrial zoning and licensing policy in Brazil [4], [8], [12], [32]. Additions to output of high polluters are prohibited in various areas within the GSPA as one means to keep the environmental situation under control.

A serious shortcoming of this type of policy is that it fails to provide incentives either for the use of control inputs or for substituting pollutant fuels, both of which could potentially aid in lowering the social cost of controls. Unless there are no possibilities of substituting polluting fuels, non-polluting fuels, and control inputs, such an approach of this type would be far more costly than others. Indeed, this was also a result obtained in the empirical study cited earlier, even though some substitution possibilities normally exist. A mitigating factor, however, is that in certain heavily polluted areas and/or highly residential locations, no addition to the stock of pollution is tolerable. Thus, rather than requiring 100% (or approximately this percentage) recovery efficiency from new entrants, it may be equally efficient, or easier for practical reasons, to prohibit any addition to output. In certain parts of GSPA, this may be the case.

Influencing the spatial distribution of output, on the other hand, is a necessary feature of almost any rational pollution control strategy. Allowing for the relocation of production could ameliorate the social cost of control. (This aspect is treated in greater detail in Section VIII.) Thus, while lowering output as a means to lower pollution may not be efficient, allowing for the spatial adaptation of producers could be an important aspect of an "optimal" approach. In the GSPA, the indirect inducement of heavy polluters who do most of the damage to relocate part of their output (Table II.6), would be a desirable outcome.

F. Conclusion

A number of alternative means have been proposed and/or adopted to lower pollution in various countries. Among them, emission tax is the one most favored by economists, even though in practice, it is the least tried. Relative to taxes, pollution standards have been more popular in actual policy. Standards share the fundamental merits of taxes. One difficulty arises when standards have to be separately determined for sources on grounds of cost of treatment differentials. In practical situations, however, a uniform abatement standard within an area could be sufficient.

Compared with emission charges and abatement standards, the other three means examined in this section are more costly. Among them, the mandatory use of control equipment generally involves the least additional cost over the "optimal" policies. Additional cost in this case arises only to the extent that a modification of fuel use is not encouraged. A policy of restricting fuel use, on the other hand, is likely to be much more costly since the important option of the use of control inputs is not encouraged. Finally, lowering the existing output in order to reduce pollution would clearly be the most costly option, since neither the use of control equipment nor the modification of fuel use is induced. Under extreme circumstances, however, addition to output may be prohibited in certain areas since absolutely no more pollution is tolerable in these regions.

Thus far, anti-pollution action in Brazil has been mostly preventive in nature. To forestall a deterioration of the environmental problem, restrictions have been placed on any expansion of certain types of output in some areas of the GSPA. Various options under consideration, in effect, have lowered the existing stock of pollution to a small extent. Thus, the possibility of adopting least-cost policy means such as taxes and abatement standards exists.

Part 3 Spatial Considerations

VI. Differentiating Sources on Cost Grounds

Two interrelated questions have been addressed so far: how much pollution should be controlled (Section IV) and how it should be controlled (Section V). A third question integrally related to the first two, is who should control pollution. Indeed, the overall cost of controlling emission not only depends upon who bears the brunt of the effort, but also how much effort is made and how. Target air quality standards are affected by the distribution of controls among sources.

There are two aspects to the question of how controls should be distributed. The first is whether sources within an area (subregion, municipality, zone, etc.) should be differentiated; the second is whether controls should be systematically different across regions. In principle, these two aspects can be addressed by adopting different emission taxes for different regions on cost/benefit grounds. Subsequently, the tax would also automatically distribute the burden of abatement cost-effectively within a region. Each source would be induced to reduce its emissions according to its ability to do so [6].

In spite of the above feature of a tax policy, in practice it is seldom adopted for a variety of reasons (see Section V). Usual procedures set different types of direct regulations. In the distribution of these regulations among sources, there is, nevertheless, a varying balance influenced by cost and benefit considerations. The purpose of this section is to elucidate how cost considerations affect optimal controls. Costs arising from variations in production and abatement technology within the same industry or among different industries are discussed. Variations in benefits across regions are introduced in the next section.

A. Main Considerations

1. Production Cost Differences

While production relations determine the size of producers, and their size often influences pollution control relations. Emissions per unit of output and control cost per unit of abatement can vary systematically with the size of the producer.

Although Annex Fig. 1 contains the same issues as Fig. III.1, two producers of different sizes (X_1 and X_2) are shown to thereby determine the industrial output X_T and pollution S_T. The effect of pollution standards S_1 and S_2 is to shift the marginal costs, thus revealing the welfare cost shown by the shaded areas. In Annex Fig. 1, the welfare cost is the increase in total cost of market output, less savings in cost due to a fall in output.

The effect of pollution control on welfare costs can be determined by integrating the shifts in MC over the ranges of smoke reduction, and output where control is effective. If demand is inelastic, Equation VI.1 reveals the welfare cost. If demand is elastic, the saving in cost due to a fall in output must be deducted.

$$WC_T = \int_{X_T}^{X_T^*} \int_{\bar{S}_T}^{S_T^*} \frac{dMC_T}{dS_T}\, dS\, dX - \int_{X_T'}^{X_T^*} \{MC_T + \int_{\bar{S}_T}^{S_T^*} \frac{dMC_T}{dS_T}\, dS - D_X\}\, dX \quad \text{(VI.1)}$$

[Total welfare cost of pollution control]	=	[Increase in total cost of producing existing output while controlling pollution]	−	[Saving in welfare cost due to reduction in output]

Equation VI.1 is the sum of WC_1 and WC_2. To minimize the cost of meeting any $\bar{S}$, the condition is that $dWC_T/(d\bar{S}_1/\bar{S}_2) = 0$, or $dWC_1/(d\bar{S}_1/\bar{S}_2) = dWC_2/(d\bar{S}_1/\bar{S}_2)$.

It has been noted that the change in cost due to a change in smoke restriction depends upon the existing degree of abatement. Babcock [5] has approximated the cost of pollution control with a function that has a value of zero at no collection and increases at an increasing rate as a higher percentage removal is attempted. This means that for any producer, the shift in MC for additional collection is larger at higher existing percentage removals.

Therefore, for identical producers, percentage removals should obviously be equal. If not, the increase in cost for one whose percentage removal is greater, would be larger than the decrease in cost for the other. Among different-sized producers as well, percentage removals should be the same as long as there are no economies of scale in smoke collection, 1/. The total abatement cost of a producer twice as large as another for removing the same percentage smoke (or twice the absolute amount) is twice as much. If, on the other hand, economies of scale exist in pollution control, overall costs can be lowered by requiring that the larger producer collect more than twice

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1/ No differences in control technology are assumed in this sub-section.

the small one. An extreme possibility is that both large and small producers reduce smoke to the same level (i.e. $\overline{S}_1 = \overline{S}_2$), thus implying greater responsibility for controls on the part of the larger producer.

Annex Fig. 2 shows optimal standards for a large and small producer, alternatively with and without economies of scale. Point A is the free market ratio of 2 for emissions among firms 1 and 2. The first curve $S = \overline{S}$ shows the welfare cost of meeting that target using different ratios of standards for 1 and 2. The lowest point of $S = \overline{S}$ is shown to be vertically above A, assuming proportionate collection is optimal.

If there are no economies of scale, all lowest points on subsequent curves ($S = \overline{S}'$ and so on) will lie along A A′. On the other hand, if economies of scale require more than proportionate abatement by the larger producer, the lowest points on higher curves lie to the left of A along AB. In the case of $S = \overline{S}''$, it is postulated that equal standards for 1 and 2 minimize cost.

It is possible that larger producers pollute less in proportion to their size. In this case, a given output loss from the smaller producer involves proportionately more pollution saving. Thus, apart from scale considerations, there could be an advantage to letting a less than proportionate output fall from the larger firm. On this count alone, relatively less stringent control would be advisable for the larger producer.

2. Treatment Cost Differences

A major reason for variations in welfare cost is difference in treatment costs among sources. Within the same industry, control technology available to individual producers may not differ. Among industries, however, large variations exist in available technology and its associated cost. (See [5], [24], [25], [42]).

In Annex Fig. 3, the shifts in MC for two producers in industries X and Y could differ for the same degree of control. To minimize overall cost, these differences in response have to be accounted for.

3. Demand Differences

When two industries are considered, differences in demand elasticities also contribute to variations in welfare costs. The less the demand elasticity, the more the welfare cost. 1/ It would therefore be desirable to set demand as relatively more inelastic.

Demand considerations could also determine the cost of policies for producers in the same industry, if they are located in separate regions. As groups of producers in the same industry may supply markets which are divided by transport costs of production and of transportation, a market area for each group is defined by consumers trying to buy at the lowest delivered price.

B. Some Estimates and Policy Implication

1. Size of Producers and Control Cost

A question raised in Section VI.A.1 was whether producers should be discriminated on the basis of size. The answer, it was noted, depended upon whether the larger producers pollute proportionately more or less than smaller ones, and whether there are economies of scale in pollution control.

1/ See Figure IV.1.

Licco, Oda and Filho [28] estimate that effluents per unit of output or emission factor, e, is constant for some industries, but declines somewhat with the size of producers, as shown in the following examples. (see also [42]).

Metallurgic Industries

Steel Foundry: Basic Oxygen	e = 6 kg/ton of output X
Iron Production:	e = 9 kg/ton of output X

Non-metallic Industries

Cement Production: Calcination Furnace	e = 6 kg/ton output.
Ceramic Production:	$e = 9.5\ X^{0.8}$ kg/ton

Chemical Industries

Production of Phosphate of Ammonia	$e = 10\ X^{0.8}$ kg/ton of output X

To the extent that e declines with output X, it is advantageous to require less than proportionate abatement from larger producers, thus allowing those who pollute less per unit of output to produce more.

On the other hand, some economies of scale in pollution control are likely to exist. Consider Babcock's equation for pollution controls cost ($/hr) which is stated as a function of Q, flue gas flow rate (ft^3/m), R, recovery efficiency (decimal), and a, b, c, which are constants.

$$n = a\ x(Q)^b \left(\frac{R}{1-R}\right)^c$$

Some estimates of n for two different control devices are given below:

Control Device	Pollution Control Cost
Wet Collector	$41.5 \times 10^{-6}\ Q^{0.91}\ \left(\frac{R}{I-R}\right)^{0.52}$
Low Voltage Electrostatic Precipitador	$75.9 \times 10^{-6}\ Q^{0.90}\ \left(\frac{R}{I-R}\right)^{0.14}$

Although these estimates were made using US data, the results should broadly apply to Brazilian industries, since control devices are not different. Estimates of the co-efficient b suggest that the control cost per unit of output declines with the size of producers. In such cases, there is an advantage in requiring more than proportionate abatement from larger producers.

In the estimation of control costs for industries under a World Bank project [45], it was found that the cost per ton of particulates collected is lower for the larger producers. This relationship is suggested in Annex Table 1, where the control costs for the largest polluters who contribute 90% of particulates in the GSPA are revealed. It is not clear whether larger producers achieve the same percentage abatement as smaller ones. Even allowing for a liberal difference in abatement (i.e. less in percentage terms for the bigger polluters), however, significant economies of scale in control seem to persist.

