THE INDUSTRIAL-POLLUTION-PROJECTION SYSTEM: CRITICAL ANALYSIS AND POTENTIAL APPLICATIONS

by

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ABSTRACT

Rapid industrialization is forcing policymakers in many developing countries to face the challenge of industrial-pollution control. The role of government in correcting this market failure is to improve net social welfare by reducing pollution until the marginal cost of pollution control equals the marginal benefit. To achieve any success in this complex task, policymakers require a substantial amount of information and strong institutional capacity. Unfortunately, both these requirements are in short supply in most developing countries.

The need for a planning tool to assist in the formulation of industrial-pollution-control policy was recognized by the World Bank in 1990 and led to the development of the Industrial-Pollution-Projection System (IPPS) using U.S. Environmental Protection Agency and U.S. Census of Manufactures data. By linking estimates of pollution intensity to sectoral production data, policymakers can use IPPS to assist in the identification of key pollutants and priority sectors, and to provide an important input to their assessments of the costs and benefits of pollution-control policy.

IPPS is based on a set of sectoral pollution-intensity coefficients drawn from a sample of U.S. manufacturing plants. As such, some error is to be expected in IPPS estimates of pollution loads, even using U.S. data. In this thesis I present some preliminary evidence that these errors may be significant. A substantial amount of work is required to identify the sources of these errors and to determine if any improvements can be made. I conclude that the potential value of the system to planners in the World Bank and client governments is sufficient to justify the additional effort.

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CHAPTER 1

INTRODUCTION: THE INDUSTRIAL-POLLUTION-POLICY IMPERATIVE

In Bangkok, Beijing, Calcutta, Jakarta, Tehran, and other urban centers in developing countries around the world, some 1.3 billion people breathe air that does not meet World Health Organization standards (World Bank, 1992). The resulting sickness and death is worse than would be expected under the same conditions in developed nations, because of pre-existing poor health and nutrition. Between 300,000 and 700,000 premature deaths are caused each year from particulate pollution alone (World Bank, 1992). Other priority pollution issues in the world's rapidly industrializing regions include the exposure of more than a billion people to unhealthy levels of sulfur dioxide and lead, loss of welfare from water-systems that have become biologically dead from the release of organic pollutants, and sickness caused by the uncontrolled disposal of toxic wastes.

The problems of urban pollution present the World Bank with one of its greatest challenges in its mission to "alleviate poverty and promote sustainable development" (World Bank, 1992). In this thesis, I examine the development by the World Bank of the Industrial-Pollution-Projection System (IPPS), a tool designed to assist in the formulation and implementation of industrial-pollution-control policy. I assess the importance of such a tool for improving the quality of environmental decision-making, then I describe the development of IPPS, and finally I critically examine the validity of the system. In order to place these issues in some context, I outline below some of the obstacles facing governments and development agencies in establishing and enforcing effective industrial-pollution policy in developing countries.

Obstacles to Effective Industrial-Pollution-Control Policy

Industrial-pollution-control policy may be characterized as government intervention to correct a market failure. Pollution is generated as an externality to industrial production. The market failure arises because incomplete information and transaction costs prevent the full social cost of pollution from being reflected in the production decision of the generating agent. As a result, net social welfare is not optimized. The social costs of pollution take a number of forms, which may be summarized in three broad categories as (1) detriments to human health, (2) loss of productive capacity, and (3) loss of aesthetic utility. Although detriments to human health may also cause a reduction in productive capacity, they are defined separately because some health effects may reduce welfare without directly affecting production. The definition of lost productive capacity includes damage to both physical capital and natural resources. Lost aesthetic utility includes the many aspects of individual enjoyment of the natural and built environment that may be adversely affected by industrial pollution, but which are difficult to quantify in monetary terms. Assessment of all these costs is further complicated by the fact that current pollution may reduce social welfare far into the future, raising the problems of social and intergenerational discounting.

Simply stated, the objective of pollution-control policy is to improve net social welfare by reducing pollution until the marginal social cost of pollution control is equal to the marginal social benefit. In practice, the assessment of both the costs and benefits is difficult. The controversy surrounding this task is highlighted by an infamous memorandum leaked from the Chief Economist of the World Bank, Lawrence Summers. Despite the well-recognized detrimental impacts of industrial pollution outlined above, Summers wrote:

> Just between you and me, shouldn't the World Bank be encouraging more migration of the dirty industries to the LDCs ? (Summers, 1992)

Understandably, this memorandum caused an international uproar. Nevertheless, behind the blunt language lurks the serious issue of the appropriate level of pollution control in lower-income nations.

Difficulties arise for policy-makers in developing countries largely because there are good grounds to believe that neither the benefits of industrial production nor the costs of industrial pollution match those in the developed world. Perhaps the most obvious social costs of pollution are those associated with adverse impacts on human health. Just as the marginal detriment to health is likely to be higher in developing countries because of pre-existing ill-health and malnutrition, so the marginal improvement in health from an increase in national income is likely to be greater than in the developed world. Possibly the most objectionable aspect of Summers' memorandum was the suggestion that the costs of health-impairing pollution depend on the foregone earnings from increased morbidity and mortality. As Jagdish Bhagwati wrote in response:

> . . . no modern economist, when his house is on fire, will pull his father out before his mother because the father earns more than the mother. Economists have learned, at least since the 1960's, to broaden their analysis to include objectives (including the environment) other than just goods and services. (Bhagwati, 1992)

If part of the aim of industrial-pollution control is to improve human health, then the human health costs of reduced national income, caused by the increased production costs associated with pollution control, should also be taken into account. By converting the abatement costs into a measure of the impact on human health, they can be directly compared with the human health benefits of pollution control. This form of analysis is complex, and it can be conducted only in approximate terms, but it is essential to do if pollution-control policies in lower-income nations are to achieve efficient outcomes.

The two essential ingredients for the implementation of effective policies to control industrial pollution are information and institutional capacity. Without reliable information, policy-makers cannot begin to determine which policies will deliver the most efficient outcomes. Without sufficient institutional capacity, the information cannot be effectively analyzed and the policies cannot be implemented. Both of these constraints are more severe in developing countries than in the industrialized world, and both can crucially benefit from the availability of effective planning tools. The development of IPPS by the World Bank was undertaken in recognition of these needs. First, IPPS is intended to allow better-informed policy-making by providing estimates of pollution emissions from widely available economic data, where emissions data was previously scarce. Second, IPPS is intended to strengthen institutional capacity in two ways. The system will allow more efficient use to be made of scarce financial and administrative resources by helping to identify priority pollutants and sources. In addition, by providing a clear framework for setting industrial-pollution-control policy, IPPS will improve the transparency of decision-making. This is especially important for government and development agencies facing political pressure in this arena.

Thesis Structure

In the next chapter of this thesis, I discuss in more detail the potential value of a tool such as IPPS for improving the quality of environmental decision-making, especially for developing countries. First, I illustrate how the system may be used to identify key pollutants and priority sectors. I then demonstrate how IPPS may be used in conjunction with economic models to assess the costs of an environmental policy, and, finally, I discuss the potential contribution of the tool in modeling ambient conditions. In Chapter 3, I describe the conceptual goal of the World Bank team who produced the initial version of IPPS, the methodology we employed, and some of the operational complexities we encountered. I critically assess the validity of our results in the Chapter 4, indicating the existence of some serious problems. I end by suggesting some further work that needs to be undertaken to improve the accuracy and utility of IPPS, arguing that the additional effort is justified by the potential contribution of such a tool to the formulation of industrial-pollution-control policies.

CHAPTER 2

THE INDUSTRIAL-POLLUTION-PROJECTION SYSTEM: IMPROVING ENVIRONMENTAL POLICY-MAKING

In the introductory chapter, I outlined the obstacles to the formulation and implementation of effective environmental policy in developing countries. Here, I demonstrate more explicitly the ways in which a tool such as the Industrial-Pollution-Projection System (IPPS) may help overcome these obstacles. In simplest terms, IPPS is a set of pollution-intensity coefficients. Each coefficient describes the amount and type of pollution that may be expected as an externality to production in a given industrial sector. Thus, IPPS is able to create estimates of the pollution load generated by a given set of manufacturing installations. In order to define more precisely the potential contributions and limitations of the system, I frame this discussion in the terms used by the World Bank, in the World Development Report 1992, "Development and the Environment" (World Bank, 1992). Chapter Four of the report is particularly salient, providing in the chapter-heading a basis for examining the potential of IPPS; "Making Better Decisions: Information, Institutions, and Participation."

Although my main argument in this chapter is that IPPS has the potential to improve environmental decision-making significantly through providing better information, I want to note at the outset that such a tool may also contribute towards institutional-strengthening and consensus-building. According to the World Development Report 1992, institutional-strengthening includes the need to develop legislation and administrative structures, provide skills, and ensure adequate funding.

Clearly, IPPS offers the potential to provide skills to the extent that such a tool enhances the technical capacity of an institution. Beyond this, better identification of priority pollutants and sources may also aid in the establishment of a more effective administrative structure, and a more efficient allocation of funds than is possible in the absence of such information. I present this argument in more detail in the first section below. Turning to the issue of participation, although the availability of an effective planning tool does not directly promote public involvement, it provides agencies with another mechanism for achieving consensus. A clearly established set of analytical techniques helps agencies to shift the debate away from political interests, to a more technical level of dialogue, at which acceptance of methodology and assumptions substantially reinforces acceptance of eventual policy conclusions.

Nevertheless, IPPS is primarily designed to raise the quality of information available for environmental decision-making in developing countries. In discussing the importance of information for the establishment of sound environmental policy, the World Development Report 1992 states:

> Ignorance is an important cause of environmental damage and a serious impediment to finding solutions. . . .It is necessary, first, to know the facts; second, to determine values and analyze the benefits and costs of alternative measures; and, third, to ensure that information is available to inform public and private choices. (World Bank, 1992, p. 85).

IPPS has a potentially important role in meeting the first two of these three necessities: the establishment of the facts and the analysis of costs and benefits. In many developing countries directly monitored industrial-pollution data are scarce and expensive to obtain, so that the facts of industrial pollution are poorly understood. In the first section below, I demonstrate the use of IPPS to estimate industrial pollution from economic data. This use of the system assists analysts in the preliminary task of establishing the total pollution load from manufacturing and, subsequently, in identifying the major source sectors. To aid in the illustration of the types of policy issue that may be analyzed, I use economic data from Indonesia, one of the most rapidly industrializing countries in the world. The purpose of this discussion is to underline the potential value of such a system; however, analysts must treat the calculated pollution loadings with a high degree of caution.

Although estimates of pollution loads are useful, they do not directly identify the appropriate level of pollution control. As I mentioned in the previous chapter, the objective of pollution-control policy is to improve net social welfare by forcing pollution abatement until the marginal social cost of control equals the marginal social benefit. In the subsequent two sections, I discuss the role of IPPS in helping to determine both the potential costs and the benefits of proposed policies aimed at controlling industrial pollution. This form of analysis is particularly pertinent in developing countries, where we do not know whether the direct transfer of western environmental standards is likely to achieve optimal social outcomes. As argued by Tobey, the marginal social cost of raising the cost of industrial production in a developing country is likely to be higher than in a developed nation, because of the relatively greater impact on what he terms "poverty-related" pollution (Tobey, 1989). He uses this term to describe the health impacts of poverty, for example, as a result of limited access to sanitation and clean water, and a low standard of nutrition. To the extent that such "poverty-related" pollution has a negative impact on human health, analysts can directly compare it to any health improvements resulting from reduced industrial pollution.

In order to examine the costs associated with a proposed industrial-pollution-control policy, analysts must link IPPS to a model of the economy in question. To examine more fully the policy issues that may be raised, I again employ economic data, this time from Massachusetts, in a simulation of a hypothetical environmental tax introduced in the Commonwealth. I chose this state because of the ready availability of a highly sophisticated regional economic model, which enables me to demonstrate the rich potential of this form of analysis. In the third section of the chapter, I turn to the benefit-side of the environmental policy calculus. I discuss in more detail the relevance and major components of a system in which analysts could use IPPS as one input in assessing the health and welfare benefits of an industrial-pollution-control policy.

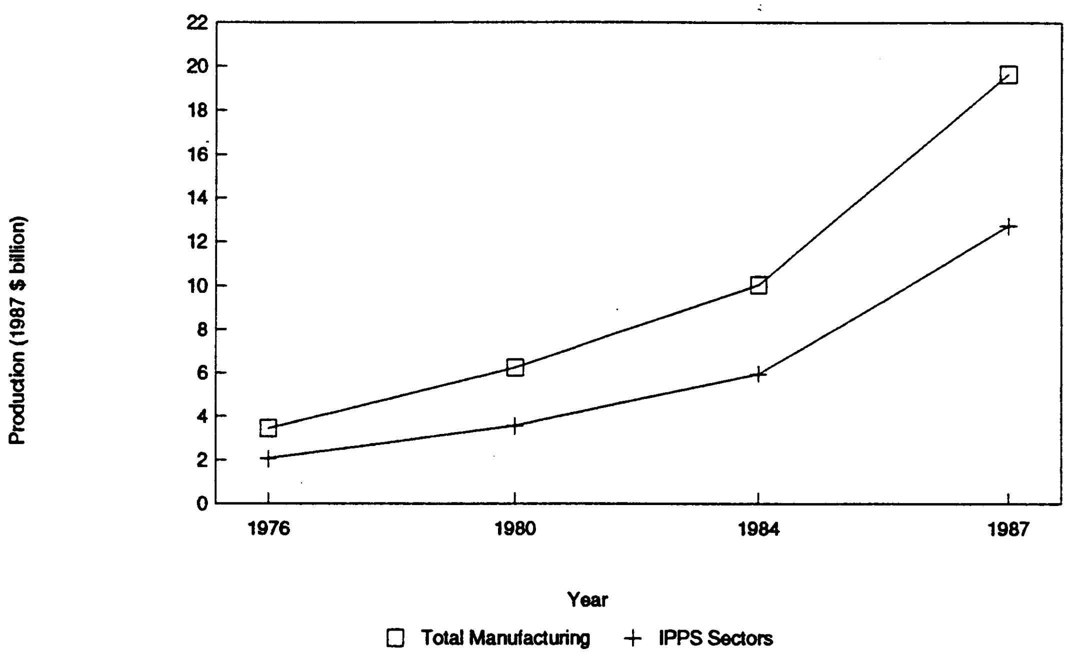
Identifying Key Pollutants and Priority Sectors: an Illustration using Indonesian Data

In this section, I demonstrate the relatively straight-forward use of the IPPS intensities to establish total pollutant loadings and to identify key source sectors. I apply IPPS to Indonesian economic data in order to demonstrate more clearly the environmental policy issues that may be analysed. As mentioned above, the use of Indonesian data is for illustrative purposes, and little reliance may be placed on the actual pollution loadings derived from the current version of IPPS.

The growth rate of manufacturing output in Indonesia reached 12.5% during the 1980s, making it one of the most rapidly industrializing countries in the world (World Bank, 1992). Government policy-makers have identified the need to control the associated growth in industrial pollution as a priority issue in the preparation of Indonesia's second 25-year plan and the sixth 5-year plan (Repelita VI). This has led World Bank officials to establish a loan to strengthen the institutional capacity for environmental management. The lack of comprehensively monitored data on industrial emissions or ambient conditions, however, severely hampers analysts' efforts to identify priority pollutants and emitters. This makes the meaningful incorporation of environmental issues into economic planning almost impossible.

