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Efficient Environmental Regulation

Case Studies of Urban Air Pollution
Los Angeles, Mexico City, Cubatao, and Ankara

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and
Sudhir Shetty

Once decisions are made — to concentrate industry, to rely on private vehicles for transportation, to subsidize a particular energy source, or to use a certain environmental policy — they acquire a certain permanence. For this reason, it is important to design policy with an eye toward longer-run concerns. In addressing urban air pollution cost-effectively, it is also important not to wait until the problem assumes crisis proportions. By closing options, delays in implementing corrective measures will raise the eventual cost of environmental protection.

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World Development Report

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This paper — a product of the Office of the Vice President, Development Economics — was prepared as a background paper for the *World Development Report 1992* on the environment. Copies of this paper are available free from the World Bank, 1818 H Street NW, Washington DC 20433. Please contact the World Development Report Office, room T7-101, extension 31393 (August 1992, 56 pages).

Levinson and Shetty review the economic principles that should guide the efficient choice of targeted policies for environmental protection. They recommend policy instruments along three dimensions: (1) whether they use economic incentives, (2) whether they target environmental damage directly, and (3) whether they specify prices, quantities, or technologies. This distinction is helpful in guiding policy choices because many discussions in the economics literature on environmental policies mistakenly claim advantages for incentive-based instruments by showing, for instance, that direct policies of this sort are less costly than indirect non-incentive measures.

After analyzing efficient responses to the air pollution problem, Levinson and Shetty come up with somewhat surprising results. For three of the cities (Ankara, Los Angeles, and Mexico City), the efficient instruments selected by this (admittedly limited) exercise are similar: indirect incentive-based policies. Only Cubatao differs in that direct non-incentive regulations are the efficient policy choice.

But choosing indirect policy instruments is not without its problems. This category is the broadest one. For instnace, while there is only a single direct incentive-based price instrument (emissions taxes), several indirect incentive-based price policies exist including taxes on inputs and on complementary and substitute products. Indirect policies also cannot simultaneously target the incentives to reduce waste generation, increase production efficiency, and reduce output to reduce pollution. A combination of indirect policies will then be required to control pollution. But if the regulatory costs of controlling additional variables are high they may outweigh the cost of monitoring and enforcing a single direct policy. Finally, indirect regulations may be accompanied by perverse incentives, such as new source bias or reduced marginal costs of polluting. Efforts to offset these perverse incentives by regulating additional variables may be subject to second-best problems: two regulations with opposite results can be costlier than no regulation at all.

The main lesson Levinson and Shetty draw from the cases examined: Once decisions are made — whether to concentrate industry, to rely on private vehicles for transportation, to subsidize a particular energy source, or to use a certain environmental policy — they acquire a certain permanence. Capital is invested and workers are trained under the prevailing laws, and these are costly to change. Los Angeles cannot reverse its emphasis on the automobile; Brazil cannot easily move its industrial center away from Cubatao; Mexico cannot quicky reduce the concentration in its capital city; and Turkey's development would suffer if energy subsidies were removed abruptly.

For this reason, it is important to design policy with an eye toward longer-run concerns. It makes sense, for example, for cities such as Ankara to begin to enact policies to prevent mobile source air pollution from worsening over the next decades.

Levinson and Shetty also point out the dangers of ignoring intermedia substitution of pollutants. In places such as Cubatao, where air quality has been cleaned up, the improvement may have come at the expense of water quality or the accumulation of hazardous wastes.

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Acronyms and Abbreviations

CAFE	Corporate average fuel economy
CARB	California Air Resources Board
CBO	Congressional Budget Office
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act ("Superfund")
CETESB	Sao Paulo Company of Technology for Basic Sanitation and Water Pollution Control
CFCs	Chlorofluorocarbons
CNG	Compressed natural gas
CO	Carbon monoxide
DF	Federal District of Mexico City Metropolitan Area
EC	European Community
EPFT	Environmental Problems Foundation of Turkey
EPA	Environmental Protection Agency
GDP	Gross Domestic Product
HC	Hydrocarbons
HNC	Hoy no Circula ("Day without a Car")
IUAPPA	International Union of Air Pollution Prevention Associations
I/M	Inspection and maintenance
JICA	Japan International Cooperative Agency
LGEEPA	General Law on Ecological Balance and the Protection of the Environment (of Mexico)
LPG	Liquified petroleum gas
MAC	Marginal abatement cost
MCMA	Mexico City Metropolitan Area
MEB	Marginal environmental benefit
μg	Micrograms
mpg	Miles per gallon
NO_x	Nitrogen oxides
NYT	New York Times
OECD	Organization for Economic Cooperation and Development
OED	Operations Evaluation Department, World Bank
Pb	Lead
ppm	Parts per million
RCRA	Resource Conservation and Recovery Act
SCAQMD	South Coast Air Quality Management District
SEDUE	Secretariat for Urban Development and Ecology (of Mexico)
SEMA	Special Secretariat of the Environment (of Mexico)
SO_x	Sulfur dioxide
tpd	Tons per day
TSP	Total suspended particulates
VMT	Vehicle miles travelled
VOC	Volatile organic compounds (non-methane hydrocarbons)
WHO	World Health Organization

I. INTRODUCTION

This paper asks the question: what choice of environmental policies is efficient, and how does that choice vary by pollutant, resource, country, or source?

"Environmental problems" refer to pollution and natural resource depletion caused directly or indirectly by human activity. These problems involve air and water pollution, solid waste, and the overuse of renewable and exhaustible resources. To correct environmental problems, governments have a wide choice of policy instruments. A considerable literature has been devoted to analyzing different types of instruments. Three common distinctions between instruments are: (1) whether the instrument relies on economic incentives by somehow pricing incremental units of pollution or resource depletion; (2) whether the instrument targets the environmental damage directly, or indirectly via some proxy; and (3) whether the instrument regulates prices, quantities, or technologies.

The goal of the first part of this paper is to review the economic principles on which policy choices should be based, and to consider how they might be applied in the real world. The second part of the paper examines four cities that continue to face serious air pollution problems. The cities chosen differ in ways that illustrate the economic principles that should guide efficient policy choice.

II. FRAMING THE PROBLEM

Environmental problems

Environmental regulators face two broad classes of environmental problems. The first is the misuse of natural resources. Naturally-occurring products of the environment that cannot themselves be manufactured, natural resources are inputs to the production process. Market equilibria with natural resources generally involve above-optimal or sooner-than-optimal use of the resource. In theory, if property rights could be assigned definitively and traded costlessly, overuse would not be a problem.[1] Usually neither is possible, and the subsequent lack of property rights results in open access to some resources and a consequent lack of consideration for future generations.

Whether renewable or exhaustible, natural resources are susceptible to overdevelopment. For renewable resources, optimal development would maintain some sustainable rate. For exhaustible resources with constant extraction costs, extraction should occur such that the price of the resource rises at the social discount rate.[2] For many reasons, real resource prices do not follow this pattern. Given imperfect capital markets, administered prices, non-infinite horizons, soft budget constraints, or capital market interest rates that differ from the social discount rate, the market allocation will not be optimal.[3]

Pollutants comprise the second class of environmental problems. Pollutants are undesirable byproducts of production and consumption activities that are released into the environment. When their adverse impacts are borne by other producers and consumers and not communicated through markets, these byproducts are economic externalities. A certain amount of such pollution is inevitable. Smoke,

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[1] This is the well-known result of Coase (1960).

[2] The theory of optimal resource extraction was first developed in Hotelling (1931).

[3] Baumol and Oates (1988), pp. 138-51.

sewage, and trash provide classic examples. The disposal services of the environmental media (air, water, and soil) into which these physical outputs are discharged can be considered economic inputs. Because property rights to these media are costly or impossible to define, pollution sources do not face the external costs of disposing of wastes and thus produce too much of the pollutant.

There are three useful characterizations of both pollutants and natural resources. Pollutants can be categorized by absorptive capacity (stock or fund), area (local or regional), and vertical damage causation (surface or global).[4] Stock pollutants like heavy metals and CFCs cannot be absorbed by environmental media, and so the damage from them is related to their total accumulation. Regional or global pollutants such as CO_2 and CFCs tend to be uniformly mixed with damage being independent of where emissions actually occur. Local or surface pollutants such as particulates and NO_x tend to be non-uniformly mixed, and have strong ambient effects. Natural resources can also be characterized this way: resources can be exhaustible or renewable; local or regional; or they can have surface or global implications (Table 1). These characteristics of environmental problems will have important implications for designing policy.

Table 1
A Common Taxonomy of Pollutants and Natural Resources

	Pollutant	Natural Resource
Absorptive capacity		
stock/exhaustible	● nuclear waste	● mineral deposits
fund/renewable	● NO_x	● fisheries
Area		
local	● noise	● soils
regional	● acid rain	● ground water
Vertical damage		
surface	● smog	● park land
global	● CFCs, carbon	● biodiversity

There are many relationships between pollutants and resources. Some pollutants (SO_2) can destroy resources (forests), and extraction and use of some resources (oil) generate pollution. Environmental problems also interact as complements or substitutes in production. Some substitutes for ozone-depleting chlorofluorocarbons may have high global warming potential. Some pollutants can be disposed of in a choice of media (air, water, land). These relationships complicate matters for regulators, who must avoid merely shifting environmental problems between media.

An important difference between stock pollutants and exhaustible resources should be noted. As a resource becomes scarce, its price rises so that less is demanded. Eventually, it should become scarce enough that substitutes become economically viable, and the remaining stock is preserved (Hotelling's rule). For stock pollutants, there is no such ameliorating mechanism. Disposal remains free to polluters and costly to society no matter how much of the pollutant accumulates.

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[4] Tietenberg (1988), p. 307.

Solid wastes form a special category of pollutants. Like other pollutants, solid wastes impose negative externalities. However, because they can be easily and covertly disposed of, they pose special problems for policy makers. Covert disposal, or "midnight dumping," harms the environment more than proper disposal. Thus the conventional externality solution--charging the polluter the marginal external damage cost from improper disposal--may not be efficient if illegal disposal cannot be discouraged easily.

The common thread running through all of these environmental problems is inefficient market allocation. Because the market fails, there may be a role for government intervention. The decision to intervene depends on the costs and benefits of doing so, which in turn depend on the method of intervention chosen. Faced with environmental problems, governments must decide in each case not only whether to intervene, but what measures to use. A discussion of the policy instruments available to regulators follows.

Policy instruments

In many countries, macroeconomic and sectoral policies encourage environmental degradation. Resource use subsidies, unaccountable public ownership and management of natural resources, trade restrictions, and other public policies can place stresses on environmental resources. Reform of such policies is often called a "no-regrets" approach because it may improve welfare even without taking account of environmental benefits. By eliminating policies that distort market incentives and themselves cause a deadweight loss, "no-regrets" reforms can costlessly reduce environmental degradation. However, even if these reforms were to be enacted--which is not always easy since they enjoy the support of strong interest groups--they would not be sufficient. As long as property rights to many environmental resources remain prohibitively costly to enforce, additional government intervention may be necessary to address the resulting externalities.

Direct public management of--and investment in providing--some environmental services is thought to be necessary because they are public goods. Ex-post clean up of pollution by sewage treatment plants, for example, is one case where collective treatment facilities, although efficient, are unlikely to be provided by the private sector. Governments also incur research and development expenditures for pollution control technologies and substitutes for natural resources.

Reliance on liability works best in a world with low information and transactions costs, and clearly defined property rights. For most pollutants, the adverse effects are too dispersed and too delayed for blame to be accurately placed.[5] The United States' Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or "Superfund"), which legislates strict, joint, and several liability for cleanup costs of unsafe hazardous waste sites, is a case in point. It is the only legislation of its type in the world, and in practice has been costly, litigious, and ineffective in cleaning up toxic waste sites.[6]

When public investment or management is too costly and reliance on liability is infeasible, governments should intervene to protect the environment by attempting to change the behavior of public and private users of environmental resources. The design of these targeted interventions is the focus of this paper.

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[5] See Mennell (1991).
[6] See Hahn (1991).

Table 2 shows three ways of categorizing choices of intervention: by the use of economic incentives (use or non-use); by the level of control (direct or indirect); and by the control variable (price, quantity, or technology). These three policy choices generate twelve possible modes of intervention. Two of the cells in Table 2, corresponding to direct and indirect non-incentive price interventions, are empty because price interventions are by definition incentive-based. While the ten other cells in Table 2 contain theoretically valid policies, some have no real-world counterparts. The choice among these policies can be made on grounds of economic efficiency; this paper will analyze such choices with regard to air pollution in four cities.

Table 2
Alternative Policies to Reduce Pollution

		Price	Quantity	Technology
Incentive	Direct	emissions tax	tradeable emission permits	technology tax on presumed emissions
	Indirect	fuel tax	tradeable production permits	subsidize R&D & fuel efficiency
Non-incentive	Direct	--	emissions stds	technical stds
	Indirect	--	product stds, bans, quotas	efficiency stds

Use of economic incentives

Economists usually focus on a narrower categorization of policy instruments than is shown in Table 2--the choice between traditional "command and control" regulations and more innovative "market-based" instruments.[7] Measures that confront polluters with a price for each additional unit of pollution can be described as incentive-based. Economists favor these approaches because they clearly internalize the external costs of pollution. Non-incentive instruments do not price incremental pollution in this manner. Instead, they require polluters to emit only certain concentrations or levels of effluent, ban some processes and mandate others, impose standards for energy conservation, or allocate resources for preservation, all without reference, or only vague reference, to the costs involved.

One variant of the incentive-based price instrument is the deposit-refund scheme. When it is difficult for authorities to prove violations of the law but simple for individuals to prove compliance, deposit-refund schemes shift the burden of proof from the regulator to the polluter. In the drink container industry, refunds for empty aluminum containers alleviate both a pollution problem (litter) and possibly a natural resource problem (aluminum). Similarly governments could require deposits in return for permits to use natural resources or construct hazardous waste dumps, and refund these only when the resource extraction or dumping has been completed in an acceptable manner.

User fees, whose purpose is to raise revenues from polluters for publicly-funded environmental projects, are often confused with incentive-based policies. Two characteristics distinguish user fees from

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[7] The notable exception is Eskeland and Jimenez (1991), which distinguishes between policy instruments in terms of the use of economic incentives as well as the level of control; p.3.

true effluent charges. First, most user fees do not tax marginal emissions, and thus do not give individual polluters the incentive to reduce emissions. Second, user fees are rarely at levels higher than marginal abatement costs for producers, and thus induce no additional reduction in the quantity of pollution.

Incentive-based quantity instruments are tradeable permits to pollute or to use a natural resource. An attractive feature of tradeable quantity permits is that they allow groups outside of the profit-making industry to participate in pollution reduction. Environmental activists could purchase pollution rights and store them. However, due to the public good aspect of these rights, it appears that even if all environmental activists in the U.S. pooled their resources, they would not affect overall pollution significantly.[8]

The use of incentive-based price instruments is growing. Some OECD countries tax leaded gasoline at higher rates than unleaded. Sweden taxes the sale of cars without catalytic converters and uses the revenue to subsidize cars with them.[9] Incentive-based quantity schemes have been used almost exclusively in the U.S. Emissions trading programs have been part of the Clean Air Act since 1975, and an inter-refinery trading program was used in phasing out leaded gasoline between 1982 and 1986. The amendments to the Clean Air Act in 1990 contained provisions for electric companies to buy and sell permits to emit SO_2, and the Chicago Board of Trade has even announced plans to begin trading futures contracts based on these permits by 1993.[10]

The literature that compares "market-based" and "command and control" policies almost universally favors the former. Yet, environmental regulators rely on the latter throughout the world. While this disparity may partly reflect regulatory error, the hypothesis here is that it is also based on an over-simplification of regulatory decisionmaking. Even on efficiency grounds alone, regulators must compare policy options on the basis of attributes in addition to whether economic incentives are used. From a regulatory perspective, the level of control or the control variable (discussed below) rather than the use of economic incentives may in many circumstances be the most important choice variable. Conclusions about the efficiency properties of incentive- and non-incentive based policies may be biased unless these comparisons also control for differences in level of control or control variable.

