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Environmental Taxes and Policies for Developing Countries

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and
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Command-and-control environmental policies and market-based incentive policies differ in administrative cost, level of control over polluters, monitoring and compliance requirements, incentives for polluters to invest in pollution abatement, and fiscal consequences to the government.

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This paper — a product of the Public Economics Division, Policy Research Department — is part of a larger effort in the department to evaluate fiscal instruments for environmental protection. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Carlina Jones, room N10-063, extension 37699 (September 1993, 74 pages).

Increasing urbanization and industrialization can exacerbate pollution problems in developing countries. Tax revenues in developing countries are too low to support adequate infrastructure for treating and disposing of wastes, but the problem is also attributable to the classic problem of externalities in production and consumption. "Externalities" means that the costs of environmental degradation are not considered by the private decisionmakers undertaking the activities that cause the problems.

Two types of policies are commonly considered to correct this market failure and improve the allocation of resources: *command-and-control policies* (such as emission and abatement standards) and *market-based incentive policies* (such as emissions charges, taxes on production and consumption, and marketable pollution quotas), which raise the price of such activities for the perpetrators.

Market-based incentives theoretically reduce pollution at least cost and increase government revenues, but may require costly monitoring to be effective, and are usually implemented in an environment of imperfect information about the costs of abatement. Sometimes command-and-control policies make more economic sense in this environment.

Efficiency gains from curbing pollution in developing countries may be large. Some polluting activities are subsidized, so curtailing them brings both fiscal and environmental benefits. Taxing polluting inputs and outputs is a particularly attractive policy in developing countries, which often lack experience in administering and enforcing other types of environmental regulation. Corrective taxes make use of existing administrative structures and increase tax revenues, which can be spent on public goods to improve environmental quality (including treatment facilities for water and sewage, waste disposal, and sanitation) or can be used to reduce other taxes (which are often highly distortionary in countries with a narrow tax base).

Which goods and inputs to single out for corrective taxation depends on the main sources of pollution, which varies from country to country. Air pollution from vehicles is growing in many countries, where increased fuel taxes, perhaps coupled with improved regulations for vehicle maintenance, may be desirable. Higher taxes on high-sulphur coal would curb both industrial and household emissions of sulphur dioxide. Charges can be implemented for fixed-site easy-to-monitor industrial emissions. Subsidies to industries that cause pollution should be phased out and those industries should be subjected to higher-than-average tax rates.

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ENVIRONMENTAL TAXES AND POLICIES FOR DEVELOPING COUNTRIES

by

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Abstract and Executive Summary

Pollution problems in developing countries are of growing concern, particularly air and water pollution in rapidly growing urban areas. In large part this problem is attributable to the classic problem of externalities in production and consumption, and can be expected to grow worse with the success of industrial development policies. In addition there is inadequate public good infra-structure for treating and disposing of waste products. This lack is due in part to inadequate levels of tax revenue in developing countries.

"Externality" describes the fact that the costs of pollution and other forms of environmental degradation are not taken into consideration by the decision-makers undertaking activities which cause these problems. A rationale exists for government policies to correct this market failure and achieve a more efficient allocation of resources. These policies include command and control type policies which restrict the quantities of harmful activities and market-based incentive policies which raise the price of these activities to the perpetrators. The former include emission and abatement standards while the latter include emissions charges, taxes on production and consumption, and marketable pollution quotas.

The available instruments of environmental policy differ in terms of administrative cost, level of control over the actions of polluters, monitoring and compliance requirements, incentives for polluters to engage in pollution abatement investment, and in terms of the fiscal consequences to the government. The primary advantages of market based incentives is that they induce polluters to reduce pollution at least cost and that they may raise needed revenue for the government. However, environmental policies are usually implemented under circumstances of imperfect information about the costs of abatement, and also require costly monitoring activity by the government to be effective. In some cases these considerations favor the use of command and control type policies.

The efficiency gains to curbing pollution in developing economies may be large. In some cases, polluting activities are subsidized so curtailing these activities has fiscal benefits as well as environmental. The use of taxes on polluting inputs and outputs is a particularly attractive policy in developing countries which often lack experience with administering and enforcing other forms of environmental regulation. Corrective taxes make use of existing administrative structures and have the additional appeal of raising tax revenue. This revenue can be spent on public goods which improve environmental quality, or used to reduce other taxes which are often highly distortionary in developing economies because of their narrow tax base.

The actual goods and inputs that should be singled out for corrective taxation depends on the major sources of pollution which varies from country to country. However, vehicular-source air pollution is rapidly growing in many countries so a policy of increased fuel taxes, perhaps coupled with improved vehicle maintenance regulations, would be desirable in these countries. Also, increased taxes on high-sulphur coal would curb both industrial and household sources of sulphur dioxide pollution. Charges can be implemented for fixed-site, easy-to-monitor industrial emissions. Existing subsidies to industries which cause pollution should be phased out, and eventually these industries should be subject to higher than average tax rates. The tax revenues raised from corrective taxes and emissions charges should be used to finance investments in water and sewage treatment, and improvements in waste disposal and sanitation facilities.

I. Introduction: Pollution Problems in Developing Countries

In this section, we introduce the nature of some of the pollution problems currently facing developing countries. The stylized facts about pollution problems in developing countries presented here are designed to contribute to subsequent discussion about the environmental impacts of fiscal reforms and environmental policies. To determine the potential effectiveness of alternative policy instruments in dealing with the emerging pollution problems in developing countries, it is important to understand the source and nature of the pollution. We classify different types of environmental degradation according to whether they are best viewed as the result of market failure, the absence of a public good infrastructure for treating or abating the pollution, or the result of traditional household practices.

A. Air Pollution in Developing Countries

Air pollution, particularly in urban areas of developing countries, is of growing concern.[1] The sources of air pollution in developing countries are varied. In Mexico City, for example, the leading source of carbon monoxide, volatile organic compounds, and nitrous oxides is the emissions from motor vehicles. In China and India, air pollution from coal burning is at a very high level and attracting the attention of organizations like WHO. In these countries coal burning is used, not only for industrial processes and electricity generation, but also for domestic heating and

cooking. In contrast, in sub-Saharan African countries the use of biofuels for cooking is of greater concern. While it is difficult to draw a general picture of air pollution problems applicable to all developing countries, following Krupnick (1990) we attempt to describe the nature of air pollution problems common to many developing countries and note the difference relative to typical air pollution problems in more developed countries.

Air pollution is generated by point sources (e.g. manufacturing industries and electrical power plants), domestic sources (e.g., the burning of coal, firewood, or animal dung for heating and cooking), and mobile sources (e.g., cars, trucks, buses, and scooters). In many developing countries, the burning of coal for industrial processes and heating is a major source of suspended particulates and sulphur dioxide. We have already mentioned China and India in this regard. Many Eastern European countries suffer from the same industrial source of air pollution. For example, Poland meets three-fourths of its current energy needs through the combustion of locally mined coal (Jimenez and Eskeland, 1990). This compares unfavorably with Western Europe and the United States, which meets approximately only one-fourth of their energy requirements with coal-fired power plants. In Eastern Europe the burning of coal, and the resulting emission of sulphur dioxide and suspended particulates, contributes to serious respiratory and other health problems.

In rural areas of many developing countries, indoor air pollution poses a serious health threat, particularly to women and children. The use of coal, firewood, and animal dung for heating and cooking purposes, generates harmful particulates, carbon monoxide, and nitrous oxides. The level of exposure of individuals in the household to these indoor air pollutants depends on the type of fuel consumed, the degree of ventilation, and the type of stove used. Indoor air pollution in many urban areas throughout the developing world may not be as serious a problem as in rural areas because the urban population tends to rely upon relatively cleaner fuels (e.g., gas and coal briquettes) for cooking. As reported by Krupnick (1990), Smith (1987, 1988) provides a comprehensive discussion of the environmental consequences of household fuel consumption patterns in developing countries.[2]

Mobile sources of air pollution are a growing concern in many developing countries. In 1980, there were over thirty-five cities with populations exceeding four million, and by the year 2000, that number is expected to nearly double (World Health Organization, 1988). In many of these large cities, concentrations of air pollutants exceed WHO guidelines, and one of the major sources of conventional air pollutants are mobile sources.

Although auto ownership and use rates are much lower in developing countries than in developed countries, air pollution from mobile sources is rising rapidly. According to Krupnick

(1990), the United Nations (1989a) reports automobiles per 1000 people in developing country cities are generally less than fifty, as compared to between two and five hundred in developed countries. However, all developing countries reporting vehicle-kilometers-traveled in 1977 and 1987 experienced significant increases. In another United Nations study (1989b), it is reported that vehicle ownership is growing tremendously in many developing countries. In Indonesia vehicle ownership tripled from 1970 to 1981, in Brazil and Lagos it more than doubled, while in Nigeria vehicle ownership quintupled. In some cities, the problem may be critical in the near future. Vehicle ownership in Greater Bangkok is projected to increase from less than six-hundred thousand in 1989 to two million by the year 2006 (Jimenez and Eskeland, 1990).

The pollution problems attributable to mobile sources are particularly pronounced in some cities. Nuccio, Ornelas, and Restrepo (1990) report that atmospheric pollution in Mexico City is a grave problem. While industry contributes twenty percent of the annual total of atmospheric contaminants to the Metropolitan Zone of Mexico City -- approximately 393,000 tons of sulphur dioxide, 130,000 tons of hydrocarbons, 114,000 tons of carbon monoxide, 91,000 tons of nitric oxide, and 383,000 tons of diverse particulate matter -- these totals are dwarfed by the contribution from mobile sources, which account for over eighty percent of the tonnage emitted. The serious air pollution problem in Mexico City is the result of several factors: the growth in the number of

vehicles (which grew six times as fast as the population in the Federal district between 1940 and 1980), the types of fuel used in them, the lack of strict control over the maintenance of motors, and the atmospheric conditions prevailing in the area. The heavy reliance on leaded gasoline in Mexico City, and throughout the developing world, contributes to elevated lead levels in the blood of residents.[3]

In nearly all developing countries leaded gasoline is more common than unleaded. In contrast, nearly all developed countries have taken steps to phase out leaded gasoline. With the increased use of gasoline, lead is rising in the blood of people living in the industrial areas of developing countries (Krupnick, 1990). Young children are at the greatest risk of adverse effects due to lead. In reviewing studies conducted in a number of countries, Branigan (1988) notes that children with elevated blood lead levels tend to have slower rates of mental development. Lead has also been linked with high-blood pressure and heart attacks in men, and it is associated with decreased fertility, increased miscarriage, and neonatal morbidity in women.