IPPS offers the potential for analysts to use the relatively comprehensive data from the Indonesian Census of Manufactures to identify both the priority pollutants and the priority sectors for the control of industrial pollution. IPPS intensity coefficients are available for about two-thirds of Indonesia's total industrial output in the period 1976-1987 (see Figure 2.1). For this example, I used the census information and the IPPS intensities to estimate the total release in Indonesia of four pollutants in 1976, 1980, 1984, and 1987. The pollutants are carbon monoxide (CO), nitrogen dioxide (NO_2), particulates (PT), and sulphur dioxide (SO_2). I calculated the release from each sector as the product of the recorded value of output and the IPPS pollution intensity, and then I summed the sectoral data to derive

Figure 2.1
Indonesia - Industrial Production, 1976-1987
Total Production and Production from IPPS Sectors
(1987 $ billion)



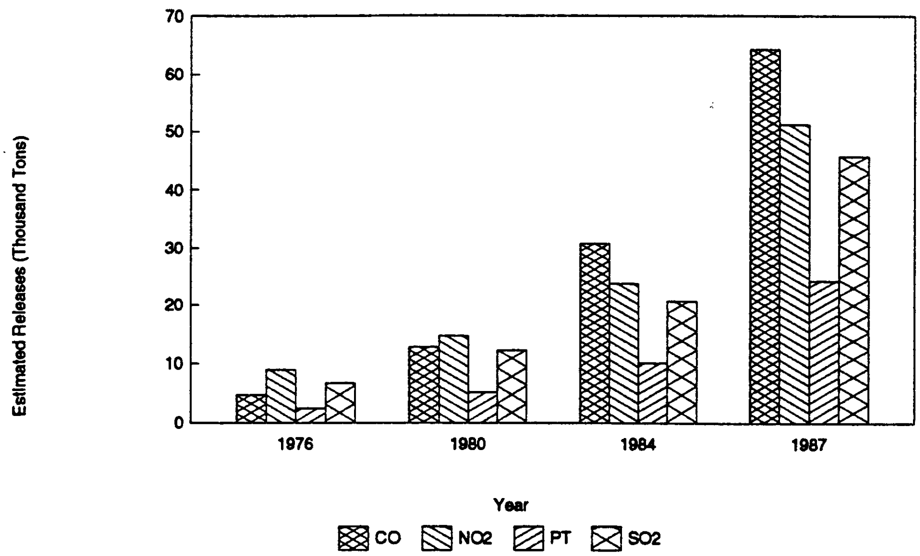
IPPS - Industrial Pollution Projection System
Source: Industrial-Pollution-Projection System, World Bank
Indonesian Census of Manufactures, 1976-1987

the total emissions. By using this procedure, I ignored the pollution from those sectors for which IPPS intensities are unavailable, amounting to one-third of the total value of industrial output. However, the contribution of these sectors to the total pollution load is likely to be small, because IPPS includes the most pollution-intensive industries.

Figure 2.2 charts the total estimated releases of the four pollutants over the eleven-year period. As can be seen, the annual release of each pollutant increased approximately tenfold between 1976 and 1987. The greatest increase was in the emission of CO, which jumped from about 5,000 tons in 1976 to over 60,000 tons by 1987. Although we might expect most of this increase to be a direct result of the growth in manufacturing output, it is also possible that the structure of the industrial sector is becoming more pollution intensive. Figure 2.3 illustrates this issue by charting the pollution intensity of manufacturing output (calculated as the total release from manufacturing activity divided by total manufacturing output) for the four pollutants between 1976 and 1987. This chart indicates that in 1987 every million dollars of manufacturing output released more than three tons of CO, compared to less than half that amount in 1976. The intensity of particulate emissions also almost doubled, while the intensity of NO_2 and SO_2 emissions remained relatively stable. The conclusion to be drawn from this analysis is that the growth in output from the more CO and PT intensive sectors exceeded that of the manufacturing sector as a whole, whereas the NO_2 and SO_2 emitting sectors grew at approximately the same rate as total manufacturing output.

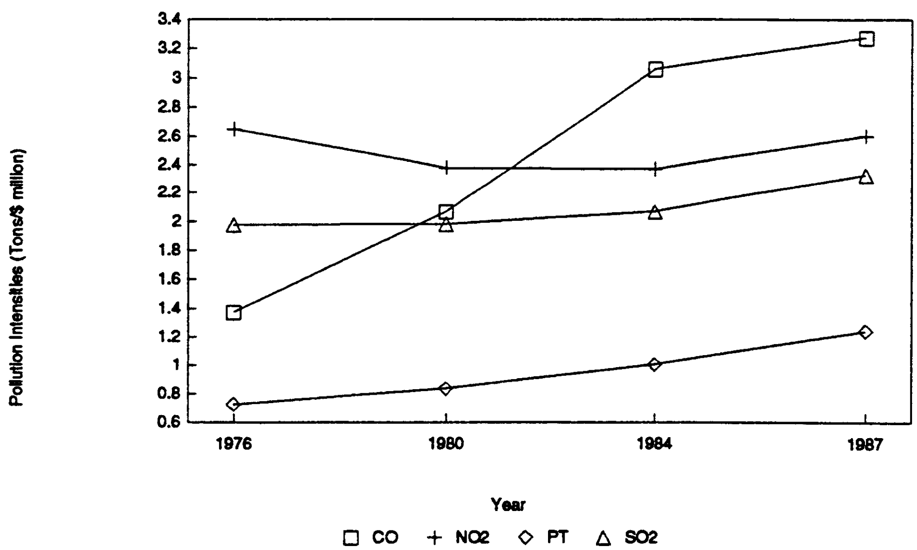
Figures 2.2 and 2.3 illustrate the potential of IPPS for

Figure 2.2
IPPS Estimates of Total Releases of Selected Pollutants
From Indonesian Manufacturing, 1976-1987
(Thousand Tons)



CO - Carbon Monoxide
IPPS -Industrial Pollution Projection System
NO2 - Nitrogen Dioxide
PT - Total Particulates
SO2 - Sulphur Dioxide
Source: Industrial-Pollution-Projection System, World Bank
Indonesian Census of Manufactures, 1976-1987

Figure 2.3
IPPS Pollution Intensity Estimates
Indonesian Manufacturing, 1976-1987
(Tons/$ million)



CO - Carbon Monoxide
IPPS -Industrial Pollution Projection System
NO2 - Nitrogen Dioxide
PT - Total Particulates
SO2 - Sulphur Dioxide
Source: Industrial-Pollution-Projection System, World Bank
Indonesian Census of Manufactures, 1976-1987

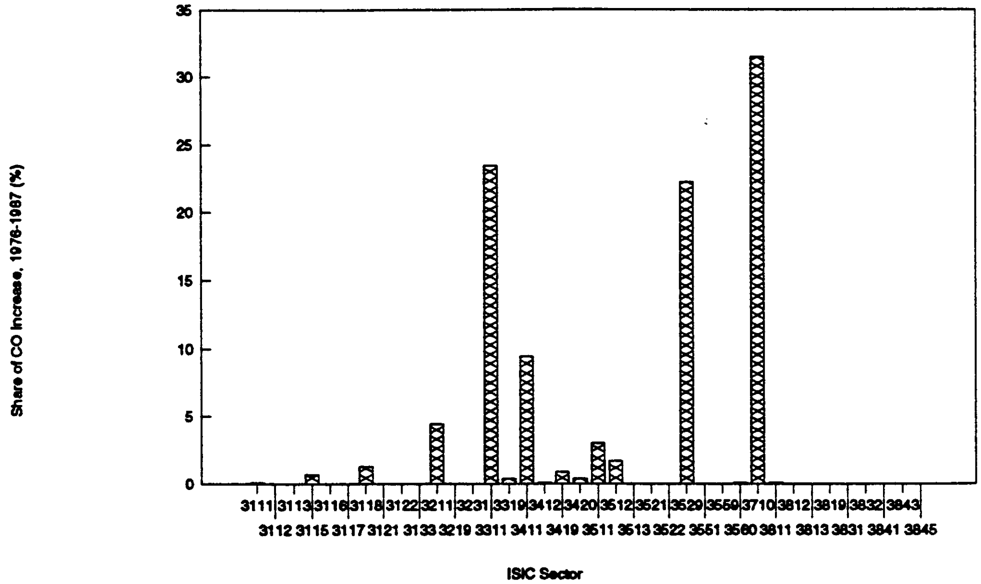
identifying priority pollutants. An equally important function of the system is to identify the key polluting sectors. In particular, in order to establish and enforce effective environmental controls for a rapidly industrializing economy, policy makers must gain some understanding of the activities that contribute most to the increase in pollution, such as the tenfold increase charted for Indonesia in Figure 2.2. The sector-specific pollution intensities provided by IPPS allow estimates to be made of the sectoral contributions to the total increase in pollution. Figures 2.4-2.7 present these estimates for the four pollutants studied in this example. The height of each bar represents the percentage share of each sector in the total increase in emission of each pollutant in Indonesia from 1976 to 1987.

The most important aspect of Figures 2.4-2.7 is the relatively few sectors that account for almost the entire increase in the emission of each pollutant. Indeed, for each of the four pollutants illustrated, the top nine sectors (the top quartile) account for at least 90% of the increase. In the case of CO emissions, the top quartile caused 98% of the increase in emissions. Six sectors appear in the top quartile for all four pollutants. These sectors are:

ISIC 3118, Sugar Factories and Refineries;
ISIC 3211, Spinning, Weaving and Finishing Textiles;
ISIC 3311, Sawmills, Planing and Other Wood Mills;
ISIC 3411, Pulp, Paper and Paperboard;
ISIC 3512, Fertilizers and Pesticides; and
ISIC 3710, Iron and Steel.

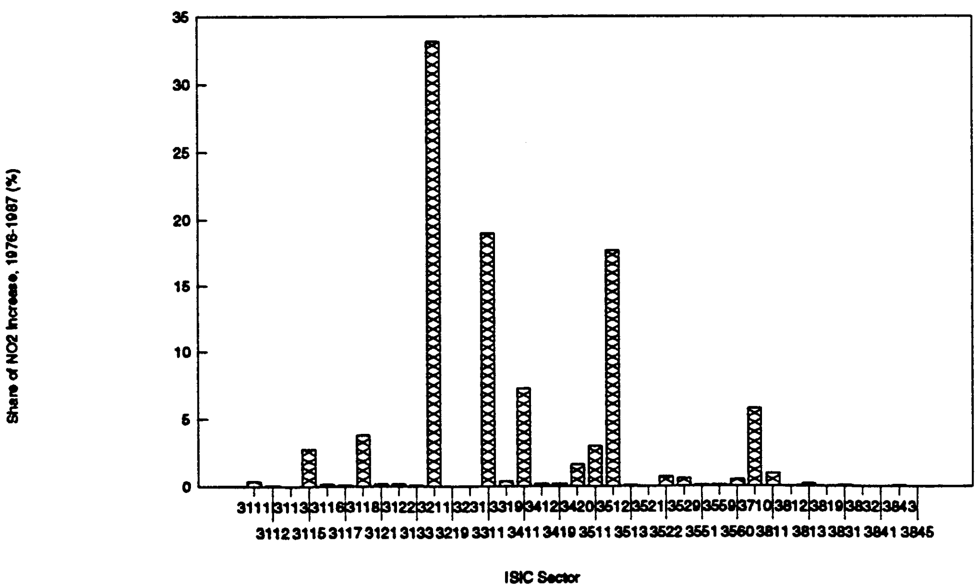
The significance of this finding is the indication that over the last decade, Indonesia could have controlled 90% of its industrial emissions of four key pollutants by focusing on only six sectors of

Figure 2.4
IPPS Estimates for Indonesia
Sectoral Share of CO Increase, 1976-1987
(Percent)



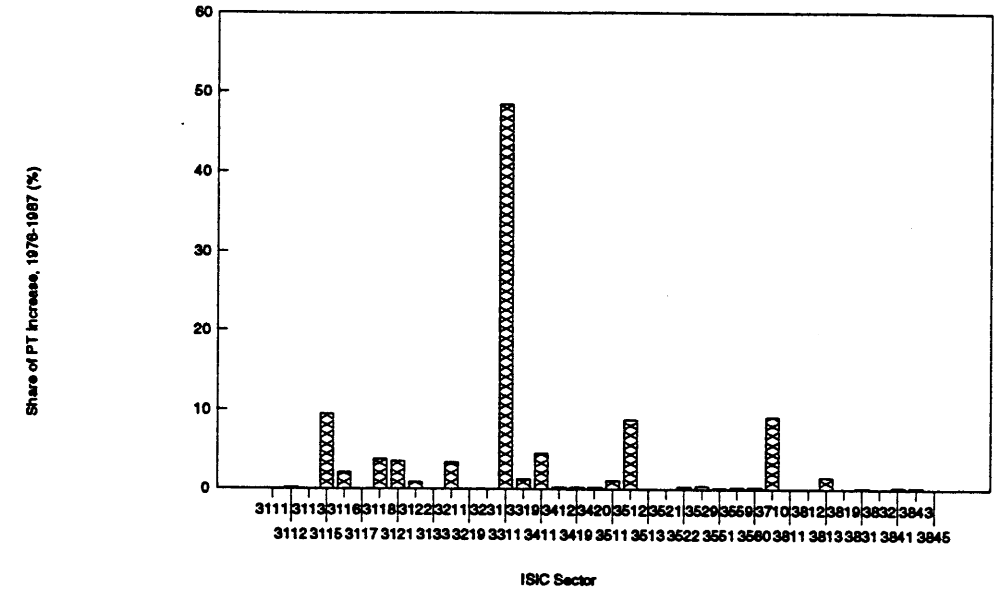
CO - Carbon Monoxide
IPPS - Industrial Pollution Projection System
ISIC - International Standard Industrial Classification
Source: Industrial-Pollution-Projection System, World Bank
Indonesian Census of Manufactures, 1976 and 1987

Figure 2.5
IPPS Estimates for Indonesia
Sectoral Share of NO2 Increase, 1976-1987
(Percent)



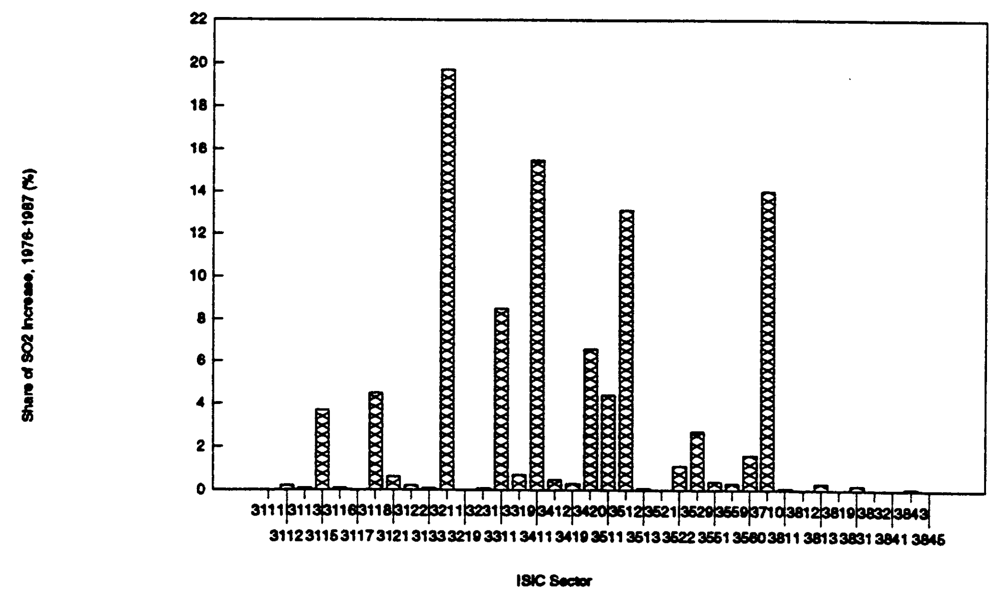
NO2 - Nitrogen Dioxide
IPPS - Industrial Pollution Projection System
ISIC - International Standard Industrial Classification
Source: Industrial-Pollution-Projection System, World Bank
Indonesian Census of Manufactures, 1976 and 1987