Level of control

The only pure direct control variable is environmental damage. But damages are usually impossible to measure accurately. Thus, policies that target emissions are typically considered to be direct. This distinction would be inconsequential if pollutants were all uniformly dispersed, with all sources affecting ambient quality equally regardless of location. Alternative indirect variables include variable inputs to or outputs of production, fixed inputs to production, and substitutes or complements to any of the above. Given the number of these alternatives, a variety of indirect regulations is possible.

Indirect policies can target any of three parts of the pollution process: waste generation itself, the efficiency with which inputs are converted into outputs, and demand for the pollution-intensive product (see Figure 1).

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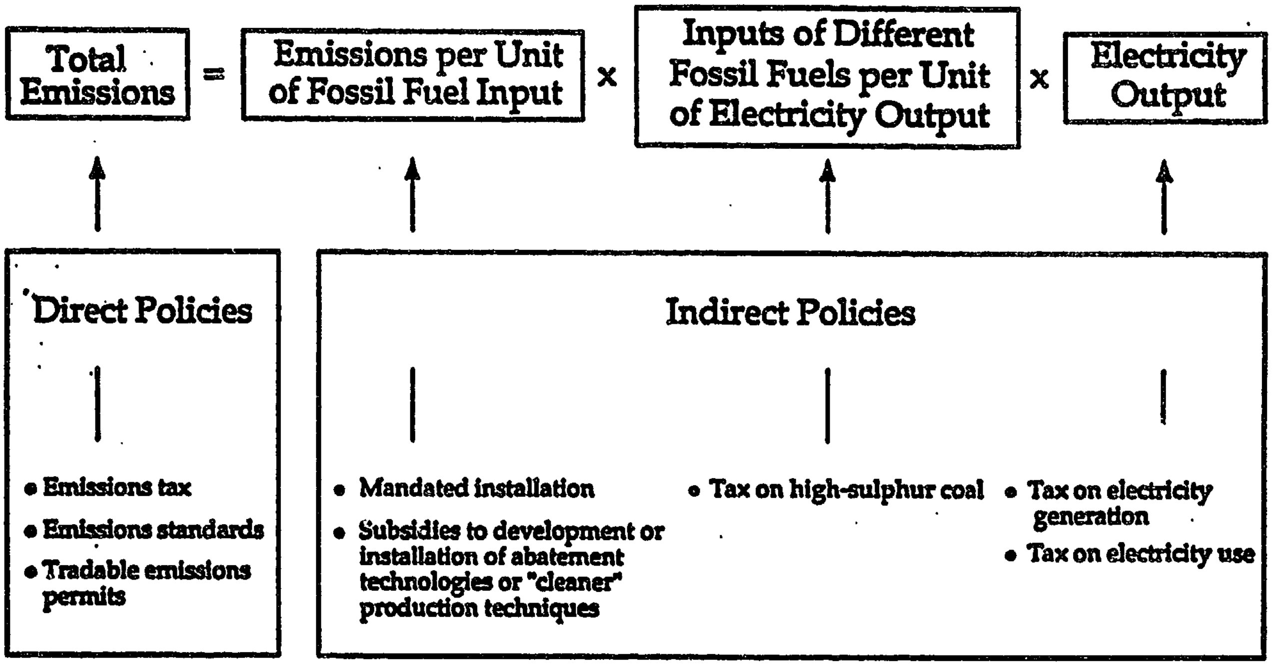
[8] Bohm and Russell (1985), p. 421.

[9] Bernstein (1991), p. 49.

[10] Financial Times, 7-24-91.

Figure 1 Direct and indirect policies to reduce sulfur dioxide from electric power generation



Emissions can be expressed as:

EMISSIONS = (EMISSIONS/INPUT) * (INPUT/OUTPUT) * (OUTPUT).

For example, for automobile emissions this expression corresponds to:

EMISSIONS = (EMISSIONS/GALLON FUEL) * (GALLONS/MILE) * (MILES DRIVEN).

Requiring catalytic converters reduces emissions per gallon of fuel burned. The corporate average fuel economy (CAFE) regulation in the U.S. is an example of the second type of policy, one which reduces inputs per unit output. Finally, fuel taxes, public transport subsidies or parking taxes would reduce the total vehicle miles travelled in passenger vehicles by shifting demand to other transport modes.

Direct instruments are cost-effective because they equate marginal abatement costs across all methods of pollution abatement. Indirect instruments omit some of the possible methods. Catalytic converters reduce emissions per gallon but do not directly affect energy efficiency (gallons/mile) or demand (total miles). Nor do indirect instruments necessarily equate marginal abatement costs within even one of the three parts of the process. A tax on the sulfur or carbon content of coal targets the emissions per unit input by inducing electric utilities to switch to cleaner fuels. It might also indirectly decrease electricity demand and increase the efficiency of the generating process. However, a sulfur tax would provide no incentives to develop or install abatement technology such as flue gas desulfurizers (scrubbers). An emissions-based instrument, on the other hand, would provide incentives to reduce emissions by all possible methods.

Indirect policies, if designed poorly, may also provide perverse incentives. For instance, while the CAFE regulations in the United States have improved the fuel efficiency of the "process" of driving, more fuel-efficient vehicles have also tended to increase miles driven by decreasing the marginal cost of driving. The average fuel efficiency of passenger vehicles in the U.S. rose by about 22% between 1980 and 1988, which by itself should have contributed to reduced emissions. However, aided by falling gasoline prices, greater fuel efficiency meant that in real terms the fuel cost per mile fell by over 60% during this period, and contributed in part to the 16% increase in passenger miles driven per capita. As a result, air quality in many American cities has not improved significantly in recent years.

Indirect instruments that target processes often do so based on the technology involved. In a sense, all such technology instruments could be described as indirect, since they can never provide a full set of incentives to reduce pollution. Nevertheless, technology instruments that operate directly on emissions are classified here as "direct" in order to contrast them with technology instruments which focus on alternatives to emissions, such as process or fuel efficiency. Hence, technology is viewed here as a control variable along with price and quantity.

Control variables

Regulators must choose either prices, quantities, or technology as a basis for regulation. It is often difficult to discern the true control variable. For example, in the U.S. the EPA sets effluent standards for water pollution based on the assumed use of specific control technologies. While firms are free to use any technology to achieve the standards, they know the technology used by EPA. They minimize their research expenditure and their legal risk by implementing only the EPA's test technology. Thus while the EPA standard is nominally based on quantity, it is effectively based on technology.[11]

Although the above discussion has focused on pollution reduction, policies aimed at natural resource problems can also be characterized usefully by this three-way classification. Regulators can target the price or quantity of the resource, or the extraction technology. They can use economic incentives, and can control resource use and extraction directly or indirectly.

Evaluating policy instruments

Clearly, policymakers use many criteria in choosing between alternative policies to address environmental problems. However, this paper is concerned with examining how the efficiency properties of different policies depend on the characteristics of the environmental problem, rather than with explaining actual policy choices. Therefore, different policies are compared according to two criteria--cost-effectiveness and administrative cost. Other criteria such as the distributional impacts and revenue potential are important to the political feasibility of alternative policies but less relevant to their economic efficiency.[12]

Cost-effectiveness

Cost-effectiveness is necessary but not sufficient for economic efficiency in addressing environmental problems. For a set of environmental policies to be efficient, they must yield the socially

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[11] OECD (1987) as cited in Bernstein (1991), p. 8; Tietenberg (1988), p. 416.

[12] See Baumol and Oates (1988) for a discussion of these issues, and Buchanan and Tullock (1975) and Hahn (1989) for analyses of the political economy of environmental policy choice in the U.S. Although intermedia substitution effects are relevant to economic efficiency, these are not analyzed in detail here since air pollution is the only concern of this paper.

optimal quantity of pollution or natural resource depletion, a well defined but abstract goal. Cost-effectiveness, on the other hand, merely requires that these policies achieve a given improvement in environmental quality at least cost.

To be cost-effective, a pollution abatement policy must equalize marginal abatement costs across polluters. Otherwise, an equivalent amount of pollution reduction could be achieved by allowing the high abatement cost polluter to produce one more unit of pollution, and requiring the low abatement cost polluter to abate by one more unit. The difference between their marginal abatement costs would be the cost savings generated by such a policy change.

Only direct incentive-based policy instruments are necessarily cost-effective. Price instruments set the marginal abatement cost through the effluent tax. Each polluter should respond by reducing pollution until its marginal abatement cost equals this tax. Incentive-based price instruments include taxes and subsidies, and both types of measures provide the same signals to polluters or resource users in the short run. However, taxes or charges are superior in terms of dynamic cost-effectiveness. Subsidies provide perverse incentives to consumers by reducing the price of pollution-intensive goods, and unless entry is restricted, would eventually lead to more firms producing the same or greater total pollution at inefficiently small scales.[13]

Incentive-based quantity instruments such as tradeable permits are cost-effective because the market for permits sets the marginal abatement cost for a target pollution level. In a perfect permit market, each polluter's marginal abatement cost curve will be its demand curve for pollution permits, and the market price of those permits will be equal to each polluter's equilibrium marginal abatement cost.[14] The cost-effectiveness of tradeable quantity schemes depends on the size and competitiveness of the market for permits. The larger the number of polluting or resource-using firms, however, the higher the monitoring and administrative costs of the program. Whether there exists a market size small enough to have low administrative costs, yet large enough for efficient trading to occur, remains unanswered in practice because few incentive-based quantity instruments have been implemented.

Well-designed non-incentive policies may approximate cost-effectiveness. Some have argued that non-incentive rules negotiated by skilled regulators at the plant level can allow enough flexibility for marginal abatement costs to be equated across sources. In the U.K. and Japan, for instance, pollution abatement decisions are based on confidential negotiations between regulators and individual plants.[15] It seems unlikely that such collaboration would work in the United States, with its suspicious attitudes towards "captured" regulators, or in countries that lack adequate safeguards against corruption.

In the long run, however, non-incentive policies are even less likely to maintain any approximation of cost-effectiveness. To be dynamically cost-effective, policies must respond well to three types of changes in the economy: demand changes, inflation, and technological change.[16] In the first two cases, changes in the economy alter the incentive structure generated by the regulation. With technological change, pollution control regulations themselves can have important effects on its pace and

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[13] Baumol and Oates (1988), chapter 14; Eskeland and Jimenez (1991), pp. 16-17; Pearce and Turner (1990), p. 108.

[14] Pearce and Turner (1990), p. 110.

[15] CBO (1985); Kopp, Portney, and DeWitt (1990), p. 22; Wheeler (1991), pp. 73-4.

[16] Tietenberg (1988), p. 327.

direction.

In the face of increasing demand for pollution-intensive goods, no policy can be entirely flexible. Even incentive-based policies have some rigidities. Quantity instruments maintain the level of pollution, while abatement costs and hence consumer prices rise. Price instruments keep abatement costs constant but allow more pollution. The advantage of incentive-based policies is that despite such changes they maintain static cost-effectiveness. Even well-designed non-incentive policies can lose their cost-effectiveness quickly in the face of such demand changes.

Inflation erodes the real value of any price-based policies. Most textbook treatments thus assume that over time, price instruments will result in more pollution. In many cases, however, pollution taxes have risen faster than inflation over time, perhaps because governments phase in taxes gradually in order to ease the shock to the economy and the political system.[17] Either way, nominal price-based policies will not be dynamically cost-effective in an inflationary world.

The third measure of dynamic cost-effectiveness is the policy's response to and effect on technological change. Dynamically efficient instruments encourage the development of new technologies for pollution reduction and abatement. Inefficient instruments stifle innovation. Incentive-based price and quantity instruments provide incentives for firms to innovate in order to reduce their costs of pollution. Non-incentive emissions standards could conceivably cause firms to conceal technological advances in order to deter regulators from tightening their standards,[18] and technological standards lock in the status quo.

Administrative costs

Cost-effectiveness refers to the abatement costs borne by polluters. Of equal importance in economic terms are the costs that regulators face in administering environmental policies. Under this category fall many related costs, of which monitoring and enforcement expenditures are the most important. These costs should not differ significantly between incentive and non-incentive instruments. To administer either instrument, regulators must identify polluters, measure their baseline and continuing levels of emissions, monitor ambient pollution, and punish violations of the law.[19]

Analogously, it might be true that the administrative costs do not differ much by control variable. For price and quantity standards, regulators must have detailed information about emissions and their relationship to ambient quality.[20] To successfully implement a technology standard, regulators must have equally complex information about available technologies for pollution control and their relationships to ambient quality. Depending on the number of polluters, the complexity of abatement technologies, and the ease of evading each type of regulation, emissions monitoring or technology monitoring could be more costly.

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[17] Hahn (1989), "Economic prescriptions," p. 107.

[18] Tietenberg (1988), p. 318.

[19] Bernstein (1991), p. 27; and Wheeler (1991), p. 22.

[20] Administrative costs might be lower for incentive-based price policies compared to those based on quantities because regulators are more familiar with the using taxes rather than tradeable permits. From the U.S. experience, which has emphasized quantity-based rather than price-based instruments in using economic incentives, this difference appears not to be substantial.

While administrative costs may not vary significantly with the use of incentives or the control variable, they would be expected to differ considerably between direct and indirect controls. Because direct policies are tied closely to environmental damage, they focus on actions specific to individual sources of pollution or resource use. For these policies to be effective--whether or not they rely on economic incentives, the regulatory authority must monitor the behavior of individual sources and enforce their compliance. Indirect policies, by contrast, have less onerous monitoring and enforcement requirements because, as with input and output taxes, they apply at a more aggregated level than the emissions or resource use of individual sources. In comparing direct and indirect policies, an important consideration, therefore, would be the difference in administrative costs.

The parameters of efficient policy choice

The efficient policy combination for the purposes of this paper is defined as that mix of instruments that is cost-effective in static and dynamic terms, including the costs of administering the policies. The focus below is on characterizing real-world parameters that can be used to determine each of three characteristics of the efficient policy mix: the level of control; the use of incentives; and the control variable. The decisions about these three attributes themselves are not separable and cannot be analyzed as the sum of three independent discrete choices. In general, the outcome depends on the order in which the three choices are made. For example, if technology instruments are preferred to price or quantity instruments, this generally also has implications for whether economic incentives should be used. Nevertheless, it is useful to regard the choices separately both for analytic clarity and because in practice parameter values and trade-offs are never so clear that the ordering of choices matters significantly.

Reliance on economic incentives

The deadweight loss associated with using non-incentive rather than incentive policies increases with the variance of abatement costs among polluters. If all polluters have identical abatement costs, then even a regulation that mandates a percentage reduction in emissions would be cost-effective. The more the marginal abatement cost curves differ, the higher the gains from switching to an incentive-based policy. The range of production technologies, perhaps as measured by the variance in the age of installed capital or in the capital-labor ratio, might serve as a proxy for variance in abatement costs.

Due to their physical location, the emissions of some polluters cause more damage. These ambient effects influence the cost-effectiveness of incentive-based policies. Their net impact depends on how closely they are correlated to abatement costs. With incentive instruments, high marginal abatement cost polluters will abate less. If emissions from high abatement cost polluters also cause more damages, this would be an undesirable result. If, on the other hand, high abatement cost polluters have lower ambient effects, an incentive-based policy would be even more cost-effective.[21]

The stringency of the regulation also affects the cost-effectiveness of incentive-based policies. Tietenberg (1988) describes a nonlinear negative relationship between control stringency and cost savings from incentive-based policies. For moderate ambient standards, higher standards favor incentive policies more. For stringent standards, however, higher standards reduce the relative cost advantage of incentive policies.[22] There are (at least) three possible explanations for this negative relationship (see Figure 2).