Annex Table 1 implies that there are benefits to a strategy which focuses its attention on the largest polluters. For example, to achieve 85% (90% x 94%) abatement in Annex Table 1, the distribution of responsibility over the remaining 10% smaller polluters seems to raise overall costs. It is unlikely, however, that in meeting an abatement standard higher than 85%, it is better to raise the standards for the larger producers i.e., over 94%. Most likely, smaller polluters should be included in the operation. It is also unclear whether the same 85% can be met at a lower cost by raising the standards for the larger polluters, while lowering it for the smaller ones among those contributing 90% of the smoke.

There is considerable variation in the size of producers, even within the same industry in Brazil. Annex Tables 2 through 5 show that the average size of producers in the non-metallic, chemical, and mettalurgic industries in big and small industrial centers varies among the states of Sao Paulo, Minas Gerais and Parana. In controlling pollution in the state of Sao Paulo, the approach has been to require industries to use "the best available" technology to control each type of pollution. In general, producers within an industry may thus be expected to apply equipment with the same control efficiency, thereby achieving comparable percentage removals.

In principle, therefore, the present strategy is not to differentiate among producers on the basis of size. We have not conclusively revealed, however, that this is inefficient. In practice, as seems logical, the present approach is to aim toward achieving compliance from the larger producers. It was noted in Section II.C that approximately 90% of particulates and 74% of SO_2 are discharged respectively by only 5% and 10% of the largest polluters. Thus, whether it is economically sound to urge proportionate collection regardless of size, the major battle will be won if the largest producers can be made to comply with the regulation.

2. Different Industries and Control Costs

While the control technology available for air emissions varies among industries, the efficiencies of available equipment also varies for different industries. For both these reasons, the per unit abatement cost at a given efficiency differs among industries. 1/

Annex Table 1 reveals wide variations in per ton control cost for nonmetallic, chemical, and metallurgic industries. These differences arise from the estimated cost differnces of using fabric filters, wet scrubbers or multicyclones for various industries. Comparisons are not precise because (as shown in the table) the collection efficiency of equipment available in the market for these industry types also differs. Nevetheless, it is apparent that non-metallic industries, which contribute the bulk of particulate emissions (76%; in Annex Table 1, excluding fuel combustion), face significantly lower control costs than chemical and metallurgic industries. Industries excluded in the table have still higher costs.

Focussing on the largest polluters among non-metallic, chemical and metallurgic industries, who contribute 90% of overall industrial particulate effluents, a cost of Cr$3200/ton (or $225) effluent for 1977 is indicated. About 85% overall abatement can be achieved at this cost. At higher abatement levels, the cost would probably increase substantially as other polluters are included.

1/ A number of studies discuss inter-industry differences for Sao Paulo. See [13], [19], [26], [33].

Table VIII.2 shows that abatement costs can vary widely within the above three industrial classes. The range of cost difference is apparent in comparing a low control cost industry, cement, with iron foundry, one that is highly costly. It should be emphasized, however, that these are estimates based on industrial projections at a time when the majority of polluters had yet to use control equipment. As a greater variety of equipment becomes available in the market, and experience accumulates, cost differences are likely to diminish.

The inter-industry cost variation, nevetheless, implies savings through an approach that differentiates among producers on cost grounds. A given overall abatement can be more efficiently met by focussing on those more capable of abating. At higher abatement levels, those with higher per ton cost would be included.

The importance of the above consideration depends on the level of overall abatement aimed for. At low levels, 50% overall abatement, for example, it would be cost-efficient to regulate only the top producers polluting 53%, assuming their control efficiency is 94%. If much higher abatement, perhaps 85%, is justified on cost-benefit grounds, clearly more industries will have to be involved to attain these levels. Also, beyond a certain control efficiency, the additional control cost for a low-cost industry to abate more is generally greater than for another high cost industry to initiate a few controls. Thus, the overall abatement standard and feasible control efficiency for industries determine what number of industries ought to be involved in an efficient control strategy.

Cost data available indicates the advantage of focussing on large polluters in the non-metallic, chemical and metallurgic categories. To lower industrial particulate discharge 85%, it seems logical to regulate 90% of the top polluters in these industries, assuming an average control efficiency of 94%. Smaller particulate polluters of other industrial categories (eg. pulp and paper, textiles, food products) will also need to be included, yet at much higher overall abatement targets.

Although non-metallic industries show lower control costs, the regulation of larger polluters (i.e. belonging to 90%) in this category alone, will not achieve an 85% overall abatement target. As Annex Table 1 shows, the top non-metallic polluters (belonging to 90%) emit about 72% of all industrial effluents (i.e. $104 \div 140/.97$). At a 95% control efficiency relevant for non-metallic industries, only 68% industrial particulate effluents will be removed. The inclusion of smaller non-metallic producers belonging to 97% at a 95% efficiency does not permit a significant increase in overall abatement. Thus, to reach 85% or more abatement, the higher cost industries will also need to be involved.

In principle, cost considerations would justify discrimination among the three major types of industry. At low overall abatement targets, non-metallic types would bear the brunt of the control, while chemical and metallurgic industries would be included at higher targets. If an 85% or higher overall abatement goal is to be met, it is not clear that it is feasible to differentiate within these industry types. As some of the metallurgic and chemical industries obviously must be regulated, it may not be practical to consider whether particular industries can be differentiated under the regulation (to meet cost criteria), beyond distinguishing them by polluter size (previous sub-section).

C. Conclusion

Variation in production relations, control costs and demand conditions relevant for different industries invariably gives rise to differences in the social cost of achieving an improvement in air quality through controlling one group of producers as opposed to another. For this reason, an optimal strategy would differentiate among sources in the setting of standards. It may not be possible or even cost-effective, however, to always differentiate among sources within given areas (districts, municipalities, states) for practical and political reasons. Broad differences in emphasis, on the other hand, could reduce costs. In Sao Paulo, for example, it seems sensible to focus on the relatively few largest polluters of non-metallic, chemical and metallurgic industries (in that order).

Across areas where the composition of industries differs significantly, considerable differences of control cost can result. These differences should clearly influence the priority given to places under regulation. Spatial cost differences, however, will have to be viewed in conjunction with an even more important criterion, benefit difference, which is the subject of the next section.

VII. Differentiating Locations on Benefits Grounds

A. Main Considerations

Differences in production costs and/or pollution control costs which affect the welfare cost of pollution control have been the reasons offered thus far for possibly differentiating among producers within the same industry or between different industries. Differences in the welfare benefits of reducing discharges is another consideration governing the distribution of controls. The main effect of accounting for benefit differences would be to call for variation in the overall standards (i.e. $\overline{S}$) among locations, since within particular areas damages per unit of smoke emitted by different producers may not be very extensive. If overall standards differ between two locations, producers in each locale would be required to meet different standards. Different standards result from cost and benefit differences, and sometimes due to differences in demand schedules (See [37]).

To reveal the implications of benefit differences, we may consider two industries, X in location A and Y in location B, with identical cost functions for their outputs X and Y, identical control costs for pollution S_A and S_B, and identical demand functions D_X abd D_Y. Assuming, however, that location A is more densely populated than B, incremental damage MD from a unit of pollution in A (MD_A) is higher than in B (MD_B).

These differences are reflected in $(MC_X + MD_A)$ and $(MC_Y + MD_B)$ in Figure IV.1 which reveals the incremental social cost associated with each level of X or Y. In the absence of abatement, kdek and kdfk are respectively the total social cost of pollution in addition to the cost of producing X and Y, or the welfare benefit of control. Identical anti-pollution policy for X and Y facing the identical MC_X and MC_Y shift the marginal cost to the same level MC'_X and MC'_Y. Given the same D_X and D_Y, the same welfare cost bjdc shown by the shaded areas results. The welfare benefit of equal abatement, however, is different. Net benefits (i.e. total welfare benefit less welfare cost shown by the shaded area) for location A, are given by abcdea and for B by gbcdfg. Suppose gbcdfg is the maximum possible net benefit in location B, meaning that marginal benefits and marginal costs of effluent reduction at $\bar{S}_B$ are equal. Then at $\bar{S}_A$ ($= \bar{S}_B$) marginal benefits are greater than marginal cost of abatement, implying that optimal $\bar{S}_A$ is less than optimal $\bar{S}_B$ i.e. stricter controls are justified in A.

Differences in the density of population was the reason offered above for spatial variation in incremental benefits, since the detrimental effects of smoke are multiplied in heavily crowded areas. Of course, a variety of other important reasons are also relevant. First and most importantly, when the stock of pollution is already high, the incremental damage of an increase in smoke is usually higher than if the stock were low. Thus, the marginal benefits of control are higher in highly polluted areas. Second, geographical and meteorological factors govern the ability of the environment to harmlessly absorb emission [45]. Where these factors are unfavorable, incremental damages are also likely to be higher.

B. Likely Benefit Differences Within Brazil

In a country as large and diverse as Brazil, spatial differences in the factors determining benefits to society from pollution control are likely to be large. Table VII.1 examines some of these factors for the neighboring states of Sao Paulo, Minas Gerais and Parana (Map 2). Within each state, selected municipalities are included, and while some are highly urbanized, others represent more rural situations. Sao Paulo, Belo Horizonte and Curitiba are large urban centers, while Aruja, Tres Coracoes and Toledo represent more rural conditions in the states of Sao Paulo, Minas Gerais and Parana respectively.

Differences in air quality among and within these states is reflected by data on the density of industries and vehicles. Variation in the concentration of industries indicates likely differences in particulates and SO_2, while vehicles indicate likely differences in CO. With over 30 industrial establishments/km^2 and 840 vehicles/km^2, Sao Caetano must face far worse air quality between the highly industrialized areas like Sao Paulo, Santo Andre, Sao Bernardo and Sao Caetano. In places such as Aruja, the air quality would be much worse. Significant differences in marginal benefits from cleaning up the air can be expected between the highly and mildly polluted areas.

The more heavily polluted locations in Table VIII.1 are generally more densely populated. Thus, existing pollution levels in these more industrialized/urbanized areas imply relatively more damages to people than in other areas. These two factors seem to provide compelling reasons for focussing anti-pollution measures in the seriously damaged areas. Table VII.2 spells out differences among municipalities within the GSPA in total air pollution. Once again, it is revealed that the likely variation in air quality across locations is considerable.

To what extent the likely benefit variations provide grounds for differentiating pollution sources across locations is both an empirical and practical matter. We do not have quantitative benefit estimates for guidance in this issue. A rule of thumb, however, would be that incremental damages (benefits) for a given smoke level in a place twice as densely populated is twice as much as the benefits accrued in another. 1/ If so, a strong case is provided for being spatially selective in pollution regulation. In practice, however, it may not be possible to make fine distinctions among areas. Political jurisdictions at the municipality level, or even at the state level, may have to be relied upon.