Although there is much uncertainty about the link between conventional air pollutants and chronic respiratory disease and mortality, in part because dose-response relationships have not been quantitatively established in developing countries, there are reasons to be concerned about the health effects of air pollution

in the developing world. Krupnick (1990) notes that there is well-documented evidence that mortality from chronic pulmonary disease and acute respiratory infections are very high in developing countries, and that morbidity rates are high in urban areas of developing countries compared to rates in developed countries. He reports that, according to the Chinese Ministry of Public Health, the incidence of chronic bronchitis is ten times higher in Chinese cities polluted by coal emissions than in control areas, and children are more likely to have worse health if they live in a coal burning household. Rates of chronic bronchitis are three to four times as great in countries like India and Nepal as they are in the United States. Thomas (1985), in a study of air pollution in Brazil, reports that poor air quality in recent years may be significantly linked to mortality in San Paulo.

In summarizing the serious nature of air pollution problems in developing countries, Krupnick (1990) contends that "rapid growth of urban areas of developing has led to major violations of ambient air quality standards and is probably responsible for significant degradation of health. The future, with leaps in urban population and income, is even less promising for the urban environment without policies in place to address the major current problems of industrial, diesel, vehicle and cooking (plus heating) emissions, and the emerging problems associated with emissions from gasoline vehicles" (p.47).

B. Water Pollution in Developing Countries

Unfortunately, serious water pollution problems are prevalent in many developing countries as well. Water, of course, serves several functions. Pearce and Turner (1990) report that human and livestock consumption account for five and three percent of world water use respectively. Industry and mining account for twenty-two percent, while irrigation accounts for seventy percent of world water use. The percentage accounted for by irrigation is considerably higher in some developing countries.

Some of the water pollution problems in developing countries can be traced to irrigation and fertilization practices and a growing reliance on pesticides. Agricultural runoff from lands heavily fertilized and crops intensively sprayed with pesticides often finds its way back to the rivers which provided the irrigation water and which also serve as the source of drinking water for downstream populations. The use of pesticides and fertilizers is often subsidized by government. For example, in Egypt, cotton farmers use organophorphorus and organochlorine pesticides to protect their crop, and the Egyptian government spends over $200 million each year to subsidize this practice (Choucri, Brown, and Haas, 1990).

The damming of rivers for perennial irrigation and permanent water supplies is sometimes not without unintended, but adverse,

environmental consequences. The High Dam in Egypt has created a habitat for water-disease. According to Choucri, Brown, and Haas (1990), "schistosomiasis has greatly increased, migrating south from Cairo, and now thirty-six percent of the population suffers from the disease. The portion is higher among the rural population, for whom it is an occupational hazard. The disease is extremely debilitating, and it costs Egypt on the order of $500 million a year" (pp. 103-4).

Water pollution problems are often very pronounced in urban areas. In Cairo, enteric diseases and dysenteries are the major causes of death among young children (The World Bank, 1989). Much of the problem is due to the strain placed on sewage treatment systems by a growing population. Most sewage in the Cairo area is only partly treated or untreated before it is discharged to open drains.

The lack of access to safe drinking water is a problem common to many developing countries. According to UNICEF's report entitled, The State of the World's Children 1985, in fifteen countries, access to safe drinking water was available to only twenty percent or less of the population (reported in Pearce and Turner, 1990). Some cities, like Calcutta for example, represent dramatic failures in terms of the provision of adequate water supplies and sanitation facilities, and quite often, urban areas are fairly characterized as possessing both serious air and water

pollution problems. In Mexico, the focus of some of our discussion of air pollution problems, water basins serving fifty-nine percent of the population are classified "most polluted" (Jimenez and Eskeland, 1990).

The global picture is no more encouraging. Munasinghe (1990), in a World Bank Environment Department Working Paper (No.41), describes the situation as follows (on p.3):

> In 1980 some two billion people lacked adequate water and sanitation. Global coverage of water supply (defined as access to a safe water supply) stood at about 40 percent. Sanitation coverage (defined as access to a facility for the storage, transportation, or processing of waste) was lower, at about 25 percent. Coverage was lower in rural areas than in suburban areas and for lower income people wherever they lived. At the end of the Decade [the 1980's], it is becoming clear that the original goals [of the United Nations, that all people have access to clean water and adequate sanitation by 1990] will be reached only by a few countries. While there are significant variations among geographic regions, the overall progress has not been encouraging for both water supply and sanitation coverage, from 1970 to 1990.

Population growth, particularly in urban areas, poses a major challenge to the public sectors of many developing countries in their attempts to reach water and sanitation goals. As discouraging as the coverage picture is in many urban areas, it is often worse in rural areas of developing countries (Munasinghe, 1990). While an additional 310 million rural residents received access to an adequate and safe water supply from 1980 to 1988, by the end of 1988 there were still approximately 915 million without access. By the end of 1988 there were over 1.4 billion rural residents without access to an appropriate means of excreta disposal.

C. A Problem of Market Failure or Lack of Infrastructure?

Many water pollution problems in developing countries are probably best viewed as failures to provide the appropriate public good infrastructure for treating the water. That is, given the difficulty of monitoring nonpoint water pollution, the expenditure of public funds on treatment facilities for dealing with raw sewage, in particular, may represent the least cost alternative for remedying a serious pollution problem.[4] However, least cost does not mean inexpensive.

In order to provide all citizens access to clean water and adequate sanitation, one estimate suggests that governments in developing countries must invest US$15 billion annually starting in 1990 (Munasinghe, 1990). Currently, total foreign aid flows to the water sectors in developing countries is approximately US$1 billion, less than ten percent of the aforementioned water investment requirement. It should be noted that *complete* coverage of water supply and adequate sanitation may be an unrealistic and overly ambitious goal; nevertheless, the overwhelming majority of the water sector and waste treatment investments required to provide improved access to safe drinking water may have to be financed internally within these typically capital-scarce developing economies. The revenue requirements to remedy serious water pollution problems should serve to focus attention on the

importance of fiscal reform and the potential benefits of environmental taxes and user charges.

In contrast, many of the air pollution problems previously discussed are best viewed as examples of market failure, in which industrial firms fail to internalize the full social cost of their productive activity or the operators of motor vehicles fail to internalize the social cost of their diesel or gasoline consumption. This dichotomy, between pollution problems as a failure in the provision of public infrastructures for treatment versus pollution as market failure, will be important as we discuss fiscal reforms and environmental policies and their link to environmental degradation and improvement.

II. The Foundations of Environmental Policy

In this section we briefly discuss the rationale for government policies toward environmental control and regulation, and the role that the tax system can play. The criteria of economic efficiency and cost minimization are stressed, although possible conflicts with distributional considerations are noted.

A. Rationale for Public Policies: Missing Markets

A market economy relies on price and profit signals to direct resources into highly-valued uses. Firms seeking to maximize profit and consumers seeking to acquire material well-being are all led to achieve their ends at least cost to themselves. While such private cost-minimizing behavior is a social virtue when goods and factors are priced to reflect their costs to society, it results in economic inefficiency and reduced social welfare if markets are missing and externalities are present. In particular, it results in excessive pollution and environmental degradation.

Environmental quality can be considered an economic good and the degradation of the environment caused by other economic activities can be considered as an input or cost into those activities. Unlike most commercial goods, environmental quality is naturally endowed rather than produced. But the production and/or consumption of other commercial goods may reduce the level of environmental quality, therefore it is in variable supply like other goods. For example, the supply clean air and water, which are valued for their own sake, are used up by production processes that dump waste products into the environment.

The demand for environmental quality comes from people who wish to enjoy air and water which is clean and safe to breathe

and drink. Like any good, the willingness to pay for more of it declines as the amount of it available rises, and rises as the ability to pay for it (household income) rises. The supply of environmental quality comes from producers and consumers of pollution-generating activities who supply more of it when they reduce the level of polluting activities or when they purchase equipment that reduces the amount of pollution caused at given levels of production. The cost of providing more environmental quality is the **net** value of foregone output (that is, value of output less the value of the resources released) or the extra costs of the pollution abatement equipment, respectively. Normally we expect that the marginal cost of "supplying" an extra unit of environmental quality to rise as the amount supplied rises (i.e., as the amount of pollution abatement rises). The "optimal" level of pollution occurs where the marginal willingness to pay for an increase in environmental quality is just equal to the marginal cost of supplying it.

Environmental degradation arises as an economic policy problem because of a market "failure" or a "missing" market. There is no way for demanders and suppliers to express their relative willingness to pay for, or marginal willingess to accept a reduction in, the quantity of environmental quality. Correspondingly, there is no price to be paid by firms and consumers who degrade environmental quality by their activities. Polluters treat the degrading of environmental quality as

practically costless to themselves and ignore the costs they impose on others. When an input is free, a cost-minimizing producer wants to use a lot of it, so excessive environmental degradation results. But the degradation of the environment is not free to the economy as a whole. Rather, high social costs are imposed on the economy in terms of reduced recreational opportunities, health hazards, reduced productivity of workers, general unpleasantness of day-to-day life, etc.

Why does a market for environmental quality not exist like those for other goods? The reasons have to do with the absence of private property rights and the fact that environmental quality is a public (i.e, non-rival) good. In order for something to be priced by the market, it is necessary to have a legal right to control its use. The environment is owned by everyone and hence by no one. A "common property" cannot be priced for its use and therefore there is competitive overuse.[5]

Coase (1960) pointed out that such overuse is not an inevitable outcome. In principle, the demanders of higher environmental quality should be willing to find some way to "bribe" polluters to reduce the level of pollution to the efficient level. This doesn't happen because environmental quality is also a non-rival or public good. Clean air purchased for oneself yields benefits to everyone, but there is no way the purchaser can charge for the benefits he provides to others. Moreover, since the

marginal cost of an extra consumer of environmental quality is zero, it would not be optimal to charge a price even if it were possible. As a result, no individual has much incentive to pay polluters to reduce their pollution. Collective action is needed to prevent free-riding.

B. The Role of Government Policies

The above suggests the rationale for government policy. One possibility is to force payments by the people who enjoy the increased environmental quality. In this case a tax is placed on everyone in the economy and the proceeds are used to pay the polluters to reduce the level of pollution they cause. This is an "consumers pay" policy.

Coase's proposition suggests another possibility. According to Coase, it doesn't matter whether the property rights are given to the polluters or to the consumers of environmental quality. In the latter case the consumers can demand compensation from the would-be polluters. When environmental quality is very high, the amount polluters would be willing to pay to degrade the environmental by some amount is more than the people need to receive (their marginal willingness to accept) in order to tolerate some amount of degradation. Thus polluters are willing to pay for and households are willing to accept some level of environmental degradation. This is the "polluters pay" scenario.

This outcome can be achieved if the government charges an emissions fee to producers for polluting the environment. Alternatively it could regulate the level of pollution that firms can do. Both of these are "polluters pay" policies. With lump-sum taxation, either a "consumers pay" or a "polluters pay" policy can achieve the economically efficient level of pollution (environmental quality). The two types of policies differ in terms of their distributional impact, their administrative ease, and the revenue implications for the public sector.

C. Pigouvian Taxes for Environmental Control

As described above, pollution levels are excessive because polluters do not bear the full social cost of their actions. Over seventy years ago, A. C. Pigou suggested that the government should impose taxes on activities that involve external social costs and provide subsidies for activities that confer external social benefits. "External" denotes costs and benefits which are not incorporated into the market prices faced by private economic decision-makers.