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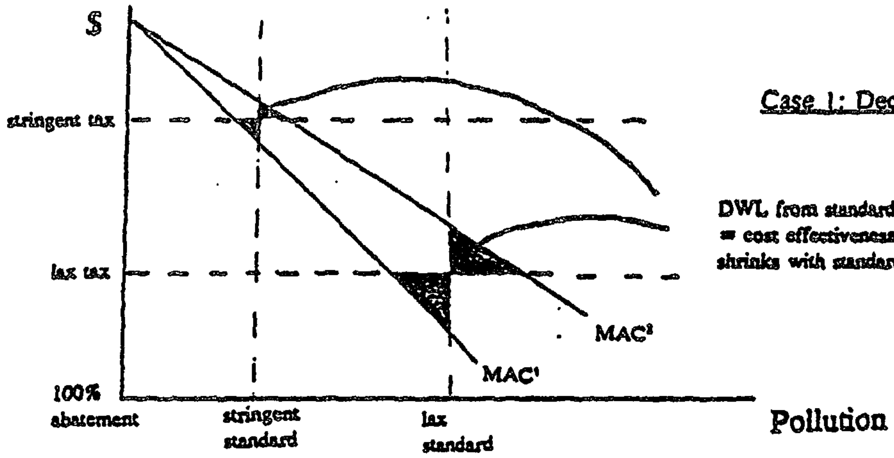
[21] See Miltz et.al. (1988)

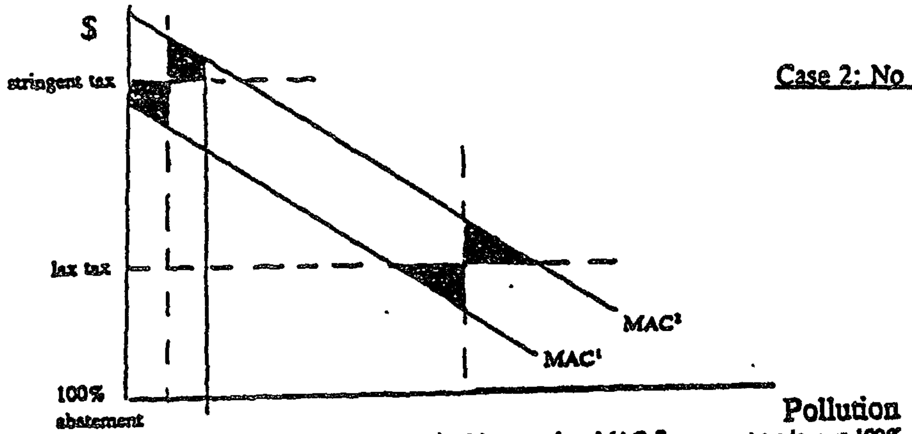
[22] Tietenberg (1988), p. 345.

Figure 2 Stringency and cost-effectiveness: three cases



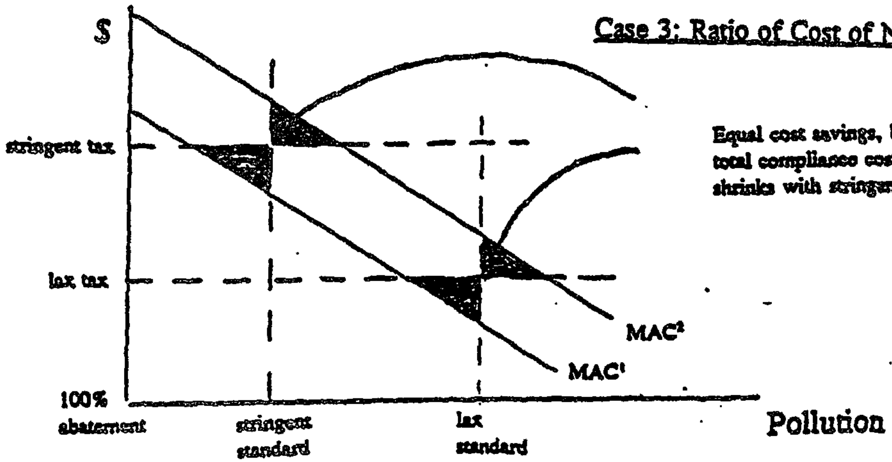
Case 1: Declining Marginal Abatement Cost Variance

DWL from standard (non-incentive)
= cost effectiveness savings from tax (incentive),
shrinks with standard stringency.



Case 2: No Abatement Beyond 100%

Emissions trading constrained because low MAC firm cannot trade past 100%.



Case 3: Ratio of Cost of Non-incentive/Incentive Policy Declines

Equal cost savings, but ratio to
total compliance costs
shrinks with stringency.

The interfirm variation in abatement costs may depend on the control stringency. In this case the result is straightforward. Stringent uniform standards move all firms onto the portion of their marginal abatement cost curves that is less variable across firms. Second, no polluter can abate beyond 100 percent. If regulations are stringent enough so that some firms cannot abate more without going out of business, then cost savings will be constrained. The third reason for this negative correlation between cost savings and stringency has to do with the way this difference is measured (Tietenberg 1988)--as the ratio of costs of non-incentive to incentive policies (always ≥ 1). Even if absolute cost savings are independent of stringency, they will shrink relative to total compliance costs, which obviously rise as stringency increases.

The cost-effectiveness of incentive-based policy depends on the assumption that polluters minimize costs. For this reason, incentive-based regulations will probably not be optimal to control pollution by public enterprises or regulated industries, where cost minimization may not be an appropriate behavioral assumption. Finally, higher economic growth and inflation will imply a greater need for regulations to be dynamically efficient. In more rapidly changing economies, the flexibility of incentive policies in adapting to these changes makes them more attractive.

Of course, environmental regulatory systems need not fall neatly into the incentive/non-incentive classification. Many systems are mixed, utilizing elements of each type of regulation.[23] Baumol and Oates (1988) make a strong case for supplementing incentive-based systems with non-incentive policies in circumstances where the environmental regulations must change rapidly in response to random events.[24] In the face of unexpected weather changes, for example, they argue that standards are easier to change than taxes, with more predictable quantitative results.

Direct and indirect policies

As discussed above, there are three means of reducing pollution: reducing waste generation per unit of input; increasing output per unit of input; and reducing output demand. Only direct price or quantity instruments equate marginal abatement costs across and within all three. Requiring abatement technologies, although considered a direct instrument, only gets at the first and third. Upstream (input) instruments only induce input substitution and perhaps a demand effect via price. Downstream (output) instruments only induce output substitutions. These limitations of indirect policies are tolerable so long as the targeted abatement method is indeed cheapest. However, if input switching is more costly than technological abatement, then input taxes will be less cost-effective. The substitution elasticity for a pollution-intensive input has little effect on the cost-effectiveness of an input tax. If it is low, more abatement will result from demand reduction; if it is high, polluters will substitute inputs. From a regulator's perspective, this does not matter. However, with low substitution elasticities, using an input tax is more likely to miss a cheaper alternative, such as installing abatement equipment.

Theoretically, if the deadweight loss from the imposition of indirect taxes (relative to an emissions tax) is less than the savings in administrative costs, then indirect taxes should be used. A small subset of the optimal tax literature has examined indirect taxes and externalities.[25] In most of these models,

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[23] Bernstein (1991), p. 18.

[24] Baumol and Oates (1988), pp. 190-206.

[25] See for example Balcer (1980); Stevens (1988); Green and Sheshinski (1976); Sandmo (1976); Wijkander (1985).

the government's goal is revenue generation, not environmental quality. Thus behavioral change, which is the goal of environmental taxes, generates efficiency losses in these models. For indirect environmental taxes, only behavioral change other than that sought by the policy should count as a loss. These models also explicitly assume that a good is untaxable, rather than costly to tax. So there is no representation of the trade-off between the cost of administering a direct tax and the welfare loss from an indirect tax. In sum, these models do not apply directly to the comparison of direct and indirect policies for environmental protection.

The question remains: what parameter might best describe the likely superiority of indirect over direct policies? As a first cut, the number of sources may be a good proxy for administrative costs--the higher the number, the more it seems an indirect policy will be optimal. Some measure of the competence of the environmental regulator would also reflect the costs of using direct policies.

Regulators may also find it easier to enact direct instruments in law-abiding societies. Japan, for example, has been called a "consensus society."[26] It improved its air quality quickly and significantly in the 1970s, mostly because people and firms strived to achieve air quality standards set by the government. When the U.S. auto industry failed to meet NO_x emissions standards in the 1970's, declaring the standards "impossible," the U.S. government's bluff had been called. It could not harm this important industry and instead revoked the standard. Meanwhile, Japan's auto industry successfully achieved an equally stringent standard.[27] The more law-abiding a society, the more its environmental regulators will be able to rely on self-reporting to monitor compliance with direct policy instruments.

Finally, when a pollutant is non-uniformly dispersed, even an emissions-based instrument would not be truly direct. Using an even more indirect instrument could well target damage better than regulating emissions. For example, most pollutants from automobile exhaust are non-uniformly dispersed. Emissions in rural areas at night cause less damage than urban rush-hour emissions. An emissions tax would ignore these different ambient effects. An even more indirect instrument, such as a parking tax at downtown garages, might target damages better than an emissions tax would. The existence of ambient effects does not help policy makers choose between what have been labelled direct and indirect instruments; it only removes directness as a basis of comparison. All possible policies become effectively indirect, but policies that affect proxies for emissions may have cost-effectiveness and monitoring advantages over instruments that target emissions.

Some situations are especially suitable for indirect instruments. In developing countries where the administrative apparatus is less sophisticated and the informal sector is large, indirect instruments may be the only feasible policies. If informal enterprises pollute a lot, regulators must look hard for their connections with the formal economy. Regulations attached to these connections would be necessarily indirect. Here too, clever solutions may lie in mixing systems of regulations with different levels of control. For example, a mixed approach has been recommended for regulating automobile emissions, which are not amenable to direct monitoring. A fuel tax, combined with an initial capital tax on new cars based on their emissions characteristics, would provide incentives for reduced driving, fuel efficiency, and the development and use of abatement technology.[28]

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[26] Takemoto (1989), p. 4.

[27] IUAPPA (1988), p. 83.

[28] Mills and White (1978), p. 386; Eskeland and Jimenez (1991), p. 33.

Control variables

The choice between price and quantity instruments has been explored in the theoretical literature begun by Weitzman (1974). If abatement costs are certain, regulators can use either price or quantity instruments to achieve the same equilibrium level of pollution abatement. With uncertainty however, the optimal policy depends on the relative shapes of the abatement cost and environmental benefit functions.[29] The shapes of these function measure society's relative sensitivity to deviations from either the optimal price or quantity of environmental protection. Intuitively, if the marginal abatement cost curve is steeper (relative to the benefit curve), equilibrium abatement costs will be sensitive to the quantity chosen, and it is less risky to use a price instrument. If the marginal abatement cost curve is less steep, the equilibrium quantities will be sensitive to the price chosen, and it will be less risky to use a quantity instrument.

Changes in the economy over time provide an analogous situation. In the face of such change, regulators must decide whether to stabilize pollution levels or abatement costs. Quantity instruments maintain the overall level of pollution, while abatement costs, and hence consumer prices, increase. Price instruments keep constant the marginal abatement cost, but allow more pollution. As in the static case, the preferred policy depends on the relative shapes of the abatement cost and environmental benefit functions.

It is difficult to derive these functions for actual cases. Marginal abatement cost curves have, in some instances, been approximated by engineering studies. While environmental benefit functions are even more difficult to estimate, they have two components: the relationship between pollution and environmental damage, and that between damage and its monetary value. The first means that more toxic pollutants will have steeper marginal benefit curves. To the extent that environmental quality is income elastic, the second aspect implies that wealthier societies will also have steeper benefit curves. Developed countries, in particular, would therefore be more likely to regulate toxic pollutants with quantity instruments.

Price or quantity instruments both incur administrative costs due to the need to monitor emissions. Technology instruments also face administrative costs based on the technical and industry expertise necessary to require appropriate abatement equipment and monitor its usage. The trade-off between these types of administrative costs should determine which control variable is preferable. However, technology instruments are typically not cost-effective, either in static or dynamic terms, because they only operate on one aspect of total emissions even when they are intended to reduce emissions directly. Scrubbers on coal-fired power plants, for example, reduce emissions but provide no incentive for utilities to use cleaner coal or for consumers to conserve energy. As is typical of indirect policies, these missing incentives mean that technology instruments do not equalize marginal abatement costs across methods of abatement.

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[29] See Baumol and Oates (1988), chapter 5. Note, however, that uncertainty regarding the benefits of pollution reduction (the marginal environmental benefit curve) does not affect the choice between price- and quantity-based policies.

Table 3
Parameters Affecting Policy Choice

Policy Choice	Theoretical Parameters	Measurable Parameters
Incentive v non-incentive	• variance of MACs (and ambient effects if correlated to MACs) • stringency • need for dynamic efficiency • incentives for cost minimization	• variance of vintage of K, K/L ratios; Covariance [ambient effects, MACs] • degree of control • inflation & growth rates • size of public enterprise sector; degree of competition
Direct v indirect	• administrative cost of direct policies • law abiding nature • deadweight loss from indirect tax • ambient effects	• number of polluters; administrative competence • tax compliance • relevant elasticities • transfer coefficients
Price v quantity; v technology	• relative slopes of MAC and MEB curves • development stage/ value placed on health • cost of monitoring emissions versus technology	• toxicity • GDP/capita • ease of installing and verifying use of control technologies

Table 3 summarizes the theoretical parameters, and their measurable counterparts, which determine efficient policy choice. In the next section, this framework is applied to the problem of urban air pollution in four cities in order to draw some general conclusions about the design of efficient pollution control policies.

PART III: POLICY INSTRUMENTS FOR CONTROLLING URBAN AIR POLLUTION:
Four Case Studies

Urban Air Pollution

Urban air pollution is among the most visible and widespread of environmental problems. It plagues rich and poor neighborhoods in both developed and developing countries, and has local, regional, surface, and global effects. Some air contaminants are stock pollutants, others are fund pollutants. Major sources of air pollution include industry, transportation, energy production, and households. Because of the variety of issues raised by urban air pollution, it provides good examples of the principles discussed in the previous section.

The gaseous components of the atmosphere are presented in Table 4 below. The principal gases (N_2, O_2, Argon, and CO_2) do not naturally react with one another or with unreactive trace gases. Reactive trace gases, which have a finite residence duration, must be inserted into the atmosphere by either natural or anthropogenic (man-made) events. When the sources are human, these reactive trace gases can result in pollution (Table 5).

The reactive trace gases are, with the exception of SO_2, predominantly supplied by natural sources. Over time the background concentrations of these gases have remained constant.[30] This indicates that the absorptive capacity of the troposphere, the lowest 8 to 16 km of atmosphere, has adequately processed the additional contributions of humans. On a world-wide scale, most air pollutants are fund pollutants. While they can cause lasting damage, such as that from acid rain, it is related to their flow rather than their cumulated stocks in the atmosphere. Moreover, the damage from these pollutants depends on the concentration of uncontrolled sources as well as the volume of their emissions.

Table 4
Components of Dry Air in the Lower Troposphere[31]

Principal Gases	Concentration		Residence Time
Nitrogen (N_2)	73.0	%	permanent
Oxygen (O_2)	20.9	%	permanent
Argon	0.93	%	permanent
Carbon Dioxide (CO_2)	0.032	%	20 years
Non-Reactive Trace Gases			
Helium	5.2	ppm	permanent
Neon	18.0	ppm	permanent
Krypton	1.1	ppm	permanent
Xenon	0.086	ppm	permanent
Hydrogen	0.5	ppm	unknown
Nitrous Oxide (N_2O)	0.25	ppm	8-10 yrs
Reactive Trace Gases			
Carbon Monoxide (CO)	0.1	ppm	0.2-0.3 yrs
Methane (CH_4)	1.4	ppm	< 2 yrs
Non-Methane Hydrocarbons (HC)	0.02	ppm	unknown
Nitric Oxide (NO)	0.002-0.2	ppm	2-8 days
Nitrogen Dioxide (NO_2)	0.004-0.5	ppm	2-8 days
Ammonia (NH_3)	0.020-6.0	ppm	1-4 days
Sulphur Dioxide (SO_2)	0.0012-0.03	ppm	1-4 days
Ozone (O_3)[32]	0.0-0.05	ppm	unknown

In addition to the reactive pollutants, human activities produce two inert gases--both stock pollutants--which cause environmental problems. Carbon dioxide, along with other greenhouse gases, may raise the temperature of the earth. Both emissions and concentrations of CO_2 have been increasing, indicating that the natural carbon sinks are unable to keep pace with carbon sources. Chlorofluorocarbons (CFCs) have no known tropospheric sink. Above the troposphere though, they react with stratospheric

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[30] Strauss and Mainwaring (1984), p. 3.