Furthermore, to what extent benefit variations justify the differential treatment of sources also depends upon the kind of cost differences discussed in Section VI. It is possible that high potential benefits in one area relative to another is partly or fully offset by high costs. As an example, we may compare the likely costs and benefits of industrial pollution abatement in metropolitan Sao Paulo and Rio de Janeiro. On the benefit side, the higher intensity of industrial activity and population density combined with the city's unfavorable geographic and climatic characteristics (Section II.B)

1/ Most damage functions assume increasing marginal damages [11], [37], [43].

may be expected to imply higher incremental damages (i.e. marginal benefits from pollution control) at existing pollution levels in Sao Paulo than Rio. According to the 1970 Industrial Census, the value of production in Sao Paulo was 8.6 times Rio (CR 65.5 ÷ 7.6 m). Total particulate effluents are clearly higher in Sao Paulo than in Rio. The difference indicated in Table VII.3 for 1979, however, is only 11%. This, nevertheless, is due to a serious underestimation of fugitive dust in Sao Paulo, as explained in the table. Excluding fugitive dust sources, quarry and asphalt plants, Sao Paulo's effluents exceed Rio's by 145%. Given Sao Paulo's larger area, however, pollution concentration would not exceed that of Rio by such an extent. According to FIBGE, in 1970 the density of population in Sao Paulo exceeded that of Rio by 17% (3991 vs 3405 hab/km). This difference would be larger at present, thereby providing a significant difference in the marginal benefit of pollution control among the two places.

On the cost side, on the other hand, Kowatczyk's results in general imply lower control costs for Rio's industries than those in Sao Paulo's. A survey compared control costs for the major polluting industries in Sao Paulo and Rio belonging to non-metallic, chemical and metallurgic categories. Including quarry and asphalt plants, a large difference in per ton cost of 210% between Sao Paulo and Rio has been observed (Table VII.3). For reasons given earlier, however, a better comparison is provided by excluding quarry and asphalt plants. A 60% difference in per ton abatement cost is indicated. Some reasons for the cost differences between Sao Paulo and Rio in Table VII.3 are offered by Kowatczyk. Due to the inclusion of fugitive dust emissions in the Rio inventory, differences in asphalt plant control appear.

Due to their small sizes, ceramic plants in Rio can use water spray systems instead of more expensive bag filters. Rio's higher per ton cost for foundries and steel mills, on the other hand, appears due to smaller size facilities which cost more per ton for initial abatement hardware.

Thus, while higher apparent pollution damages in Sao Paulo call for more serious abatement activity in Sao Paulo than in Rio, the generally higher range of cost in Sao Paulo puts limits on the relative stringency of controls justified. In the absence of better estimates of damages (benefits) and costs, however, we are unable to conclude in this paper whether it is socially beneficial to treat Sao Paulo and Rio equally or differently under optimal anti-pollution strategy. With more information, however, a cost-benefit ranking of the various control options for each area, with implications for differential treatment for the two areas, would indicate the proper priority scheme.

C. Conclusion

Due to the geographic concentration of industrial activity in Brazil, wide spatial differences in environmental pollution prevail. Often, the more heavily polluted areas, are also more densely populated, thus multiplying damages from pollution. A clear reason is thereby provided for treating certain locations under policy more favorably than others.

Under an optimal approach to equate air quality everywhere, existing benefit differences are unlikely to justify large enough abatement in the heavily polluted areas relative to others in Brazil. As seen in Section VI, the additional cost of more stringent controls in an area increases, thus rendering extreme controls in that area unacceptable. But in terms of percentage abatement, the heavily damaged places such as the GSPA would undertake more actions than other states, primarily due to large spatial differences in the potential benefits from pollution control.

Table VII.1: SELECTED MUNICIPALITIES OF SAO PAULO, MINAS GERAIS, PARANA: SOME INDICATORS OF EXISTING LEVEL OF DAMAGES FROM POLLUTION - 1970

	Population Density	Density of Industrial Establishments	Density of Vehicles	Rough Estimates of Smoke from Metalurgical Industry 1/	
				Particulates	Sulfur dioxide
	(hab/km^2)	(no./km^2)	(no./km^2)	(tons/day)	(tons/day)
Sao Paulo					
Sao Paulo	3991	13.56	361	41	361
Santo Andre	2634	4.91	288	7	20
Sao Bernardo	632	1.85	n.a.	5	13
Sao Caetanao	6257	31.20	841	4	10
Mogi das Cruzes	186	0.31	n.a.	3	7
Aruja	100	0.03	n.a.	0.01	0.03
Minas Gerais					
Belo Horizonte	3687	5.63	315	5	18
Juiz de Fora	167	0.49	n.a.	0.06	0.21
Gov. Valadares	66	0.11	n.a.	0.04	0.11
Pouso Alegre	71	0.41	n.a.	0.03	0.09
Itajuba	184	0.22	n.a.	0.09	0.03
Tres Coracoes	43	0.07	n.a.	0.05	0.16
Parana					
Curitiba	94	0.17	n.a.	0.78	2.22
Londrina	108	0.21	n.a.	0.06	0.16
Ponta Grossa	73	0.49	n.a.	0.17	0.49
Maringa	239	0.20	n.a.	0.01	0.03
Cianorte	68	0.13	n.a.	0.02	0.07
Toledo	33	0.05	n.a.	0.002	0.01

n.a. = not available

1/ Calculated using a fixed emission factor between value of output and emission - separately for particulates and sulfur dioxide - observed for all GSPA in 1977.

Sources: 1970 Industrial Census, [17], 1970 Demographic Census [18] and IPEA [22].

Table VII.2: GSPA: DISTRIBUTION OF AIR POLLUTION BY MUNICIPALITY
AIR POLLUTANTS (TONS/DAY) - 1977

Municipality	Particulate Matters			Sulfur Dioxide			Carbon Monoxide			Nitrogen Oxide			Hydrocarbons		
	Ind. Proc.	Fuel Comb.	Total	Ind. Proc.	Fuel Comb.	Total	Ind. Proc.	Fuel Comb.	Total	Ind. Proc.	Fuel Comb.	Total	Ind. Proc.	Fuel Comb.	Total
Sao Paulo	138	32	170	13	418	431	56	31	87	-	39	39	98	3	101
Santo Andre	26	5	31	n.a.	76	76	2	1	3	n.a.	8	8	8	1	9
Sao Bernado do Campo	25	6	31	n.a.	76	76	4	2	6	n.a.	13	13	13	1	14
Sao Caetana do Sul	34	2	36	2	53	55	1	1	2	-	6	6	1	n.a.	1
Mogi das Cruzes	19	5	24	2	65	67	25	14	39	n.a.	6	6	3	1	4
Maua	1	2	3	7	46	53	5	1	6	-	5	5	2	n.a.	2
Others	76	5	81	1	76	77	8	2	10	-	8	8	7	2	9
Total	319	57	376	25	810	835	101	52	153	n.a.	85	85	132	8	140

n.a. = not appreciable

Source: CETESB

VIII. Pollution Abatement and Industrial Location

The previous sections provided grounds for the possible differential treatment of sources under optimal anti-pollution policies. These sections also revealed that depending upon the degree of controls, there can be not only differential changes in output, but also implicit incentives for the spatial relocation of production. It was shown that the shares of two producers with production cost differentials in an industry in the same location can change as a result of optimal controls (See Annex figure 1). In the same area, optimal policy may treat various industries differently on grounds of cost of treatment differentials and demand variation. Thus, while one or more industries may be induced to displace part of its production, others may not (Annex figure 3; also IV.A.3). On welfare cost grounds alone, producers of the same industry located in different regions may face non-identical controls, which can induce relocation of some output. A more compelling reason for so doing under an optimal policy, however, was benefit differences which call for some spatial re-distribution of output (Figure IV.1).

A. Spatial Adaptation of Industrial Output

The spatial impact of policies may be brought out by considering the same industry located in two different regions (Annex figure 3). 1/ The existing distribution of output X between locations A and B - X_1 assumed to be

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1/ A similar discussion could be applied to the case of two different industries X and Y located respectively in A and B.

in A and X_2 in B - is the result of both cost and demand considerations. Pollution restrictions change production costs - possibly differentially in A and B - and, furthermore, some demand changes may follow. The net result could be a displacement of part of the existing output from one location to another. In addition, quite different incentives may be implicitly provided for the location of new potential output in A or B. The influence on new output could be further accentuated if the policy explicitly sets different restrictions on existing and new output, as will be discussed in sub-section D of this section.

In Figure VIII.1 it is assumed that only location A with output X_1 faces anti-pollution policy. This could be optimal if location B containing X_2 suffers negligible damages from smoke. As a result of the restriction, MC_1 shifts to MC_1', and output in location A falls from X_1^* to X_1' as a first-order effect. This decline in output is the normal reaction of consumers' demand to a price increase. In addition, there could be a second order effect: a change in the price of X_1 with no change in the price of X_2 can affect the market area of each. In figure VIII.1 the second-order effect of the price differential between X_1 and X_2 created by pollution control is a leftward shift in the demand for X_1 from D_{X_1} to D_{X_1}' and a rightward shift in for X_2 from D_{X_2} to D_{X_2}'. The result is a further decline in the output in location B to X_2''.

A number of factors govern the degree of the above type of relocation of production. In Figure VIII.1 the degree of differential treatment offered in locations A and B, the ability of X_1 to adapt to control (i.e. the shift of MC_1), elasticities of MC_1 and MC_2, elasticities of D_{X_1} to D'_{X_2} and the responses of D_{X_1} to change in the price differential between A and B, are all determinants of shift in output among the two locations.

1. <u>Changes in Existing Output</u>

In Figure VIII.1 output in A falls by $X_1^* X_1''$ and increases in B by $X_2^* X_2''$. Total change in output X is the sum of these changes, X_1 and X_2.

According to Figure VIII.1,

$$\frac{\Delta X}{\Delta S_1} = \left[\frac{\Delta X_1}{\Delta S_1}\right] + \left[\frac{\Delta X_2}{\Delta S_1}\right]$$

$$\frac{\Delta X}{\Delta S_1} = \left[\left\{\frac{\Delta X_1}{\Delta MC_1}\,\frac{\Delta MC_1}{\Delta S_1}\right\} + \left\{\frac{\Delta X_1}{\Delta P_1}\,\frac{\Delta P_1}{\Delta S_1}\right\}\right] + \left[\frac{\Delta X_2}{\Delta P_1}\,\frac{\Delta P_1}{\Delta S_1}\right] \qquad \text{(VIII.1)}$$

[Sum of absolute values of changes in output due to change in smoke restriction $\overline{S}_1$]	=	[First-order effect on output X_1 of a shift in MC_1 from change in $\overline{S}_1$]	+	[Second-order effect on X_1 of an increase in P_1 resulting from change in $\overline{S}_1$]	+	[Second-order effect on X_2 of an increase in P_1 resulting from change in $\overline{S}_1$]

The above equation may be approximated assuming linearity of the MC and D_X schedules in Figure VIII.1 in the range of small changes from equilibrium.

$$\frac{\bar{S}_1}{X}\frac{dX}{dS_1} = \left[\left\{\left(\frac{dX_1}{dMC_1}\frac{dMC_1}{dS_1}\right)\frac{\bar{S}_1}{X_1}\frac{X_1}{X}\right\} + \left(\frac{dX_1}{dP_1}\frac{dP_1}{dS_1}\right)\frac{\bar{S}_1 X_1}{X_1 X}\right] + \left[\left(\frac{dX_2}{dP_1}\frac{dP_1}{dS_1}\right)\frac{\bar{S}_1}{X_2}\frac{X_2}{X}\right] \quad \text{(VIII.2)}$$

From Figure VIII.2 it is seen that

$$\left(\frac{dX_1}{dMC_1}\frac{dMC_1}{dS_1}\right)\frac{\bar{S}_1}{X_1} = \frac{\eta_1 \; X_1^*/P_1^*}{(1+\eta_1/\varepsilon_1)}\frac{dMC_1}{dS_1}\frac{\bar{S}_1}{X_1}$$

$$= \frac{\eta_1}{(1+\eta_1/\varepsilon_1)}\frac{dMC_1}{dS_1}\frac{\bar{S}_1}{MC_1} \quad \text{(VIII.3)}$$

where η_1 is price elasticity of demand (absolute value) and ε_1 price elasticity of supply of X_1.