Figure 2.6
IPPS Estimates for Indonesia
Sectoral Share of PT Increase, 1976-1987
(Percent)



PT - Total Particulates
IPPS - Industrial Pollution Projection System
ISIC - International Standard Industrial Classification
Source: Industrial-Pollution-Projection System, World Bank
Indonesian Census of Manufactures, 1976 and 1987

Figure 2.7
IPPS Estimates for Indonesia
Sectoral Share of SO2 Increase, 1976-1987
(Percent)



SO_2 - Sulphur Dioxide
IPPS - Industrial Pollution Projection System
ISIC - International Standard Industrial Classification
Source: Industrial-Pollution-Projection System, World Bank
Indonesian Census of Manufactures, 1976 and 1987

production. This has important implications for the current round of economic and environmental planning. As policies are drawn up for the Repelita VI, the next five-year plan, IPPS could be combined with projected sectoral outputs to identify the sectors that are likely to be of gravest concern in the years ahead. If future emissions continue to be dominated by a few sectors there may be sufficient grounds for explicitly incorporating this expectation in current planning for environmental management. In particular, the institutional structure, capacity, and mission of the national environmental agency should be designed to ensure that the priority sectors are favored in the allocation of resources for the monitoring and enforcement of pollution control objectives. In the 1992 World Development Report, World Bank staff explicitly indicate the importance of favoring these sectors, stating:

> Since all countries face multiple environmental problems, governments must set priorities on the basis of informed analysis so that they can make the most efficient use of scarce administrative and financial resources. (World Bank, 1992, p. 87)

By aiding in the establishment of priorities, IPPS offers one mechanism by which governments of rapidly industrializing countries and development agencies may improve the quality of environmental decision-making and enforcement, given their limited resources.

Assessing the Costs of Industrial-Pollution-Control Policies

In the preceding section, I illustrated the use of IPPS to estimate sectoral emissions of key pollutants and indicated the value of this information for establishing environmental priorities. Beyond this relatively straightforward application, IPPS also offers the potential for a very detailed analysis of the links between environmental policy and economic outcomes. Any policy aimed at achieving a given pollution-control objective will affect the costs of production to some degree; consequently, it may be expected to affect regional output and employment. The objective of industrial-pollution-control policy is to improve social welfare by accounting for the costs associated with the externalities of industrial production. To ensure a net improvement in welfare, however, the efficiency gains must not be outweighed by any losses due to reduced levels of production. This consideration is particularly significant in developing countries, where the marginal impact on human health and welfare of a lost unit of production is likely to be far greater than in the developed world. This observation underlines the need to provide policy-makers in developing countries with a means of assessing the economic impact of proposed environmental policies.

In this section, I demonstrate the use of IPPS in conjunction with a regional economic model to assess the economic outcome of a hypothetical environmental policy. The objective is to illustrate the policy issues that may be analyzed given a suitable economic model and not to make any specific regional policy recommendations. I have selected the Commonwealth of Massachusetts to demonstrate this application because of the ready availability of an appropriate regional economic model, the Regional Economic Models Inc. (REMI) EDFS-53 model of the Massachusetts economy. The REMI model makes dynamic regional forecasts at a very detailed level, including employment, wages, and output for 53 sectors, personal income, and net regional migration (REMI, 1992).

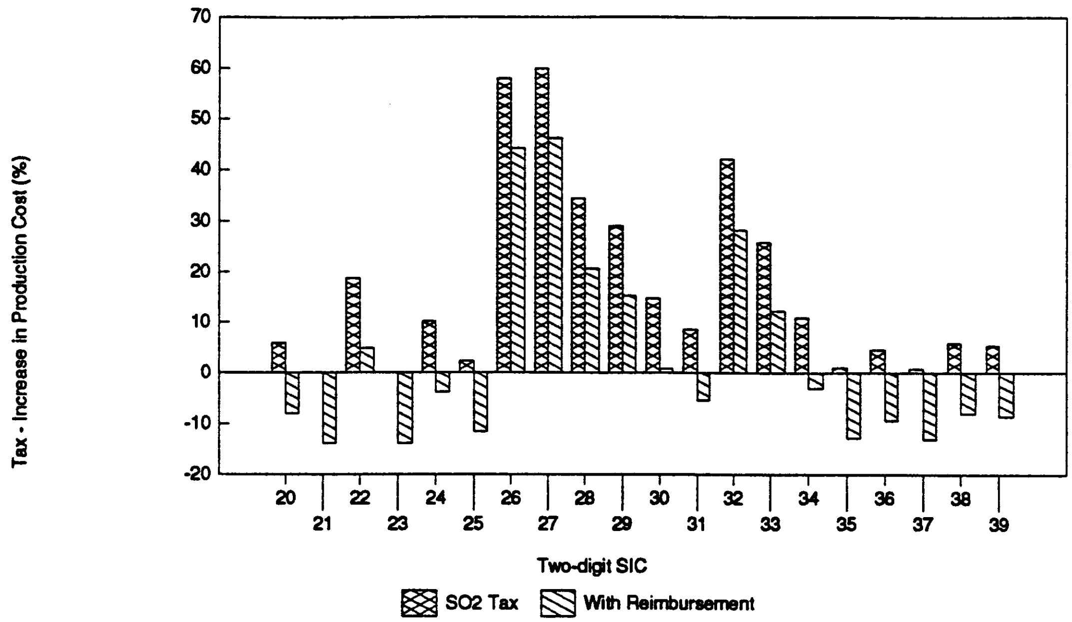
As an environmental objective, analysts frequently target total emissions of a given pollutant, expressed as a percentage of current emission levels. For this illustration, I established a hypothetical objective to stabilize releases of SO_2 from manufacturing industries in Massachusetts at the 1992 level by the year 2005. To meet this objective, I simulated the impact of an SO_2 tax that met the following two requirements.

1. The tax should be levied in proportion to SO_2 releases, in order to provide clear incentives for SO_2 reduction.
2. The tax should be revenue neutral. All revenue should be redistributed to the taxed industries, so that no additional tax burden is imposed on the economy as a whole.

I ran an initial simulation without the tax, in order to establish a control forecast of the economy and SO_2 emissions up to the year 2005. In subsequent runs, I simulated the tax in the REMI model as a change in the cost of production. A percentage change in the cost of production is equivalent to a percentage tax on output in the REMI model, as total costs equal the value of output. In order to create a revenue-neutral tax, the funds raised were redistributed to the same manufacturing sectors. However, while the tax was raised on the basis of SO_2-weighted output, it was reimbursed according to unweighted output. Accordingly, the net tax rate was higher on the more SO_2- intensive sectors. The requirement that the tax be revenue-neutral significantly complicated the procedure, as the reimbursement stimulated the economy, increasing SO_2 emissions, while a higher tax depressed output and, as a consequence, reduced net revenue.

Although I recognized the fact that Massachusetts requires a balanced budget, due to time constraints, I stopped the model runs at the sixth iteration, at which point the net tax revenue was negative $870 million (in 1987 dollars), over the 15-year period. In other words, the government was forecasted to spend an average $58 million per year in excess reimbursements above the amount taken in revenue from the tax. Further iterations would have enabled the SO_2 target to be reached with no net expenditure, through fine-tuning of the tax and reimbursement balance. Figure 2.8 presents the SO_2 tax rates and the rates net of reimbursement that I used in the last iteration. The SO_2 tax on its own amounts to a levy of $45.68 on every kilogram of SO_2 released. The rate of reimbursement was 13.8%, so that the top tax rate was reduced from 60.0% to a 46.2% increase in production costs, and the two sectors with no tax received a subsidy that reduced production costs by 13.8%. I illustrate the success of this taxation scheme in meeting the environmental objective in Figure 2.9. Under the control forecast, the estimated SO_2 emission in 1991 amounted to over 250,000 tons, rising to 350,000 tons by the year 2005. With the tax rates shown in Figure 2.8, the SO_2 emissions in 2005 were still only 250,000 tons. Because I assumed that the sectoral pollution intensities were constant over the forecast period, I achieved the reduction in SO_2 releases solely by altering the structure of the Massachusetts economy in favor of the less

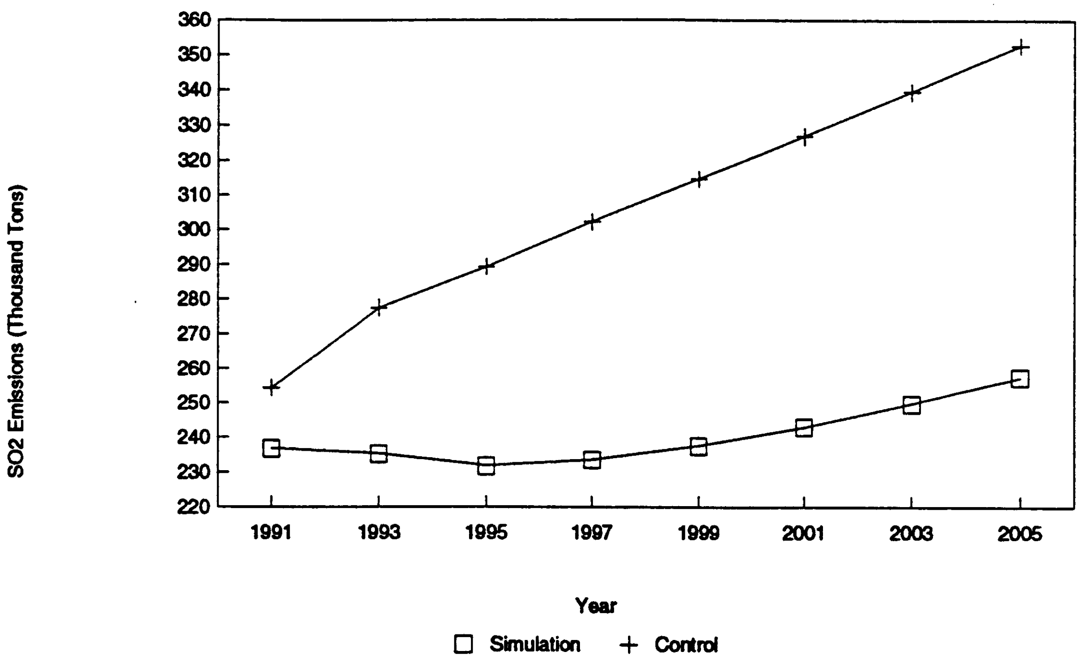
Figure 2.8
Hypothetical 1990 Massachusetts Economy
Simulated SO2 Tax and Net Tax with Reimbursement
(Percent Increase in Production Costs)



Two-digit SIC	Description	SO2 Tax (%)	SO2 Tax Net of Reimbursement (%)
20	Food	5.90	-7.91
21	Tobacco	0.00	-13.81
22	Textiles	18.57	4.76
23	Apparel	0.00	-13.81
24	Lumber	10.12	-3.69
25	Furniture	2.24	-11.57
26	Paper	58.02	44.21
27	Printing	59.97	46.16
28	Chemicals	34.43	20.62
29	Petroleum	29.06	15.25
30	Rubber	14.65	0.84
31	Leather	8.47	-5.34
32	Non-metallic Minerals	42.02	28.21
33	Primary Metals	25.94	12.13
34	Fabricated Metal	10.89	-2.92
35	Non-electric Machines	1.17	-12.64
36	Electric Equipment	4.48	-9.33
37	Transport Equipment	0.86	-12.95
38	Instruments	5.91	-7.90
39	Miscellaneous Manufacturing	5.36	-8.45

SIC - Standard Industrial Classification
SO2 - Sulphur Dioxide
Source: Author's calculations based on the World Bank's Industrial-Pollution-Projection System, and the REMI model of Massachusetts

Figure 2.9
Estimated Industrial SO2 Emissions in Massachusetts
Control Forecast and Simulation with SO2 Tax
(Thousand Tons)



SO2 - Sulphur Dioxide
Source: Author's calculations based on the World Bank's Industrial-Pollution-Projection System, and the REMI model of Massachusetts

SO_2-intensive sectors.

The true value of combining IPPS with the REMI model in this analysis is the rich picture that can be drawn of the regional economic impact of introducing the proposed taxation scheme. Although the tax was slightly revenue-negative, the increase in output from those sectors receiving a net subsidy was not sufficient to off-set the reduction in output from those suffering a net tax, reducing manufacturing output by about 2%. An important aspect of the REMI model is that it allows people to migrate into and out of the region in response to changes in personal income and employment opportunities. Consequently, as manufacturing output falls relative to the control forecast, reducing regional employment, regional population falls through net out-migration. By 1999 the population is predicted to drop more than employment, so that the crude employment rate (total employment divided by total population) is actually higher than in the control forecast by 2005. Although the increased employment, in turn, augments real disposable per capita income, the income is still about 1% lower than in the control forecast by the end of the period, despite higher predicted average nominal wages, because consumer prices are pushed up by 2% relative to the control.

The rise in consumer prices can be explained by the forecast change in regional industrial structure. Eight of the 12 manufacturing sectors receiving a net subsidy under the SO_2 tax and reimbursement scheme produce durable goods, while six of the eight sectors subject to a net tax produce nondurables. Consequently, production of durable goods increases from 19.7% to 22.7% of total output by 2005, and nondurable production falls from 12.6% to 10.2%. This narrowing of the sectoral mix in favor of durable goods not only increases consumer prices, but also forces the regional economy to become more outward-orientated, with a greater reliance on export markets for durable goods, and higher imports of the more pollution-intensive nondurable products. Indeed, this simulation may be seen as a regional example of the much-debated international phenomenon of the export of "dirty" industries from developed nations to developing countries.

Analysts already use regional economic models to assess environmental policies in the United States. For example a version of the REMI model has been used by the South Coast Air Quality Management District (SCAQMD) in the Los Angeles area of California to assess the socioeconomic impacts of the District's rules and regulations for air-quality control. As I have argued above, this form of analysis is even more critical in developing countries, where the marginal impact on individual welfare of job losses or reduced real disposable income per capita is likely to be higher than in industrialized countries. In applying this to Massachusetts, I predicted real disposable income to be about 1% below the control forecast after 15 years as a result of the proposed environmental policy. In the United States, this loss of welfare might be considered negligible, especially in light of the anticipated environmental benefits. In contrast, this loss of income in a developing country is far more likely to translate into a measurable loss of health, because the marginal impact on health of a change in income is likely to be higher. Depending on the extent of the detrimental health effect, environmental policy-makers might conclude that it outweighs the health benefits from lower levels of industrial pollution.