[31] Strauss and Mainwaring (1984), p. 2.

[32] Hydrocarbons and NO_x form ozone in a reaction which appears to approximate a fixed-coefficients function. Scientists believe that when the VOC/NO_x ratio exceeds 10, ozone production is determined by the amount of NO_x in the atmosphere. Similarly, when the VOC/NO_x ratio is less than 8, ozone production is determined by VOCs. (DF (1991), p. 2-3.)

ozone, reducing the earth's protection from harmful solar radiation. If anthropogenic emissions of CO_2 and CFCs ceased today, it would take decades or centuries for the background concentrations of these gases to stabilize.

Table 5
Human and Natural Sources of Air Pollution[33]

Gas	Quantity: Human (million tons/yr)	Quantity: Natural (million tons/yr)
SO_2	146	6-12
CO	300	>3000
NO_2	50	60-270
NH_3	4	100-200
N_2O	>17	100-450
HC	88	500-1800
CO_2	15,000	150,000

The first step in controlling air pollution has been to measure ambient concentrations. Many governments and international organizations have set targets for air quality, which constitute upper limits on the airborne concentration of pollutants. This section examines four cities where ambient concentrations for at least a subset of the criteria pollutants have exceeded World Health Organization (WHO) standards during the 1980s: Los Angeles, USA; Mexico City, Mexico; Cubatao, Brazil: and Ankara, Turkey. Table 6 contains air quality standards set by WHO and the four countries containing these cities.

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[33] Strauss and Mainwaring (1984), p. 3).

Table 6
Ambient Air Quality Standards[34]

Pollutant	Standards ($\mu g/m^3$ unless otherwise noted)		
	1 hour	24 hour	1 year
SO_2			
WHO	350	125	40-60
USA		365	80
Brazil		365	80
Mexico		365	80
Turkey	900	400	150-250
Particulates			
WHO		150-230	60-90
USA		260	75
Brazil			80
Mexico		260	75
Turkey		300-400	150-200
CO			
WHO		30	
USA	40 (35 ppm)	10 (8 hr; 9 ppm)	
Brazil	40	10 (8 hr; 9 ppm)	
Mexico	40	10 (8 hr)	
Turkey		30	
NO_x			
WHO	400	150	
USA			100
Turkey		300	100
Lead			
WHO			0.5-1.0
USA			1.5 (3 months)
Mexico			1.5
Turkey			2.0
Ozone			
WHO	120	60 (8 hr)	
USA	235	.12 ppm	
Mexico	235		
Turkey		240	

Each of the cities has topographic characteristics that worsen the pollution problem. Since concentrations of pollutants are the problem, emissions which are quickly dispersed pose little harm to local populations. In locations where winds are stagnant, emitted gases linger in high concentrations, and the problem is exacerbated by thermal inversions. Three topographic features cause inversions: proximity to water, high altitude, and nearby mountains. These characteristics reduce the normal tendency for air temperature to cool with altitude, which allows hot air to keep rising, even as it cools. When this

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[34] Data compiled from various sources by Wendy Ayres; Faiz, et. al. (1990), p. 9.

temperature difference is reversed, because a hot air mass lies above a colder one, smoke does not disperse into the upper atmosphere.

Once ambient concentrations are known, the next step is to construct emissions inventories which list the sources of the criteria pollutants. This task is difficult, and the uncertainties even in emission inventories for large U.S. cities range between 30 and 50%. For developing countries the uncertainty is probably even greater.[35] Depending on the objective of the inventory, sources can be categorized by process or by industry. The type of inventory needed by policy makers depends on the policies under consideration. For an output tax, an inventory by industry is useful while for an input tax, an inventory by process would be more applicable. To weigh the pros and cons of input and output taxes, both types of inventories would be best. Of course, accurate inventories for developing country cities by either source category are rare.

LOS ANGELES

The Los Angeles air basin contains the most populous region of the most populous state in the U.S. It encompasses parts of 4 counties and more than 12 million people. Four million more people, and two million additional housing units are expected over the next 20 years, despite air quality that is already the worst in the United States.[36]

The basin has well-known geographic characteristics conducive to poor air quality. It abuts the Pacific Ocean and is surrounded by mountains. Sunshine triggers photochemical reactions between VOCs and NO_x, forming the highest concentrations of ozone in the nation. In winter months, inversion layers at ground level trap high concentrations of CO and NO_x. High ozone concentrations lead to poor visibility, as a result of which some regional airports fail to meet state visibility standards (10 miles on days with humidity less than 70%) up to 260 days per year. Air pollution has reduced average visibility in downtown Los Angeles by more than 75 percent.[37]

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[35] DF (1991), p. 7-87.

[36] SCAQMD (1991), p. 3-11.

[37] Fawcett (1990).

Table 7
RELATIVE AIR QUALITY IN LOS ANGELES[38]

Pollutant	EPA std	% of time exceeding EPA std	
		1975-77	1988-90
O_3 (ppm) 1 hour	.12	53	42
PM_{10} $\mu g/m^3$ 24 hour	150	--	16
CO (ppm) 8 hour	9.0	38	15
NO_2 (ppm) 1 hour	--	19	2
SO_2 (ppm) 24 hour	0.14	0	0
Pb $\mu g/m^3$ qtrly avg	1.5	100	0

As a case study of urban air pollution, Los Angeles has both pros and cons. Because the problem and ensuing regulations have been present for several decades, there are plentiful data. However, California and Los Angeles, in particular, lead the world in the stringency of air quality regulations.[39] So, most of the sources that could have abated emissions at low cost have already relocated from the region or cleaned up. Unlike most cities in developing countries, therefore, regulators in Los Angeles are left only with expensive options or must seek more innovative ways to reduce pollution.

Sources of Air Pollution

Mobile, non-point sources emit approximately 70 percent of current air pollution by weight in the Los Angeles basin.[40] Most air pollution from mobile sources is emitted by on-road sources (motor vehicles). Ships, the only exception, emit 28 percent of sulfates.

In some respects California and the U.S. have made tremendous progress in regulating air pollution from motor vehicles. Fuel efficiency standards, accompanied by market pressures from higher gasoline prices, have decreased the amount of fuel burned per vehicle mile travelled (VMT). Sales-weighted fleet average fuel economy in the U.S. has increased from 14.9 miles per gallon in 1967 to 27.3 in 1987, up 83 percent. In addition, catalytic converters, which reduce the pollution per gallon of fuel

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[38] SCAQMD (1991), pp. 2-2 and 2-3.
[39] Faiz et al (1990), p. 73.
[40] SCAQMD (1989).

burned, have been required on 80 percent of new cars since 1975 and 100 percent since 1981.[41] The catalysts can reduce emissions of HC by 87 percent, CO by 85 percent, and NO_x by 62 percent.[42]

Unfortunately for air quality, demographic trends in Southern California have operated against these technological improvements in pollution control. In 1950 there were 2.1 million motor vehicles registered in the four-county region. By 1980 there were more than 6.5 million, and by 2010 there are expected to be over 10 million. In addition, the number of miles travelled per vehicle has increased, so that total vehicle miles travelled (VMT) has increased even faster than the number of vehicles.[43]

The region's population growth and economic growth are partly responsible for the growth in VMT. But the VMT growth has derived from two other factors: the falling marginal cost of driving because of increasing fuel economy and lower real gasoline prices; and substantial public investment in automobile-based infrastructure. The first few miles of Southern California's well-known freeway system were constructed in 1940. By 1980 the region had over 700 miles of freeways.[44] So although much progress has been made to reduce the pollution from individual cars, and new automobiles emit much less air pollution than their predecessors, the region's growth has ensured that air pollution remains a problem, and mobile sources still account for most emissions.

Stationary sources account for the other 30 percent of Los Angeles' criteria pollutants. They emit almost all the particulates, half the VOCs, a third of the sulfates, and a quarter of the nitrates. However, even among stationary sources, the distinction between point- and non-point sources is useful for policy purposes. The vast majority of the particulates come from non-point sources like paved roads, construction and demolition sites, and farming. Moreover, about two-thirds of stationary-source VOC emissions arise from solvent use, mostly surface coatings (Table 8). On the other hand, of the stationary-source sulfate emissions, about a third is from petroleum refining, and another half, along with virtually all of the stationary nitrate, comes from fuel combustion at industrial sites, electric utilities, and other services and commerce.

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[41] Faiz, et. al. (1990), pp. 69-71.

[42] French (1990) cited in Faiz, et. al. (1990), p. 69; Only 60 percent of the hydrocarbons emitted from motor vehicles pass out through the tail pipe. The other 40 percent escape through the crankcase, the fuel tank, and the carburetor. The other motor vehicle pollutants (CO and NO_x) are emitted through the tailpipe (Strauss and Mainwaring, 1984).

[43] Fawcett (1990); SCAQMD (1991), p. 3-11.

[44] Fawcett (1990).

Table 8
Emissions in the Los Angeles Basin: 1987[45]
(percent of total average annual tons per day)[@]

Source	VOC (%)	NO_x (%)	CO (%)	SO_x (%)	PM_{10} (%)
Stationary					
Fuel combustion	1	22	2	17	1
Waste burning	0	0	0	0	0
Solvent use	34	0	0	0	0
Petrol process, storage and transfer	8	1	0	14	0
Industrial processes	3	1	0	6	4
Misc. processes	4	0	0	0	88*
Total Stationary	50	24	2	37	94
Mobile					
On-road vehicles	44	55	87	24	5
Off-road mobile	6	21	11	39	1
Total Mobile	50	76	98	63	6
Total	100%	100%	100%	100%	100%

* Mostly construction and road dust.
@ Columns may not add due to rounding.

Los Angeles has had much more success controlling emissions from point sources than from dispersed non-point sources. Comparing Tables 7 and 8, one can note that point sources such as industrial processes contribute mostly to pollutants which meet, or are close to meeting, the federal standards. The standard most frequently violated is that for ozone. Los Angeles is one of the only cities in the U.S. in which ozone levels are determined by the level of VOCs in the air, rather than the amount of NO_x.[46] About 40 percent of VOCs are the result of the use of evaporating paints, petroleum products, and other solvents, predominantly by non-point sources. Regulators in Los Angeles have turned only recently to these activities as potential sources of pollution reduction.

Policy Options

Serious pollution control efforts in Los Angeles date back to the 1940s. At that time, regulations were passed and enforced by the individual cities and counties which share the airshed. To attempt to deal with air pollution consistently throughout the region, four existing county air pollution control districts were merged in 1977 to form the South Coast Air Quality Management District (SCAQMD). Because Los Angeles has had air pollution regulations for so many years, the interesting policy question is that actually faced by SCAQMD: given that regulations have been enforced for decades, and the air is still dirty, how should policy choice be altered?

SCAQMD's goals are the U.S. ambient standards for air pollutants. To achieve these goals in Los Angeles, SCAQMD will have to enforce much more stringent emissions standards than the rest of the country. In 1988, only lead and SO_2 concentrations met the federal standard. NO_x slightly exceeded

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[45] SCAQMD (1991), p. 3-5.
[46] Conversation with Bill Dennison, of Dennison & Associates.

the standard, PM_{10} concentrations were twice the standard, and CO and O_3 concentrations were over two and a half times the standard. Based on the emissions data (Table 8), the regulatory emphasis should be on controlling mobile and stationary sources of VOCs and PM_{10}.

Use of economic incentives: market versus non-market policies

Because motor vehicles all use almost identical technology, the variance of marginal abatement costs should be low. And although a continuum of model years exists, retrofitting old models with control equipment appears prohibitively expensive. An oil company's offer in Los Angeles to purchase and scrap pre-1971 cars for $700 apiece suggests that retiring older cars is roughly comparable in cost to adding catalysts to new ones. However, abatement costs may still differ at the margin because drivers derive widely varying benefits from using vehicles. So, despite similar technologies, some incentive-based measures may still have a cost-effectiveness advantage in controlling automobile emissions.

In Los Angeles, automobile emissions have been regulated for decades, suggesting that these sources have already used the cheapest available methods of abatement; further reduction will come at a higher cost. In addition, even though SCAQMD has historically used non-incentive regulations, cost-effectiveness has been an important consideration in their design.[47] To the extent that regulators succeeded in roughly equating marginal abatement costs across sources, many of the gains to be had from relying on incentive-based systems for sources already being regulated may already have been realized. For these reasons, additional incentive-based policies to control emissions from mobile sources may not be much more cost effective in Los Angeles.

Stationary non-point sources of VOC emissions, however, may provide a more attractive target for incentive-based policies. Until recently these sources were not controlled. There are many technologies involved in controlling their emissions, and thus there is likely a high variance of marginal abatement costs. Also, since stationary non-point sources are only just beginning to be controlled, they will face less stringent controls. Thus, incentive-based policies are more likely to provide efficiency gains in Los Angeles if used for stationary non-point sources rather than for mobile sources.

Level of Control: direct versus indirect policies

SCAQMD is a relatively capable regulatory agency with an 1989 budget of $72 million, including salaries and employee benefits of $40 million. Its Air Quality Management Plans demonstrate that it has detailed information about emissions, ambient air quality, and abatement technologies. SCAQMD should be capable of monitoring fairly complex instruments. However, it is not clear that setting up monitoring systems for direct policies would be the most cost-effective investment to make in Los Angeles. Non-point sources are obviously the most difficult to monitor. A biennial vehicle inspection system is already in place in California, and reportedly cost consumers $190 million and state and local governments $130 million in 1988.[48] Setting up systems to monitor emissions of other non-point sources is likely to be even more expensive than for vehicles. So despite the fact that SCAQMD is a capable regulator, the sources of emissions of VOCs and PM_{10} in Los Angeles may not lend themselves very well to the use of direct policies.

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[47] Hahn and Noll (1982).

[48] CARB (1990b).

Moreover, most of the damage from non-point emissions of VOCs and PM_{10} is local, with pronounced ambient effects that depend on the time and location of emissions. If a combination of indirect instruments can be identified that better matches these ambient effects, damages could be reduced at a lower cost than with direct policies.

Control variable: price or quantity versus technology

The remaining mobile and non-point source pollutants (lead has already been virtually eliminated) are not highly toxic at their current levels in Los Angeles. But given their affluence, residents may place relatively more value on pollution reduction. These two considerations have opposite effects on the slope of the environmental benefit curve, leaving no clear choice between price and quantity instruments.

Technology instruments in Los Angeles are starting to get expensive. The low cost solutions have been implemented, leaving only high-cost options which do less to improve air quality.[49] Vehicle control equipment consumes 79% of annual consumer expenditures on mobile source pollution control in California.[50] While this figure does not represent marginal abatement costs, it demonstrates the predominance of technological controls. Catalysts add \$360 to \$1080 (or 4% to 20%) to the price of new vehicles.[51] The more expensive these tailpipe abatement technologies get, the more efficient it is to rely on demand reduction or process changes, such as fuel switching.

Surprisingly, controls of mobile sources seem to have been more effective than stationary- source controls. Though California consumers spent two-thirds of their pollution control dollars on mobile sources, these generated 79% of the overall reduction in emissions in 1989.[52] Although these figures, which include the costs of regulatory programs, suggest that the average costs of targeting emissions reductions from mobile sources has been lower they say nothing about the relative marginal abatement costs which may in fact be lower for a variety of non-point stationary sources.