Consider the act of consuming a gallon of gasoline which entails an external cost. If the gasoline market is well functioning in other respects, the consumer pays the full marginal cost of production in the purchase price[6]. But when the consumer burns the gasoline in an automobile engine, another social cost is

incurred which the consumer does not pay. The combustion of the gasoline contributes, albeit slightly, to the level of air pollution in the area. A small increment in air pollution in the area of a large population can have a finite marginal cost because air pollution is a "public" bad--that is, it is a bad incurred on many people in the community. The consumer of gasoline ignores this part of marginal social cost when deciding whether to consume an extra gallon of gasoline.

Because the consumer does not pay the full social cost of burning gasoline, the activity appears cheaper than it really is. The idea of the Pigouvian tax is to impose a tax on gasoline equal to that part of the marginal social cost which is **not** included in the production price--the external marginal cost. The tax-inclusive price faced by the consumer is then equal to the marginal social cost of the product. For example, if the production cost of gasoline is a dollar per gallon and its combustion increases the social cost of pollution by 10 cents, then the marginal social cost of a gallon of gasoline is $1.10. The consumer pays only a dollar per gallon in the absence of government policy, but with a 10 cent Pigouvian tax the consumer will perceive the socially correct price of $1.10[7].

In the above example the Pigouvian tax achieves the outcome that would have occurred if, somehow, the consumers of air quality were able to charge the gasoline consumers for the costs of the

pollution. It is not necessary, indeed under some circumstances it is undesirable[8], that the proceeds of the Pigouvian tax be used to compensate consumers of the air quality for their loss. The revenue collected can be added to general revenue and used to make overall reductions in tax rates or to purchase public goods.

The separation of the efficiency and distributional impacts of correcting pollution levels means that there are alternative ways of imposing the Pigouvian tax. For one, a general tax can be imposed on the population with the revenue used to bribe consumers of gasoline to reduce their consumption. In this case. the government offers consumers (say) a ten cent per gallon payment to reduce their gasoline consumption. Again the consumer of gasoline perceives the cost of consuming gasoline as $1.10--a dollar for the gasoline plus the ten cent foregone payment from the government.[9] Although the incentive to reduce gasoline consumption provided by the two policies are the same, they differ in their distributional impact--in the first case the consumer is worse off, in the second he is better off.

While the concept of a Pigouvian tax is simple, it may be difficult to implement due to imperfect information and monitoring costs. These difficulties are discussed in detail in subsequent sections. It is useful, however, to discuss what the policy can accomplish in abstraction from these difficulties.

Two efficiency objectives should be achieved in reducing the level of pollution. First, a given amount of pollution abatement should be accomplished at least social cost. This objective is sometimes called "cost effectiveness". It should be stressed that an improvement in the level of environmental quality will be costly to the economy. Other economic activities will have to be curtailed and their value to society foregone, or more costly methods of production or consumption must be used. An advantage of Pigouvian taxes, and other "market based incentives", is that they *automatically* achieve the reduction in pollution at least cost.

Second it is desirable that the right amount of pollution abatement be done. Too much pollution abatement is undesirable as well as too little. Accomplishing this objective requires that the Pigouvian tax be set at a rate such that the economically efficient level of pollution is attained. This is a more informationally-demanding objective than cost effectiveness.

A third objective must also be kept in mind--the distribution of income in the country. Different environmental policies have different distributional impacts and this may be an important consideration.

We now examine in more detail the policy of Pigouvian taxes and its ability to achieve the stated objectives.

i) Cost Effectiveness

Continuing the gasoline example, suppose that there are two types of gasoline consumers. Type I, who commutes to work from a location not served by public transport, finds it very costly to reduce gasoline consumption and would be willing to pay a high price to continue using gasoline for commuting purposes. Type II drives mostly for pleasure and would not be willing to pay a lot to continue using gasoline for this purpose. Pollution abatement achieved by curtailing type I's gasoline consumption has high marginal cost while the abatement achieved by curtailing type II's consumption of gasoline has low marginal cost.

If the government mandates less use of gasoline by all consumers, say in equal amounts or proportions, pollution abatement would **not** be accomplished at least social cost. At the mandated total gasoline consumption level, letting type I consume an extra gallon and requiring type II to reduce by an extra gallon would leave total consumption unchanged but yields social cost savings. The least cost method of pollution abatement requires that the low abatement cost consumers reduce gasoline consumption more than the high abatement cost consumers. The least cost abatement policy requires that each type of consumer reduce his consumption of gasoline until the marginal cost of abatement, and therefore the marginal willingness to pay for a gallon of gasoline, is equal to that of every other type.

To mandate pollution abatement at the least social cost, the government would have to know the marginal abatement cost for each type of consumer and set mandated consumption levels accordingly. The advantage of the Pigouvian tax is that this is done automatically. The government simply imposes a Pigouvian tax sufficient to reduce total gasoline consumption to the desired level. The consumers with high costs of reducing gasoline consumption will reduce their consumption by a small amount with the bulk of the reduction coming from consumers with low costs of reducing consumption. In this way, the reduction is accomplished at least social cost.[10]

ii) Economic Efficiency

To accomplish an efficient level of pollution abatement, the Pigouvian tax must be set so that the tax-inclusive price of the activity is equal to its total marginal social cost. Facing this market price, private economic decision makers will undertake the activity only if the marginal benefits are at least this high, and are thereby be led to make efficient choices.

There are many difficulties in implementing this policy. First the external marginal social cost element must be determined so that the Pigouvian tax can be set equal to it. Compounding the problem is the fact that this cost element may depend on the level of the activity undertaken. For example, the marginal social cost

of pollution resulting from burning an extra gallon of gasoline may be low when gasoline consumption is low and high when gasoline consumption is high. The simplest cases occur when the external cost element is invariant to the amount consumed and the Pigouvian tax can be imposed at a rate which is fixed per unit of the activity, or when the external cost element is a constant fraction of the market price so the Pigouvian tax can be imposed at a rate which is fixed as a percentage of market price. Either case would be fortuitous.

In practice the best alternative is often to determine the level of the polluting activity which is the most desirable and set the tax to achieve that level. This can be done using estimates of the elasticities of market supply and demand. If the supply curve is horizontal, the appropriate tax rate can be determined directly from the price elasticity of market demand.

The Pigouvian tax is imposed over and above any tax that is imposed for revenue purposes. For example, gasoline may already be taxed as part of a country's value-added tax. The Pigouvian tax is added to this "revenue tax". A Pigouvian subsidy to an economic activity with a positive externality implies a tax rate below the going revenue tax rate. The tax rate may be, but is not necessarily, less than zero (i.e., a nominal subsidy).

iii) The Distributional Impact

A tax on a particular economic activity will raise the price to the consumer and/or lower the price to the producer. These price effects, and subsequent effects in other markets, determine the incidence of the tax. In the simplest case where the supply curve is horizontal, the price to the consumer rises by the amount of the tax. The relative incidence of this tax across consumers depends on the income elasticity of the taxed good. If the good is income inelastic (elastic), the budget share of the good rises as the income of the consumer falls (rises) implying that the tax burden is distributed regressively (progressively).

An important problem arises if a Pigouvian tax falls on goods which have low income elasticity. To the extent that the tax increases the price to consumers, the burden will be borne disproportionately by lower income groups. A potential conflict exists in this case between environmental and distributional policies. We briefly discuss the importance of this conflict and possible remedies.

One issue is the extent to which low income elasticity of the taxed good in fact implies regressivity. First, as Poterba (1991) shows in the case of gasoline, consumption may be inelastic with respect to income but proportional or even elastic with respect to expenditure. Expenditure increases less than proportionally with

income so that, in principle, all goods for present consumption could be income inelastic. What matters is whether a good is more or less income elastic than the average. Poterba argues that the expenditure elasticity of a good may be a better criterion for determining whether a tax is regressive. Also, empirical studies indicate that annual expenditure tends to be proportional to "permanent" or lifetime income, which may be a better indicator of ability to pay than annual income. Income which is saved will be spent by the household in the future and does not escape taxation altogether. The burden of those future taxes is ignored when judgements concerning the progressivity/regressivity of a tax are based on how current spending on the taxed good is related to current income. As an alternative, estimates of lifetime incidence of a commodity can be used, although these are not readily available, particularly for developing countries.

A second consideration in determining the distributional impact of a Pigouvian tax is the distributional impact of the resulting improvement in environmental quality. If low income households benefit disproportionately from environmental improvements, then a Pigouvian tax on an income inelastic good may not be a regressive policy overall. However, the burden of the Pigouvian taxes can exceed the efficiency gains because of the so-called "primary" or revenue burden of the tax. As a result, it is unlikely that the poor will be made better off from high Pigouvian taxes on goods with very low income (expenditure) elasticities even

if they do gain disporportionately from the resulting improvements in environmental quaity. Of course, if the rich benefit disproportionately from environmental improvement, the redistributional impact is even more perverse.

The distribution of the benefits of pollution control and environmental improvement may, in fact, disproportionately favor the poor in developing countries. The poor currently have less access to safe drinking water and adequate sanitation than those with higher incomes (Munasinghe, 1990). The poor are also more likely to suffer from indoor air pollution problems (Krupnick, 1990). To the extent that environmental policies improve these particular pollution conditions, the poor are more likely to benefit. Eskeland and Jimenez (1991a) note that the poor are more likely to benefit from pollution control also because "they tend to live in poor health and sanitary conditions in polluted urban areas and cannot afford to protect themselves or move" (p.29-30). However, Eskeland and Jimenez also point out that some empirical evidence suggests that the willingness to pay for environmental improvement among wealthier individuals may be higher than that among the poor, and such differences could make the wealthy the principal beneficiaries of environmental improvement.

Where Pigouvian taxes do lead to regressivity, some alternatives are available. The first is to make a compensating change in other components of the tax system. For example, if the

country levies a personal income tax, it can be made more progressive, perhaps by giving an additional tax credit to low income taxpayers. In developing countries that depend on commodity taxation for revenue purposes, tax rates can be reduced on basic foodstuffs or low-priced clothing. This may increase the costs of administering the commodity tax system, however.

A second alternative is to structure the policy as a subsidy. Rather than taxing a polluting good with low-income elasticity, the government should provide a subsidy for conserving it. Thus, instead of taxing home heating fuel, the government can subsidize home insulation. Unfortunately, rather than generating government tax revenue, this type of policy raises the government's revenue needs. These are already severe in many developing countries.

A third alternative is to ration the available consumption of the negative-externality good and distribute the rations disproportionately toward the poor. This type of policy is very unlikely to achieve pollution abatement at least cost unless a gray market in ration coupons is permitted. If not, the distributional effects of the tax instrument would have to be quite adverse before the rationing instrument should be considered.