An important criticism of IPPS is that it represents a set of estimates of pollution intensities prevailing in the United States. In the hypothetical application discussed above, I held these intensities constant, and I achieved the SO_2 target solely by altering the sectoral composition of the economy. In other words, I made no allowance for the effect of technological improvements that reduce pollution intensities. With an emissions tax of up to 46%, there is little doubt that some emissions reduction could be achieved at a lower marginal cost than the rate of tax; the implementation of these improvements would reduce pollution intensity, and require a reassessment of the appropriate tax rate for the abating sector. The assumption of fixed pollution intensities is especially unrealistic in developing countries, where considerable improvements in pollution control may be possible. One possible adjustment to the IPPS intensities would be to incorporate the "Penetration Factors" suggested by the World Health Organization (WHO, 1989). These factors are designed to indicate the effectiveness of various end-of-pipe pollution-control options. A feasible ultimate goal for analysts would be to combine the penetration factors with estimates of associated marginal pollution abatement costs and, subsequently, link the costs to a model of the wider economy, in a similar fashion to that illustrated above. Such a system would greatly improve the accuracy with which environmental policy-makers could determine the true costs of proposed pollution-control strategies.

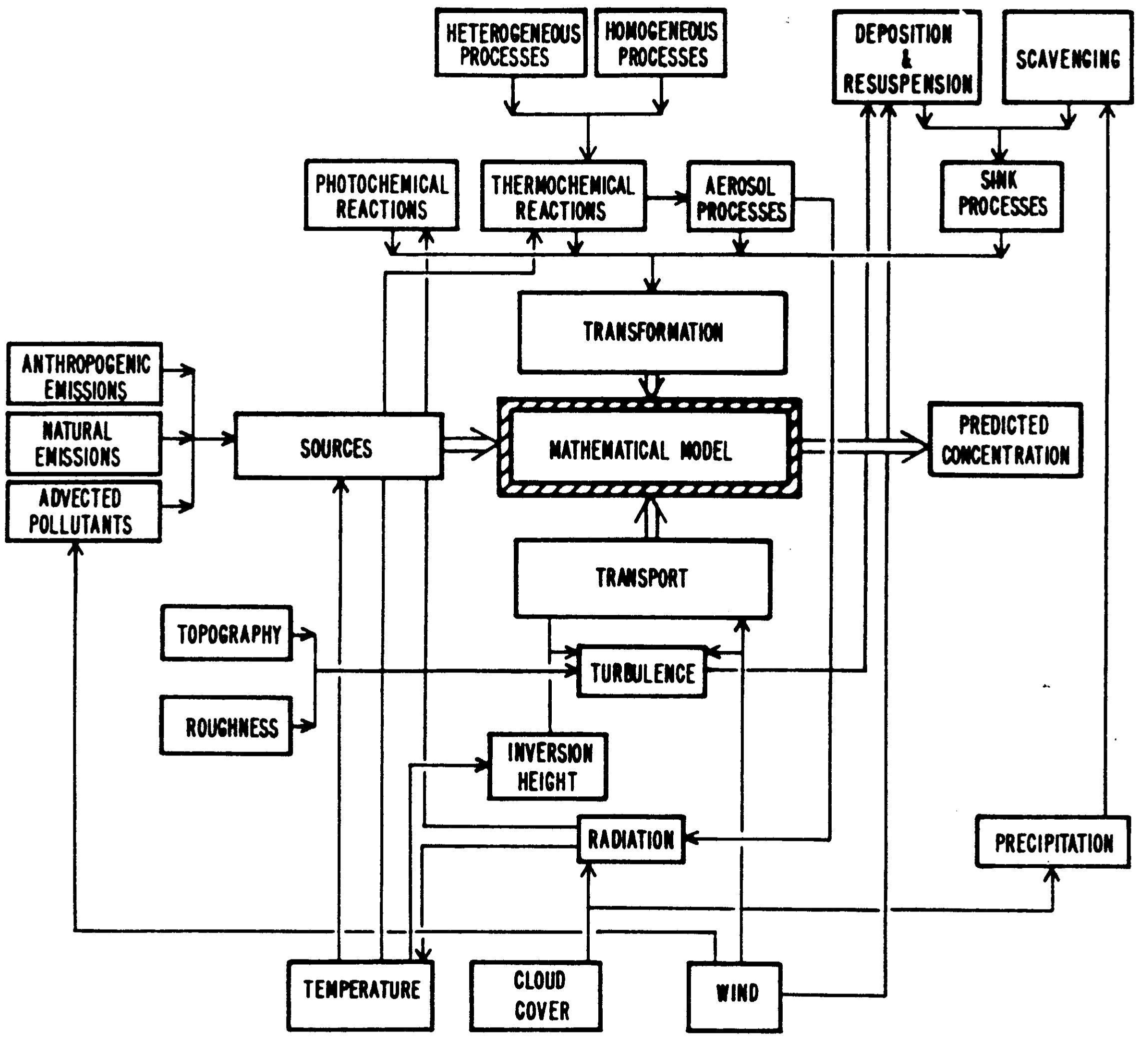
Determining the Benefits of Industrial-Pollution Control

One of the most important goals of environmental policymakers is to control ambient concentrations of anthropogenically produced pollutants in order to restrict detrimental impacts on human health and economic welfare. The extent of the impact is ultimately determined by the dose-response characteristics of the target and the pollution dose received. The dose, in turn, is a product of the length of exposure and the mean concentration of the pollutant. Information regarding the emission of a given pollutant is most useful to policymakers if it can be related to an ambient concentration and subsequent impacts.

The World Bank team designed IPPS to estimate emissions of a range of pollutants from manufacturing activities using widely available indicators of industrial activity. Although this design enables us to conduct some interesting analyses of priority pollutants and sectors and of the links between economic and environmental policies, as discussed above, we have no indication of the associated ambient conditions. IPPS, however, may provide important inputs into a model designed to estimate ambient concentrations. The following discussion continues the focus of this chapter on airborne pollutants, although the Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), and pH data in IPPS could be used in a similar fashion to model impacts on water quality.

An ambient air-quality model links pollutant emissions to atmospheric pollutant concentrations. Such a model involves considerations of emission patterns, meteorological conditions, chemical transformations, and removal processes. The potential complexity of a comprehensive air-quality model is indicated in Figure 2.10, reproduced

Figure 2.10
Components of an Air-Quality Model



Source: Seinfeld, John H. 1986. Atmospheric Chemistry and Physics of Air Pollution. Pasadena, CA. John Wiley and Sons, p. 601.

from Seinfeld, 1986. Depending on the required accuracy, and the desired temporal and spatial resolutions, air-quality models can become highly data-intensive and computationally complex. This is particularly true when the chemical kinetics become a significant factor, which is the case for primary pollutants with half-lives of less than a few hours, and for secondary pollutants, such as ozone. Nevertheless, there are models available that derive useful approximations for stable primary pollutants using commonly available meteorological data. For example, the World Health Organization's Rapid Assessments procedure (WHO, 1989) employs a model put forward by the International Institute for Applied Systems Analysis (IIASA). Using an inventory of sources categorized as low-, medium-, or high-level according to the altitude of the release, and assuming that the dispersion due to wind is equal in all directions, analysts can compute spatial average and local peak concentrations. They can introduce meteorological data as frequency factors representing the probability of a given combination of atmospheric stability and wind speed (Dennis, 1978).

The role of IPPS in conjunction with such a model would be to provide an inventory of industrial emissions from readily available economic data. Although this would aid analysts in constructing an inventory, a number of key sources remain unaccounted for, in particular:

- vehicular traffic;
- space heating;
- municipal incinerators; and
- power generation.

Fortunately, there are a number of references that provide standard emissions factors for such sources, for instance based on the distance driven by vehicular traffic, or the composition of fuel for power generation (see, for example, U.S. EPA, 1975). The importance of such nonmanufacturing sources should not be underestimated, particularly in modeling urban air quality for developing countries where the uncontrolled use of biomass and fossil fuels and poorly controlled vehicle emissions may be the primary determinants of ambient conditions.

Attempts to model ambient conditions from estimated emissions are as essential to the formulation of rational environmental policy as linking emission control policies to the wider economy, as discussed in the previous section. An industrial-environmental policymaker's objective is to improve social welfare by controlling the externalities of industrial production. The social benefits associated with the policies are directly linked to ambient concentrations of key pollutants.

Importance of Developing Tools for Industrial Pollution Policy-Making

In this chapter, I have demonstrated the essential contribution of a planning tool, such as IPPS, in the formulation of industrial-pollution policy. At the outset, I framed the discussion in terms of three components necessary for improving environmental decision-making, as identified by the World Bank in the World Development Report 1992. These are namely, better information, stronger institutions, and wider participation. I have not only indicated ways in which a tool such as IPPS may contribute to institutional strengthening and consensus-building, but I have also considered in detail the use of IPPS to improve the quality of information available to planners. Specifically, I have demonstrated the use of IPPS to:

1. identify priority pollutants and source sectors;
2. aid in the analysis of the economic costs of pollution control; and
3. help estimate the ambient concentrations of key pollutants, which, in turn, determine the benefits of controlling industrial emissions.

In each of these functions, a planner's purpose in using a tool like IPPS is to improve the rationality, transparency, and certainty of environmental policy-making. Rationality is improved by enabling planners to take into explicit consideration the costs and benefits of a proposed policy, increasing the chances that the chosen strategy will lead to an improvement in net social welfare. This is also likely to widen the political acceptability of the policy. Acceptance additionally depends on the transparency of the process by which decisions are made, and this too is enhanced through the use of clearly established models. The final consideration, certainty, is underlined by H. Jeffrey Leonard (Leonard, 1985). The lack of information available to government regulators generates uncertainty in planning that creates disincentives for industrial investment. When directly monitored pollution data are scarce, systems that allow reliable estimates to be drawn from more widely available economic data greatly enhance the certainty of industrial pollution-policy formulation and implementation, promoting industrial investment and, ultimately, economic growth.

CHAPTER 3

THE INDUSTRIAL-POLLUTION-PROJECTION SYSTEM: INITIAL DEVELOPMENT

Within the World Bank, the need for a method of estimating releases of industrial pollutants was initially recognized in 1990 by the Industry and Energy Department of the Research and Policy Vice Presidency. The development of the Industrial-Pollution-Projection System (IPPS) was later continued in the Environmental Assessments and Programs Department of the same Vice Presidency. The research team for the project consisted of three consultants (Mala Hettige, Ralph Stengren, and the author) and was led by David Wheeler.

Outside the World Bank, interest in methods of estimating industrial pollution dates back more than 20 years. Much of the early work was associated with the development of regional input-output models to incorporate environmental impacts. Although most of the work remained at the theoretical level (for example, Cumberland, 1966; Isard, 1968), some important studies used empirical data relating industrial production to emissions of pollutants. Particularly notable in this regard was Leontief's work in integrating pollution emission and abatement into a standard input-output technology matrix. This allowed him to determine the direct and indirect outputs of industrial goods and pollution as a function of final demand (Leontief, 1972). Subsequently, much interest was focused on the incorporation of pollution estimates into economic growth models, for example in the Strategic Environmental Assessment System developed by Resources for the Future in 1975. More recently, Faye Duchin *et al* (Duchin, 1992) developed parameters that use fuel-composition and combustion-technology data to represent emissions of carbon dioxide, and oxides of sulphur and nitrogen, from combustion processes. They then used this information to incorporate emissions information into a static input-output model of the world economy designed by Leontief (Leontief, 1977).

In all the studies mentioned above, however, the pollution-emissions data are based on industrial-engineering calculations. Although standard engineering estimates of pollutant releases based on mass-balance calculations are available for a large number of processes and technologies (see, for example, WHO, 1989), the World Bank team decided to adopt a different approach. The major problem with engineering estimates is that they require more detailed information about the technologies employed than is widely available for most developing nations. The World Bank team's objective was to create a system that would allow us to make reasonable estimates of pollutant releases from readily accessible national and international databases. The level of aggregation across industrial sectors in these databases is generally high. For example, the United Nations Industrial Development Organization (UNIDO) annual industrial production data are reported at the four-digit International Standard Industrial Classification (ISIC) level, which divides all manufacturing activities into 80 categories. It is clear that these data have insufficient detail to be used with the far more detailed engineering estimates.

As an alternative to mass-balance estimates, the World Bank team chose to use reported emissions from recorded industrial activities. As well as being easy to apply to highly aggregated data, an advantage of this approach is that it uses reports of real emissions, rather than engineering estimates, thus capturing the aspects of production that are difficult to model, such as the effects of different management practices.

In the next section of this chapter, I explain the conceptual goal in using reported industrial emissions to estimate sectoral pollution intensities. Subsequently, I give a brief description of the databases used by the World Bank team, and I discuss some of the more significant operational complexities encountered in developing the system.

The Conceptual Goal

To the extent that production in a particular manufacturing sector is associated with a characteristic form and amount of pollution, analysts can convert information regarding activity in that industry into an estimate of pollution. To perform this conversion, they must multiply the output data by an index of pollution intensity, expressed as a ratio of emissions per unit of manufacturing activity:

$$\text{pollution intensity} = \frac{\text{total emissions}}{\text{total manufacturing activity}}$$

The product of this index and the appropriate measure of manufacturing activity will then give an estimate of the associated pollution. The objective of the World Bank project was to develop a standard set of pollution intensity indices, for as many manufacturing sectors as possible. Analysts can then use (IPPS) to estimate industrial pollution for any region (country) for which manufacturing activity data are available.

The World Bank team was able to estimate pollution intensity, as defined above, from the emissions recorded in the U.S. Environmental Protection Agency (EPA) databases and the measures of industrial activity recorded in the U.S. Census of Manufactures (CM). Clearly, this intensity will vary according to the manufacturing activity. For example, the toxic releases from the production of industrial chemicals are likely to be much greater than those from food production. Moreover, the production of some chemicals may be more toxic than others. This raises the issue of the appropriate level of sectoral aggregation for the creation of pollution-intensity figures.

As mentioned above, a major objective of IPPS is to allow pollution estimates to be made from readily available economic data. Consequently, the World Bank project focused on developing pollution-intensity figures at the four-digit ISIC level of sectoral aggregation, this being the most detailed and comprehensive level of reporting used by UNIDO. To achieve this, we summed the reported emissions by ISIC sector and then divided by the summed measure of manufacturing activity within that sector. This procedure gives an activity-weighted average pollution intensity, rather than an unweighted average, which would be obtained if the sectoral pollution intensity was calculated as the mean of each facility's pollution intensity, as shown below.

Activity-weighted Average Pollution Intensity

$$P^a_s = \frac{\Sigma_i\ (E_{is})}{\Sigma_i\ (A_{is})}$$

Unweighted Average Pollution Intensity

$$P^u_s = \frac{\Sigma_i\ (E_{is}/A_{is})}{n_s}$$

where: P^a_s = Activity-weighted average pollution Intensity of Sector s;

P^u_s = Unweighted average pollution Intensity of Sector s;

E_{is} = Emission from facility i in sector s;

A_{is} = Measure of activity of facility i in sector s; and

n_s = Number of facilities in sector s.

Over the period 1990-1992, the World Bank team developed pollution-intensity indices for seven atmospheric pollutants, for Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), pH and flow of effluent discharges, and for the toxic releases identified in the EPA's Toxic Release Inventory (TRI) for the United States. Although we could have generated a time-series of pollution intensities, in this first stage, we only used 1987 data. We chose this year largely because it was a census year with consequently detailed CM data.

Building Blocks for IPPS

The World Bank team used a number of EPA emissions databases in conjunction with data from the CM to develop the IPPS indices. In the following sections, I give a brief description of these databases, as they are important in determining the limitations of the final system.