The above discussion suggests that SCAQMD's next step towards attainment of the federal standards should consist of a combination of indirect incentive-based instruments aimed at non-point stationary sources of VOCs. The choice of these indirect policies, implemented through taxes either on inputs or outputs related to emissions of VOCs and PM_{10} requires detailed analysis about substitution and demand elasticities and abatement technologies. The example of surface coating (paint, etc.) illustrates this point. Such coatings contribute almost 20 percent of the VOCs emitted in Los Angeles. Millions of consumers buy painting services from thousands of contractors. Directly targeting either group, with regulatory or incentive-based instruments would be prohibitively costly to administer. Instead, SCAQMD developed a proposal to tax the relatively small number of manufacturers of surface coating. Los Angeles' location in the middle of a large desert would help prevent large-scale smuggling of untaxed coating. Although the plan was eventually abandoned because of legal problems, it demonstrates how cost-effective indirect instruments could be designed for specific cases.

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[49] Hahn (1980), A Primer, p. 99.

[50] CARB (1990), Consumer Cost, p. 2.

[51] Faiz et al (1990), p. 69.

[52] CARB (1990), Consumer Cost, p. 2.

Table 9 South Coast Air Basin Average Daily Emissions (Percent of Total)

	VOC	CO	NOx	SOx	PM	PM10
STATIONARY SOURCES						
Fuel Combustion						
Oil and gas production	0.2%	0.1%	2.7%	0.2%	0.0%	0.0%
Petroleum refining	0.2%	0.2%	4.1%	2.8%	0.2%	0.3%
Other manufacturing/industrial	0.2%	0.3%	5.1%	4.2%	0.1%	0.2%
Electric utilities	0.1%	0.2%	3.9%	2.8%	0.1%	0.1%
Other services and commerce	0.3%	0.3%	3.7%	7.1%	0.1%	0.2%
Residential	0.1%	0.3%	3.1%	0.6%	0.1%	0.2%
Other	0.2%	0.2%	1.2%	1.1%	0.0%	0.1%
Total Fuel Combustion:	1.3%	1.6%	23.7%	18.7%	0.7%	1.2%
Waste Burning						
Agricultural--debris		0.0%				
Range management	0.0%	0.0%			0.0%	0.0%
Incineration		0.0%	0.1%		0.1%	0.0%
Other	0.7%	0.0%	0.1%	0.3%	0.0%	0.0%
Total Waste Burning:	0.7%	0.1%	0.2%	0.3%	0.1%	0.1%
Solvent Use						
Dry cleaning	1.3%					
Degreasing	2.0%					
Architectural coating	6.1%					
Other surface coating	12.5%		0.0%		0.1%	0.1%
Asphalt paving	0.4%					
Printing	0.7%		0.0%			
Consumer products	5.3%					
Industrial solvent use	1.4%					
Other	0.8%					
Total Solvent Use:	30.4%		0.0%		0.1%	0.1%
Petroleum process, storage & trans						
Oil and gas extraction	2.3%	0.0%	0.1%	1.8%	0.0%	0.0%
Petroleum refining	1.3%	0.1%	0.7%	13.8%	0.2%	0.2%
Petroleum marketing	3.3%		0.0%	0.1%	0.0%	
Other	0.1%	0.0%			0.0%	0.0%
Total Petroleum Process:	7.0%	0.1%	0.8%	15.6%	0.2%	0.2%

Table 9 (cont.)

	VOC	CO	NOx	SOx	PM	PM10
Industrial Processes						
Chemical	0.7%	0.0%	0.1%	2.7%	0.1%	0.1%
Food and agricultural	1.6%	0.0%	0.0%		1.2%	1.5%
Mineral processes	0.0%	0.0%	0.7%	2.9%	0.4%	0.5%
Metal processes	0.1%	0.1%	0.1%	0.5%	0.4%	0.7%
Wood and paper					0.7%	0.9%
Other	0.8%		0.0%		0.0%	0.0%
Total Industrial Processes:	3.2%	0.1%	1.1%	6.1%	2.9%	3.8%
Misc Processes						
Pesticide application	0.9%					
Farming operations	2.9%				3.5%	3.1%
Construction and demolition					18.7%	22.1%
Entrained road dust--paved					59.2%	52.7%
Entrained road dust--unpaved					3.4%	3.8%
Unplanned fires	0.7%	2.4%	0.2%		0.9%	1.5%
Waste disposal	0.4%					
Natural sources					5.5%	5.1%
Other	0.2%	0.0%	0.1%	0.2%	0.0%	0.1%
Total Misc Processes:	4.2%	2.4%	0.3%	0.2%	91.1%	88.4%
TOTAL STATIONARY SOURCES:	46.8%	4.3%	26.0%	40.9%	95.0%	93.9%
MOBILE SOURCES						
On Road Vehicles						
Light duty passenger	32.1%	54.2%	31.2%	12.1%	2.0%	1.7%
Light and medium duty trucks	10.2%	18.5%	10.1%	4.7%	0.5%	0.5%
Heavy duty gas trucks	2.4%	10.6%	4.6%	2.4%	0.1%	0.1%
Heavy duty diesel trucks	1.8%	1.4%	13.8%	5.8%	1.5%	2.5%
Motorcycles	0.7%	0.5%	0.2%	0.1%	0.0%	0.0%
Heavy duty diesel urban buses	0.1%	0.1%	1.2%	0.3%	0.1%	0.2%
Total On Road Vehicles:	47.3%	85.4%	61.1%	25.5%	4.3%	5.0%
Other Mobile						
Off road vehicles	1.7%	2.0%	1.0%	1.1%	0.0%	0.1%
Trains	0.3%	0.1%	1.7%	1.7%	0.1%	0.1%
Ships	0.1%	0.1%	3.1%	27.5%	0.1%	0.2%
Aircraft--government	0.7%	0.3%	0.3%	0.4%	0.1%	0.2%
Aircraft--other	0.6%	1.3%	1.2%	0.7%	0.0%	0.0%
Mobile equipment	1.4%	3.6%	5.4%	2.1%	0.3%	0.5%
Utility equipment	1.0%	2.8%	0.2%	0.2%	0.0%	0.0%
Total Other Mobile:	5.9%	10.3%	12.9%	33.7%	0.7%	1.2%
TOTAL MOBILE SOURCES	53.2%	95.7%	74.0%	59.1%	5.0%	6.1%
TOTAL SOUTH COAST	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

SOURCE: CARB. "Emission Inventory 1987," March 1990.

MEXICO CITY METROPOLITAN AREA

Los Angeles is a good case study because data about sources of emissions and ambient air quality are abundant. However, it may be a bad model for developing countries because of its relative affluence, and because air pollution has been regulated for decades. Mexico City faces similar air quality problems, but until recently pollution sources were mostly unregulated.

The Mexico City Metropolitan Area (MCMA) covers 1250 km^2, including the Federal District (DF) and 17 surrounding municipalities in the State of Mexico. About half its 20 million people currently live in the DF, but this number has been shrinking. Population growth in the MCMA is currently about 5%--1.3% in the DF and 8.8% outside the DF. People are migrating from rural areas and other cities to the Mexico City and from the DF to the surrounding municipalities.[53] So although the people and industries of Mexico have increasingly concentrated in the MCMA, the relative density of the city itself has declined, as the metropolitan area has spread into the Valley of Mexico.

The concentration in Mexico City has been partly induced by policy. Mexican industrialization began in the 1940s, spurred by government incentives and distorted prices which favored location in the capital.[54] In 1930 Mexico City had 3180 industrial establishments, 6.8% of the establishments in Mexico. By 1980 it had 38,492, 29% of the establishments in Mexico. These establishments employed 47% of Mexico's labor force and produced 48% of the country's GDP. This concentration has probably decreased somewhat in the last few years due to the establishment of free trade zones along the U.S. border.[55]

Like Los Angeles, Mexico City's topography is not conducive to concentrated industry and population. Because it lies in a high altitude valley (2240 meters) surrounded by mountains, atmospheric inversions are frequent. The combination of high altitude and low latitude provide ample sunlight for the photochemical reactions which produce smog. In addition, the altitude reduces the efficiency of internal combustion engines, increasing their emissions of HC by 30% and CO by 100% relative to sea level.[56]

Particulates and ozone present the biggest air quality problems in the MCMA (Table 10). Next in order of severity are CO and SO_2. But because its health effects are exacerbated by Mexico City's altitude, and the Mexican standards are relatively lax, the CO problem may be worse than is indicated by the frequency with which Mexican standards are exceeded.[57]

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[53] Sebastian (1990), "Mexico City diagnostic," p. 5.
[54] DF (1991), p. 2-22.
[55] DF (1991), p. 4-15; and Harris and Puente (1990), p. 506.
[56] Harris and Puente (1990), p. 506.
[57] DF (1991), p. 7-26.

Table 10
Relative Air Quality in the MCMA[58]

Pollutant	WHO std	EPA std	Mexican std	% of time exceeding Mexican std	Max concentration	Annual arithmetic avg
O_3 (ppm) 1 hour	0.10	0.12	0.11	88%	0.44	--
TSP $\mu g/m^3$ 24 hour	260	260	275	--	1300	520*
CO (ppm) 8 hour	9	9	13	20%	24	--
NO_2 (ppm) 1 hour	0.21	--	0.2	6%	.32	0.13
SO_2 (ppm) 24 hour	--	0.14	0.13	1%	.14	0.061
Pb $\mu g/m^3$ qtly avg	0.5-1.0@	1.5	--	--	2.4	1.8

* Annual geometric mean.
@ Yearly average range.

Mexico City is also burdened by several more toxic air pollutants, such as lead and fecal dust. Some of these have obvious direct technical solutions. To get lead out of the air, Mexico has begun introducing unleaded gasoline. To eliminate airborne fecal dust, sewers need to be built to serve more of the population. Currently 30% of Mexico City residents are without sewerage.[59]

Until recently, virtually no abatement equipment had been installed by either transportation or industry. As a result, Mexico City has often been called the most polluted city in the world. (This label is used lightly, and has been attached to many cities.) For some pollutants, ambient levels may be six hundred times the accepted standard for humans, and air pollution is thought to cause or contribute to 90 percent of the region's respiratory illnesses.[60] As a result of the mounting crisis (and partly as a result of bilateral pressures involved with the Free Trade Agreement), a consensus in favor of environmental regulation finally seems to have developed.

Sources of Air Pollution

Substantial amounts of pollution are emitted by 4000 of the approximately 30,000 industrial establishments in Mexico City, due to their size and the nature of their processes. The worst offenders are petroleum refineries, petrochemical plants, iron and steel foundries, non-metallic mineral extraction

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[58] DF (1991), pp. 7-9 to 7-24; WHO (1988), pp. 63 and 67.
[59] Schteingart (1989), p. 43.
[60] Schteingart (1989), p. 43.

and processing, pulp and paper plants, and lead, aluminum, grey iron, copper, and alloy foundries. For many of these industries, abatement equipment is either absent or deficient.[61]

A few of the worst industrial sources are remarkably concentrated (Table 12). Power generation by the Jorge Luque and Valle de Mexico plants contributes 9 percent of air pollution from industry, commercial, and service sources, and 28 percent of SO_2 from all sources. Six percent of all VOC emissions come from fuel production, storage, and distribution.[62] But the rest of the stationary sources are dispersed widely. Waste disposal accounts for 20% of VOCs emitted from all sources. Service facilities, classified under stationary area sources, include twelve thousand public baths, bakeries, hotels, hospitals, and clubs. These sources use a variety of fuels including fuel oil, diesel and liquified petroleum gas (LPG), while dry cleaners use a number of organic solvents.

The bulk of Mexico City's air pollution, however, is generated by transportation. Mobile sources combined emit 76 percent of pollution in the MCMA, half from 2.6 million private vehicles, and half from 56,500 taxis, 7500 buses (of which 3500 are Ruta 100, the state-owned bus system), 54,500 collective vehicles, and 256,000 trucks.[63] A recent consultant's report (DF 1991, p.3-34) concluded that because earlier planning and technological choices favored highway-oriented modes, including buses and microbuses, attempts to reduce air pollution from mobile sources by reversing this trend would involve substantial costs.

Two technical issues dominate the transport problem. First, the gasoline burned by Mexico City's vehicles is not correctly manufactured for its altitude and low oxygen concentration. The resulting inefficient combustion causes excess pollution. Second, the diesel oil used by vehicles and industry contains unusually high sulfur concentrations. Desulfurization before combustion would reduce ambient SO_2 levels significantly.

To address the current air quality crisis in Mexico City, attention can be limited to a few sources. The two power plants and the refinery (since closed) combine for 6% of NO_x and 35% of SO_x. Miscellaneous industrial sources, a more difficult target, emit 13% of NO_x and 25% of SO_x. But despite these sources' high profiles and relative ease of regulation, controlling their emissions will not clean up Mexico's air enough or for long. The major target should be mobile source emissions which are too important and growing too fast to ignore. Private cars alone emit 25% of VOCs and 24% of NO_x, which combine to make ozone, Mexico City's worst pollutant, as well as 45% of CO. Other mobile sources, mostly trucks and buses, many of which are state owned, contribute about the same amount.

Policy Options

Use of economic incentives: market versus non-market policies

There is probably considerable variation in marginal abatement costs across sources in Mexico City. The fact that little abatement existed as of the late 1980s means that initial abatement will cost relatively little. Standards will not need to be stringent, relative to Los Angeles for example, and the cost-effectiveness gains from implementing market solutions may be large.

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[61] DF (1991), p. 2-31.
[62] DF (1991), p. 2-33.
[63] DF (1991), pp. 2-33 and 3-8.

On the other hand, some considerations do not favor the use of economic incentives as part of the solution in Mexico City. The public sector does play a role in many of the source categories. The large point sources and half the bus fleet are state-owned. In the long run, to stem the growth of vehicle miles travelled the public transport system must be improved. Where public sector enterprises cannot be assumed to minimize costs, incentive-based regulations will not necessarily be cost-effective. However, the largest source of air pollution in Mexico City--privately owned vehicles--will be amenable to the use of incentive-based policies.

Level of control: direct versus indirect policies

Unlike Los Angeles, Mexico City lacks a well-supported environmental regulator. Most analysts agree that Mexico City's environmental regulatory agency, SEDUE, does not have the skill to implement many of Mexico's current regulations, nor the ability to administer sophisticated direct instruments.[64] Its Secretary has complained that it lacks adequate financial resources, administrative mechanisms, and legal authority to perform its job satisfactorily.[65]

A further reason to doubt the applicability of direct instruments for pollution control in Mexico City is the variety and diffusion of emissions sources. Most emissions come either from mobile sources or from non-point industrial sources. A World Bank study concluded that:

> "apart from the current shortage of staff in a situation of strong budgetary constraints, the sheer scale of the problem involving more than one thousand plants included in contingency plans for air pollution emergency alert, hundreds of thousands of vehicle-trips in the city streets, and some very powerful industrial complexes raises serious questions about the feasibility of implementing the pollution control strategies through direct administrative controls."[66]

The only sources which present obvious targets for direct price, quantity or technology instruments are the two power plants and the PEMEX refinery. In fact, SEDUE closed the refinery in March 1991.

As in Los Angeles, ambient effects may also reduce the relative efficiency of direct instruments in this case. Vehicle emissions have different effects during morning rush hour and for weekend driving outside the city. Therefore emissions-based controls may not be most efficient even if they were feasible. Indirect controls, such as a downtown parking tax, may approximate ambient effects and damages more closely.

Control variable: price or quantity versus technology

In the short-run, Mexico City faces a crisis. There is little room for uncertainty in the quantity of pollution reduction. As a result, quantity or technology instruments dominate price instruments. Pollution reduction technologies which have been used in developed countries for years, such as catalysts, unleaded gasoline, and inspection equipment, might tempt Mexican authorities to impose technology

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[64] Harris and Puente (1990), p. 514.

[65] DuMars and Beltran Del Rio (1988), p. 807.

[66] Sebastian (1990), "Mexico City diagnostic," p. 39.

standards. Also, the two existing problems with Mexico City's transport fuels, high sulfur content and inefficient combustion at altitude, are appealing targets for technical controls. However, technology standards are not dynamically cost-effective. To mitigate this inefficiency, SEDUE might consider using quantity instruments where the standard is set according to currently available technology. This would allow industrial sources or vehicle manufacturers to comply with the regulations in the short run by installing available equipment and in the long run by developing alternative technologies.