Similarly,

$$\left(\frac{dX_1}{dP_1}\frac{dP_1}{dS_1}\right)\frac{\bar{S}_1}{X_1} = \frac{\varepsilon_1}{(\eta_1 + \varepsilon_1)}\frac{d^D X_1}{dP_1}\frac{dP_1}{dS_1}\frac{\bar{S}_1}{X_1} \quad \text{(VIII.4)}$$

And

$$\left(\frac{dX_2}{dP_1}\frac{dP_1}{dS_1}\right)\frac{\bar{S}_1}{X_2} = \frac{\varepsilon_2}{(\eta_2 + \varepsilon_2)}\frac{d^D X_2}{dP_1}\frac{dP_1}{dS_1}\frac{\bar{S}_1}{X_2} \quad \text{(VIII.5)}$$

where η_2 and ϵ_2 are absolute values respectively of the demand and supply elasticities of X_2.

Substituting (VIII.3), (VIII.4) and (VIII.5) into (VIII.2)

$$\gamma = \left[\left\{ \frac{\eta_1}{(1+\eta_1/\epsilon_1)} \sigma_1 \; s_1 \right\} + \left\{ \frac{\epsilon_1}{(\eta_1 + \epsilon_1)} \beta_1 \; s_1 \right\} \right] + \left[\frac{\epsilon}{(\eta_2+\epsilon_2} \beta_2 s_2 \right] \quad \text{(VIII.6)}$$

where γ is elasticity of sums of output changes (absolute values) in A and B with respect to emission control in A, S_1; σ_1 is the elasticity of MC_1 with respect to $\overline{S}_1$; β_1; β_2 are elasticities of D_{X_1} and D_{X_2} respectively with respect to S_1; and s_1 and s_2 are respectively shares of X_1 and X_2 in X.

Example

Illustrative calculations of (VIII.6) are presented for the case of iron and cement production using the implied estimates form in Babcock's measures of emcost [5]. For the blast furnace in iron production, it is estimated that at an existing 90% control efficiency, a further 7% increase in collection, or equivalently a 60% reduction in emission results in a .05% increase in production cost. For cement production, it results in a 0.2% increase production cost. Rough estimates of (% MC ÷ % S) for iron and cement production are, respectively, 0.001 and 0.003. If η = 1 and

$\varepsilon = 2$, the first order effect of a 1% change in $\overline{S}$ of output in A is a decline of about 0.001% of iron and 0.002% of cement production. Equivalently, it means that for a 1% increase in control efficiency at an existing 90%, respectively, a 0.02% fall in output and cement output in A is indicated. If A comprises 2/3 of total output in each case, these latter figures mean a 0.006% and 0.01% fall in total output. At one extreme, if no second-order effects are assumed to exist, these figures represent all output changes. If, at another extreme, the entire fall in A's output is assumed to be absorbed by B, the latter's output increases by 0.02% and 0.04% for the cases of iron and cement respectively. To obtain the full output change from pollution control, perhaps 95% smoke removal, an integral of output effects at various efficiencies (low at low efficiencies, rising increasingly at higher efficiencies) will need to be calculated.

2. Effect on Potential New Output

The previous sub-section discussed relocation caused by regulation of existing output. In addition, decisions of potential new entrants can also be affected. In particular, if potential new sources face stricter regulation than existing regulation in location A, incentives to locate in B rather than A are strengthened. Various other possibilities need to be considered depending upon the differential treatment of existing and new sources in A and B. Some of these will be examined in VIII.D.

B. Net Benefit from Spatial Adaptation

As long as locational variations exist in benefits and/or costs from smoke reduction, optimal anti-pollution policy is likely to be non-uniform, thus presumably inducing some spatial adaptation on the part of producers. Non-optimal policies that are non-uniform, can also induce the relocation of production. Spatial adaptation on the part of industries can potentially be beneficial but there is an assumption that even with such inducements, or partly because of them, non-optimal policies may not necessarily provide net social benefits. Under optimal policy, on the other hand, spatial adaptation which reduces the welfare cost of controls can raise overall net benefits.

In Figure IV.1, as a result of smoke reduction to $\bar{S}_A$ (which corresponds to an output of X) ajdea of damages are reduced at a cost of bjdhb, thus implying net benefits of abhea. Allowing for a decline in output from X* to X´, an additional net savings (i.e. net benefits) of cdh is achieved. cdh, the addition to benefits from an output adjustment, may be approximated by $(1/2\,\Delta X_1\,\Delta MC_1)$ where $\Delta X_1 = X_1' X_1^*$ and $\Delta MC_1 = hd = \int_{\bar{S}_1}^{S_1} \frac{dMC_1}{dS_1}\, dS$.

At X´, total benefits of the policy are ajdea, and total cost bjdcb, giving net benefits of abcdea. Of the total cost of bjdcb, bjicb is the cost incurred on pollution control while producing X´, and cid is the gross cost due to the fall in output from X* to X´. Part of cid could be recovered if some of X´X* were produced elsewhere to meet the demand of consumers in location A indicated by D_{X_1}. This is assumed to be the case in Figure VIII.1 where an option for consumers in location A to buy from B is allowed for. Whether and how much consumers in A will choose to switch, depends on the price-inclusive of transport cost, at which they can receive output from B. In Figure VII.1, it assumed for simplicity that at the initial equilibrium with $P^*_1 = P^*_2$, each location is self-sufficient. With controls, P^*_1 rises to P'_1 , and as long as $P'_1 > P^*_2 + t$, where t is the unit transport cost between e and B, some of the existing consumers in A will buy from B. ΔX_1 is the fall in output in A, and X_2 the increase in output in B or the part of previous consumption in A that is bought from B. By switching part of consumption from a presently high cost area A, to a low cost area B, society would save approximately $\Delta MC \cdot \Delta X_2$, if t were zero. Including the transport cost, $\Delta X_2(\Delta MC_1 - t)$ is the approximate saving. Total saving from spatial adaptation W is:

$$W = \frac{1}{2}(\Delta X_1 \Delta MC_1) + \Delta X_2 \cdot (\Delta MC_1 - t) \quad \text{(VIII.7)}$$

$$\begin{bmatrix}\text{Saving}\\ \text{from}\\ \text{spatial}\\ \text{adapta-}\\ \text{tion}\end{bmatrix} = \begin{bmatrix}\text{Saving in industry's}\\ \text{pollution control}\\ \text{cost due to a re-}\\ \text{duction in output in}\\ \text{location A}\end{bmatrix} + \begin{bmatrix}\text{Benefit to consumers}\\ \text{from buying from B part}\\ \text{of the lost output in A}\\ \\ \end{bmatrix}$$

Equation (VIII.7) assumes that all costs of relocation are reflected by MC_2 in Annex Figure 5 and that no negative externalities other than pollution are relevant. In reality, many other considerations, economic and political, are important in evaluating the benefits from spatial shifts induced by policy. The employment effect is perhaps the most serious consideration. Whether net benefits accrue depend on how such considerations affect the savings noted above from spatial adaptation.

C. Pollution Reduction from Control of Output

Direct restrictions are often placed on industrial location in certain areas which directly lower pollution. 1/ This indirect effect may be part of an overall pollution abatement strategy. Sometimes, the air quality impact may be an unintended effect of an industrial location policy guided by other considerations.

A given air quality objective in an area can obviously be met by setting direct controls on allowable emissions by industry or by controlling the volume of industrial output in that area. The welfare cost of these two approaches, however, is quite different. The regulation of output, an indirect means to regulate emission, is more costly than directly restricting emission (see Section IV). The costs of these alternative means, however, would not be much different if few possibilities existed in substituting pollutant fuels and using control equipment. In such a case, the only way to lower smoke would be in fact to cut down on production. There may also be circumstances where consequences of further deterioration in air quality are prohibitive. In such cases, rather than placing ridiculously high emission restrictions, it may for practical reasons, be easier to prohibit addition to output.

The cost differences between a direct emission restriction and an output restriction may be identified in Figure IV.1. Emission reduction to

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1/ Zoning and licensing policies for industries in Sao Paulo belong to this category. See [8], [12], [32].

S_A in location A can be achieved by setting a standard $\overline{S}_A$; alternatively, output in A may be restricted to a maximum of $\overline{X}$. The additional welfare cost of the latter approach is given by ibc.

D. Spatial Effects of Alternative Policies

A uniform smoke regulation may have little spatial impact, while a spatially selective approach might induce the displacement a significant part of output from one place to another. Where the intent of policy is solely to limit discharges into the air, the resultant transfer of output may be an unintended effect. On the other hand, limiting industrial concentration may be a goal in itself while the control of pollution thus achieved may be a side effect.

Chart VIII.1 sets out the likely spatial effects-intended or unintended of some approaches to emission control. The directions of change under alternative policies are indicated, while the degree of change would clearly depend upon the intensity of controls and its differential between locations. Not shown in the chart is the policy with the most likely spatial effect - i.e. limiting output itself in certain regions.

Three policies are considered: (i) an optimal policy, Policy I, which sets maximum allowable emissions according to the net benefits of so doing in various places; (ii) a Policy II, which requires a uniform percentage abatement on the part of pollution sources irrespective of their location, and (iii) a Policy III, which sets the same maximum allowable emission in all places, thus spatially equating the level of discharges. In the particular example considered in Chart I, location A is assumed to contain large producers, and B relatively smaller ones. Compared to B, A faces greater incremental damages from pollution, since it is more polluted and also more densely populated. The possible spatial effects of applying each of the three above policies to this situation are shown. Given the relative seriousness of the pollution problem in A, it is also worth considering the possibility under each of policies I, II, III that the existing policy is only concerned with location A, while B is free to pollute. Furthermore, often for administrative, political and sometimes economic reasons, potentially new entrants are the targets of more stringent policies. Hence, Chart I also distinguishes possible differential stringency for existing and new sources under each of the policies.