III. Possible Environmental Policy Instruments

The government has a number of instruments available for pursuing policies aimed at improving environmental quality. In this section we describe the set of instruments from which the government may choose and in the next section we discuss the criteria for selecting one instrument over another and identify the circumstances in which the Pigouvian tax is the likely to be the preferred instrument.

A. Assignment of Relevant Property Rights

In section II.A we argued that a major reason why there is excessive pollution in the first place is that, typically, environmental quality is a common property resource. Often there are no private property rights established for an environmental resource so everyone is free to use it. When the use of the resource by one individual reduces its availability to others, it imposes costs on them but no price reflects this fact to the user since ther is free access.

For example, suppose there are many users who have free access to a lake. Each desires clean water but in using the lake he reduces its cleanliness for others. With many users and free access, no user has the incentive to maintain the cleanliness of the lake. Suppose, however, that private property rights are

established to the lake allowing the owner, in effect, to sell the use of the water to the various users. The price for which the water can be sold, and hence the profitability to the owner, depends on its cleanliness. In this case, the private owner has an incentive to maintain the cleanliness of the lake at its economically efficient level.

In many cases the assignment of property rights is not a very good instrument to accomplish environmental policy objectives. The assignment of property rights could create a monopoly, or it may be impossible for a private owner to monitor the use of the resource by others and therefore charge the appropriate price. Also, many environmental assets have a "public good" quality to them so it is not be efficient to charge prices for enjoying the asset in some of its uses. In these cases other solutions may be possible.

B. Marketable Pollution Quotas

A related idea is a policy of marketable pollution quotas. This policy may emerge naturally from a policy of regulation. Under a regulatory policy, firms are limited in how much pollution they can cause--for example, how much sulphur dioxide they may emit into the air or how much effluent they can dump into a watershed. Often these limits or pollution "quotas" are the same for all firms. Typically, different firms have different costs of pollution abatement. As discussed in the previous section, the

cost of pollution abatement is not minimized if firms with different marginal abatement costs are required to do the same amount of abatement.

Marketable pollution quotas are a method of ensuring that pollution abatement is done at least cost. Keeping the total amount of pollution permitted constant, the government can allow firms to "sell" their pollution quotas to other firms. Firms with low marginal costs of abatement are willing to sell their quotas and firms with high marginal costs of abatement are willing to buy them at some intermediate price. The pollution quota market is in equilibrium when the price of a pollution quota is just equal to the marginal cost of pollution abatement to all polluters. In this way the least cost pollution abatement is obtained for a regulatory policy, as in the case of a Pigouvian tax. For this reason, marketable pollution quota and Pigouvian taxes are lumped together as market-based incentives (MBIs). In fact, except for the distributional impact of the policies and the fact that the Pigouvian tax policy raises revenue, the two policies are equivalent under perfect information.

A policy of marketable pollution quotas can be carried out at different levels of formality. The most informal policy is simply to let pollution quotas be traded within the firm. In this case a firm can increase the pollution emitted by one of its plants if it makes a compensating or more than compensating reduction in

pollution emission by another. Alternatively, the firm may increase emissions in one year if it decreases them in another. These informal trading arrangements are incorporated in policies variously referred to as *offsets, bubbles* and *banking*. An even more market-oriented approach is to allow inter-firm trading. This can range from informal trading among firms to a formally established market in pollution rights like that recently announced by the Chicago Board of Trade for sulphur dioxide emissions.

C. Indirect Taxes on Inputs and Outputs

Rather than taxing the pollution-causing activity itself, the government may levy excise taxes on outputs and inputs closely associated with the pollution-causing activity. This approach has the advantage that the government may already have in place an indirect tax system on goods and services. Thus environmental policy can be accomplished simply by setting the existing tax rates to incorporate a Pigouvian element. Also, taxable outputs and inputs usually are readily monitored as part of raising public revenue. This policy would be as good as taxing the pollution-causing activity if the latter occurs in fixed proportions with the taxable output or input.

One difficulty is that taxing an output or input is that it may be too blunt of an instrument. In the gasoline example of section II, an output tax on gasoline is used instead of taxing the

pollution-causing activity itself--the burning of the gasoline. Since gasoline is generally purchased only to burn it, and if all methods of burning gasoline contribute equally to air pollution, the output tax is almost as good of a policy as taxing the burning of gasoline. But suppose gasoline can be used in ways that do not cause air pollution? A gasoline tax would discourage these socially harmless activities as well as those that cause pollution. In the process of trying to correct one economic inefficiency, another would be created.

In fact, it can be shown that a small tax on gasoline will improve economic efficiency even if gasoline is used for other, harmless purposes. But the existence of the harmless uses limits the amount of welfare improvement that can be attained through this policy. Taxing output is a "second-best" policy in that there is an additional cost element to the policy--the cost of discouraging socially harmless uses of the output. Whether one has to settle for second-best or choose another instrument can only be determined with further analysis and information.

A special example of this problem occurs when pollution is caused by consumption of the output (say, gasoline) but can be mitigated by the purchase of a pollution-abating input (say, catalytic converters for cleaner burning). Again an output tax will not accomplish the least cost method of reducing pollution. The output tax by itself provides no incentive to purchase the

pollution-abating inputs even though they may be the least-cost method of reducing pollution. Similarly, subsidizing the abating inputs provides no incentive to reduce polluting output, in fact it may increase it.

The least cost method of reducing pollution can be achieved, however, if an output tax is imposed on a polluting firm and some of the revenue is used to subsidize the purchase of the pollution abating inputs. This policy would leave unchanged the relative cost of reducing pollution by decreasing output or by increasing abatement inputs since the after-tax prices of the output and the pollution-abating are reduced in the same proportion. This ensures that an efficient means of reducing pollution is chosen. Alternatively, as an approximation, one could combine a tax on output with regulatory standards (see F and G below) requiring the use of pollution abatement inputs. In the gasoline example, a tax on gasoline could be combined with a regulation that requires that cars be equipped with catalytic converters or requires that cars be subject to emissions tests and fuel carburation adjustments.

D. Effluent and Emissions Charges

In general, in the absence of monitoring and other information costs, the best policy is to tax the activity most directly related to the pollution-causing activity. This requires information about how the pollution comes about and the production technology

available to reduce it. It also may require monitoring and taxing activities which are not normally taxed for revenue purposes.

Where the effluent emitted by the polluter can be monitored, the most direct policy is to impose an effluent fee. For example, firms dumping waste water into a watershed may be required to pay an effluent fee per unit dumped. This is perhaps the closest example of a pure Pigouvian tax there is. Unfortunately, there are perhaps few cases where such a policy is administratively feasible.

E. Content Taxes.

In between excise taxes on inputs and outputs and taxes or charges on the polluting effluents or emissions themselves are what might be called content taxes. With this instrument, a tax is levied on the amount of a particular component in a commodity. The best known example is the "carbon" tax levied by Finland and some other Scandinavian countries which tax the carbon contained in fossil fuels. Other examples could include a "sulphur" tax which taxes fossil fuels according to their sulphur content, or the B.T.U. tax (British Thermal Unit) under consideration in the United States which taxes all energy commodities on the basis of their heat content.

The case of the carbon tax is illustrative. The main pollutant here is carbon dioxide, a greenhouse gas, which is

thought to be the main contributing factor to global warming. Taxing the actual emissions of carbon dioxide is difficult or impossible since they are not readily monitored. On the other hand, an *ad valorem* (equal percentage) tax on all carbon-bearing fuels is less than ideal since some fuels contain much more carbon per unit of energy than others. For example, a low carbon fuel like natural gas would be taxed at the same rate as a high carbon fuel like coal. Rather, if one desires to reduce carbon dioxide emissions, it is bettter to target the tax on the carbon contained in the fuel. Thus a $5 a ton (say) carbon tax translates into a 13% tax on coal, which contains .605 tons of carbon per ton of coal, and a 5% tax on natural gas, which contains .207 tons of carbon in a volume which has the same pre-tax value as a ton of coal.[11]

An important consideration in judging the suitability of content taxes is appropriate targeting. A carbon tax is most appropriate in the case where the policy maker is most concerned with reducing carbon dioxide emissions to slow global warming. Although such a tax may also reduce other pollutants, most notably carbon monoxide, it is not targeted specifically at them and therefore may be a second best policy if the other pollutants are the main environmental concern. For example, where sulphur dioxide is a prime concern, the carbon tax provides no incentive to substitute low sulphur-content coal for high sulphur-content coal,

although it will undoubtedly lead to lower sulphur dioxide emissions over all.[12]

Of course, content taxes can be combined. Thus, a sulphur tax can be levied along with a carbon tax. The total tax on a unit of fossil fuel will then depend on both its sulphur and carbon contents.

F. Emission (Abatement) Standards

This is perhaps the most common environmental policy adopted. In effect, it amounts to a non-marketable pollution quota. Strict limits are set on the quantity of emissions that a firm or economic agent can produce during a given period. Alternatively and equivalently a firm may be required to reduce its emissions by a certain amount relative to what it has done in the past.

While the firm is required to satisfy some standard on the level of its emissions, typically the government does not control or care about how it accomplishes this objective. The firm may reduce the level of its economic activity or install pollution control equipment. It is left up to the firm to choose the least cost method.

G. Abatement Technology Standards

With this policy the firm is required to install certain pollution abatement equipment or adopt certain abatement methods. That is, the government specifies the method which the firm must use to reduce its emissions, unlike for the policy of emission standards. While such a policy seems to obstruct the goal of least cost emission reductions, it may be desirable if the level of emissions is difficult or costly to monitor whereas confirming the use of the technology standard is not (see the discussion in the next section). Also, as mentioned, it may be a useful policy in conjunction with output taxes.

IV. Criteria for Comparing Policy Instruments

In this section we introduce criteria for evaluating alternative policy instruments for achieving environmental improvements associated with pollution control. Policy instruments differ in administrative expense, level of bureaucratic control over the actions of polluters, flexibility afforded polluters in abating emission levels, requirements for monitoring and enforcing compliance, incentives for polluters to engage in the research and development of new pollution abatement technologies. Lastly, policy instruments for pollution control differ in their ability to meet other fiscal policy objectives of government.

A. Level of Control by Regulators and Flexibility Offered Polluters

Several of the policy instruments previously discussed in Section III share the property that the environmental regulatory authority directly controls the quantity of pollution generated by particular firms or consumers (e.g., emission or abatement standards) or, at the very least, the aggregate quantity of pollution generated by an entire industry or set of industries (e.g., marketable pollution permits). In some instances, the regulatory authority even directly controls the method of pollution generation and abatement (e.g., abatement technology standards, mandated input mix for particular production processes). Controls on permissible quantities of pollution or methods of pollution generation and abatement constitute the most direct form of government intervention into markets with environmental externalities. Mandating emission levels and abatement technologies gives polluting firms little flexibility in achieving the abatement targets.