For the few point sources that emit substantial pollution, direct non-incentive quantity or technology instruments are probably optimal. For the more diffuse industrial sources and the mobile sources, indirect incentive-based quantity or technology instruments make more sense if precision about pollution abatement is valued highly.

This discussion suggests that a combination of policies, differentiated by type of source, may be efficient. For point sources that are large polluters, such as the power plants, direct non-incentive based quantity or technology policies are efficient. For the non-point stationary sources and state-owned vehicles, non-incentive technology policies such as replacing engines and installing abatement equipment would be appropriate at least in the short run. Finally, for privately-owned vehicles, indirect incentive-based price instruments such as a gasoline tax would be cost-effective and administratively feasible. Currently, Mexican gasoline prices are among the lowest in the world (Table 11).

Table 11
Regular Unleaded Retail Gasoline Prices[67]
(January 1992)[a]

Country	$/gallon	tax
Italy	$4.55	$3.32
Japan	3.62	1.58
Netherlands	3.74	2.66
France	3.39	2.47
U.K.	3.06	1.94
Mexico	1.55	.14
U.S.A.	1.09	.34

[a] Except Netherlands (February 1992) and Mexico (November 1991).

Although fuel taxes will reduce the overall amount of driving and shift demand to other, possibly less polluting modes (depending on the demand elasticity), they will not induce car owners to install abatement equipment. Therefore, a fuel tax would have to be supplemented with other indirect policies--regulatory, such as mandatory emissions standards and inspection programs and retrofitting of high-use vehicles for cleaner fuels, as well as incentive-based, including automobile taxes based on emissions characteristics.[68]

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[67] Energy Detente, June 28 and July 18, 1991.

[68] For a detailed cost-effectiveness analysis of many of these options with and without a fuel tax, see Eskeland (1991).

What has Mexico done?

Until recently, most attempts to combat Mexico City's growing air quality problem had failed. The first National Urban Development Plan began in 1978. Despite its goal to discourage the growth of the MCMA, the federal share of investment in the MCMA grew from 1984 to 1988, which may indicate rising subsidies for locating in Mexico City. Recent plans continue to profess the intention to move business away from Mexico City.[69] SEDUE operates a computerized network of 25 automatic air quality monitoring stations throughout Mexico City. Unfortunately, SEDUE considers less than 80 percent of the data they generate to be valid, less than 50 percent from some stations. Plans for an upgrade of the systems do exist.[70]

The policies that have been effective are direct, largely non-incentive based, and applied to stationary point sources. Since 1982-83, Mexico has stopped licensing new manufacturing in the DF. In addition, 17 industries have been singled out for encouragement to move outside the city. Relocation incentives include the construction of approximately 350 industrial parks, the creation of free industrial zones at the southern and northern borders of the city, and the provision of training, administration, and credit facilities.[71] Since 1986, PEMEX has produced a special light fuel oil with 3 percent sulfur (as opposed to 4.2 percent normally), which now has 42 percent of the market in the MCMA.

In 1989 Mexico launched a three-stage attack on air pollution because air quality was continuing to deteriorate (Table 4). So far it has been made up entirely of non-incentive and largely indirect measures. The "Emergency" program ran from 1989 to 1990. In 1993, Mexico will be the first Latin American country to build cars to U.S. emissions standards.[72] A vehicle inspection program, implemented in 1989, requires annual checks on all gasoline and diesel vehicles. It is virtually identical to the first U.S. programs of the early 1980s.[73] Mexico appears to be headed in the direction that the U.S. has taken with regard to mobile sources.

Additional mobile source controls include the replacement of engines for taxis and 3500 Ruta 100 city buses, the Hoy no Circula (HNC) program that restricts automobile use, gas retrofits for high-use vehicles, gasoline additives to improve vehicle efficiency at altitude, and the expulsion of cars from 50 square blocks in the city center. The HNC program is particularly noteworthy because it provides an example of an indirect policy where ill-considered incentives have produced perverse results. Under HNC, each car is banned from driving for one weekday. The plan has backfired, with families having purchased second cars, usually older and dirtier, rather than face time on Mexico City's crowded public transport system.

Many of these non-incentive indirect measures, including vehicle inspections and mandated technology have been used in Los Angeles. In the face of growing demand for driving, these have not cleaned Los Angeles' air and they will not be enough to improve Mexico City's. To reduce the demand for driving, it may be more effective for Mexico City to combine these with a policy that Los Angeles has not adopted--raise gasoline taxes in line with those in Western Europe.

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[69] DF (1991), pp. 5-1 and 5-17 to 5-22.
[70] DF (1991), p. 2-35.
[71] Sebastian (1990), "Mexico City diagnostic," p. 35.
[72] Sebastian (1990), "Mexico City diagnostic," p. 36.
[73] DF (1991), p. 1.

For point sources, recent efforts include closure of the PEMEX refinery, mandatory fuel switching for dozens of industries, and gas substitution at power plants. SEDUE has also signed agreements with pollution-intensive industries, so that when the air pollution reaches critical levels, SEDUE can close factories temporarily. By 1990 there had been several such closures.[74] As noted before, this type of command and control policy has been advocated as a complement to incentive-based instruments, since it provides more flexible reactions to unpredictable weather changes.

Currently Mexico is in the middle of its "Integrated" or "Short-term" program, which will run through 1992. It will be followed by a "Medium-term" program, which will run from 1992 through 1997. Table 14 compares Mexico City's plan with SCAQMD's. Regulators in neither city plan to use incentives extensively. Not surprisingly, Los Angeles' technological plans appear to be many years ahead of Mexico City's. While Mexico will be building sewers and solid waste dumps, Los Angeles hopes to be achieving drastic reductions in transportation emissions from unspecified technological advances. It is unclear as to which city's plans are more realistic. The second noticeable difference between the two plans is that Los Angeles has given up on public transport options while Mexico City has not. Both cities are currently investing in public transportation, but only Mexico City has considered this investment a part of its campaign against air pollution. Again, it is difficult to tell which is more realistic.

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[74] Sebastian (1990), "Mexico City diagnostic," p. 25.

Table 12

EMISSIONS INVENTORY FOR MEXICO CITY METRO AREA
(tons/year)

	VOC	PM	NOx	SOx	CO
Stationary point sources:					
Power plants (2)	113	3,545	6,613	58,247	560
Oil refinery (1)	6,402	1,154	3,233	14,781	52,645
Oil marketing & storage	25,328	0	0	0	0
Foundries (39)	0	1,279	83	455	6,770
Non-metallic minerals (12)	49	4,123	5,512	13,254	18
Petrochemical plants (23)	3,511	2,593	0	4	7,131
Pulp & paper plant (1)	0	35	0	724	0
Industrial comb. sources	191	2,212	23,288	51,295	1,897
TOTAL:	35,594	14,941	38,729	138,760	69,021
Stationary Area Sources:					
Commercial and services	121	2,469	3,988	22,060	466
Burning wastes	7,456	3,578	785	131	22,227
Dry cleaning	7,838	0	0	0	0
Architectural coating	6,148	0	0	0	0
Other coating	17,176	0	0	0	0
Printing processes	2,981	0	0	0	0
Degreasing agents	2,087	0	0	0	0
Agricultural activities	0	5,293	0	0	0
Re-entrained road dust	0	224,973	0	0	0
Forest fires	881	623	146	0	5,135
Waste disposal (old and new)	115,619	0	0	0	0
TOTAL:	160,307	236,936	4,919	22,191	27,828
Mobile Sources:					
Private cars	141,059	4,398	41,976	3,557	1,328,133
Taxis	31,986	997	9,518	806	301,162
Collectives	33,904	945	8,412	554	338,589
Light gas	8,844	117	1,647	301	65,892
Buses	7,737	841	26,320	18,286	18,872
Transport trucks	67,864	1,186	16,994	2,760	779,585
Diesel heavy trucks	7,293	923	26,126	955	16,515
Other mobile sources	36	26	192	19	139
Aircraft operations	1,657	116	2,506	232	4,901
TOTAL:	300,380	9,549	133,691	*44,774	2,853,788
Natural Sources, TOTAL:	75,820	189,173	0	0	0
TOTAL ALL SOURCES:	572,101	450,599	177,339	205,725	2,950,637

* This column does not add due to an error in the source.
Source: DF (1991), pp. 2-36, 7-31, 7-35, 7-45, 7-48, 7-71.

Table 13

EMISSIONS INVENTORY FOR MEXICO CITY METRO AREA
(percent of total)

	VOC	PM	NOx	SOx	CO
Stationary point sources:	----	----	----	----	----
Power plants (2)	0%	1%	4%	28%	0%
Oil refinery (1)	1%	0%	2%	7%	2%
Oil marketing & storage	4%	0%	0%	0%	0%
Foundries (39)	0%	0%	0%	0%	0%
Non-metallic minerals (12)	0%	1%	3%	6%	0%
Petrochemical plants (23)	1%	1%	0%	0%	0%
Pulp & paper plant (1)	0%	0%	0%	0%	0%
Industrial comb. sources	0%	0%	13%	25%	0%
TOTAL:	6%	3%	22%	67%	2%
Stationary Area Sources:					
Commercial and services	0%	1%	2%	11%	0%
Burning wastes	1%	1%	0%	0%	1%
Dry cleaning	1%	0%	0%	0%	0%
Architectural coating	1%	0%	0%	0%	0%
Other coating	3%	0%	0%	0%	0%
Printing processes	1%	0%	0%	0%	0%
Degreasing agents	0%	0%	0%	0%	0%
Agricultural activities	0%	1%	0%	0%	0%
Re-entrained road dust	0%	50%	0%	0%	0%
Forest fires	0%	0%	0%	0%	0%
Waste disposal (old and new)	20%	0%	0%	0%	0%
TOTAL:	28%	53%	3%	11%	1%
Mobile Sources:					
Private cars	25%	1%	24%	2%	45%
Taxis	6%	0%	5%	0%	10%
Collectives	6%	0%	5%	0%	11%
Light gas	2%	0%	1%	0%	2%
Buses	1%	0%	15%	9%	1%
Transport trucks	12%	0%	10%	1%	26%
Diesel heavy trucks	1%	0%	15%	0%	1%
Other mobile sources	0%	0%	0%	0%	0%
Aircraft operations	0%	0%	1%	0%	0%
TOTAL:	53%	2%	75%	* 22%	97%
Natural Sources, TOTAL:	13%	42%	0%	0%	0%
TOTAL ALL SOURCES:	100%	100%	100%	100%	100%

* This column does not add due to an error in the source.
Source: DF (1991), pp. 2-36, 7-31, 7-35, 7-45, 7-71.

Table 14
Comparing Two Pollution Control Plans*

LOS ANGELES	MEXICO CITY
Tier I (by 1993)	Emergency program (1989-90)
• new solvent technologies • technologies for petroleum production & distribution • add on controls for industrial processes • energy conservation measures • pesticide restrictions • offsetting new sources • best available retrofit control technology • phase out fuel oil and coal use • tighten new source review stds • motor vehicle controls • urban transport planning	• emissions stds for new 1991 vehicles • Hoy no Circula • oxygenate gasoline (5% MBTE) • inspection & maintenance • fuel switching oil-fired power plants to natural gas • replacement of bus engines • expanded emissions monitoring
Tier II (by 2000)	Short-term program (1990-1992)
• 40% use of low-emitting passenger vehicles • 70% low-emitting freight vehicles • 100% low-emitting transit buses • 50% reduction in off-road mobile emissions • 50% reduction in solvent & coating emissions • 50% reduction in fuel combustion emissions	• improve quality of oil-based fuels • restructure urban transport • modernize production technologies • improve vehicle and industry emissions monitoring • ban new polluting and relocate existing polluting • protect and recover fragile areas • build sewers and solid waste dump
Tier III	Medium-term program (1992-97)
• extremely low-emitting technologies for vehicles	• study to control VOCs in solvents/coatings, emissions from industry, transport, public sector, land use, other mobile • traffic control, I/M, CNG & LPG fleets • fuel reformation • public transportation

*SCAQMD (1989), pp. 15-16, 21-27; DF (1991), pp. 6-1 to 6-2.

CUBATAO

Thirty years ago the district of Cubatao, 162 sq. km. in the state of Sao Paulo, Brazil, was a sparsely populated agrarian region devoted mostly to banana plantations. But because it is 20 km west of Santos (Brazil's busiest port) and 69 km from Sao Paulo, one of the largest cities in the world, Cubatao was targeted for development as an industrial center.[75]

Today Cubatao has a population of about 100,000 and contains Brazil's largest concentration of petrochemical activity, as well as steel mills and other heavy industry. In 1983 the region produced a major portion of Brazil's industrial intermediate goods, amounting to $1 billion in exports.

Table 15
Cubatao Produces Much of Brazil's Industrial Intermediate Goods[76]

Product	Percent of Brazil's total (1983)
nitrogen	47 %
steel	40
fertilizers	38
phosphoric acid	32
polyethylene	30
chlorosoda	25
bottled gas	18
gasoline	12

Unfortunately for the local environment, Cubatao's atmosphere does not have the absorptive capacity to handle the air pollution emitted by that much industry. Like Los Angeles, it lies between an ocean and mountains (the Atlantic and Serra do Mar in this case). On winter mornings, surface inversions are frequent, trapping air pollutants near ground level. Despite this, growth proceeded unchecked and unplanned. By 1981 Cubatao had become known as "the valley of death" and "the most polluted place on earth." No birds or insects lived there. A member of the city council claimed not to have seen a star for 20 years. The city had only one kilometer of sewerage, and no garbage collection. Respiratory diseases flourished, and the infant mortality rate in the first year of life was 35 percent, 10 times the Sao Paulo state average.[77] In 1980, average daily TSP was 1200 $\mu g/m^3$, well in excess of Sao Paulo state standards in which 625 micrograms constitute a state of "alert," and 875 an "emergency."[78]

Atmospheric studies have shown that Cubatao is really divided into two separate air basins: Cubatao-Centro and Cubatao-Vila Parisi.[79] Hit hardest by the pollution were the 15,000 people living in Vila Parisi, an impoverished neighborhood adjacent to many of the sources, notably fertilizer companies and steel mills.[80] Air quality standards for particulates and ozone in Vila Parisi were violated 72 percent of the time from 1984 to 1986.

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[75] Nogueira (1988), p. 10.
[76] Findley (1988), p. 52.
[77] Findley (1988), p. 52.
[78] Findley (1988) pp. 53; and CETESB (1986), p. 20.
[79] CETESB (1986), p. 8.
[80] CETESB (1986), p. 11.

In addition to causing health problems, the air pollution produced acidic rains that killed vegetation on the slopes of Serra do Mar. The potential for landslides threatened the safety of 35,000 people living in shanties on the slopes, as well as the highways and the railroads connecting Cubatao to Sao Paulo and the rest of Brazil.[81]

In 1980 the head of SEMA (the federal Special Secretariat of the Environment), suggested relocating the people of Vila Parisi. The Vila Parisi residents objected. They preferred that the state control pollution sources sufficiently for them to continue to live close to work. The turning point came in 1984. In February, a Petrobras pipeline under Vila Soco (another of Cubatao's slums) burst, leaking 700,000 liters of gas and causing a fire that destroyed 1000 homes and killed 100 residents. In September, an atmospheric inversion caused such pollution that the governor of Sao Paulo ordered the evacuation of Vila Parisi and the shutdown of nine industries. Finally, in January of 1985 a fertilizer plant in Vila Parisi leaked ammonia, again forcing evacuation. By then, Vila Parisi residents had changed their minds--they wanted to be relocated.

As Table 16 shows, emissions in Cubatao seem to have peaked in the mid-1980's:

Table 16
Emissions of Air Pollutants in Cubatao[82]

	(tons per day)		
Pollutant	1980	1984	1988
TSP	148	236.6	25.5
SO_2	182	78.4	17.8
NO_x	41	61.1*	18.8
HC	31	90.0	7.2

*Nitrogen dioxide, NO_2.