In general, the least spatial shifts are induced by a uniform abatement policy (II). If new sources are singled out in anti-pollution policy, or if they face significantly stricter restrictions, the existing locational pattern between A and B tends to be frozen. If producers in A alone face restriction, however, relocation in B is encouraged. In the present example, an optimal policy (I) would normally require more abatement in A, thereby encouraging both some displacement of existing output from A to B, and inducing new entrants into B. An extreme, but realistic possibility, is that an optimal policy concerns itself with only A, which may be a highly built-up urban center, and sets no control in B, which could represent a highly rural situation. Under an optimal policy, new entrants would bear a heavier burden of cleaning up the air only if their control costs (economically as well as administratively) are less than existing ones. A uniform maximum emission policy, (III), requires relatively more smoke collection from larger polluters who are assumed to be located in A. Such an approach would be more stringent for A and may thus displace more output from A to B compared to the optimal policy, II, if pollution levels in A and B differ widely. The reason that this is likely is that as abatement is increased in A, incremental costs rise faster relative to incremental benefits, such that maximum allowable emission in A may stop short of equalling that in B under an optimal policy (II). A mitigating possibility is that if economies of scale in pollution control are significant, II and III may be close to each other in their effects. If new entrants are discriminated against under III, the effect would generally be felt much more by potentially larger producers in A and B. If the regulation applies only to A, the likely shift to B is increased.

In most instances, regulations are uniform across space, as, for example, in the case of "process weight" standards in the US. New sources often (for example, in the US) face stricter standards which are also spatially uniform. As a result, incentives for the relocation of output by industries are kept low, as discussed above (See Chart 2-11.a). 1/ In Brazil, federal legislation seeks uniform air quality targets everywhere. If this were to be met in practice, inducement for relocation of output would be very great indeed (Chart 3-III.a). In reality, however, uniform abatement rather than uniform standards are enforced. Besides, most efforts are devoted to limiting pollution by new sources. This would have implied very little spatial adjustment of output, if it applied to all places. In reality,

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1/ Pollution regulations in the US are complex, however, and not easy to characterize in these terms. See [6], [30]. Although, basically a uniform approach as a first cut at reducing air quality problems has been applied, the "optimal" approach in problem areas as a final step in cleaning up remaining problems is being instituted.

however, anti-pollution measures are effective only in certain areas, most importantly in the GSPA. As a result, implicit emphasis is contained in the strategy to induce some output away from these places. Within metropolitan Sao Paulo, licensing policies further contribute to this effect.

E. Conclusion

Through its effect on production cost, pollution regulation affects industrial output. When production cost is differentially affected across locations, changes in the spatial distribution of output can take place. Optimal policy would be non-uniform across locations, if net benefits of abatement are spatially non-uniform. Variations in geographic production patterns brought about by such a policy are socially beneficial.

The spatial effect on industrial output is more direct when pollution restriction is attempted through industrial zoning and licensing. In general, the social cost of affecting industrial output directly would not be justified on pollution grounds alone, except, perhaps, when any addition to pollution in an area is prohibitive. Furthermore, other goals are also sought to be met by direct industrial location regulation.

If a uniform abatement policy is expected to evolve across the country over time, little effect on industrial location would result. If, at the other extreme, it is perceived that uniform air quality is sought to be spatially achieved, substantial locational changes would result. An optimal approach would seem to lie somewhere in between for the foreseeable future. Some non-uniformity in abatement with some spatial differences in air quality persisting would be expected, thus inducing changes in industrial location away from the highly damaged areas.

A recent paper [40] relates anti-pollution policies to changes in industrial location in the GSPA. Based on industrial location surveys, it is indicated that "...a fairly strict and comprehensive industrial pollution policy may be expected to have fairly immediate spatial consequences on the geographic pattern of industrial growth....."

FIGURE VIII.1

SPATIAL EFFECT OF DIFFERENTIAL CONTROLS FOR THE SAME INDUSTRY IN TWO LOCATIONS

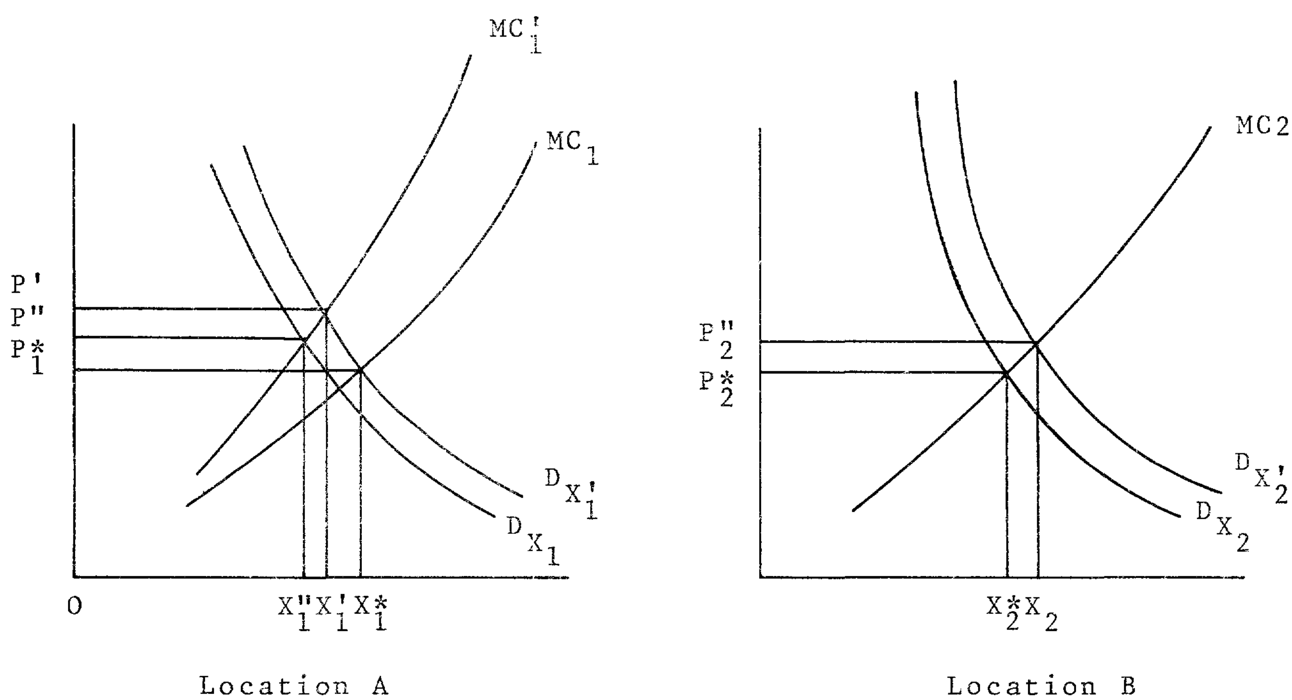


Chart VIII.1: Likely Effects of Pollution Control on Industrial Location*

Type of Policy	1. Existing Sources Only	2. New Sources Only	3. Existing and New Sources Alike
I "Optimal" Policy			
a. More abatement	Not applicable unless new sources face distintly higher abatement costs than existing ones	Not applicable, unless new sources face distinctly lower abatement costs and existing pollution does not warrant controls	On pollution grounds alone, the effect is to encourage relocation of part of existing output from A to B; new entrants encouraged to locate in B
b. Special Case-Control in A only	See 1-Ia	See 2-Ia	Relatively more shift to B encouraged than in 3-I(a) above.
II. Uniform % Abatement			
a. In A and B alike	Incentive to relocate part of existing output in either place. New entrants indifferent	Relocation discouraged in A and B. New entrants indifferent Special Case: Stricter policy for new sources, as in the US giving similar result.	No incentive to relocate particularly on the part of larger producers (i.e. in A) if there are economies of scale in abatement. New entrants indifferent.
b. In A only	Incentive to relocate in B. New entrants indifferent.	Relocation discouraged in A. New entrants encouraged to locate in B. A variant of the special case under 2-IIa with quite different results. likely situation in **Brazil.**	Relocation from A to B induced, but less from larger producers if they enjoy scale economics. New entrants favor B on pollution grounds.
III. Equal Max. Allowable Emission			
a. In A and B alike	Incentive to relocate in either place,but more so from A to B. New entrants indifferent.	Relocation discouraged in A and B. Smaller new entrants encouraged in A and B.	Incentive to relocate part of output from A to B,unless there exist strong economies of scale in pollution control. Smaller new entrants encouraged in A and B.
b. In A only	Incentive to relocate in B, particularly for larger producers. New entrants indifferent.	Relocation discouraged in A. New entrants, particularly the larger ones encouraged to locate in B.	Incentive to locate in B

*Assumptions: Location A is highly polluted, densely populated and contains larger producers on the average of industry A. Location B is mildly polluted, thinly populated and contains smaller producers on the average of industry Y. The two industries face identical pollution control cost schedules. X and Y are the primary polluters in locations A and B respectively.