By contrast, several of the policy instruments described in Section III affect the prices firms or consumers face for goods and services (e.g., indirect taxes and content taxes), some policy instruments establish prices for nonmarket goods like pollution (e.g., effluent charges, marketable pollution permits), and others influence the cost or price of pollution abatement (e.g., abatement subsidies). These are the so called "market based incentives" for

pollution control or the "price-type" policy instruments. They allow polluting firms flexibility when implementing pollution abatement strategies. Market based incentives for pollution control establish artificial prices for environmental externalities directly, as in the case of effluent charges, or indirectly, as in the case of well-functioning markets for tradeable pollution permits which establish a market price for a unit of pollution. Once prices for pollution are established, firms and consumers determine the quantity of pollution (conversely, abatement) to generate. Profit maximizing firms facing a per unit effluent charge will abate pollution as long as the marginal cost of abatement is less than the per unit price of generating the effluent. Profit maximizing firms will purchase permits (and pollute) as long as the market price for a permit (on a per unit basis) is less than the marginal cost of abatement. In this context, the cost of abatement includes reductions in outputs, the cost of altering the input mix, as well as the cost of installing and operating the abatement equipment.

The key feature of market based incentives or price-type policy instruments is that they delegate control over decisions about the relevant quantities to the self-interested firms and consumers. Much of the subsequent analysis about the relative desirability of market based incentives or price-type instruments versus command-and-control regulations or quantity-type instruments

focuses on the informational settings and circumstances under which such delegation is desirable or undesirable.

B. Monitoring and Enforcing Compliance

Regardless of the form of environmental regulation chosen by the policy maker, regulations will have little success in controlling the generation of pollution and its damaging effects if compliance with the regulations is not adequately monitored and enforced. Many environmental economists view enforcement as the weakest link in the efforts to control pollution. Most environmental policy instruments impose costs on polluters, and these costs can be avoided if polluters do not comply with the intent of the environmental policy. To circumvent polluters' incentives to not comply, regulators must implement monitoring and enforcement procedures and strategies.

Nearly every form of environmental regulation entails an enforcement burden. Regulators must ensure compliance with quantity-type emission standards by monitoring and punishing violators. If effluent charges are the regulation of choice, the regulator must collect the appropriate revenue. If abatement technology standards are employed, the regulator must check that the appropriate equipment is installed and is subsequently operated and maintained.

The best policy instrument in a given environmental and industrial context may depend critically on the associated enforcement considerations. Without considering monitoring and enforcement, effluent charges may seem the most desirable because of their efficiency properties when compared with inflexible policy instruments such as uniform abatement technology standards. If, however, it is nearly impossible to monitor the discharge of effluent accurately, it will be impractical and prohibitively expensive to collect the effluent fees from, and therefore obtain the efficient level of pollution abatement by, the targeted industry. On the other hand, it may be relatively easy to monitor the installation and operation of mandated abatement technologies. Similarly, indirect taxes on polluting inputs and outputs, or content taxes, may be easier to collect than effluent and emissions charges, and properly designed fiscal reforms may be more efficient than environmental regulations.

C. Incentives for Innovation in Pollution Abatement Technology

Choosing one policy instrument over another affects not only the allocation of resources and the associated level of net benefits enjoyed by society in the present, but also in the future by increasing the incentive for polluters to invest in newer and cost-reducing abatement technologies. In the presence of a pollution tax the polluter incurs two types of costs. First, the costs of abatement and, second, the tax revenue which is paid on

units of pollution which are not abated. If a polluter can reduce the marginal cost of abatement by R&D investment, he not only enjoys the savings in abatement costs, he also reduces the amount of pollution taxes paid to the government by increasing the level of abatement. Under a pollution tax, the polluter determines the level of abatement by equating the marginal cost of abatement to the pollution tax. Thus the incentive to invest in abatement cost-saving technology includes the tax savings from any additional abatement which becomes worthwhile. The polluter adopts the new technologies if the present value of future cost savings, including savings of pollution taxes, covers their R&D costs.

Contrast this to the case where the same polluter faces a quantity-type regulation such as an emission standard. The polluter initally faces the cost of complying with the regulation, which is the total cost of abating pollution to the allowable level. If, thereafter, the polluter invests in measures to reduce abatement costs, the only return on the investment is the cost saving of meeting the mandated level of abatement. In particular, the polluter does not have the incentive of cost savings achievable by reducing abatement levels below those mandated

Thus, we might expect less investment in more efficient methods of pollution abatement by polluters who face quantity-type environmental regulations as compared with those subject to market based incentives for pollution reduction. These differences may be

even more pronounced once the incentives of the regulators are considered. If the regulator sets a pollution tax so as to equate the marginal benefit of abatement with its marginal cost, then the best policy response to a reduction in the marginal cost of abatmement is to lower the per unit pollution tax. This lowers the tax costs to the polluter even further and, if anticipated, further increases the polluter's incentive to invest in reducing abatement costs. On the other hand, when an emission (or abatement) standard is used and set so as to equate the marginal benefit of abatement to its marginal cost, the best policy response to a reduction in the marginal cost of abatement is to tighten the abatement standard. If this is anticipated, it reduces further the polluter's incentive to invest in reducing abatement costs.

D. Fiscal Policy Objectives

This discussion of the incentive effects (for R&D) of the alternative policy instruments does not mean that regulated polluters prefer market based incentives like taxes to quantity controls. On the contrary, the increased incentive for investing in new abatement technology under a pollution tax occurs because of the revenue burden associated with the tax policy instrument, a burden which is not welcomed by the polluters.

However, the revenue generated by pollution taxes may be very welcome to the government, particularly in revenue-short developing

countries. Pollution tax revenue can support programs of environmental improvement or help achieve other fiscal policy objectives. In addition, to the extent that the revenue from pollution taxes replaces revenue obtained from distortionary taxes, there can be a further efficiency gain over the regulatory instruments.

Environmental regulations seldom can be considered in isolation of other government policies. Industries subject to environmental regulation may also be subject to other tax/subsidy policies designed to promote growth. In the next section we explore the welfare implications of alternative environmental policy instruments in greater detail, including an examination of the impact of environmental regulations where there are pre-existing fiscal policy distortions.

V. Welfare Analysis of Environmental Policy Instruments

In this section we extend the analysis of the relative merits of different policy instruments for pollution control. In particular, we consider in greater detail the importance of uncertainty, asymmetric information, enforcement, and fiscal policy objectives.

A. The Equivalence of Different Instruments with Perfect Information

In a world of certainty and full information, the choice of one pollution control instrument over another may, in fact, be of little consequence. In this idealized world, quantity instruments such as emissions standards and market based instruments such as emissions charges achieve the same objectives at the same costs. To achieve efficiency, the regulator can set an effluent tax, an emission standard, or issue pollution permits--it makes no difference, at least in the short run. As long as the policy instrument effectively equates the marginal benefit of pollution abatement to the marginal cost, the inefficiency due to the pollution externality is eliminated.

As economist Martin Weitzman (1974) forcefully noted, under conditions of full information and perfect certainty, there is a complete equivalence between price-type planning instruments and quantity types. The regulator can either mandate the optimum quantity directly or induce indirectly the optimum quantity from the self-interested parties by setting the right prices.

B. Comparative Advantage of Policy Instruments under Uncertainty

Weitzman's seminal work illustrates how this equivalence breaks down in the more realistic context of uncertainty and

asymmetric information. Uncertainty in the environmental policy context may result from several sources. First, it may result from imprecise estimates of the levels of pollution damage and the benefits of environmental improvement. While much of the environmental economics literature of the last three decades has been devoted to the development and improvement of techniques designed to measure pollution damage or elicit information about the willingness to pay for environmental improvements, benefits measurement is still inexact.

A second kind of uncertainty may confront regulators: asymmetric information. Asymmetric information describes a situation where one party to a transaction possesses relevant private information that the other does not. Environmental regulators typically have less information about the abatement capabilities and costs than the polluting firms themselves do. Firms have a better understanding of the production process and therefore better information about the least cost way of obtaining a particular level of pollution abatement.

Weitzman considers a situation in which a regulator chooses between a price-type instrument and a quantity-type instrument. The objective is to maximize the expected net benefits (the difference between expected gross benefits and expected total costs). The policy instrument must be chosen under conditions where both types of uncertainty described above prevail: that is,

general uncertainty about the benefits and asymmetric information about abatement costs. The important question in choosing between these policy instruments is the desirability of delegating the decision about the quantity of abatement to the firm, a delegation which occurs under the price-type instrument. The firm has better information about costs; however, its self-interest does not coincide with the social interest.

In particular, let gross benefits be the willingness to pay for pollution abatement (and the corresponding environmental improvement), and let total costs be the costs of pollution abatement. To simplify, assume that the regulator knows the shape and slope of the marginal benefit and marginal cost curves of abatement (see Figures V.1 and V.2), but not their heights (vertical intercepts). Although the height of the marginal benefit curve is uncertain to all parties, the height of the marginal cost curve is known by the polluting firm but not the regulator. The polluter knows the marginal cost of abatement and, in the case of a pollution tax, chooses the level of abatement which equates the marginal cost of abatement to the pollution tax. On the other hand, when the regulator mandates the quantity of abatement directly, the firm need simply comply with the mandate. We consider later the possiblity that the firm can choose to comply or not.

It turns out that the comparative advantage or disadvantage of a price-type isntrument over a quantity-type instrument depends only on the relative slopes of the marginal benefit and marginal cost of abatement curves and on the nature of the asymmetric information about costs. Interestingly, the decision about the policy instrument does not depend on the more general uncertainty about the level of benefits. The desirability of delegating the quantity of abatement choice to the firm (by using the the price-type instrument) depends on how much better the firm's information about abatement costs is as compared to the regulator. If the price-instrument is used, the level of abatement which results is not known with certainty beforehand by the regulator: the firm resolves the uncertainty when it chooses its abatement level. If the quantity-instrument is used, the regulator fixes the quantity of abatement (assuming no compliance and enforcement problems) but the cost of the abatement is uncertain.

A quantity instrument is more likely to be preferred when the marginal cost of abatement rises slowly as the level of abatement rises and when the marginal benefit of abatement falls sharply. Under these conditions, the costs imposed by setting the "wrong" price due to the uncertainty facing the regulator will be large relative to the costs imposed by setting the "wrong" quantity of abatement. Thus, a price-type instrument, where the resulting level of abatement is uncertain, is less desirable than a mandated

quantity of abatement which achieves the same expected level of abatement (see Figure V.1) but with certainty.

On the other hand, if the marginal cost of abatement rises steeply with the level of abatement and the marginal benefit changes little, the price instrument will be preferred. In this case, setting the "wrong" quantity of abatement due to the limited information facing the regulator is more serious than setting the wrong price. It is better to set the price on the basis of the expected marginal benefits and marginal costs of abatement, and let the firms, who know the true marginal cost of abatement curve, choose the level of abatement (see Figure V.2).

In practical terms, this analysis suggests that in cases such as toxic waste disposal, where a little toxic waste may be all that is needed to have drastic and dire effects on environmental quality, the government is best off relying on quantity restrictions. Using a price instrument and relying on the firms' superior knowledge risks the possibility that the marginal cost of abatement is high to the firms and they will follow their self-interest and produce too little abatement of an activity with a very high social cost.