Sources of air pollution

World Bank studies of pollution in Cubatao concur that industry is almost completely responsible for the air quality problem there. In fact, no studies even bother cataloguing mobile or area sources. As a result, policy instruments aimed only at stationary point sources need to be considered.

Sao Paulo's state environmental regulator, CETESB, has identified 18 priority sources of air pollution. These include petrochemical plants, fertilizer factories, and processors of non-metallic minerals, paper and pulp, and cement.[83] Of these, 4 were public enterprises, 6 were multinational corporations, and 8 were privately owned domestic companies. The bulk of the pollutants were emitted by the state enterprises, including over 95 percent of the NO_2 and HC, over 75 percent of the SO_2, and

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[81] Findley (1988).

[82] 1980 data are from Findley (1988), p. 53; 1984 data are from CETESB (1986), p. 40; and 1988 data are from CETESB (1989), p. 16.

[83] CETESB (1987), p. 16.

about 50 percent of the TSP. Private Brazilian companies emitted less than 1 percent of the NO_2 and HC, less than 10 percent of the SO_2, and less than 50 percent of the TSP (Table 17).

Policy options

Two interesting questions arise in the context of this study. First, given the life-threatening emergency that existed in 1984, what were the efficient policies to adopt? Second, have these policies changed given the improved air quality in Cubatao today?

Use of economic incentives: market versus non-market policies

Public sector enterprises present the main obstacle to using incentive-based regulations for air pollution control throughout Brazil and particularly in Cubatao. There is very little private domestic ownership of heavy and pollution-intensive industries such as steel, automobiles, oil, and chemicals, which are dominated by multinationals and state-owned enterprises.[84] In Cubatao, state enterprises are particularly important. Out of 230 sources of air pollution in Cubatao, 95 were located in two firms owned by the federal government: PETROBRAS, the petroleum company; and COSIPA, the steel company.[85]

As noted before, state-owned sources will not respond to incentive-based instruments to the extent that cost minimization does not guide their decision making. The other main category of sources--multinationals likely do minimize costs, and may therefore be amenable to the use of incentive-based policies.

Level of control: direct versus indirect policies

CETESB appears quite capable of monitoring direct policies applied to large stationary sources. In 1986, it had over 2000 employees, including 650 professionals, and a budget of $33 million--90 percent from Sao Paulo state and 10 percent from consulting revenues.[86] It maintains modern laboratories staffed by 140 technicians and 120 professionals, which give it the ability to examine all types of samples and determine the pollutants present and likely sources. In addition, CETESB maintains a continuous air quality monitoring system, including three monitors in Cubatao. In order to maintain its capabilities, its staff are trained continuously in new technologies and procedures, and worn-out or obsolete monitoring and laboratory equipment is replaced. In this respect it is unique in Latin America and among developing countries.

Because only 18 large industrial plants comprising 230 individual sources were responsible for virtually all emissions in Cubatao,[87] the number of sources poses no great barrier to using direct regulations. Rather, the costs of using direct instruments would stem mainly from the difficulty of monitoring emissions. However, CETESB's competence as a regulator and the relatively small number of stationary point sources makes its air pollution problem well suited to direct regulation.

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[84] Findley (1988), p. 29.

[85] CETESB (1987).

[86] One problem with CETESB might be a conflict between its consulting role and its regulatory role. (Findley [1988]).

[87] CETESB "Acao da CETESB em Cubatao," 1989.

Control variable: price or quantity versus technology

The state of emergency that existed in 1984 suggests that at the time, quantity restrictions would have dominated price instruments. Concentrations of several air pollutants were high enough to be quite toxic, especially in Vila Parisi. The choice then, is limited to direct non-incentive quantity or technology instruments. Among these, quantity instruments would be inefficient because they do not equate marginal abatement costs across sources. However, technology instruments are inefficient because they do not necessarily minimize abatement costs across various methods of controlling emissions even for a single source. Given that in 1984 industries in Cubatao were doing virtually no abatement, and that CETESB had been researching abatement technologies for years, CETESB may have had more technological expertise than individual firms. This suggests the tentative conclusion that technology instruments might dominate quantity instruments.

Would instrument choice differ today, when the most egregious sources have been eradicated and Cubatao appears to be habitable? The number of sources is still small, CETESB still capable, and the public sector firms are still important sources of emissions. So nothing has changed to make direct non-incentive approaches less cost-effective than they were five years ago. Perhaps, however, with abatement technology in place and the emergency situation contained, it might now be more efficient to control the quantity of emissions rather than mandate control technologies.

What has Brazil done?

As in other countries, in Brazil there has been a reversal of attitudes towards the environment. At the 1972 United Nations Environmental Conference in Stockholm, the Brazilian Minister of the Interior said "a country that has not yet achieved a minimal standard of living is not in a position to spend its valuable resources protecting the environment."[88] Yet today Brazil's environmental regulatory framework looks much like that of the United States. The federal government sets air and water quality standards similar to those in the U.S., which the states are free to strengthen. The states set emissions limitations and equipment requirements that apply to individual sources. The two levels of government then share responsibility for enforcement.[89]

Because detailed pollution control legislation did not exist before 1976, CETESB devoted its first several years to developing abatement technology, training personnel, and monitoring ambient pollution. Since then, its role has expanded greatly. Today, the state has the power to (1) subsidize investment in pollution abatement or relocation to less sensitive areas, (2) fine excess pollution, (3) suspend the operations of non-complying facilities, (4) remove subsidies or tax incentives granted by Sao Paulo or the federal government, and (5) withdraw government financing from facilities.[90] The legal authority seems to be in place to enforce any type of regulation.

Until recently, CETESB focused primarily on TSP and SO_x from industrial sources. In 1980 CETESB convinced Petrobras and ESSO to agree to deliver only low sulfur fuel to Sao Paulo state from May to September (the winter months when absorptive capacity is lowest). This may explain the drop in SO_2 emissions in Cubatao from 1980 to 1984 (Table 16). Two years later, CETESB stopped issuing

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[88] Worcman (1990), p. 45.
[89] Findley (1988).
[90] Findley (1988).

construction licenses for new oil-burning sources in Sao Paulo.[91] Starting in 1985, state and local officials began taking actions to clean up Cubatao. Daily fines were imposed on several companies until toxic waste sites were made safe. Much of the regulatory focus was on steel mills, which now have higher stacks and contribute less pollution to the Vila Parisi area.[92] Parts of Vila Parisi were razed, and its occupants given public housing elsewhere in Cubatao. With the help of loans from the World Bank about 60 companies in Sao Paulo state, mostly in Cubatao, invested over $100 million in pollution control projects costing on average $1.9 million each. Many of the projects converted oil-fired boilers to electricity in order to reduce SO_2 emissions.

As seemed optimal, CETESB used mostly direct non-incentive technology approaches in Cubatao. State enterprises, which were responsible for most of the emissions initially, cleaned up the most. However, they are still the largest of Cubatao's polluters (Table 17). The results of these policies, by the end of the decade, have been surprisingly good. In 1989, CETESB reported that of the 320 (air and water) pollution sources among the 25 major industries in Cubatao, 249 (76%) were under control, 34 sources were on schedule for control, and the remaining 37 sources were behind schedule. In March 1987, Rio's leading newspaper described Cubatao as "cured," citing the evidence presented in Table 18. Ambient air quality has undoubtedly improved--at least in terms of reducing instances of dangerously high pollution (Table 19).

Table 17
State Enterprises Cleaned up Most in Cubatao[93]

	State-owned (4)		Multinationals (6)		Domestic private (8)		Total
	tpd	%	tpd	%	tpd	%	tpd
1984							
NO_2	58.8	97.4	1.0	1.7	.5	.9	60.1
TSP	157.7	47.8	27.3	8.6	138.5	43.6	317.5
SO_2	61.0	78.6	10.7	13.7	5.9	7.6	77.6
HC	62.4	96.4	2.0	3.2	.3	.4	64.7
Recently							
NO_2	44.9	96.7	1.0	2.1	.5	1.2	46.4
TSP	68.0	80.0	3.5	4.2	13.5	15.9	85.0
SO_2	32.3	66.9	10.1	20.9	5.9	12.2	48.3
HC	9.8	95.3	.2	2.2	.3	2.5	10.3
% change							
NO_2	-23.3 %		0.0 %		0.0 %		-22.7 %
TSP	-55.2 %		-87.1 %		-90.2 %		-73.2 %
SO_2	-47.0 %		-5.1 %		0.0 %		-37.7 %
HC	-84.3 %		-88.9 %		0.0 %		-84.1 %

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[91] Findley (1988).
[92] CETESB (1986), p. 11.
[93] Facsimile from CETESB.

Table 18
Air Pollutant Emissions in Cubatao were Quickly Controlled[94]

Pollutant	1983 (tons per day)	1987 (tons per day)
TSP	236	33
NO_x	78	11
fluoride	90	12

Table 19
Episodes of Poor Air Quality in Cubatao Decreased[95]

Level of Pollution	1984	1985	1986	1987	1988
"Alert"	16	14	6	4	3
"Emergency"	1	1	0	0	0
TOTAL	17	15	6	4	3

Recent events cast some doubt on the extent of Cubatao's recovery. In July 1991, ambient particulate concentrations in Vila Parisi reached 2000 $\mu g/m^2$ due to a thermal inversion. CETESB responded by closing 8 of the local industries, mostly producers of fertilizer. By the end of the day the particulate concentration had fallen to 150 $\mu g/m^2$. So now CETESB faces two problems in Cubatao. It has to ensure that air quality does not worsen as Brazil's economy grows and demands more industrial inputs. CETESB must also examine the extent to which air pollution has been cleaned up by transferring pollution to other environmental media. Although Cubatao's factories no longer emit as much waste into the air, these could be ending up either in surface water or in landfills and have the potential to worsen water pollution or create hazardous waste problems in the future.

ANKARA

Like all the cities studied here, Ankara lies in a setting that is not conducive to dispersing large amounts of air pollutants. Mountains rise 400 meters above the city on three sides, and Ankara itself is at moderately high altitude (900 meters). Light wind speeds and frequent atmospheric inversions keep pollutants in high concentrations for long periods.[96] In addition, Ankara has become famous for its London-type fogs, which are exacerbated by particulates from burning poor quality fuels.[97]

Before the 1960s, when Ankara's population did not exceed 600,000, air pollution was not a problem. But today, with its population having risen above 2 million, and expected to grow by 2.5-3.0 percent annually for many years, Ankara's air quality is cause for concern.[98] Moreover, Turkey's

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[94] Findley (1988), p. 63.

[95] CETESB. "Acao da CETESB em Cubatao" mimeograph 1989, p. 9.

[96] Altaban and Guvenc (1990), p. 152.

[97] EPFT (1989), p. 44.

[98] Altaban and Guvenc (1990), pp. 152, 157.

application to join the European Community (EC) has brought its air pollution regulations under greater scrutiny and led to calls for remedial action .[99]

Of the cities studied here, Ankara has the poorest available ambient air quality information. Only SO_2 and TSP are monitored adequately. Ambient levels of ozone, HC, CO, Pb, and NO_x are unknown. While this poses obvious problems for the analysis here, it is not an unusual situation for a developing country. Environmental regulators often must deal with as little or even less data than are available for Ankara.

Table 20
Relative Air Quality in Ankara[100]

Pollutant	WHO std	EPA std	Turkish std	3-month avg 1984/5	Max 24-hr concentration
SO_2 ($\mu g/m^3$) 24 hour	125	365	400	350-900	1000-2000
PM_{10} ($\mu g/m^3$) 24 hour	70	150	300-400		
TSP ($\mu g/m^3$) 24 hour	125	260		159-227	500+

Sources of air pollution

Emissions data for Ankara are barely better than the air quality data. From what little is known about the relative contributions from various broad categories of sources, stationary non-point sources appear to emit most of the pollution.

Table 21
Estimated Emissions In Ankara from Combustion[101] (1990)

Pollutant	Transport (tons/yr)	Home Heating (tons/yr)
TSP	1160	20,100
SO_2*	870-3151*	56,500-58,510
NO_x	252,290	3650
HC	54,000	5700
CO	311,650	27,700

* Emissions during the winter of 1984-85.

There is very little industry in Ankara. Large point sources of pollution are limited to a cement factory, a few asphalt preparation plants, a sugar plant, a gunpowder factory, two gas plants, and a tractor

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[99] Plinke, et. al. (1990), p. 75.

[100] Sebastian (1990), "Ankara diagnostic," pp. 15, 20; notes of Wendy Ayres.

[101] Sebastian (1990), "Ankara diagnostic," p. 8.

factory. Industry employs only 12.5% of Ankara's labor force, compared to 75% for social service and commercial, and 4.5% for agriculture.[102]

Ankara also has relatively few motor vehicles. The density of the city, forced in part by the mountains surrounding it, limits the possible commuting time to below the average for cities of its type.[103] In 1983 Ankara had only 185,000 motor vehicles, but the number has been growing by 10% a year.[104] At this rate, Ankara would have over a million vehicles by 2000, and a potentially serious transportation-related air pollution problem.

Currently however, Ankara's air quality problems appear to stem not from industry or transport, but from its energy sector. Since the initiation of Turkey's New Economic Plan in 1980, rapid economic growth, urbanization, and a structural shift towards industry away from agriculture, have stimulated large increases in energy demand. In recent years, Turkey's energy demand has grown faster than its GDP, causing the Turkish economy to become increasingly energy-intensive. One common measure of energy intensity--total primary energy requirements per unit of GDP--was 0.60 for Turkey compared with 0.32 for Western Europe.[105]

Ankara's energy sector is also relatively dirty. Domestic lignite, high in ash and sulfur and low in energy, is burned to produce electricity. Turkey's SO_2 emissions exemplify its pollution intensity. Per capita, Turkey emits less SO_2 than any EC country except Portugal. However, Turkey emits more SO_2 for each unit of primary energy consumed than twice the EC average, and more SO_2 per dollar of GDP than any other EC country.[106]

Only lately has there been a shift towards hydroelectric power and, starting in 1987, natural gas imports from the USSR.[107] This change should be a very important step towards decreasing pollution from the Turkish energy sector. Because Turkish energy is so pollution-intensive, pollution will rise faster with economic growth than it has in other countries.

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[102] Sebastian (1990), "Ankara diagnostic," p. 11; JICA (1986), p. 14.

[103] Altaban and Guvenc (1990), p. 153.

[104] JICA (1986), p. 123.

[105] Plinke, et. al. (1990), pp. 1, 76.

[106] Plinke, et. al. (1991), p. 7-9.

[107] Sebastian (1990), "Ankara diagnostic," p. 5.

Table 22
Turkey's Energy Sector is Pollution-Intensive[108]

Emissions	Turkey (1978)	F.R. Germany (1980)
Per capita (kg)		
SO_x	16	52
NO_x	8	50
TSP	3	12
Per unit primary energy (kg/TOE*)		
SO_x	26.9	16.0
NO_x	14.3	15.4
TSP	5.2	3.6

Table 23
Lignite is Pollution Intensive and Energy Inefficient[109]

	Turkish Lignite	Imported Coal
Sulfur Content (%)	1-6 %	0.8-1.0 %
Volatiles (%)	17-20 %	20-24 %
Ash (%)	10-41 %	4.5-6.5 %
Heat Content (Kcal/kg)	1000-5750	6000
Moisture (%)	3-50 %	8 %
Cost (Turkish lira/ton)	14,000	120,000

Forty-three percent of Turkey's energy requirements are met by imported oil (Table 24). Domestic lignite's share has risen to 20% from 10% in the 1970s, and imported hard coal produces another 9%. Hydroelectricity, natural gas from the USSR, and various non-commercial sources such as fuel wood and agricultural wastes provide the balance.[110]

Lignite, which constitutes 90% of all Turkish domestic coal production by weight (80% on an energy equivalence basis), has been promoted as a substitute for imported oil.[111] In 1983 industrial lignite prices were 91% of prices for equivalent imported coal. But thanks to price distortions, the power sector, which consumes 85% of the domestically produced lignite, paid only 68% of the cost of imported coal. In addition, a $10/ton tariff was applied to imports of hard coal in 1986.[112]

Within the energy sector, much of Ankara's air pollution is produced by space heating. Because lignite is burned by individual homes and businesses in the winter, this is when air quality levels are at

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[108] Plinke, et. al. (1990), p. 77.