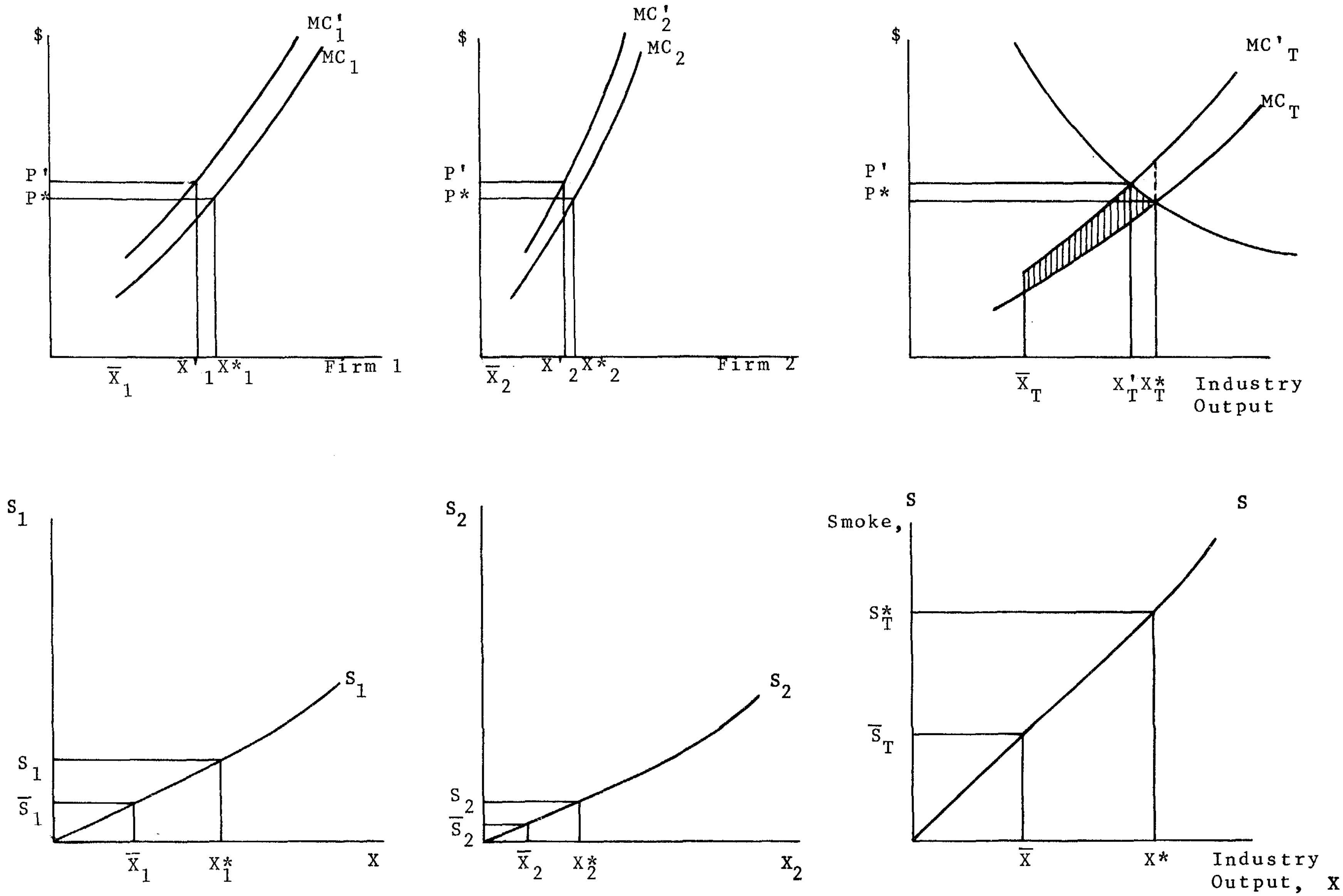
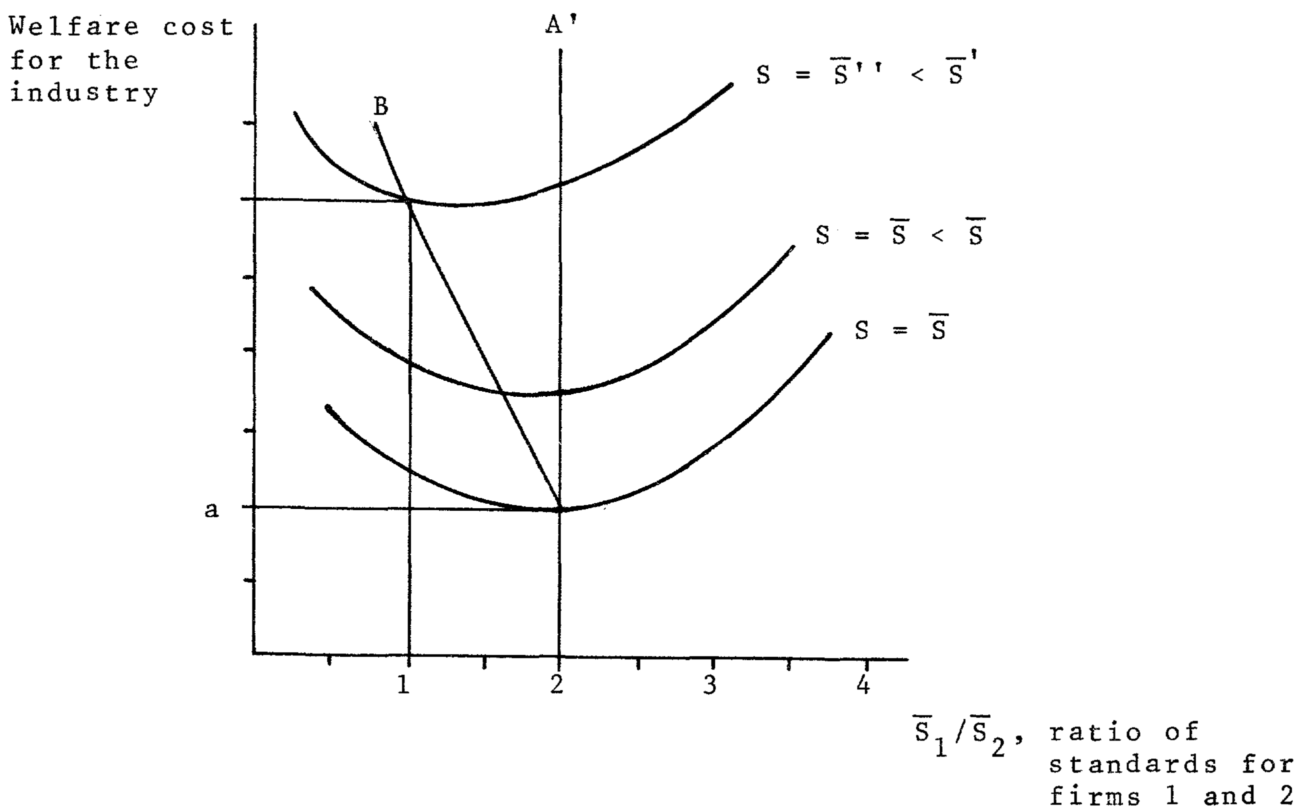


FIGURE 1

WELFARE COST OF POLLUTION CONTROL FOR TWO FIRMS CONSTITUTING AN INDUSTRY

FIGURE 2

WELFARE COST OF ALTERNATIVE DISTRIBUTION OF CONTROLS AMONG DIFFERENT SIZED PRODUCERS



ANNEX

FIGURE 3

WELFARE COST OF POLLUTION CONTROL FOR TWO INDUSTRIES

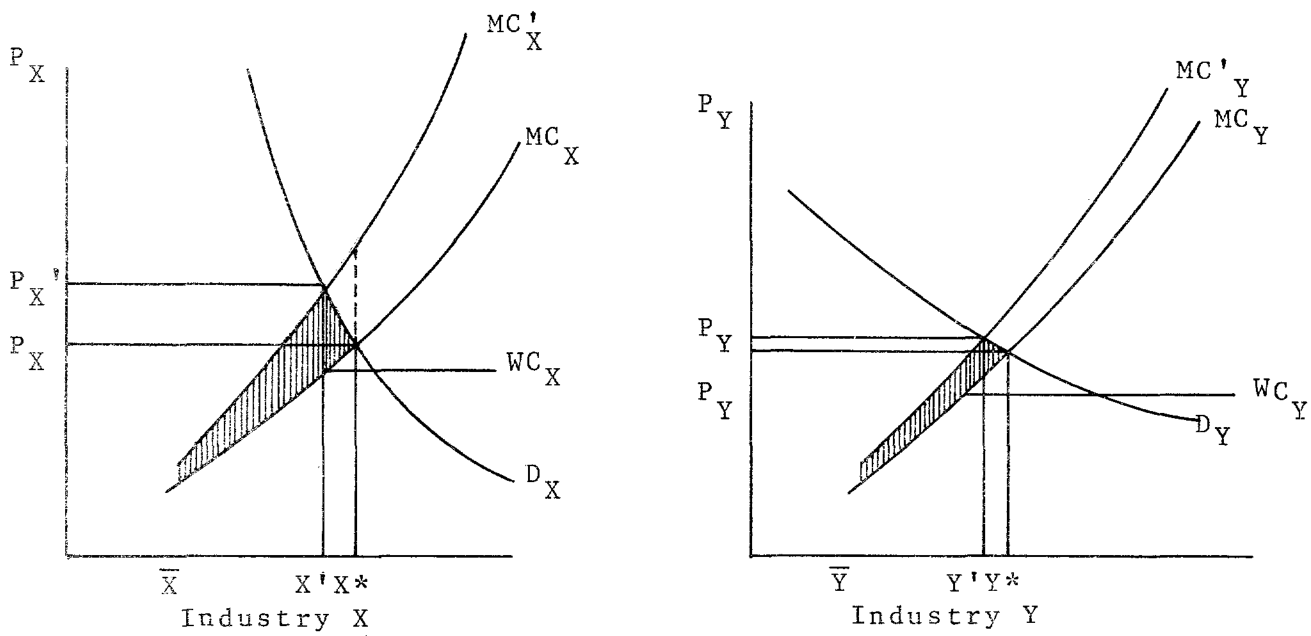


Table 1: CONTROL COST FOR INDUSTRIES CONTRIBUTING 97 PERCENT OF PARTICULATE EMISSIONS IN THE GSPA - (1000 CR$)

	No. of Industries /d	Emissions (T/Yr)	Control Efficiency	CONTROL COSTS - 1970 ESTIMATES						TOTAL COST 1980/81 Estimate
				CAPITAL COSTS		INSTALLATION COST		TOTAL COST		
				Total	Per Ton	Total	Per Ton	Total	Per Ton	
I. Non-Metallic /a	110	107,015	NA	NA	NA	NA	NA	443,870	4.15	1,194,600
- Average		973	NA	NA	NA	NA	NA	4,035	4.15	10,860
Top 90% /b	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 /c		9,600	NA	10,000	1.04	10,000	1.04	20,000	2.08	54,000
- Low /c		400	NA	2,600	6.50	1,600	4.00	4,200	10.50	11,300
II. Chemicals /a	20	16,030	NA	NA	NA	NA	NA	122,190	7.62	328,900
- Average	-	802	NA	NA	NA	NA	NA	6,110	7.62	16,445
Top 90% /b	6	15,360	80%	43,200	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 /c		3,300	NA	6,550	1.98	5,200	1.59	11,800	3.57	31,760
- Low /c		980	NA	6,550	6.68	3,950	4.03	10,500	10.71	28,300
III. Metallurgic /a	115	17,110	NA	NA	NA	NA	NA	397,270	23.22	1,069,170
- Average		110	NA	NA	NA	NA	NA	2,563	23.22	6,898
Top 90% /c	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 /c		2,200	NA	10,700	4.86	10,700	4.86	21,400	9.72	57,590
- Low /c		430	NA	3,000	6.98	2,000	4.65	5,000	11.63	13,460
IV. All Industries	285	140,155	NA	NA	NA	NA	NA	964,330	6.88	2,592,670
- Average		492	NA	NA	NA	NA	NA	3,384	6.88	9,097
Top 90%	53	101,690	94%	222,010	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	22,880

\- Not relevant or not available

/a, /b - Biggest polluters contributing about 97% and 90% respectively of particulates

/c - High and low, excluding extremes

/d - Particulates involve a total of about 1,150 enterprises

SOURCE: World Bank Mission estimates and CETESB.