On the other hand, in the case where firms generate non-toxic air pollutants which degrade the environment by lowering visibility, it may be advantageous for the government to use a

price or market-based instrument. The marginal benefit of abating this type of pollution is not likely to change much as the quantity of abatement changes. But if the firms have heterogeneous costs of abatement, it might be wise for regulators to set effluent taxes and let each firm, which possesses better information about its own costs, decide the level of abatement. The cost savings from firms choosing minimum cost abatement levels is likely to outweigh the costs of having the "wrong" overall level of abatement due to regulator's uncertainty.

C. Enforcement Considerations

Another practical consideration facing regulators is the fact that the polluting agents may not comply with regulations. Just because a regulator forbids emissions beyond a particular level does not guarantee that polluters will not continue to exceed those limits. Similarly, just because a regulator establishes a price for pollution by setting an effluent charge does not guarantee that firms will honestly report their discharges and pay the correct fees. And if the firms don't pay the fees they won't have an incentive to choose the optimal level of pollution abatement.

There is anecdotal evidence of noncompliance with technology based standards even in the United States where institutions are well developed. While it is fairly easy to check that mandated abatement equipment has been installed, if operating the equipment

is costly, firms may circumvent the regulation by "unhooking" the equipment when regulators are not looking.

We discuss below the implications of costly monitoring and enforcement for the case where regulators set emission or abatement standards. Much of what we have to say applies with equal force to price-type policy instruments. The analysis is based on the economics-of-crime analysis of Becker (1968). Becker argued that "rational" criminals will commit crimes as long as the private marginal benefit of the crimes exceeds the expected marginal cost of committing the crimes.[13] Similarly, when deciding whether to comply with an environmental regulation, firms will compare the cost of compliance with the expected value of the consequences of noncompliance.

Denote the probability of detection and prosecution of noncompliance as p (determined by the enforcement budget and strategy of the regulator) and suppose further that, if found in violation of an emission standard, the firm must pay a fine F and comply with the standard incurring abatement costs of C. A risk-neutral firm will choose to comply if $C < p(F + C)$ or if $C < (pF/(1-p))$. This simple model of firm behavior suggests that the lower the costs of compliance, the greater the chance that a firm will comply. It also suggests that where firms have heterogeneous costs, some will comply while others, which have the higher

abatement costs, will not. Finally, compliance is more likely the greater is the probability of detection and the larger is the fine.

Interestingly, enforcement considerations affect the standard-setting process. Viscusi and Zeckhauser (1979) point out that tightening standards (i.e., requiring more abatement) may have perverse consequences. Suppose a regulated industry, where firms have different abatement costs, is confronted with a uniform abatement standard per firm. If enforcement is costly, so that the probability of detecting violations is less than one, firms with high abatement costs may choose not to comply with the standard while other firms, with lower abatement costs, do. This determines the aggregate level of pollution abatement obtained. If the standard is tightened by increasing the required amount of abatement per firm, then abatement will rise to the extent that firms who complied with the less stringent standard continue to comply. However, some of the firms who complied with the less stringent standard will find it in their interest not to comply with the more stringent standard. For these firms, who have intermediate levels of abatement cost, the cost of complying with the new standard is too great, so they will now cheat and their abatement will fall. The non-complying firms will continue not to comply. If the increase in pollution from the second group of firms is greater than the decrease from the first, pollution may rise as standards are tightened.

While this perverse outcome from tightening pollution standards is not always the rule, it is a fairly general result that the optimal pollution standards are less stringent in the presence of imperfect monitoring and costly enforcement than in the idealized world of perfect monitoring and costless enforcement.

An important implication is that the level of environmental quality depends on the level of compliance with environmental regulations in practice, and not on how "tough" the environmental standards are in statutes. Unfortunately, as reported by Eskeland and Jimenez (1991b), monitoring, enforcement, and regulatory capacities have been weak in developing countries (p.16):

> In Mexico, for instance, the influence of regulations has been limited by the resources of the enforcement agency and the low level of fines. In Columbia, laws have included formulas for calculating a tax on discharges to water, but no apparatus has been in place to monitor and bill polluters. In India, inefficient legal processes have reduced the disincentive effects of lawsuits against polluters.

Indeed, enforcement efforts have been weak in some developed countries as well. Magat, Krupnick, and Harrington (1986) conducted a study of regulatory effort to enforce safety and environmental regulations in the United States during the 1970's and early 1980's and found that the resources devoted to enforcement were inadequate.

Several economists have emphasized recently the importance of targeting current monitoring and enforcement efforts and resources on particular firms chosen on the basis of their past compliance

records.[14] Monitoring firms with a record of previous violation of environmental regulations more frequently than firms with no such record is found to lower the enforcement costs of obtaining a given aggregate level of compliance from the regulated industry. That is, costs are lower when past performance is used as a factor in targeting enforcement expenditures than when all firms are monitored with the same frequency regardless of their past performance. This feature of optimal enforcement practice emphasizes the importance of accurate record keeping regarding (non)compliance.

D. Constraints on Environmental Policy in Developing Countries

There are a number of differences between developing and developed countries that should be considered when setting environmental policy in the former. Among these differences are the facts that in developing countries per capita income is much lower, access to quality medical care is lower, the baseline level of pollution control is lower, the capital base is often older and not as well maintained, institutions in charge of administering fiscal reforms and promulgating and enforcing environmental policies are generally weaker (among other things this means the expertise, funds, and technology for data collection and monitoring are often lacking), and the demand on the public sector for the provision of public goods is greater while the revenue base is much narrower.

From this list we emphasize low per capita income and the lack of medical care for much of the developing world's population. These are important determinants of the level of pollution control or abatement that is beneficial and cost effective. In developed countries, there is evidence that the demand for environmental quality depends positively on income--that is, environmental quality is a normal good. Although estimates of the income elasticity for environmental quality from developed countries should not be used as precise estimates for their counterparts in developing countries, it is likely to be the case that the demand for environmental quality in developing countries will rise as their economies grow.

In the initial stages of growth, perhaps only modest reductions in optimal level of pollution are warranted on the basis of the income elasticity of environmental quality. However, the existing levels of pollution presently suffered by residents of Mexico City, Calcutta, Cairo, Beijing, or Warsaw are far from optimal. Up until now, very little pollution control measures have been employed in the developing world, and even modest reductions in pollution emissions or modest improvements in the treatment of polluted water could produce large gains in the welfare of the general population. In addition, with so much of the population lacking adequate medical care, modest improvements in environmental quality may represent one of the least cost methods of improving health in developing countries.

The differences between developing and developed economies also are relevant to the question of instrument choice--in particular the relative desirability of marketable pollution permits versus regulations or pollution taxes. In developed countries, one can argue that marketable pollution permits may be a very attractive alternative to command and control regulations or to indirect (and distortionary) taxes designed to curtail pollution. First, the formal market economy is comprehensive and well established, so there is reason to believe that pollution permits will be traded among firms with heterogeneous pollution abatement costs.[15] Second, by establishing a price for pollution (the price of a permit), profit-maximizing firms with heterogeneous abatement costs should equate the marginal cost of abatement with the price of pollution. Equating the marginal cost of abatement across firms of all cost types is a necessary condition for cost effectiveness in an environmental regulation. Third, environmental regulatory agencies have existed for over two decades in most developed countries, and monitoring and enforcement practices are well established, so it is expected that firms in a developed country are more likely to comply with the pollution restrictions inherent in the permit system.[16]

In contrast, in developing countries the formal market economy is not as comprehensive, so there is reason to question whether a market for pollution quotas would match buyers and sellers efficiently. Furthermore, with a system of pollution quotas, the

regulatory authority must monitor the quantity of pollution emitted at each source (and account for the changing pollution rights of individual firms as trades of quotas occur). If meager enforcement budgets and a lack of technological expertise preclude effective monitoring, the supposed efficiency properties of marketable pollution permits will not be realized.

E. The Efficiency Value of Environmental Taxation in Developing Countries

Other facts about environmental regulation in developing countries (viz., the lack of administrative expertise in environmental policymaking, general weakness of legal institutions, and potentially small enforcement budgets) enhance the desirability of using environmental policy instruments which are similar in structure to existing fiscal instruments. These are instruments with which developing countries have administrative experience, and which minimize enforcement requirements. As a first step toward curbing pollution, developing countries should reduce their sizeable energy subsidies to highly polluting industries. Kosmo (1989) notes that governments in many developing countries keep energy prices at levels well below the world prices. These subsidies result in excessive energy-related emission of pollutants in the industries relying on subsidized energy as an input.

A second step in reducing industrial pollution in the energy-consuming sectors is to tax energy inputs, in addition to removing

the subsidies. A tax on energy inputs is likely to have lower enforcement costs than alternative regulatory approaches. For example, an environmental tax on polluting inputs requires less monitoring than levying an emissions tax or enforcing an emissions standard. Purchases of important inputs to production, like energy, should be relatively easy to document. Of course, as Krupnick (1990) notes, "such an approach only provides incentive to reduce purchase of the input, not necessarily to find the least-cost means of reducing pollution and, if the input is not chosen with a careful eye towards substitutes, there is no guarantee that emissions will fall. Nevertheless, on balance, this approach seems to be a reasonable second-best policy" (p.34).

The second-best policy of taxing polluting inputs (e.g., energy, leaded gasoline, pesticides) is particularly appealing in developing countries because it draws upon the administrative capability most of them possess from levying commodity taxes. Most developing countries do not have extensive experience with administering and enforcing other forms of environmental regulation. Assistance from international agencies and academics is changing this, but the change is slow. The lack of government expertise, record keeping capability, and enforcement funds probably rule out, for the present, the more sophisticated regulatory schemes being tried in parts of the developed world (e.g., tradeketable pollution permits).

The use of environmental taxes, whether on polluting inputs and outputs, content taxes, or emissions fees, have the added appeal that they generate revenue, unlike emission standards, abatement technology standards, or chemical bans which collect no revenue and are costly to enforce. By the same logic, pollution taxes are superior to abatement subsidies. The former generate revenue, and the latter add to the government's revenue requirments. Public sector budgets in many developing countries are severely limited, and raising additional revenue through the existing tax structures can involve large inefficiencies because the tax bases are typically quite narrow and taxation badly distorts resource allocation decisions. To the extent that environmental tax revenues replace those obtained through more distortionary means, environmental taxes have an additional "efficiency value". As Terkla (1984) explains, "it is defined as the reduction in excess burden resulting from the substitution of these revenues for current and future resource distorting tax revenues" (p.107).