EPA Emissions Databases

The World Bank team used three major EPA databases in developing IPPS:

1. The Toxic Chemical Release Inventory;
2. The Facility Subsystem of the Aerometric Information Retrieval System; and

3. The Permit Compliance System of the National Pollutant Discharge Elimination System.

In addition, we employed the Human Health and Ecotoxicity Database to provide common units for the chemicals reported in the Toxic Chemical Release Inventory. I describe each of these databases more fully below.

The Toxic Chemical Release Inventory (TRI) contains information on annual releases of toxic chemicals to the environment. It was mandated by the "Emergency Planning and Community Right-to-Know Act" (EPCRA) of 1986, also known as Title III of the Superfund Amendments. The law has two main purposes: (1) to provide communities with information about potential chemical hazards, and (2) to improve planning for chemical accidents.

The TRI requirements cover all U.S. manufacturing facilities that meet all of the following conditions:

- they produce/import/process 50,000 pounds or more of any TRI chemical, *or* they use 10,000 pounds or more in any other manner;
- they are engaged in general manufacturing activities; and
- they employ the equivalent of ten or more full-time employees.

The original TRI requirements, which applied for the 1987 reports, set a threshold of 75,000 pounds of TRI chemicals produced, imported, or processed, which was lowered to 50,000 pounds in 1988. Under the 1987 definition, some 20,000 facilities filed TRI reports, which was reduced to 18,846 as a result of the delisting of six major chemicals and increased to 19,762 facilities following the lowering of the reporting threshold.

The TRI chemicals vary widely in toxicity. No nontoxic substances or other environmental parameters, such as chemical or biological oxygen demand (COD/BOD), are recorded. TRI facilities must report to the EPA annually all releases of TRI substances to air, water, or land, whether routine or accidental, and all transfers of TRI substances for off-site disposal. Although the identity of a particular substance may be claimed as a trade secret if justified in advance, only 23 of more than 70,000 TRI reporting forms submitted in 1988 included trade secret claims. Quantitative estimates in pounds must be provided for releases and transfers of TRI chemicals in each of a range of categories, including:

- fugitive or nonpoint air emissions;
- stack or point air emissions;
- discharges to streams or receiving water bodies;
- underground injection on-site;
- releases to land on-site;
- wastewater discharges to Publicly Owned Treatment Works (POTWs); and
- transfers to off-site facilities for treatment, storage, or disposal.

The World Bank team used the EPA's Human Health and Ecotoxicity Database (HHED) to provide a common unit of toxicity for the 322 chemicals reported under the TRI requirements.

The Aerometric Information Retrieval System (AIRS) is the management system for the U.S. national database for ambient air quality, emissions, and compliance data. It is divided into four subsystems:

1. the Geo-Common Subsystem, a database of necessary codes;
2. the Air Quality Subsystem, containing ambient air-quality data;
3. the Area/Mobile Source Subsystem, which includes estimates of

emissions from mobile sources and large-scale, point emission sources; and

4. the Facility Subsystem (AFS).

The data used in the creation of IPPS were drawn from the AIRS Facility Subsystem (AFS). This contains the emissions and compliance data mandated by the Clean Air Act that are collected at individual facilities monitored by the EPA and state agencies. Compliance data for over 100,000 point sources are stored in AFS, but emissions estimates are only available for some of them. These are generally plants emitting more than 100 tons per year of one or more of the criteria pollutants: Particulate Emissions, Carbon Monoxide (CO), Sulfur Dioxide (SO_2), Nitrogen Dioxide (NO_2), Lead, and Volatile Organic Compounds (VOCs). Although the EPA started collecting air-emissions data in 1973, they have only entered the information from 1985 onwards into the AFS. Access to information from years prior to 1985 is more difficult (U.S. EPA, 1991a).

The Permit Compliance System (PCS) was developed by the EPA to meet the information requirements of the National Pollutant Discharge Elimination System (NPDES). The database contains the self-monitoring reports of facilities with NPDES permits for discharges of wastewater, both the permits and the monitoring being mandated by the Clean Water Act. Some 60,000 point sources file such reports, based on monitoring that they perform on a monthly basis; of these there are approximately 50,000 industrial sources, the rest being Publicly Owned Treatment Works (POTWs). In the database as a whole, over 2,000 parameters are reported, leading to considerable overlap with the substances reported for the TRI. Some of the more important additional parameters are Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), pH, and temperature. The length of the time series varies regionally, the longest being about ten years; however, the data are most complete from 1987 onwards, following the most recent modification of the database (U.S. EPA, 1990).

Longitudinal Research Database

For industrial activity data, the World Bank team used data drawn from the Longitudinal Research Database (LRD). The LRD is an establishment-level database, constructed from information contained in the Census of Manufactures (CM) for the years 1963, 1967, 1972, 1977, 1982, and 1987, and the Annual Survey of Manufactures (ASM) for 1973 through 1989. It is administered by the Center for Economic Studies (CES), which was set up within the Census Bureau in 1982 to develop the database, to use the data for the improvement of Census Bureau operations, and to make the data available to outside users.

The CM is a complete enumeration of all manufacturing establishments, as classified by the Census Bureau according to the Standard Industrial Classification System (SIC). In contrast to the CM, the ASM is a sample of establishments, selected after each census for data collection over the following five years. The annual data available in the LRD for all establishments from 1972 to 1989 include:

- establishment name, address, four- and five-digit SIC codes;
- payroll statistics, including total salaries and wages;
- cost of materials and energy;
- capital expenditures; and
- total value added.

In addition the LRD contains some variables that are only available for ASM establishments and others that are only collected in census years. The additional ASM information relates to capital assets, rents, depreciation, retirements and repair. The data available only for census years include (1) the quantity and cost of material goods consumed; and (2) the quantity and value of product shipped. The product information collected by the CM (quantity produced, quantity shipped, and value shipped) is collected at the seven-digit SIC level, which is so detailed that, on average, each facility reports by three or four product categories.

Because establishment-level data are collected by the Census Bureau under the authority of Title 13 of the US Code, the Census Bureau prohibits the release of information that could be used to identify or closely approximate the data for an individual establishment or enterprise. Consequently, only a limited number of researchers working as Special Sworn Employees (SSEs) and Census Bureau staff have direct access to the LRD.

Construction of Pollution-Intensity Indices

Our first task in the development of a pollution-intensity index from the EPA and LRD data was to match the two sets of information at the facility level. This matching was necessary to ensure that the sector-specific intensities were calculated using emissions and production data from the same set of facilities. Unfortunately, there is no common code to identify the same establishment in the databases, which necessitated the use of a complex matching process, using the facility address and Standard Industrial Classification (SIC) code for product sector, with a final alphabetic match on facility name. This lengthy procedure met with mixed success. Of some 20,000 plants reporting TRI information in 1987, we matched about 13,000 to their corresponding LRD data for that year. Emissions data were available on AIRS for some 20,000 plants, of which we matched about 6,000 to the LRD. Unfortunately, this figure was cut to 3,000 because not all the facilities reported emissions for 1987. The least successful match was achieved for the PCS; of the 50,000 industrial sources, we only matched 3,000 to the LRD. Further, when multiple point sources for single facilities were accounted for, only some 1,500 plants were matched.

Once the matched data-sets had been created, we constructed the pollution-intensity indices, as outlined above. Although the concept of an index of pollution intensity is relatively clear, with pollutant emission as a numerator divided by manufacturing activity, in practice a number of questions arose in relation to the choice of numerator and denominator.

Choice of Numerator

The choice of numerator is relatively straightforward for the criteria aerometric pollutants, which may all be expressed in units of mass, as may the Biological Oxygen Demand (BOD) and Total Suspended Solids (TSS) statistics drawn from the PCS. Matters are rather more complicated for pH figures and toxic releases.

Unlike the reported releases of other pollutants, which are expressed in units of mass, pH is a measure of concentration. This makes a direct summation meaningless. The obvious alternative is to calculate an average pH for each sector. This is again complicated by the fact that a neutral pH has the value 7, with acidic and basic pH's lying on either side of this value. It is clearly meaningless to take the average of an acidic and a basic discharge from two facilities within the same ISIC sector, deriving a more neutral mean discharge, as this misses the issue of concern. A final complication is that the PCS only reports the minimum and maximum pH values of each facility's discharges, which may themselves fall either side of neutral. Each of the pH values also has an associated flow, measured in gallons per day. The solution adopted by the World Bank team was to calculate flow-weighted average minimum and average maximum pH for each sector as shown below.

Flow-weighted Average Maximum pH

$$Mx_s = \frac{\Sigma_i\ (MaxpH_{is} * MaxF_{is})}{\Sigma_i\ MaxF_{is}}$$

Flow-weighted Average Minimum pH

$$Mn_s = \frac{\Sigma_i\ (MinpH_{is} * MinF_{is})}{\Sigma_i\ MinF_{is}}$$

where:

	Mx_s	= Flow-weighted average maximum pH in sector s;
	Mn_s	= Flow-weighted average minimum pH in sector s;
	$MaxpH_{is}$	= Maximum pH for facility i in sector s;
	$MinpH_{is}$	= Minimum pH for facility i in sector s;
	$MaxF_{is}$	= Flow associated with maximum pH for facility i in sector s; and
	$MinF_{is}$	= Flow associated with minimum pH for facility i in sector s.

We made a final refinement in order to deal with situations in which the set of maximum pHs or the set of minimum pHs for a single sector contained values on either side of neutral. In order to make the results interpretable, we derived the average minimum pH only from the acidic minimum values and associated flows, unless there were none within the sector, in which case the minimum basic values were used. Similarly, we calculated the average maximum pH using only the basic maximum values and associated flows, unless there were none, in which case we used the maximum acidic values.

The difficulty with the TRI data arises because the toxicity of the 322 chemicals reported under the TRI requirements has large variations. The list includes, for example, Saccharin and Mercury; consequently, a simple summation of the total weight of TRI chemicals released gives little indication of the toxic hazard involved. Yet, it would be very unwieldy to develop a separate pollution index for each TRI chemical. A better alternative for the comparison of risks is to weight the releases according to the multi-index categorization of toxicological potency presented in the EPA's HHED. We assigned each chemical's rating under each index to one of three toxicological potency groups, Group One being the most hazardous. We also assigned each of the ten indices to one of five categories of hazard, three of which we chose for IPPS, as follows:

1. acute human health and terrestrial ecotoxicity;
2. acute aquatic ecotoxicity; and
3. cancer risk.

We distinguished human and terrestrial ecotoxicity from aquatic ecotoxicity because of the significant variation between the toxicological potency of many chemicals to mammalian and fish life.

For the first two of these indices, we had some difficulty in converting the ordinal scale ranking of toxicological risk associated with particular chemicals to a measure of the total risk posed by all releases from a facility. The approach we adopted was to multiply the quantity of each TRI chemical reported by a facility by its toxicological potency ranking, and then to sum the risk-weighted quantities for all chemicals released by the facility. Acknowledging the questionable validity of using an ordinal scale in an arithmetic procedure, we used two forms of weighting to test the sensitivity of the results. First, we reversed the EPA toxicological potency ratings, giving a linear weighting scale from 1 to 4. We used four weights although there are only three toxicological potency ratings, because only those TRI chemicals yet to be assigned a toxicological rating were given the lowest weighting. Second, we used an exponential weighting for the four groups, rising by orders of magnitude from 1 to 1,000. In a similar fashion, we weighted the releases and transfers of chemicals posing a carcinogenic risk by multiplying the quantity by the relevant factor in the Cancer Potency scale. This factor is an estimate of the probability of contracting cancer as a result of a lifetime's exposure to a unit dose. Because this is a cardinal scale, we did not need to obtain a separate exponential weighting. Using this methodology, we generated five measures of risk-weighted releases and transfers for each facility:

1. linear acute human health and terrestrial ecotoxicity;

2. exponential acute human health and terrestrial ecotoxicity;
3. linear acute aquatic ecotoxicity;
4. exponential acute aquatic ecotoxicity; and
5. cancer risk.

In addition, we calculated two unweighted TRI figures for each facility, these being:

1. total quantity of TRI chemicals released or transferred; and
2. total quantity of metal compounds released or transferred.

Although the unweighted total of TRI releases may be useful for a first level of comparison, analysts should treat it with caution because of the extreme variation in toxicity between different TRI chemicals. We derived the unweighted measure of releases and transfers of heavy metals to assist in the estimation of the bioaccumulation of metal compounds, which present significantly different risks to those posed by flows of other TRI substances.

Choice of Denominator

The LRD provides a number of options for the measure of manufacturing activity to be used as the denominator in the pollution intensity indices. Four of the most obvious are (1) physical volume of output, (2) shipment value, (3) value added, and (4) employment.

In choosing between them, the need to develop a measure of pollution intensity that could be used for international comparisons discouraged us from using either value added or employment, because of international variations in factor proportions arising from very different relative factor prices. Conceptually, the most appealing choice is physical volume of output, but this poses practical difficulties. First, the Census uses a wide range of units to report output quantities in the LRD even within a given sector, severely complicating inter-facility analysis. Second, a purely bureaucratic problem arises in that many facilities report output volumes in special samples not included in the main LRD, significantly reducing the sample size available for analysis. Finally, the information relating to output volume in the UNIDO data, the main source for international comparisons, is not very comprehensive. Consequently, we used value-of-shipments as the measure of manufacturing activity in the denominator of the pollution-intensity index. Although this statistic has obvious relative price problems, particularly in the international context, it has the advantages of a relatively complete UNIDO coverage and the usual benefit of the dollar metric in allowing inter-sectoral comparison.

Having selected the appropriate numerators and denominators given the data limitations, the World Bank team calculated pollution-intensities by four-digit ISIC sector. We used a standard U.S. Department of Commerce concordance to assign a four-digit ISIC code to each of the facilities for which EPA data had been matched to LRD statistics. The process was complicated by the fact that the concordance matched five-digit U.S. SIC codes, defining primary product class, to the four-digit ISIC codes. This raised difficulties in dealing with those facilities reporting under more than one five-digit SIC code, especially when the facility's SIC codes matched more than one ISIC classification. The procedure we adopted to deal with this problem was to assign each facility its four-digit ISIC code with the greatest shipment value. Although this was generally 80% or more of the total shipment value, this approach inevitably contributed inaccuracies to the final estimates of pollution intensity by sector.

Results

Although I critically assess the IPPS indices in the next chapter, here I briefly describe the outputs produced using the methods detailed above. Clearly, the World Bank team could only derive pollution-intensity indices for those ISIC sectors in which EPA and LRD facility records were successfully matched. This sample was further reduced by the data disclosure requirements imposed by the CES. Unfortunately, these requirements are themselves confidential. Suffice it to say that a number of four-digit ISIC sectors contained too few facilities to meet the disclosure requirements; consequently, those matched records could be used only at a higher level of aggregation (i.e., two- or three-digit ISIC). As might be expected, the number of sectors for which we derived pollution indices varies between the EPA data-bases in relation to the total number of facility records matched. This pattern may be distinguished in Table 3.1 below.

Table 3.1 highlights two issues in particular. First, as shown in the third column of the table, we were able to calculate PCS pollution intensity indices for less than half as many sectors as TRI indices. Second, the final column in Table 3.1 indicates the number of four-digit ISIC sectors for which data from more than 50 matched facilities were available. As can be seen, of the 34 PCS sectoral indices, only 9 were calculated using data from 50 or more facilities. Clearly, with fewer facilities, there is a greater chance that an unrepresentative facility will bias the calculated pollution intensity. I cover the implications of these and other critical issues in the following chapter.