Table 2 Average Size of Industrial Polluters[1/]

(1000 cruzeiros)

	Metallurgical	Non-Metallic Minerals	Chemicals
State of São Paulo	1629	368	5935
GSPA	1746	630	5564
SP Municipio	1364	943	2802
S. André	4105	382	32649
S. Bernardo	5574	979	7678
S. Caetano	4314	4184	10360
Mogi das Cruzes	9360	313	3353
Arujá	248	97	798
Minas Gerais	3207	205	3182
Belo Horizonte	1769	167	555
Juiz de Fora	111	116	520
Governador Val.	179	71	10
Itajubá	172	30	-
Pouso Alegre	117	8	-
Três Corações	1159	6	-
Parana	302	128	4346
Curitiba	470	136	2114
Londrina	146	101	9353
Maringá	298	62	14554
Ponta Grossa	557	204	1323
Cianorte	582	14	-
Toledo	72	80	-

- nil

1/ Value of production ÷ no. establishments
Source: 1970 Industrial Census

Table 3: STATE OF SAO PAULO: MAIN INDUSTRIAL AIR POLLUTERS - 1970

No. Employees	METALLURGICAL No. of Establishment	Percent	Value of Production	Percent	NON- METALLIC MINERALS No. of Establishment	Percent	Value of Production	Percent	CHEMICALS No. of Establishment	Percent	Value of Production	Percent
Undeclared	7	0.3	3,142	0.1	3	0.1	3,142	0.1	8	0.9	22,046	0.3
1 - 4	95	3.4	6,675	0.2	29	1.1	5,675	0.2	87	9.9	28,746	0.5
5 - 9	857	30.6	74,647	3.2	1,332	50.0	74,647	3.2	188	21.5	122,612	2.0
10 - 19	689	24.6	119,772	5.0	588	22.1	119,772	5.1	198	23.0	297,165	4.7
20 - 49	606	21.6	284,888	12.0	428	16.1	284,888	12.0	189	21.6	708,976	11.2
50 - 99	261	9.3	217,583	9.2	139	5.2	217,383	9.2	98	11.2	950,653	15.0
100 - 249	176	6.3	450,000	19.0	91	3.4	450,000	19.0	73	8.3	1,492,558	23.9
250 - 499	71	2.5	404,638	17.1	29	1.1	404,638	17.1	21	2.4	648,476	10.2
500 +	40	1.4	806,778	4.1	25	0.9	806,778	34.1	14	1.6	2,064,808	32.6
TOTAL	2,802	100.0	2,366,923	100.0	2,664	100.0	2,366,923	100.0	876	100.0	6,336,041	100.0

SOURCE: 1970 Industrial Census

Table 4: STATE OF MINAS GERAIS: MAIN INDUSTRIAL AIR POLLUTERS - 1970

	METALLURGICAL				NON-METALLIC MINERALS				CHEMICALS			
No. Employees	No. of Establishment	Percent	Value of Production	Percent	No. of Establishment	Percent	Value of Production	Percent	No. of Establishment	Percent	Value of Production	Percent
Undeclared	1	0.2	(x)	-	-	-	-	-	-	-	-	-
1 - 4	4	0.9	(x)	-	10	1.3	2,215	0.4	7	7.1	24	0.7
5 - 9	168	37.1	22,982	0.9	429	57.0	19,177	3.4	29	29.6	198	5.7
10 - 19	84	18.5	26,895	0.9	154	20.5	23,041	4.1	28	28.6	408	11.7
20 - 49	72	15.9	59,819	1.9	107	14.2	55,944	9.9	23	23.5	665	19.1
50 - 99	55	12.1	140,391	4.5	27	3.6	30,483	5.4	7	7.1	524	15.0
100 - 249	44	9.7	406,025	13.1	15	2.0	110,143	19.4	1	1.0	(x)	-
250 - 499	13	2.9	798,279	25.7	6	1.0	65,947	11.6	1	1.0	(x)	-
500 +	12	2.7	1,644,772	53.0	5	0.7	260,240	45.9	2	2.0	(x)	-
TOTAL	453	100.0	3,105,269	100.0	753	100.0	567,190	100.0	98	100.0	3,489	100.0

SOURCE: 1970 Industrial Census

Table 5: STATE OF PARANA: MAIN INDUSTRIAL AIR POLLUTERS - 1970

	METALLURGICAL				NON-METALLIC MINERAL				CHEMICAL			
No. of Employees	No. of Establishment	Percent	Value of Production	Percent	No. of Establishment	Percent	Value of Production	Percent	No. of Establishment	Percent	Value of Production	Percent
Undeclared	1	0.5	(x)		1	0.2	(x)	-	-		-	
1 - 4	4	2.1	(x)		5	0.9	(x)		5	6.6	16,006	
5 - 9	96	51.3	11,716	10.9	279	52.9	13,452	7.9	11	14.5	(x)	
10 - 19	48	25.7	10,488	9.8	138	26.2	21,089	12.3	21	27.6	28,600	6.7
20 - 49	21	11.2	14,334	13.4	79	15.0	29,611	17.3	20	26.3	75,594	17.8
50 - 99	10	5.3	21,695	20.2	16	3.0	12,608	7.4	11	14.5	109,152	25.7
100 - 249	6	3.2	36,863	34.4	6	1.1	(x)		4	5.3	62,569	14.7
250 - 499	1	0.5	(x)		-		-		3	3.9	114,303	26.9
500 +	-		-		3	0.6	81,391	47.6	1	1.3	(x)	
TOTAL	187	100.0	107,292	100.0	527	100.0	171,041	100.0	76	100.0	425,061	100.0

SOURCE: 1970 Industrial Census

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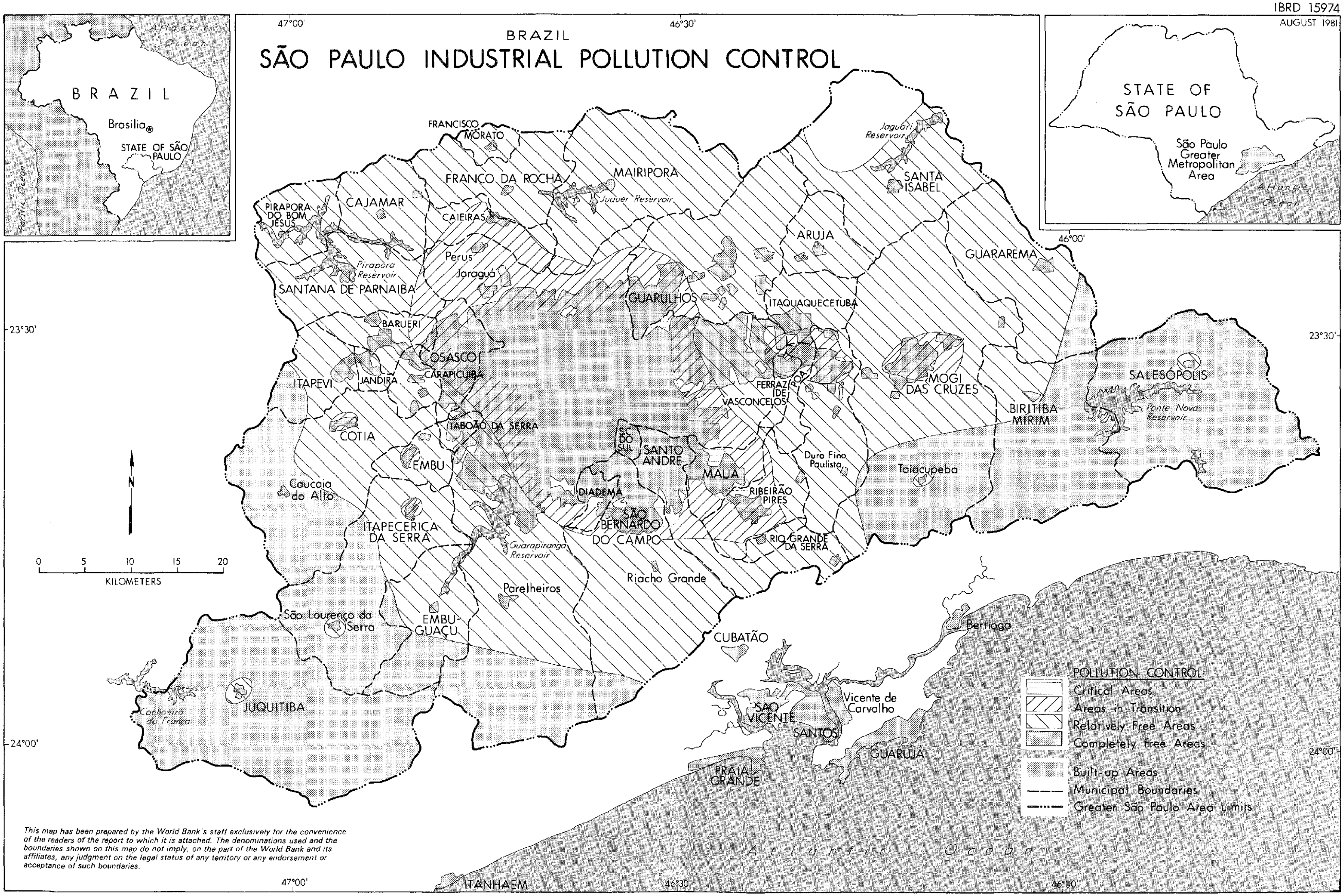