Terkla calculates the efficiency value of potential particulate emissions and sulphur dioxide taxes on stationary sources in the United States and finds that the estimated values range from a possible value of US$0.63 to US$4.87 billion (in 1982 dollars), depending on the wide range of plausible abatement cost levels and on whether environmental tax revenue replaces labor or corporate income tax revenue. His working assumption is that the

taxes would be set so as to achieve national air quality standards for sulphur oxides and particulates based on the U.S. Environmental Protection Agency emission standards for new sources. Terkla uses the mid-seventies estimate from the public finance literature of $0.35 for the marginal welfare cost of a dollar of labor income tax revenue. For the marginal welfare cost of corporate income taxation, he takes $0.56 per dollar from Feldstein's (1978) two-period life cycle model. The estimates of marginal welfare loss are consistent with figures generated more recently from a computable general equilibrium model of Ballard, Shoven, and Walley (1985).

Terkla's argument is important since so many developing countries currently raise revenue from a very narrow tax base with highly distortionary commodity taxes (The World Bank, 1990). The efficiency value of pollution taxes is best viewed as an element in the instrument choice debate. The argument is relevant whether or not the polluting inputs and outputs are already taxed as part of the country's revenue base. Suppose all taxable goods in the economy are initially taxed (for revenue-raising purposes only) so that the marginal excess burden (exclusive of the impact on environmental quality) is the same across taxable commodities. If good X is a particularly polluting commodity, either in its use as an input to production or through its consumption as a final good, its use can be curbed in two ways: a quantity restriction on polluting emissions or an increase in the per unit tax levied on

the good. Notwithstanding differences in administrative or enforcement burden, the commodity tax approach is preferable because of its additional value in raising revenue.

One way to demonstrate this is to note that an emissions standard, which limits the quantity of the polluting good X sold, creates an economic rent (the difference between the marginal willingness to pay [price] and the marginal cost [including the baseline commodity tax] of production)--a rent which would be taxed away if the revenue structure is optimized since taxes on rents are lump-sum (i.e. non-distortionary) taxes. Increasing the tax on the polluting good so as to achieve the same level of use as under the standard achieves the goal of the environmental policy and captures the economic rent as a low cost source of government revenue.

Even if environmental tax revenues are not used to reduce the revenues raised from other distortionary taxes, they provide an additional efficiency value relative to other forms of environmental regulation if the revenue is used to finance public infrastructure projects which generate large net benefits. Water treatment plants and improved sanitation facilities are good examples of the types of projects that could be financed through environmental taxes and user charges. They hold the promise of generating large environmental benefits, given the current state of water pollution problems in most developing countries.

F. Environmental Regulation and Pre-Existing Market Distortions

In developing (and developed) economies, environmental policies are formulated in the presence of existing fiscal policies aimed to raise revenue and to encourage targeted industries. In this section we analyze the relationship between environmental regulations and pre-existing fiscal policies.

We begin by considering an existing tax/subsidy structure which is clearly suboptimal. This is, unfortunately, the case in many developing countries where energy-consuming sectors are heavily subsidized while other sectors face substantial commodity taxes. In this situation, what are the welfare effects of an environmental regulation which curtails output in a heavily subsidized sector? The social costs (benefits) of the regulation are usually less (greater) than they would been if the sector was not subsidized. An example from the United States clarifies this point further.

Lichtenberg and Zilberman (1986) study the desirability of pesticide bans for agricultural crops which are heavily subsidized for political or distributional reasons. The crops under consideration receive substantial subsidies in the form of output price supports. These supports encourage an overproduction of the commodities in question (corn, rice, and cotton). Banning certain harmful pesticides not only generates desirable environmental

benefits, but welfare may be further enhanced because the ban reduces the output of the overproduced commodities. This argument is relevant in many developing country where subsidies have led to an undesirable expansion of some outputs (Kosmo, 1989).[17] On the other hand, stringent environmental regulations which reduce output in sectors which are already hampered by high rates of commodity taxation can be very costly in welfare terms. In this case, stringent environmental regulations are only warranted where the pollutant is extremely damaging.

While the existence of a polluting output or input which is subsidized or taxed too little is a particularly attractive target for a Pigouvian tax, it should be remembered that commodity tax rates can vary for sound fiscal reasons and these variations do not identify an extra efficiency reason for imposing a Pigouvian tax. Conversely, the presence of pre-existing high tax rates on polluting goods does not eliminate the argument for taxing them even more for environmental reasons. If the pre-existing tax rates are chosen as quasi-optimal--that is, optimal for fiscal reasons but without regard to the environmental impacts--they can and should be increased further if the goods cause external environmental costs. That is, the Pigouvian tax on a good should be added to whatever tax rate is appropriate for revenue purposes.

VI. A Few Specific Policy Recommendations

We have emphasized the usefulness of eliminating subsidies and increasing taxes on polluting inputs and outputs as an important first step in reducing the pollution problems prevalent in developing countries today. In addition, governments of developing countries can consider content taxes such as taxes on the sulphur, carbon and lead contents of fossil fuels. Such taxes are more finely focused on the offending agents of pollution. Beyond this, it is difficult to make specific recommendations about environmental policies which would be appropriate for all developing countries given differences in the structures of their economies and the particular pollution problems they face. However, most developing countries are confronted with the emerging problems of air pollution from vehicular sources and the industrial and domestic use of coal as a fuel. Also, nearly all developing countries are plagued with the contamination of water resources with raw sewage, agricultural runoff, and some industrial point-source pollution. For these problems, we offer a few suggestions.

Concerning air pollution problems in developing countries, Krupnick (1990) contends that the efficiency case for market-based incentives is particularly strong and that a limited system of emission fees, along with price reforms on subsidized polluting production inputs, are attractive approaches for the control of urban air pollution from industrial sources. For health reasons,

it is imperative that developing countries phase out the use of leaded gasoline. In countries with state-owned refineries this could be accomplished by fiat or by setting a high price on leaded gasoline. In countries with private refineries, regulations and hefty taxes on leaded gasoline would accomplish the same thing. More generally, controlling present and future vehicular emissions with increased fuel taxes is likely to be a very sound policy, both as a revenue-raising device and as an effective and least cost means of discouraging this increasingly important source of urban air pollution. In the case of mobile source air pollution, fuel taxes should be supplemented with programs aimed at improving vehicle maintenance. Krupnick continues (p.43):

> ...buses and trucks are such an important transport mode in developing countries and, with some exceptions, these vehicles are old and poorly maintained, more attention needs to be paid to their emissions than now (where emissions are generally ignored). Performance standards and inspection and maintenance programs specifically directed to these types of vehicles are needed. Such monitoring and enforcement requirements are likely to result in inexpensive carburation and other adjustments that would yield substantial emissions reductions. Automobiles and two-wheeled vehicles also need to come under these programs.

The periodic monitoring of emissions, while costly, may still be economically efficient. A fuel tax is broader than the theoretically desirable tax on individual emissions. Therefore, a fuel tax by itself, with no monitoring of actual emissions, will not induce the optimal abatement of emissions per unit of fuel consumed.

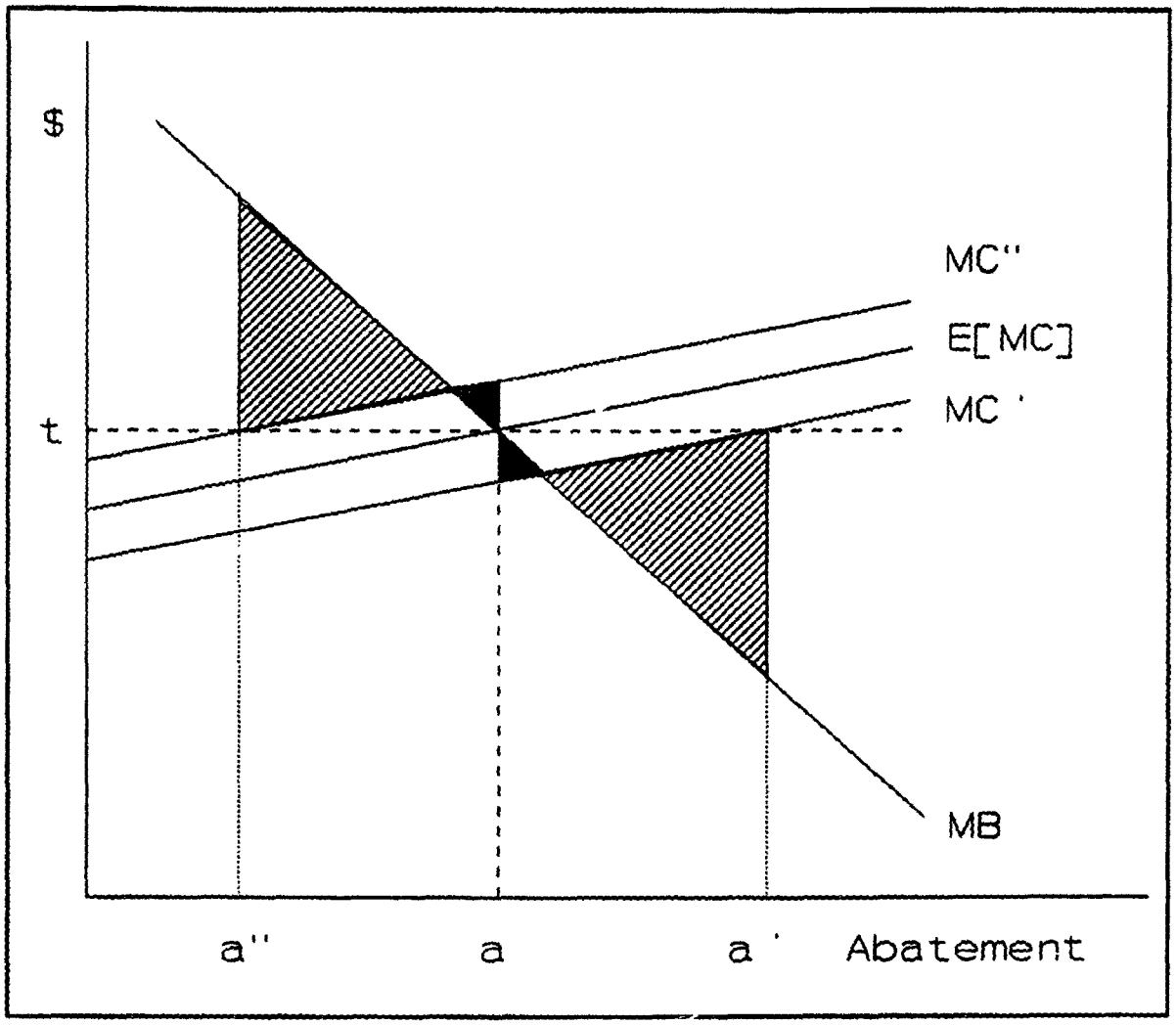
Another important source of air pollution in developing countries is that of indoor heating and cooking. Smith (1988) documents that in several developing countries, coal burning stoves are a major problem and that subsidizing improved cooking stoves for the poor may yield large benefits and be relatively cost-effective (compared to the costs of abating comparable quantities of the same pollutants generated by industrial sources). The emission of sulphur dioxide, from both industrial and domestic sources burning coal, might best be controlled by taxing high-sulphur content coal at a much higher rate than low-sulphur coal. The regulation of sulphur content in fuels has worked well in many developed countries (OECD, 1991).