Table 3.1 SUMMARY OF RESULTS

EPA Database	Facilities Matched to LRD	4-Digit ISIC Sectors with Pollution Indices	Sectors with more than 50 Facilities
TRI	13,000	74	31
AIRS	3,000	52	18
PCS	1,500	34	9

AIRS - Aerometric Information Retrieval System
EPA - U.S. Environmental Protection Agency
ISIC - International Standard Industrial Classification
LRD - Longitudinal Research Database
PCS - Permit Compliance System
TRI - Toxic Release Inventory

Source: The author's calculations from the Industrial-Pollution-Projection System, World Bank.

CHAPTER 4

THE INDUSTRIAL-POLLUTION-PROJECTION SYSTEM: CRITICAL ASSESSMENT AND FURTHER WORK

In this chapter, I examine in some detail the sectoral pollution intensities for four atmospheric pollutants, from the Industrial-Pollution-Projection System (IPPS) derived by the World Bank team using the methodology presented in the preceding chapter. After analyzing the intersectoral variation in the intensities, I discuss some potential sources of bias in the estimates, arising from the choice of data-bases and difficulties in linking them together. Subsequently, I use the standard deviation of individual plant pollution intensities within each sector to assess the statistical confidence that may be placed in the estimates. The statistical testing raises doubts about the viability of using pollution-intensity estimates at the four-digit Industrial Standard Classification System (ISIC) level of aggregation, because for many sectors there is a very wide range of intensities for plants that fall within the same sectoral category.

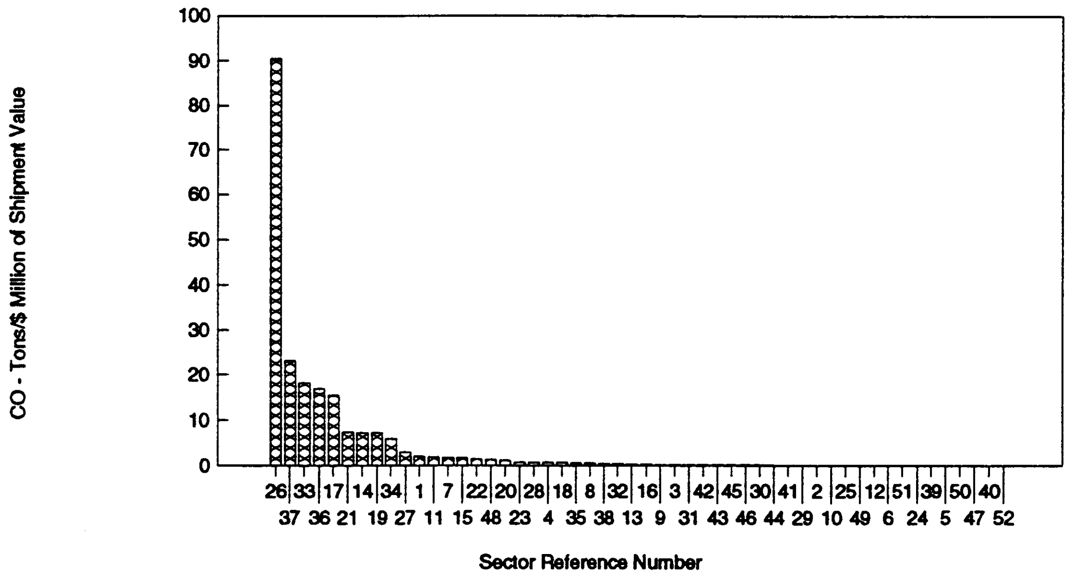
As a first indication of the inaccuracies that are likely to arise as a result of the uncertainty of the IPPS estimates, I apply IPPS to the U.S. Census of Manufactures to calculate the total emissions of four pollutants from U.S. manufacturing. I then compare the estimates with the emissions reported by the U.S. Environmental Protection Agency (EPA). Although I find one of the four estimates to be within 8% of the reported emissions, the remaining three pollutant emissions are severely over-estimated. Given that some regional variation in emissions intensities is to be expected, the IPPS estimates are likely to be even less accurate for regional modeling than for national modeling. To demonstrate this, I use the system to estimate industrial emissions of four pollutants in the South Coast Air Quality Management District (SCAQMD) from economic data in the Census of Manufactures. I compare these estimates to the emissions recorded by the SCAQMD, which I find to be far smaller in magnitude. Unfortunately, the data available were not sufficiently detailed to allow a sectoral analysis of the sources of the over-estimates from IPPS. It seems most likely, however, that the major source of error is the wide variation in pollution intensities at the four-digit ISIC level of aggregation.

I end the chapter by suggesting further work that may be undertaken by the World Bank team to improve the accuracy of the IPPS estimates. This discussion is based on a framework that distinguishes two distinct levels at which pollution intensity may vary; the production technology and the end-of-pipe pollution controls.

IPPS Indices

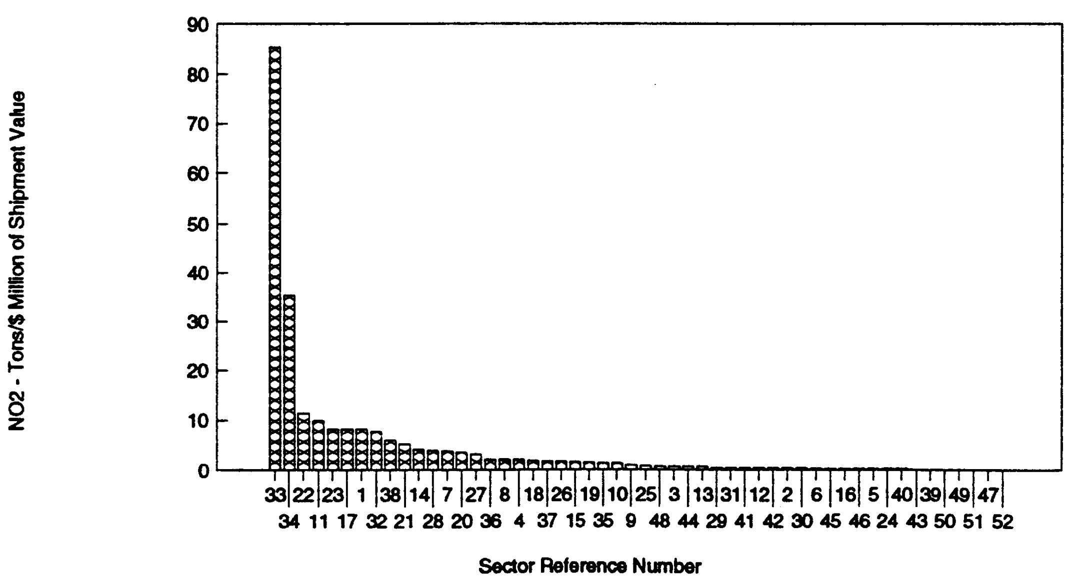
As an indication of the form of results obtained using the methodology described in the previous chapter, Figures 4.1-4.4 chart the pollution intensity for four atmospheric pollutants across the 52 four-digit ISIC sectors for which Aerometric Information Retrieval System (AIRS) data were available. The four pollutants are carbon monoxide (CO), nitrogen dioxide (NO_2), particulate matter (PT) and sulphur dioxide (SO_2). The units of the indices are tons of pollutant released per million dollars of shipment value. For ease of presentation, I assigned the sectors a reference number rather than the four-digit ISIC code and arranged them in descending order of intensity. Table 4.1.

Figure 4.1
Pollution Intensity by ISIC Sector
CO - Tons/$ Million



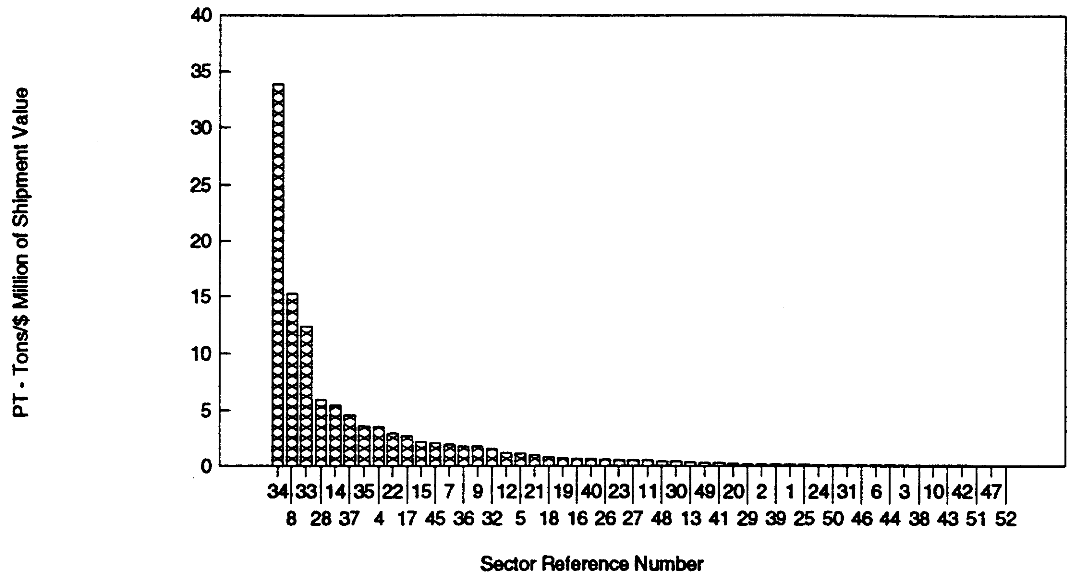
CO - Carbon Monoxide
ISIC - International Standard Industrial Classification
Source: Industrial-Pollution-Projection System, World Bank

Figure 4.2
Pollution Intensity by ISIC Sector
NO2 - Tons/$ Million



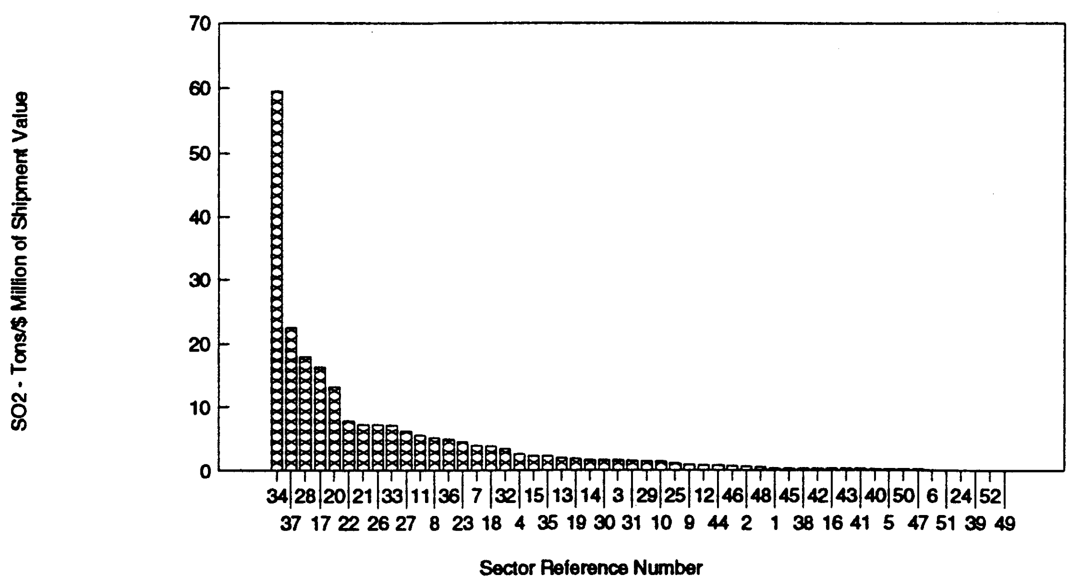
NO2 - Nitrogen Dioxide
ISIC - International Standard Industrial Classification
Source: Industrial-Pollution-Projection System, World Bank

Figure 4.3
Pollution Intensity by ISIC Sector
PT - Tons/$ Million



PT - Total Particulates
ISIC - International Standard Industrial Classification
Source: Industrial-Pollution-Projection System, World Bank

Figure 4.4
Pollution Intensity by ISIC Sector
SO2 - Tons/$ Million



SO2 - Sulphur Dioxide
ISIC - International Standard Industrial Classification
Source: Industrial-Pollution-Projection System, World Bank

Table 4.1 SECTORS WITH DATA FROM THE AEROMETRIC INFORMATION RETRIEVAL SYSTEM (AIRS) IN THE INDUSTRIAL-POLLUTION-PROJECTION SYSTEM (IPPS).

Sector Reference Number	Four-digit ISIC	Sector Description	Number of Plants in Sample
1	3111	MEAT PRODUCTS	30
2	3112	DAIRY PRODUCTS	40
3	3113	PRESERVED FRUITS & VEGETABLES	23
4	3115	OILS AND FATS	48
5	3116	GRAIN MILL PRODUCTS	45
6	3117	BAKERY PRODUCTS	13
7	3118	SUGAR FACTORIES & REFINERIES	26
8	3121	FOOD PRODUCTS, N.E.C.	32
9	3122	PREPARED ANIMAL FOODS	65
10	3133	MALT LIQUORS AND MALT	27
11	3211	SPINNING, WEAVING, & FINISHING	44
12	3219	TEXTILES, N.E.C.	12
13	3231	TANNERIES AND LEATHER FINISHING	17
14	3311	SAWMILLS, PLANING & OTHER WOOD MILLS	146
15	3319	WOOD & CORK PRODUCTS, N.E.C.	15
16	3320	FURNITURE & FIXTURES, NONMETAL	104
17	3411	PULP, PAPER, & PAPERBOARD	134
18	3412	PAPER & PAPERBOARD CONTAINERS & BOXES	35
19	3419	PULP, PAPER & PAPERBOARD ARTICLES,	27
20	3420	PRINTING & PUBLISHING	89
21	3511	INDUSTRIAL CHEMICALS EXCEPT FERTILIZER	145
22	3512	FERTILIZERS & PESTICIDES	32
23	3513	SYNTHETIC RESINS, PLASTICS MATERIALS,	60
24	3521	PAINTS, VARNISHES, & LACQUERS	34
25	3522	DRUGS AND MEDICINES	26
26	3529	CHEMICAL PRODUCTS, N.E.C.	52

(contd.)

Table 4.1 (contd.)

Sector Reference Number	Four-digit ISIC	Sector Description	Number of Plants in Sample
27	3530	PETROLEUM REFINERIES	102
28	3540	MISC. PETROLEUM & COAL PRODUCTS	75
29	3551	TIRE AND TUBES	18
30	3559	RUBBER PRODUCTS, N.E.C.	30
31	3560	PLASTICS PRODUCTS, N.E.C.	51
32	3620	GLASS AND GLASS PRODUCTS	62
33	3691	STRUCTURAL CLAY PRODUCTS	33
34	3692	CEMENT, LIME, AND PLASTER	45
35	3699	NONMETALLIC MINERAL PRODUCTS, N.E.C.	108
36	3710	IRON AND STEEL	191
37	3720	NONFERROUS METALS	85
38	3811	CUTLERY, HAND TOOLS, & GENERAL	13
39	3812	FURNITURE & FIXTURES OF METAL	32
40	3813	STRUCTURAL METAL PRODUCTS	39
41	3819	FABRICATED METAL PRODUCTS	157
42	3821	ENGINES AND TURBINES	18
43	3822	AGRICULTURAL MACHINERY & EQUIPMENT	24
44	3824	SPECIAL INDUSTRIAL MACHINERY &	35
45	3829	MACHINERY & EQUIPMENT, N.E.C.	85
46	3831	ELECTRICAL INDUSTRIAL MACHINERY	39
47	3832	RADIO, TV, & COMMUNICATION EQUIPMENT	30
48	3839	ELECTRICAL APPARATUS AND SUPPLIES,	37
49	3841	SHIPBUILDING AND REPAIRING	20
50	3843	MOTOR VEHICLES	103
51	3845	AIRCRAFT	24
52	3851	PROFESSIONAL & SCIENTIFIC EQUIPMENT	18

ISIC - International Standard Industrial Classification

Source: The Industrial-Pollution-Projection System (World Bank), and United Nations Industrial Development Organisation (UNIDO) ISIC descriptions.

links the reference numbers to the ISIC classifications and sector descriptions and shows the number of plants that were used to calculate the intensity for each sector.