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STATE OF SÃO PAULO
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STATE OF SÃO PAULO
São Paulo Greater Metropolitan Area
47°00'
46°30'
46°00'
23°30'
24°00'
FRANCISCO MORATO
FRANCO DA ROCHA
MAIRIPORA
Juquer Reservoir
Jaguari Reservoir
SANTA ISABEL
PIRAPORA DO BOM JESUS
CAJAMAR
CAIEIRAS
Perus
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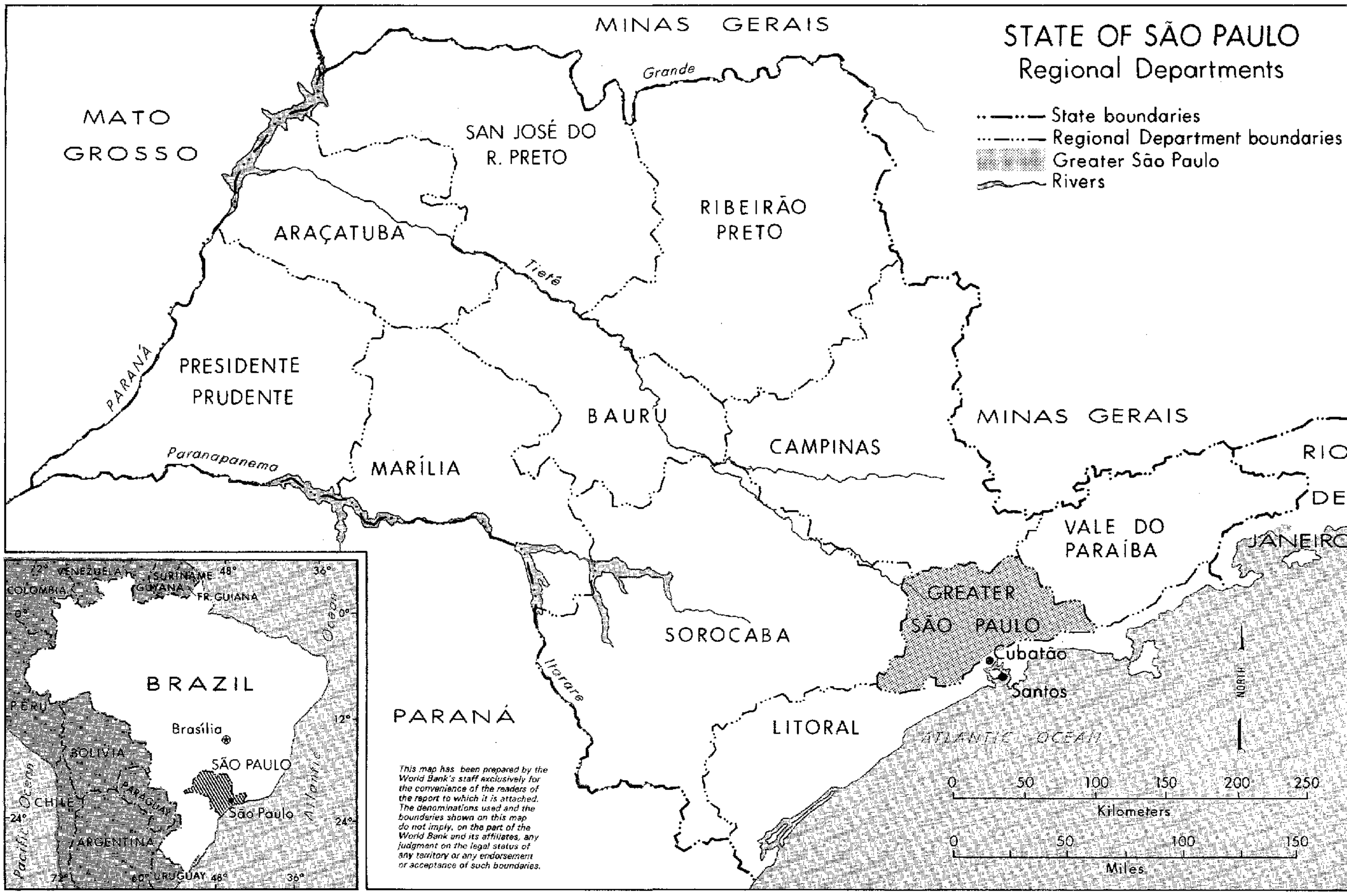
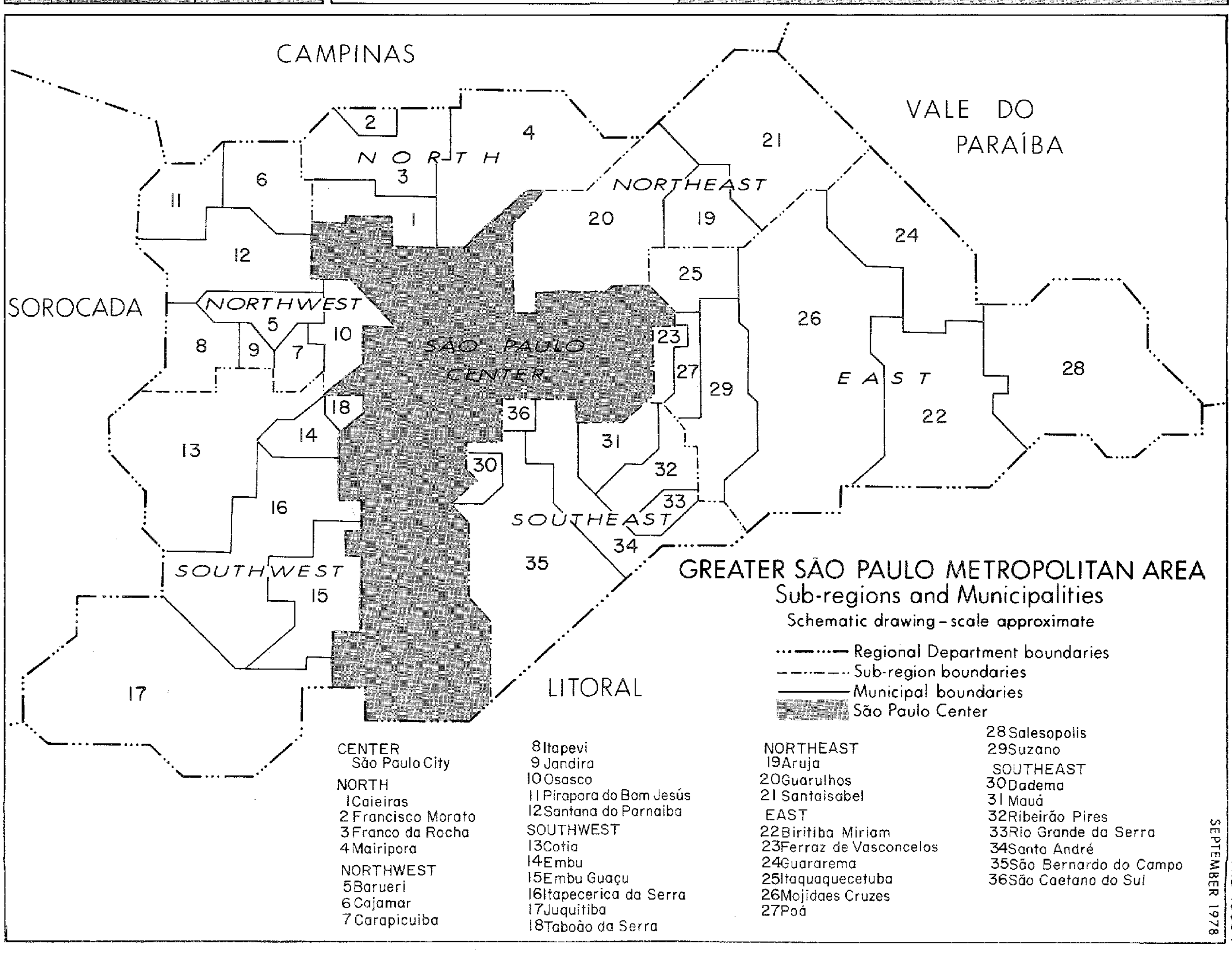
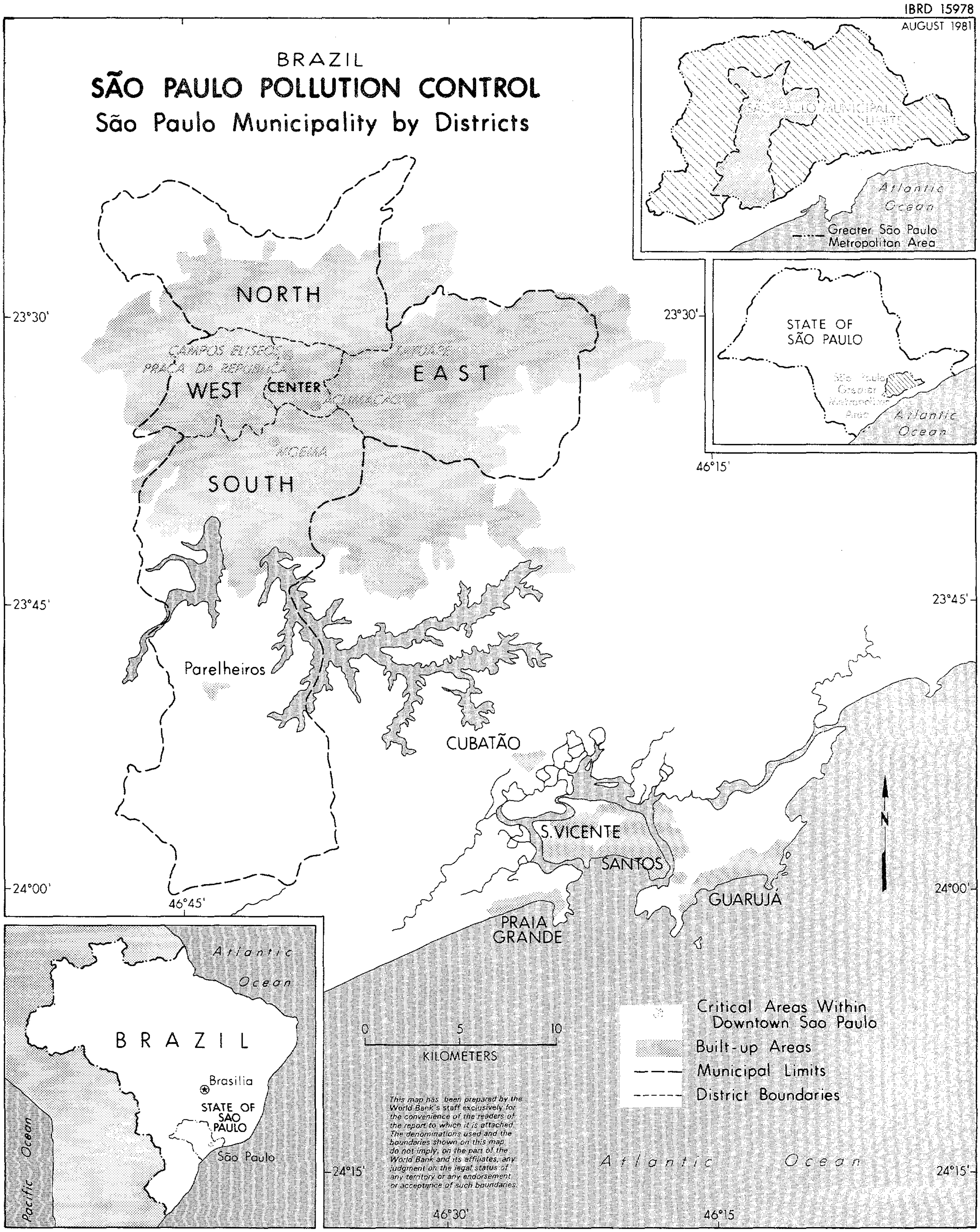
GUARULHOS
ITAQUAQUECETUBA
BARUERI
OSASCO
CARAPICUIBA
JANDIRA
ITAPEVI
COTIA
TABOÃO DA SERRA
EMBU
Caucaia do Alto
FERRAZ DE VASCONCELOS
POÁ
MOGI DAS CRUZES
BIRITIBA-MIRIM
SALESÓPOLIS
Ponte Nova Reservoir
S.C. DO SUL
SANTO ANDRE
MAUA
Duro Fino Paulista
Taiacupeba
DIADEMA
RIBEIRÃO PIRES
SÃO BERNARDO DO CAMPO
RIO GRANDE DA SERRA
ITAPECERICA DA SERRA
Guarapiranga Reservoir
Riacho Grande
Parelheiros
0 5 10 15 20
KILOMETERS
São Lourenço da Serra
EMBU-GUAÇU
CUBATÃO
Bertioga
Cachoeira da Franca
JUQUITIBA
SÃO VICENTE
SANTOS
Vicente de Carvalho
GUARUJÁ
PRAIA GRANDE
ITANHAEM
Atlantic Ocean
POLLUTION CONTROL:
Critical Areas
Areas in Transition
Relatively Free Areas
Completely Free Areas
Built-up Areas
Municipal Boundaries
Greater São Paulo Area Limits
This map has been prepared by the World Bank's staff exclusively for the convenience of the readers of the report to which it is attached. The denominations used and the boundaries shown on this map do not imply, on the part of the World Bank and its affiliates, any judgment on the legal status of any territory or any endorsement or acceptance of such boundaries.

BRAZIL
SÃO PAULO INDUSTRIAL POLLUTION CONTROL PROJECT
Greater São Paulo Metropolitan Area





IBRD 13884
SEPTEMBER 1978


IBRD 15978
AUGUST 1981
BRAZIL
SÃO PAULO POLLUTION CONTROL
São Paulo Municipality by Districts
NORTH
EAST
WEST
CENTER
SOUTH
CAMPOS ELISEOS
PRAÇA DA REPUBLICA
Parelheiros
CUBATÃO
S. VICENTE
SANTOS
GUARUJÁ
PRAIA GRANDE
23°30'
23°45'
24°00'
24°15'
46°45'
46°30'
46°15'
Atlantic Ocean
Greater São Paulo Metropolitan Area
STATE OF SÃO PAULO
BRAZIL
Brasilia
STATE OF SAO PAULO
São Paulo
Pacific Ocean
0 5 10
KILOMETERS
Critical Areas Within Downtown Sao Paulo
Built-up Areas
Municipal Limits
District Boundaries
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PUB HG3881.5.W57 W67 no.501
Thomas, Vinod.
Pollution control in Sao
Paulo, Brazil : costs,
benefits and