[109] Sebastian (1990), "Ankara diagnostic," p. 23.

[110] Plinke, et. al. (1991), pp. 4-5.

[111] Plinke, et. al. (1991), p. 1.

[112] Kosmo (1989), pp. 30-32.

their worst.[113] During the winter of 1984/5, it is estimated that 90% of SO_2 emissions were from domestic and commercial coal and lignite burning for heat, 75% from lignite alone.[114] Though more lignite is burned in power plants than in homes, home heating is less efficient and more polluting.

There are many methods of reducing pollution from space heating. Some require substantial public infrastructure investments, and are thus only applicable to the long-run (LR). A few examples include

- pre-treating lignite before distribution,
- improving boiler/stove technology,
- substituting imported coal for natural gas (LR),
- providing district heating, possibly through cogeneration of steam from power plants (LR),
- insulating homes and businesses to reduce demand (LR).

In addition, developed countries have accumulated considerable knowledge about pollution abatement technologies for coal-fired electric power plants. Unfortunately none of it is directly applicable to Turkey's brand of lignite.[115] Turkey's Environmental Agency cannot simply apply an existing control or process technology already being used elsewhere.

Analysts have assumed that Ankara's only air pollution problem stems from the combustion of lignite. This conclusion also deserves some caution due to the lack of available information. While we know that the transport sector is responsible for most of the NO_x, HC, and CO emitted, we do not know whether these pollutants exceed safe levels. If policy makers focus only on SO_2 and TSP, the two pollutants that are known to be out of compliance, they may be making a serious omission. But for a developing country such as Turkey, an error of commission such as regulating a pollutant for which emissions are within acceptable limits, may be equally costly. One necessary step, therefore, is to improve ambient monitoring for pollutants such as CO and HC. Another step is to recognize that even though pollution from transport is not problematic now, Ankara will likely face this problem in the future. Policy makers would be wise to begin dealing with it now, before more infrastructure is built for private gasoline- or diesel-powered vehicles.

Policy options

The ignorance about Ankara's current air quality makes policy choice even more difficult. Yet distinctions can still be drawn between general policy options that are available. Space heating, presumed to be the largest source of pollution, differs the most from the emissions sources that have been examined in the other city case studies. The power sector is state-run, and thus is most amenable to administrative fiat. Future transport sector pollution can be avoided through current investment in public transport infrastructure, and by adopting the technologies already in use in developed countries.

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[113] Plinke, et. al. (1990), p. 76.

[114] Sebastian (1990), "Ankara diagnostic," p. 22.

[115] Sebastian (1990), "Ankara diagnostic," p. 20.

The policy goals can be considered in stages. The first should be to remove the price distortions that favor the use of domestic lignite. The second stage should induce substitution away from high sulfur fuels for households, industry, and the power sector. A 1987 policy substituted lower sulfur South African and Chinese coal for domestic lignite, but did little to improve air quality. Illegal high sulfur coal reached Ankara in sufficient quantities to maintain ambient SO_x levels.[116] Even if it had not, population growth would likely soon overtake any gains from switching fuel types. In the long run, the policy goal should be to connect more areas of the city to a collective home heating infrastructure, especially natural gas and district heating.

Use of economic incentives: market versus non-market policies

For the household sector incentive-based policies may work well. A fuel tax based on sulfur content seems reasonable. Such a tax would also have an effect on Ankara's few industries, which are mainly large private sector companies.[117] The main problem with incentive-based policies would be its potentially regressive distributional effects. Unlike a gasoline tax in Mexico City, which would affect mainly the wealthiest in the population who account for most driving of automobiles, Ankara's poorest citizens may suffer most from a fuel tax. This objection could be surmounted by refunding the tax equally to all citizens or by using the revenues to finance progressive expenditures.

Level of control: direct versus indirect policies

Turkey's lack of regulatory ability, combined with the number of individual sources involved in home heating, suggest that direct policy instruments are probably infeasible. Turkey's monitoring and enforcement capacity will hopefully improve, but for the present, Ankara's pollution regulations will have to be indirect.

Control variable: price or quantity versus technology

The choice between price and quantity instruments is made difficult by the missing air quality information. Because regulators do not know how much pollution needs to be controlled, they do not know how stringent the regulations need to be, nor can they guess the benefits from improving the air quality. In other words, regulators have no information about the shapes of either the abatement cost or the environmental benefit functions.

Technology instruments are limited by the lack of knowledge about how to deal with Turkish lignite. Because existing technologies are unsuitable, new research will need to discover ways to burn lignite more cleanly. Eventually, this may be the best solution to Ankara's air pollution problem, and regulators must ensure that they do not sacrifice this goal for short-run gains.

What has Turkey done?

Turkey established an Undersecretariat of the Environment in 1978, passed the Environmental Protection Law in 1983, and the Regulation on the Protection of Air Quality, which set ambient standards

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[116] EPFT (1989), p. 44; Sebastian (1990), "Ankara diagnostic," p. 23.

[117] Kosmo (1989), p. 36.

for large sources of common pollutants, in 1986. Until now these laws have had little effect, as they have been dominated by policies aimed at rapid industrialization. As a result of its attempt to join the EC, Turkey has reformed its attitude towards environmental issues. However, only ambient SO_2 and TSP are monitored, and none of the standards is enforced.[118] With insufficient monitoring and non-existent enforcement, Turkish air quality standards cannot be taken seriously.

In 1986 a large scale program began converting small vehicles to diesel fuel.[119] This was a curious policy choice given the potentially disastrous consequences it could have for ambient SO_2 and particulate levels, which are already serious problems. While it would improve ambient ozone levels, this is not currently thought to be a problem. This policy was followed in 1989 by the introduction of a fledgling motor vehicle inspection program. While this step is important, its effectiveness should be examined and changes made in light of the experiences of other countries with such programs. As point sources are brought under control or leave Ankara, and as Ankara's population increases and becomes more prosperous, the relative contribution of vehicles to emissions will grow quickly. It seems wise to put regulatory institutions and control policies in place now, before the problem grows worse.

A high pressure natural gas network was financed by a World Bank loan. The loan also converted the old gas distribution network, which served about 100,000 users, from manufactured to natural gas. Future plans include extending natural gas service to an additional 200,000 customers. To the extent this system replaces the use of lignite for home heating, it will improve air quality.

So far, all of the steps Turkey has taken rely on public investments or actions by state-owned energy companies. If Ankara is to improve its air quality, policies must also begin to affect the behavior of individuals and firms. Further, as is beginning to happen in Mexico City, the belief that environmental goals stand in the way of development needs to be changed, while the institutional framework for designing and implementing environmental policies needs to be strengthened.

PART IV: CONCLUSION AND POSSIBLE EXTENSIONS

Conclusion

Economists examining the choice of environmental policies have emphasized the use of economic incentives, usually with reference to direct price or quantity instruments, and have ruled in favor of incentive-based policies. Many of these policy discussions, however, have confused the issue by comparing direct incentive-based policies to indirect non-incentive policies. Positive attributes of direct policies are then mistakenly used to demonstrate the superiority of incentive-based policies. Alternatively, incentive-based price instruments are compared to non-incentive quantity instruments, and the advantages of price (over quantity) instruments are cited to support the use of economic incentives. This paper has tried to separate these three issues (use of incentives, level of control, and control variable) in order to make general observations about policy choice.

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[118] Sebastian (1990), "Ankara diagnostic," p. 19.

[119] Sebastian (1990), "Ankara diagnostic," p. 16.

Despite the theoretical advantages of incentive-based direct policies, regulatory agencies in developed countries have relied almost exclusively on non-incentive direct policies. When environmental regulations were first enacted, incentive-based policies were less popular than they have since become, especially within the environmental movement. As a result, non-incentive policies remain on the books, in part due to the expense and political cost of changing policy regimes. Another reason non-incentive policies are more pervasive may be the transfer effect of such instruments. Incentive policies have been called (quite misleadingly) "polluter pays twice" policies by industry groups, who fear paying both the abatement costs and the taxes or permit prices. Apart from limited schemes in France, Japan and Southern California, emissions charges have not been used for air pollution even in OECD countries.[120]

Developing countries seem to have followed suit, but have failed to enforce many of their policies. The monitoring and enforcement costs associated with direct policies may be too high in developing countries. By not enforcing these, many of these countries might as well have had no environmental regulations at all. Recently, as a result of lethal environmental problems, at least two of the cities examined here have become serious about improving environmental quality. Their new attitudes towards environmental protection merit a fresh consideration of the policy choices available to them.

After analyzing efficient responses to the air pollution problem in four very different cities, the results that emerge are somewhat surprising (Table 25). For three of the cities, the efficient instruments selected by this (admittedly limited) exercise are similar: indirect incentive-based policies. Only Cubatao differs in that the efficient policy choice is probably direct non-incentive regulations.

Table 25
For Most Cities, the Efficient Policies are Similar

	Los Angeles	Mexico City	Cubatao	Ankara
pollutant	O_3, PM_{10}, CO	O_3, TSP, CO	TSP, SO_x, NO_2, HC	TSP, SO_x, ?
source	non-point	non-point	point	non-point
regulator	strong	weak	strong	weak
public polluters	no	some	most	few
toxicity	low	high	high	?
optimal policy ● incentive use ● control level ● control variable	● incentive/non- ● indirect ● --	● incentive/non- ● indirect ● quantity/technology	● non-incentive ● direct ● quantity/technology	● incentive ● indirect ● --

Though the conclusions shown in Table 25 favor indirect policies, several caveats must be noted. When indirect policies are preferred, combinations of such policies may be efficient. Indirect policies cannot simultaneously target the incentives to reduce waste generation, increase production efficiency, and reduce output in order to reduce pollution. A combination of indirect policies may have a better chance of reducing emissions. However, the regulatory costs of controlling additional variables have only

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[120] Opschoor and Vos (1989).

been noted in passing here. If these costs are high they may outweigh the cost of monitoring a single direct instrument.

Second, indirect regulations can be accompanied by perverse incentives, such as new source bias or lowered marginal costs of polluting. Efforts to offset these perverse incentives by regulating additional control variables may be subject to second-best problems: two regulations with opposite results can be worse than no regulation at all.

Third, this paper has not characterized fully the efficiency losses that arise from using indirect instruments and may, therefore, have biased policy choice in favor of indirect instruments. These losses depend on a complicated set of relationships, and their precise estimation in the context of environmental problems has not been attempted here.

Last, indirect instruments comprise the broadest policy category. Some of the cells in Table 2 contain a limited number of conceivable policies. The direct incentive-based price instrument cell, for example, contains only one instrument--emissions taxes. The indirect incentive-based price instrument cell, however, contains a large number of policies--taxes on inputs, outputs, complements, and substitutes. For this reason, by favoring indirect policies, part of the work in choosing efficient policies has been avoided. The remaining task--choosing the combination of indirect policies that minimizes this ill-defined efficiency loss--remains but would require substantially more detailed information than has been available in these case studies.

Several general lessons can also be learned from the cases examined. One involves the constraints imposed by previous policy decisions. Once decisions are made--whether to concentrate industry, to rely on private vehicles for transportation, to subsidize a particular energy source, or to use a certain environmental policy--they acquire a certain permanence. Capital is invested and workers are trained under the prevailing laws, and these are costly to change. Los Angeles cannot reverse its emphasis on the automobile; Brazil cannot easily move its industrial center away from Cubatao; Mexico cannot quickly reduce the concentration in its capital city ; and Turkey's development would suffer if domestic energy subsidies were removed abruptly. For this reason it is important to design policy with an eye towards longer-run concerns. It makes sense, for example, for cities such as Ankara to begin to enact policies to prevent mobile source air pollution from worsening over the next decades.

A related lesson involves the cost of waiting too long before addressing environmental issues. The three developing countries in this paper all placed economic growth above the environment on their policy agendas until too late. Now that the environment has become a critical issue, policy makers have been forced to use quantity-based instruments to reduce pollution, regardless of the cost involved. Delays in undertaking policies for environmental protection may increase the eventual cost of acting because many options are foreclosed.

A particularly important caveat to the discussion here is that the dangers of intermedia substitution of pollutants are often ignored. In places such as Cubatao, where air quality has been cleaned up, the improvement may have come at the expense of water quality, the accumulation of hazardous wastes, or the excessive use of natural resources. This raises the further issue of whether the principles for policy choice illustrated in this paper apply also to environmental problems other than air pollution, including possibilities for inter-media substitution. Some thoughts on this issue follow.

Applications to other Environmental Problems

Water pollution provides the closest parallel to urban air pollution. Effluents (into water) and emissions (into air) from factories and households are both the result of similar processes. Airsheds are similar in size and nature to water basins. The main difference is that with pollution of rivers and streams the externality goes in only one direction: upstream polluters impose costs upon downstream victims without bearing any return costs. All of the policy instruments considered for urban air pollution have analogues for water pollution control. Water pollution is easier to monitor and therefore more likely subject to direct controls. But because it has more pronounced ambient effects (there are no global or uniformly dispersed water pollutants), the cost-effectiveness advantage of direct policies is more ambiguous since even policies that target emissions are effectively indirect.

Hazardous materials, because they are easily transported, pose a special set of problems. There is a tension between the two policy goals of reducing the output of waste and ensuring its proper disposal. In the U.S., for instance, the manifest system required by RCRA tracks all off-site shipments of toxic waste, addressing only the latter goal. Any attempt to address waste generation directly by taxing or limiting toxic output would jeopardize the goals of RCRA because of its undesirable effects on compliance with the manifest system. Because hazardous wastes are easy to dump covertly, a direct policy may reduce the level of compliance and unintentionally increase the amount of improper disposal. Only a carefully designed deposit-refund scheme or indirect policies, such as feedstock taxes, could avoid this problem.

Natural resources, as the physical input to the production process, might appear to be the least likely to fit within the framework used above. Yet emissions have an analog in resource use. Both proxy for the cost to society, which is the truly direct control variable. Policies to reduce resource use to an optimal level can be direct or indirect; incentive or non-incentive; and price, quantity or technology-based. Table 26 below adapts Table 2 to illustrate policy alternatives for natural resource management.

Table 26
Alternative Policies to Reduce Natural Resource Extraction

		Price	Quantity	Technology
Incentive	Direct	resource extraction fee (stumpage fee)	tradable extraction permits (grazing permits)	tax on extraction technology (drift nets)
	Indirect	resource access tax	tradable access rights	tax on related technology (boats)
Non-incentive	Direct	--	extraction quotas	limits on extraction technology (strip mining)
	Indirect	--	access quotas	limits on related technology (boat permits)

For water pollution and hazardous wastes there are likely to be both public and private sector polluters. So the decision to use incentive-based policies should depend on the same set of considerations that was used in the case of urban air pollution. Natural resources are also likely to have large public sector enterprises involved in their extraction, as well as small informal sector "poachers." The former will respond best to direct non-incentive instruments, the latter to indirect incentive-based instruments.

By studying air pollution alone we have avoided the difficult question of intermedia substitution. Air pollution is also probably the least toxic and least long-lasting of the three pollution media. However, it is also the most politically charged. Air pollution is visible to everyone, affects everyone, and is in part caused by everyone. Individual consumers and businesses must bear most of the nominal costs of reducing air pollution. Water pollution, hazardous wastes, and natural resources are more often the bailiwick of governments, which will bear the cleanup costs. In the end, governments must face all the environmental problems together, for they are inextricably related. Accounting for intermedia substitution, however, requires that pollutants be compared across environmental problems, which in turn requires that the benefits of abatement be measured. This paper has focused on cost-effectiveness rather than efficiency precisely because those benefits are difficult to quantify accurately.

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