The most immediately striking feature of Figures 4.1-4.4 is the approximately exponential distribution of pollution intensities across the sectors. I have found this pattern to hold not only for the four pollutants illustrated, but for all others included in IPPS. The clear implication of this distribution is that the total pollution load from manufacturing may be dominated by releases from a relatively few sectors. According to the IPPS estimates, for example, a ton of output in Sector 33, Structural Clay Products (ISIC 3691) will produce more than twice as much NO_2 as a ton of production in the next most NO_2-intensive sector, which is Sector 34, Cement, Lime, and Plaster (ISIC 3692). Further, the production of cement, lime and plaster is more than twice as NO_2-intensive as the third-ranked sector, Sector 22, Fertilizers and Pesticides (ISIC 3512). This provides considerable hope that problems associated with industrial pollution can be effectively ameliorated by measures targeted at only a few sectors. However, it should be borne in mind that this index does not rank total sectoral releases, so that it is quite possible for a highly pollution-intensive sector to have little effect on the total level of releases and transfers if it has only a tiny share in the local economy.

Despite a few surprises, such as the seventh ranking in NO_2-intensity of Sector 1, Meat Products (ISIC 3111), Figures 4.1-4.4 generally confirm the intuition that the most pollution-intensive sectors in terms of atmospheric pollution per dollar of output are building-materials, industrial-chemicals, plastics, paper, and metals industries. The lowest-ranked sectors are generally those associated with the production of high-value goods, such as Sector 52, Professional and Scientific Equipment (ISIC 3851), Sector 51, Aircraft (ISIC 3845) and Sector 47, Radio, TV and Communications Equipment (ISIC 3832).

Sources of Bias

The methodology used in this study contains a number of sources of bias that may be reflected in the pollution-intensity results obtained. I discuss three of the more significant below.

At the very outset, the conditions that must be met before a facility is required to file a Toxic Release Inventory (TRI), AIRS or Permit Compliance System (PCS) report (see the previous chapter) impose two obvious sampling biases, the net outcome of which is unclear. First, because only those facilities releasing more than a threshold annual amount of pollution (50,000 pounds of TRI chemicals, 100 tons of AIRS criteria pollutants, or a sufficient discharge to warrant a National Pollutant Discharge Elimination System (NPDES) permit) are required to report, there will be no record of the very cleanest plants, even though other plants of a comparable scale of production within the same sector may be reporting. This will tend to bias the indices derived in this study towards over-estimates of average sectoral pollution intensity. Second, there may be a number of small facilities with very high pollution intensities (relative to levels of production) that nevertheless do not release or transfer more than the threshold quantity of pollutant. The omission of these plants will thus underestimate true mean levels of pollution intensity.

The third source of bias arises out of the standard procedure used to aggregate the 5-digit SIC data to the 4-digit ISIC level. Under this procedure, those facilities with Standard Industrial Classification (SIC) codes that matched onto more than one ISIC code were assigned the ISIC code with the highest shipment value. As a result, all releases and transfers from such facilities were attributed to a single ISIC code, although in reality some proportion were associated with activities in a different ISIC category. It is conceivable that this approximation might lead to some systematic understatement of pollutant intensities in the true ISIC sectors, because there may well be scale economies associated with the higher total shipment value activities that permit better waste-management practices to be employed.

Statistical Confidence in the IPPS Indices

It is clear from the preceding discussion that there are a number of reasons why estimates of pollutant releases using IPPS may be systematically biased, but beyond these methodological considerations lies the issue of the statistical significance of the IPPS estimates of sectoral pollution intensity. In a statistical sense, the IPPS indices were calculated from a sample of major U.S. emitters, and they are therefore estimates of the true parameters of that population. Other samples from the same population would have produced different estimates, the scale of the disparity being determined by two major sources of variation. First, each four-digit ISIC sector covers a range of products, processes, and pollution-control technologies, so that the pollution intensity of individual plants within a sector may be widely dispersed about the mean. This would not be a serious concern if each sample contained the same mix of production, as the weighted average pollution intensity would always be the same. I expect, however, that the mix of products, processes, and pollution-control technologies, measured in terms of share of sectoral output, will vary from sample to sample; consequently, the estimated weighted average pollution intensity for each sector will be a random variable distributed about the national mean.

By analyzing the variation in pollution intensity of the individual plants in each IPPS sector, analysts can gain some idea of the probability that the *un*weighted average IPPS pollution intensities will approximate the national *un*weighted average pollution intensity in that sector. If the distribution of pollution intensities within each sector is approximately normal, then I can use the IPPS sample to specify an interval that will contain the average pollution intensity of the population with a known degree of confidence. The interval is specified as follows:

$$UP_s - (t_{\alpha/2} * sd/\sqrt{n}) \quad \text{to} \quad UP_s + (t_{\alpha/2} * sd/\sqrt{n})$$

where:

UP_s = unweighted average pollution intensity in sector s;

$t_{\alpha/2}$ = the critical value of t for a confidence level of $1-\alpha$ with n-1 degrees of freedom;

sd = the standard deviation of pollution intensity around the sectoral unweighted average; and

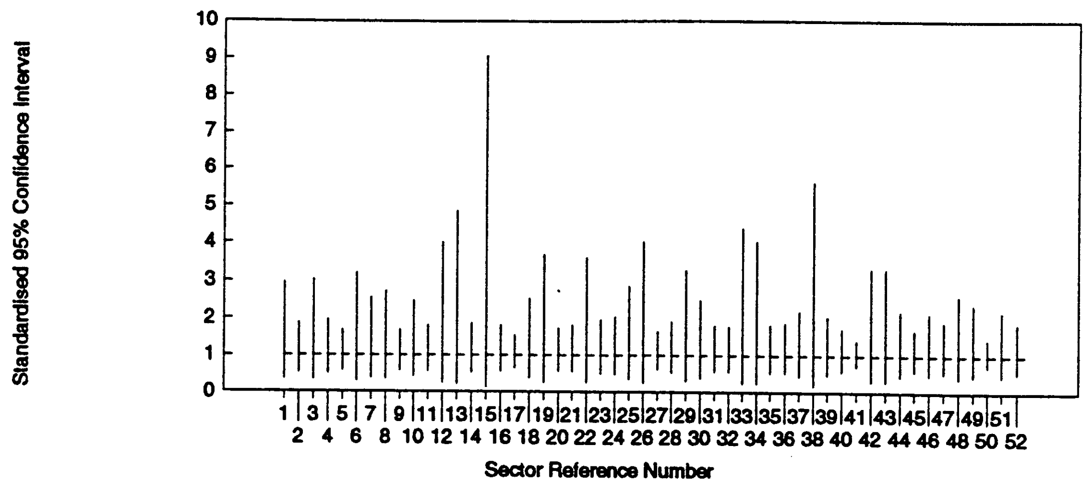
n = the number of plants in the IPPS sample in sector s.

The t-distribution can only be used in calculating the confidence interval if the population from which the sample is drawn is normally distributed, although the procedure is relatively robust to departures from this assumption (Weiss and Hassett, 1991). Figures 4.1-4.4 indicate that the distribution of sectoral pollution intensities within manufacturing is approximately exponential. I have found this pattern to be reflected at all levels of sectoral aggregation. Thus, within the four-digit ISIC sectors, the pollution intensities of the individual plants are also approximately exponentially distributed (unfortunately these data cannot be reproduced here for reasons of confidentiality). This means that the logarithms of the intensities will be approximately normally distributed. Under this assumption the t-distribution is more correctly applied to the logarithms of the sample values, so that in the formula above, UP_s is equal to the average of the log pollution intensity in sector s, and sd is equal to the standard deviation of the log intensities.

I used the log intensities of CO, NO_2, PT, and SO_2 to calculate 95% confidence intervals, which I transformed into normal form in Figures 4.5-4.8. The sector reference numbers are linked to ISIC classifications in Table 4.1. There is a 95% probability that the national unweighted geometric mean pollution intensity for each sector falls within the range illustrated. In order to make inter-sectoral comparisons, I standardized the values, setting the geometric mean of each sectoral sample equal to a value of one. The intervals extend further above unity than below, because they are symmetric in the logs.

For each pollutant in Figures 4.5-4.8, more than half the sectors have an upper limit to the 95% confidence interval that is more than double the geometric mean of the sample. Consequently, there is a 5% probability that the true value of the geometric mean pollution

Figure 4.5
Standardised 95% Confidence Intervals
Geometric Mean of CO Intensity

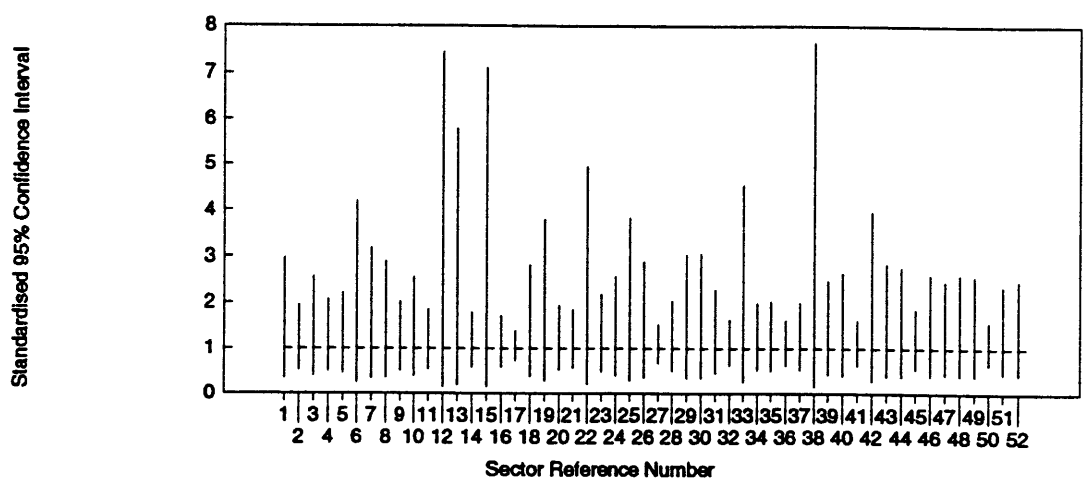


CO - Carbon Monoxide

Note: The confidence intervals are calculated from the natural logs of the pollution intensities of each plant within a sector. These values are then plotted in exponential form, and standardised so that the geometric mean of the intensity is equal to unity.

Source: Industrial-Pollution-Projection System, World Bank

Figure 4.6
Standardised 95% Confidence Intervals
Geometric Mean of NO2 Intensity

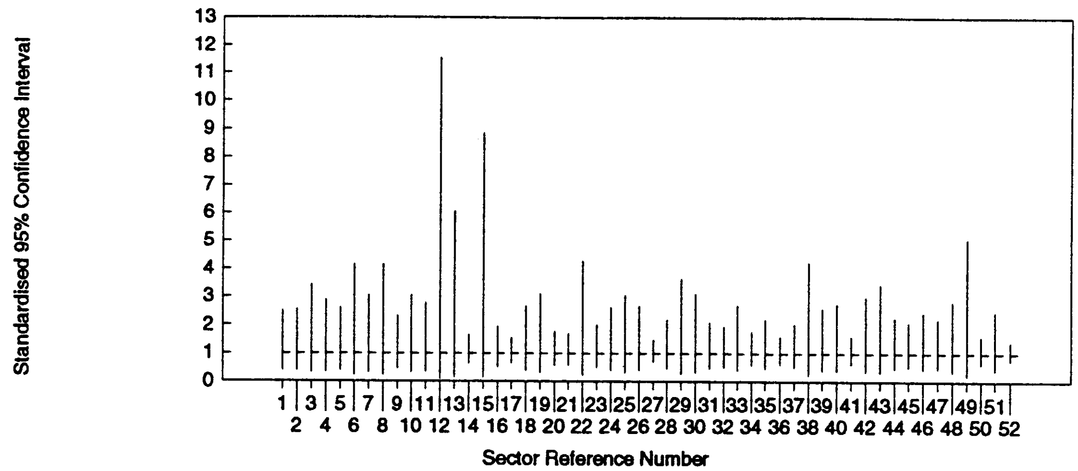


NO_2 - Nitrogen Dioxide

Note: The confidence intervals are calculated from the natural logs of the pollution intensities of each plant within a sector. These values are then plotted in exponential form, and standardised so that the geometric mean of the intensity is equal to unity.

Source: Industrial-Pollution-Projection System, World Bank

Figure 4.7
Standardised 95% Confidence Intervals
Geometric Mean of PT Intensity

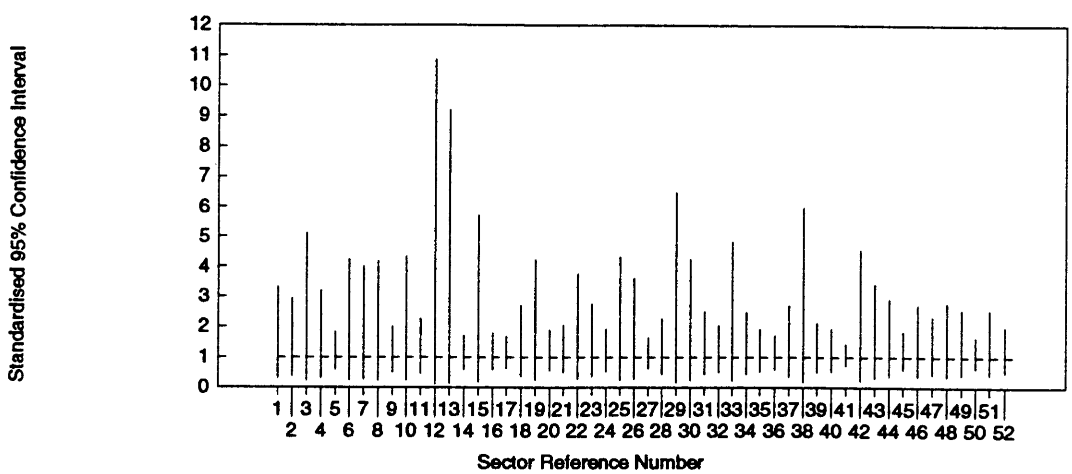


PT - Total Particulates

Note: The confidence intervals are calculated from the natural logs of the pollution intensities of each plant within a sector. These values are then plotted in exponential form, and standardised so that the geometric mean of the intensity is equal to unity.

Source: Industrial-Pollution-Projection System, World Bank

Figure 4.8
Standardised 95% Confidence Intervals
Geometric Mean of SO2 Intensity



SO2 - Sulphur Dioxide

Note: The confidence intervals are calculated from the natural logs of the pollution intensities of each plant within a sector. These values are then plotted in exponential form, and standardised so that the geometric mean of the intensity is equal to unity.