In the case of water pollution, a mix of policy instruments designed to curtail pollution is needed, in addition to the publicly financed expansion of treatment and sanitation facilities. To partially finance the expansion of water treatment plants, the water authorities in developing countries should institute a system of user charges for those municipalities and industrial sources whose effluent is to be treated. User charges like these have been employed successfully in Germany. Large industrial polluters whose water effluent can be easily identified and measured could be charged a per unit effluent fee. Most agriculturally-based water pollution problems are of a nonpoint nature, and monitoring runoff is impractical. Consequently, input taxes (on manure, chemical

fertilizers, pesticides, and irrigation water) are the most practical and reasonably efficient policy instruments available.

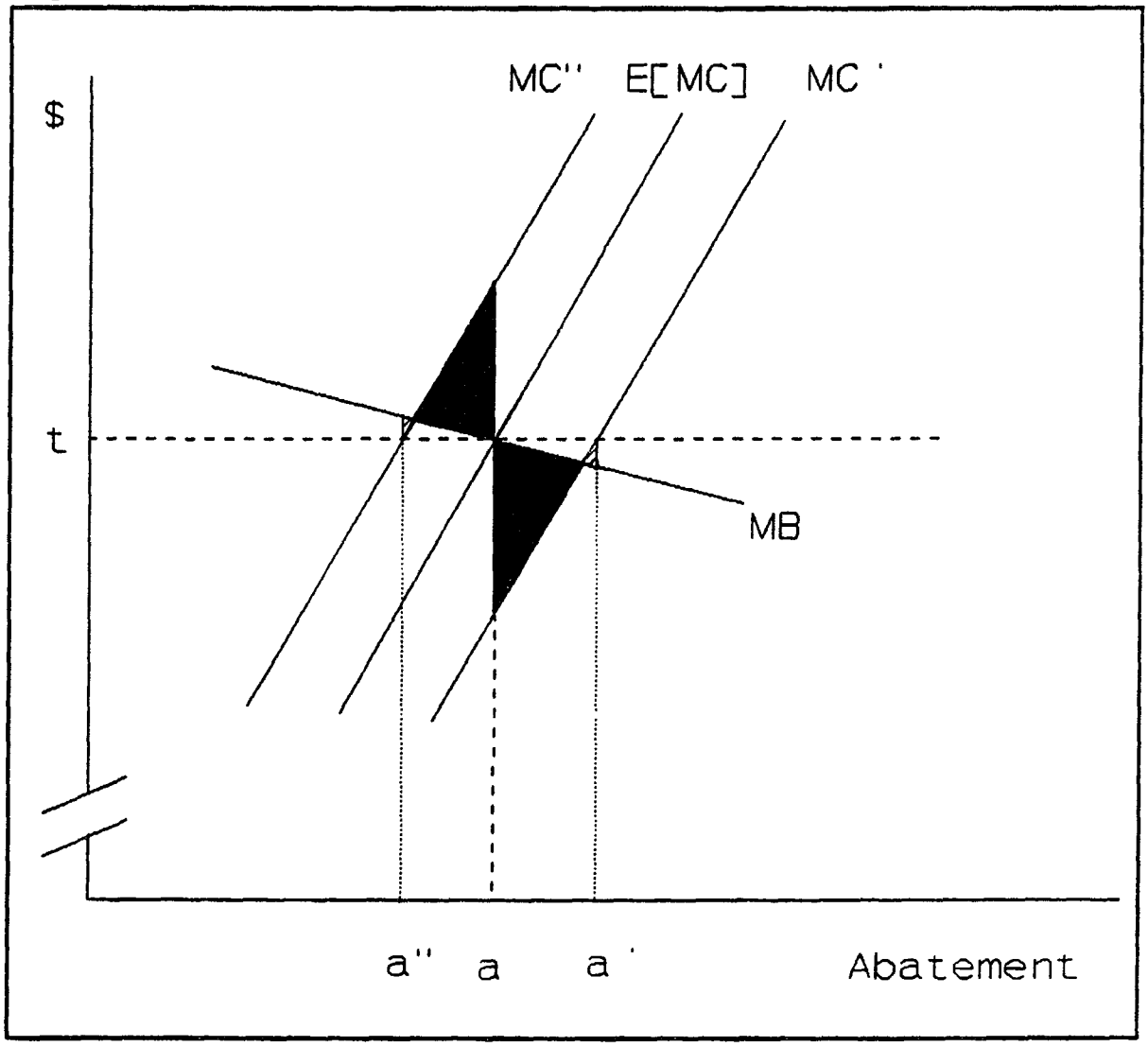
We have argued the case for indirect commodity taxation as a useful instrument for controlling many of the pollution problems in developing countries. This case is based on the limited administrative expertise in environmental policymaking, general weakness of legal institutions, and potentially small enforcement budgets found in many developing countries. However, for certain classes of pollutants, strict command and control regulations are warranted. Toxic pollutants should not be controlled with market-based incentives like emission fees or indirect commodity taxes on inputs. In these circumstances, where the marginal damage from a pollutant depends critically on the quantity emitted, the quantity should be controlled directly with an outright ban or a vigorously enforced limit.[18]

Figure V.1 Taxes Versus Standards--Standard Preferred



A pollution abatement standard is preferred to a pollution tax. The regulator, who must set either a tax, t, or a standard, a, in the face of uncertainty about the exact location of the marginal cost of abatement curve, will choose to equate the expected marginal cost, E[MC], with the marginal benefit, MB, of abatement. The optimal level of abatement will, in contrast, be given by the intersection of the true MC of abatement (either MC" or MC') with the MB of abatement. A tax, t, will induce abatement of only a" units from a firm with high costs (MC") and a very large amount, a', from a firm with low costs (MC'). These abatement levels are not close to the optimal levels, and they result in losses of societal net benefits measured by the large lined triangles. In contrast, an abatement standard, a, will come much closer to the optimal level of abatement when costs are either high or low, and the resulting welfare loss is smaller (measured by the small darkly shaded triangles). The comparative advantage of a standard to a tax emerges because of the relatively steep slope of the MB of abatement curve.

Figure V.2 Taxes Versus Standards--Tax Preferred



A pollution tax is preferred to an abatement standard. The regulator, who must issue a tax, t, or a standard, a, in the face of uncertainty about the exact location of the marginal cost of abatement curve, will equate the expected marginal cost, E[MC], with the marginal benefit, MB, of abatement. A tax will induce abatement levels of a" or a' if the true marginal cost is MC" or MC' respectively. These abatement levels (a" and a') are close to the optimal abatement levels (given as the abatement levels which equate the true MC of abatement with the MB). In contrast, if the standard is used, far too much abatement is required of a firm with high abatement costs (MC") and far too little abatement is required of a firm with low abatement costs (MC'). The relatively large errors occur because the marginal cost of abatement curve is steeply sloped, compared to the MB curve.

Footnotes

1. Much of our summary of air pollution problems in developing countries is taken from a paper written by Alan J. Krupnick entitled "Urban Air Pollution in Developing Countries: Problems and Policies." It was prepared for a UNU/WIDER Conference on "The Environment and Emerging Development Issues," Helsinki, September 3-7, 1990.

2. Indoor pollution poses less of a social problem, invoking the need for a government policy, because the cost of such pollution is borne mostly by the polluter himself. Rather than being an externality, the problem of indoor pollution may be one of lack of information or mis-information, as well as an inadequate market structure which makes alternative fuels unavailable to rural households.

3. Paradoxically, recent steps by the state-run oil company PEMEX to reduce lead in gasoline may have had the effect of raising ozone levels in Mexico City. In the absence of catalytic converters on most Mexican cars, the unleaded gasoline introduced by PEMEX in 1986 caused ozone levels to shoot up. The relatively modest ozone standard of 0.11 ppm is exceeded on more than 300 days each year (Nuccio, Ornelas, and Restrepo, 1990).

4. For a discussion of benefit-cost techniques for evaluating public infrastructure projects in developing countries, the interested reader is directed to Dixon and Hufschmidt (1986). In one chapter, they evaluate the benefits and costs of additional water treatment facilities in a suburban region of Beijing.

5. This was first noticed in medieval Europe where common pasturelands were typically overgrazed and less productive than private pasturelands. Much of a country's air and water resources are common property and subject to this "tragedy of the commons".

6. In fact to the extent that the refining of gasoline involves external costs of air pollution, the price paid at the pump is less than the social cost of producing the gasoline.

7. This assumes that the private supply price of gasoline remains constant at one dollar when the Pigouvian tax is imposed. More generally, the private supply price of gasoline may fall when a tax is imposed.

8. Payments to consumers would be undesirable under circumstances where such payments may attract "nuisance" claims--for example, households moving into areas of high pollution, at a cost to themselves, in order to receive the compensating payments.

9. Because the policy of paying not to consume gasoline would elicit false representations about the level of gasoline that the consumer would purchase in the absence of the payment, this policy is inferior to the more direct policy of taxing gasoline consumption on practical grounds.

10. To achieve least cost pollution abatement it is also necessary that gasoline consumption by each consumer type impose the same social cost of pollution on the economy.

11. These figures are based on Table 3 in Poterba (1991).

12. Shah and Larsen (1991) have shown that a carbon tax could appreciably reduce emissions of local and regional pollutants such as nitrous oxides, carbon monoxide, particulates and sulphur dioxide.

13. Strictly speaking, the comparison between *expected* marginal benefits and costs of crime is appropriate only if the individual is risk-neutral. For a discussion of the optimal frequency and magnitude of fines under conditions of risk-aversion, see Polinsky and Shavell (1979).

14. Harrington (1988) and Russell (1990) both use a Markov game model of enforcement which emphasizes the importance of past firm behavior. Enforcement costs associated with a target level of compliance are found to be lessened by placing firms into categories with different monitoring probabilities based on past performance records.

15. While tradeable permit programs have been somewhat successful in the United States, and the new Clean Air Act encourages their future use as an integral part of the regulatory structure of the U.S., Hahn (1989) and Hahn and Hester (1987) have also noted their failure to deliver on their theoretical efficiency properties in practice.

16. Enforcement practices in the United States and other developed countries are far from optimal. Magat, Krupnick, and Harrington (1986), Russell, Harrington, and Vaughn (1986), and Russell (1990) suggest that increasing enforcement budgets, restructuring enforcement procedures, and stiffening fines for noncompliance would be desirable.

17. Baron (1985) has an interesting model of noncooperative regulatory behavior in which an environmental protection agency must take as given the pricing policies of a utility regulator. Not surprisingly, welfare is lower in the noncooperative equilibrium than in a cooperative one in which pricing and environmental policies are coordinated.

18. The case for command and control environmental regulations is also strengthened for industries comprised of only a few relatively homogeneous firms where the efficiency advantages of flexible market-based incentives are not likely to be large. Large state-controlled industries may be examples of this.

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