Source: Industrial-Pollution-Projection System, World Bank

intensity for these sectors is more than double the value calculated from the IPPS sample. The most extreme variation is seen in the upper limit of the PT and SO_2 confidence intervals for Sector 12, Textiles N.E.C. (ISIC 3219), which is more than an order of magnitude above the geometric mean of the sector sample. The wide range of the 95% confidence intervals indicates that at the four-digit ISIC level of aggregation there is substantial variation in the pollution intensities of individual plants within sectors. As a result, it is likely that there will be considerable inaccuracies in the IPPS estimates of sectoral emissions.

Testing the IPPS Estimates at the National and the Regional Level

I have demonstrated above that there is considerable variation in the pollution intensities of different plants within the same four-digit ISIC category. To explore the problems this causes in estimating pollutant releases for other samples, I used IPPS to model the emission of four criteria atmospheric pollutants nationally for the United States, and regionally for the South Coast Air Quality Management District (SCAQMD). The pollutants selected were CO, NO_2, PT and SO_2.

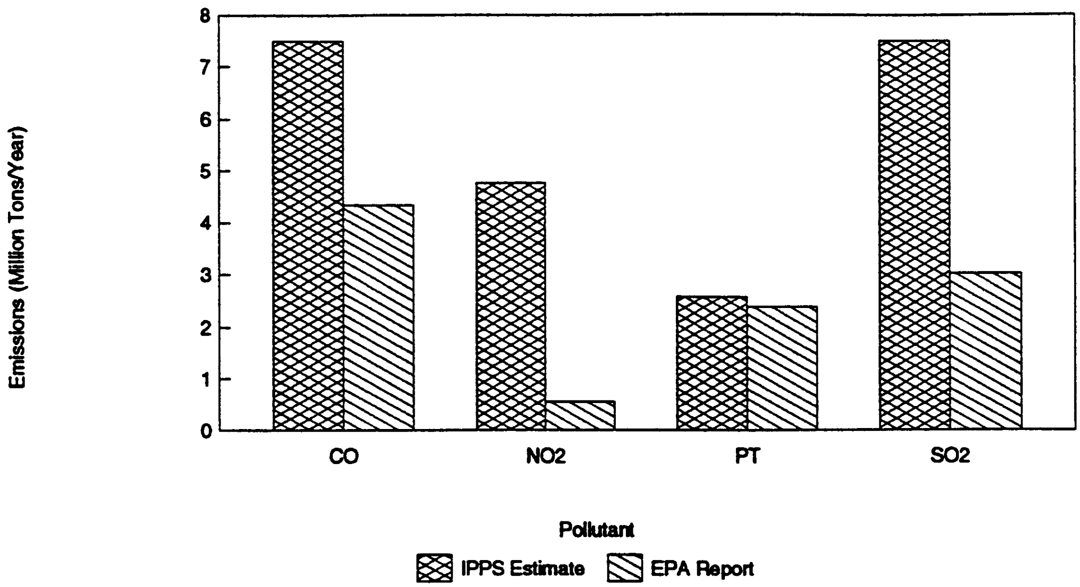
IPPS Estimates of National Emissions

As I have discussed, the World Bank team calculated the IPPS intensities from a sample of U.S. manufacturing facilities, the sample selection being primarily determined by the success of the match between the EPA and Census of Manufactures data-bases. I have indicated that the interval within which the true sectoral pollution intensity can be expected to fall with 95% probability is relatively wide, for each sector. In addition, I have discussed some ways in which the sample selection may be systematically biased. Both these sources of error are likely to cause the IPPS estimates of pollution from U.S. manufacturing to differ from the reported figures.

As an initial test of the extent of these accuracies, I used the IPPS intensities in conjunction with the U.S. Census of Manufactures to calculate the total U.S. release of CO, NO_2, PT and SO_2 from manufacturing in 1987. I then compared these estimates with the releases from industrial processes reported by the EPA in the "National Air Quality and Emissions Trends Report" (U.S. EPA, 1991b). The results are illustrated in Figure 4.9. As can be seen, IPPS is at least successful in estimating the total emission of PT, over-estimating the reported emission by only 8%; however, the estimates for the other three pollutants are all seriously upward-biased. The estimate for CO is 73% above the reported release, the SO_2 estimate is 149% above the report, and the NO_2 estimate is 751% above the total reported by the EPA.

Before the true significance of the over-estimates can be determined, a closer examination of the potential sources of error is required. The most optimistic finding would be that the "National Air Quality and Emissions Trends Report" referred to a smaller set of facilities, perhaps due to a minimum-size threshold in reporting. As a first test of this hypothesis, I compared the emissions totals published in the report to the totals recorded in the AIRS data used in the construction of IPPS. These figures are presented in Table 4.2 below, together with the IPPS estimates of national emissions.

Figure 4.9
U.S. Emissions
IPPS Estimates and EPA Reports (1987)



CO - Carbon Monoxide
EPA - U.S. Environmental Protection Agency
IPPS - Industrial Pollution Projection System
NO2 - Nitrogen Dioxide
PT - Total Particulates
SO2 - Sulphur Dioxide
Source: Industrial-Pollution-Projection System, World Bank
U.S. Census of Manufactures, U.S. Census Bureau
National Air Quality and Emissions Trends Report, 1991, EPA

Table 4.2 U.S. EMISSIONS FROM MANUFACTURING

Data Source	Pollutant (Million Tons Emitted Per Year)			
	CO	NO_2	PT	SO_2
EPA Trends Report[1]	4.3	0.6	2.4	3.0
AIRS Total[2]	4.4	2.8	1.3	5.0
IPPS Estimates[3]	7.5	4.8	2.6	7.5

AIRS - Aerometric Information Retrieval System
CO - Carbon Monoxide
EPA - U.S. Environmental Protection Agency
IPPS - Industrial-Pollution-Projection System
PT - Particulates
NO_2 - Nitrogen Dioxide
SO_2 - Sulphur Dioxide

Sources:

1. 1987 emissions from "Industrial Processes" as reported in: U.S. Environmental Protection Agency, 1991. National Air Quality and Emissions Trends Report, 1991. Research Triangle Park, NC. Office of Air Quality Planning and Standards.

2. Emissions from manufacturing facilities as recorded in AIRS.

3. Emissions from manufacturing facilities as calculated from the 1987 Census of Manufactures, using IPPS.

Table 4.2 indicates two important issues. First, that there are serious differences between the total emissions from manufacturing recorded in AIRS and those published in the "National Air Quality and Emissions Trends Report". Although AIRS records almost five times as much NO_2 released as published in the report, the report gives a figure for PT that is almost double that in AIRS. The lack of a consistent direction of discrepancy between AIRS and the report is of particular concern. The second issue worth noting is that the IPPS estimates are consistently greater than the emissions recorded in AIRS. One possible explanation is that the AIRS minimum emission threshold of 100 tons per year cuts out a substantial number of manufacturing facilities that are recorded in the Census of Manufactures. Alternatively, larger facilities may have higher pollution intensities than smaller plants, which would cause the IPPS estimates to be upward-biased, as the intensities are calculated as size-weighted averages. At the end of this chapter, in the discussion of the need for further work, I stress the importance of examining these issues in more detail.

IPPS Estimates for the South Coast Air Quality Management District

In the preceding section, I demonstrated that there are substantial problems with the IPPS estimates of U.S. manufacturing emissions of four criteria pollutants. These inaccuracies are likely to be magnified at the regional level for two reasons. First, changes in the composition of output within four-digit ISIC sectors will affect sectoral pollution intensities. Second, regional variations in the regulation of industrial pollution will affect the extent of end-of-pipe control. In order to investigate the degree to which these factors affect the accuracy of the IPPS estimates, I used the system to model the emission of the same four pollutants from manufacturing industry in the South Coast Air Quality Management District (SCAQMD).

The SCAQMD is a four-county area around Los Angeles, covering Los Angeles, Orange, Riverside, and San Bernardino counties. The local topography and meteorological conditions have made this air basin infamous for smog and poor air quality, attracting considerable legislative attention to the issue of air pollution in the district.

The wealth of data generated as a result of this attention makes the SCAQMD an ideal choice for a case study.

The initial task was to generate the IPPS estimates of atmospheric emissions by manufacturing industry within the four counties. In order to make these calculations, I used the U.S. Department of Commerce (DOC) 1987 Census of Manufactures, Geographic Area Series (U.S. Department of Commerce, 1990), which gives aggregated shipment values down to the four-digit SIC level. I then matched these figures to the four-digit ISIC classifications used by IPPS. I encountered a number of difficulties at this stage, stemming from the DOC disclosure regulations. At the geographic level of the county, there are a number of four-digit SIC sectors that contain an insufficient number of facilities to pass the disclosure requirements. Indeed, for the four counties of the SCAQMD, 35% of the four-digit SIC sectors were prevented from reporting shipment values.

To overcome this problem, I also collected shipment values by three-digit SIC. This reduced the number of nondisclosing sectors to 16% of the total number of sectors in the four counties, but created a new problem. At the three-digit SIC level, a number of sectors match to more than one four-digit ISIC classification, meaning that more than one pollution intensity may be associated with each sector. The accurate solution to this difficulty would be to calculate a weighted average according to the relative share of each ISIC within the three-digit SIC. Unfortunately the limited disclosure of more detailed data prevented this approach. As a second-best alternative, I estimated two sets of emissions, the first using the most pollution-intensive ISIC classification for each over-lapping three-digit SIC, and the second using the least intensive. This approach thus produced maximum and minimum estimates of total pollutant releases within each county. These are presented in Table 4.3 below, together with the estimates made from the incomplete four-digit SIC data, and the associated pollution intensities for each county.

A considerable range may be seen between the high and low releases estimated from the three-digit SIC data. In percentage terms, the smallest increase is 42% from the low to the high estimate of NO_2 for Los Angeles county. The greatest variations are in the estimates for San Bernardino county, which also has the lowest industrial output. In this county, the high estimate for NO_2 is an order of magnitude greater than the low estimate. I am not surprised that the releases estimated at the four-digit level are generally below the low three-digit estimates, as many more sectors are prevented from disclosing data at the four-digit level than at the three-digit level. However, the estimated pollution intensities at the four-digit level are comparable to the three-digit estimates, most of them falling between the high and low intensities.

The objective of creating the estimates of pollutant releases listed above was to compare them with the reported releases recorded by the SCAQMD in Appendix III-A to the Air Quality Management Plan, 1991 (South Coast Air Quality Management District, 1991). For the year 1987, information on major point sources (those emitting more than 18 tons per year) is maintained in the SCAQMD's Emissions Inventory System (EIS). The EIS is updated annually with information submitted by facilities to

Table 4.3 **ESTIMATED RELEASES AND INTENSITIES FOR THE SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT.**

	Estimated Releases (Thousand Tons per Year)				Estimated Intensity (Tons per $m.)			
County	CO	NO_2	PT	SO_2	CO	NO_2	PT	SO_2
3-Digit SIC - High Estimates								
LA	434.4	149.3	157.2	321.0	4.9	1.7	1.8	3.6
Orange	77.6	26.7	36.4	61.1	3.9	1.3	1.8	3.0
River.	3.6	7.6	7.2	14.2	2.5	5.2	4.9	9.7
San B.	6.3	14.5	18.8	25.7	2.9	6.6	8.6	12.0
3-Digit SIC - Low Estimates								
LA	274.2	104.9	36.2	205.7	3.1	1.2	0.4	2.3
Orange	24.8	13.2	5.5	30.2	1.2	0.7	0.3	1.5
River.	1.3	1.2	1.1	4.5	0.9	0.8	0.7	3.1
San B.	0.6	1.2	2.0	2.9	0.3	0.6	0.9	1.3
4-Digit SIC Estimates								
LA	165.2	92.6	55.8	196.5	2.5	1.4	0.8	3.0
Orange	11.7	10.4	5.7	27.1	0.8	0.7	0.4	1.9
River.	0.9	3.9	0.8	2.6	1.9	7.8	1.7	5.3
San B.	0.3	0.6	0.8	1.7	0.3	0.7	0.9	2.0

CO - Carbon Monoxide
LA - Los Angeles
NO_2 - Nitrogen Dioxide
Orange - Orange County
PT - Particulates
River. - Riverside County
San B. - San Bernadino County
SO_2 - Sulphur Dioxide

Source: Author's calculations from the Industrial-Pollution-Projection System and the 1987 Census of Manufactures.

SCAQMD's emission fee reporting program. By combining these emissions data with the total value of shipments recorded for each county in the 1987 Census of Manufactures, I was also able to calculate the implied pollution intensities for each county. These estimated intensities and reported emissions are presented in Table 4.4 below.

Table 4.4 REPORTED RELEASES FROM STATIONARY INDUSTRIAL PROCESSES IN THE SCAQMD, AND IMPLIED POLLUTION INTENSITIES.

	Reported Releases (Thousand Tons per Year)				Implied Intensity (Tons per $m.)			
County	CO	NO_2	PT	SO_2	CO	NO_2	PT	SO_2
LA	0.3	3.2	15.7	2.5	*	0.03	0.16	0.03
Orange	1.4	0.8	3.5	0.2	0.05	0.03	0.14	0.01
River.	0.5	0.1	1.7	0.1	0.14	0.04	0.48	0.01
San B.	0.3	0.2	2.1	*	0.06	0.02	0.35	*

LA - Los Angeles
River. - Riverside
San B. - San Bernardino
* - less than 0.005

Source: Reported releases are 1987 data from the SCAQMD, Air Quality Management Plan, 1991, Appendix III-A (South Coast Air Quality Management District, 1991). The shipment values used to calculate the pollution intensities are taken from the 1987 Census of Manufactures (US Department of Commerce, 1990).

Comparing the estimated releases and intensities in Table 4.3 with the reported releases and implied intensities in Table 4.4, I show that the IPPS significantly over-estimates the emissions reported to the SCAQMD. This is also reflected in the far higher pollution intensities calculated from IPPS, even using the low three-digit SIC estimates. Across the four counties, the low three-digit SIC intensities are more than two hundred times greater than the implied CO intensities, nearly thirty times greater than the NO_2 intensities, and over four hundred times greater than the SO_2 intensities. The only pollutant for which the IPPS intensities are within one order of magnitude of the implied intensities is particulate emissions (PT), for which the IPPS estimates are on average double the implied SCAQMD intensities.

The scale of the difference between the IPPS estimates and the SCAQMD data is an issue of serious concern. Although IPPS over-estimated the national emissions discussed in the preceding section, the scale of the error was less than an order of magnitude. In contrast, some of the IPPS estimates for the SCAQMD counties are more than two orders of magnitude above the reported emissions. A number of reasons may be given for the size of the error. First, it may be that the mix of products and processes within each four-digit ISIC sector is substantially different from the mix in the sample used to calculate the IPPS indices. In the preceding discussion of the statistical significance of the IPPS intensities, I demonstrated that there is considerable variation in the intensities of individual plants within the same sector. Consequently, if stricter pollution controls in the SCAQMD formed a significant disincentive for the location of more pollution-intensive plants in the Basin, thus affecting the mix of products and processes *within* ISIC sectors, the sectoral pollution intensities might be severely affected.

The second possible explanation for the IPPS over-estimate of SCAQMD pollution is related to the first. Even if the SCAQMD mix of products within each ISIC sector is not significantly different from the IPPS sample, it is possible that the stricter control of air pollution in the SCAQMD has pushed the pollution intensity of each plant well below the national average for the particular product. Although the Los Angeles basin is one of the most polluted air-sheds in the United States, this is largely due to meteorological conditions and motor-vehicle emissions (SCAQMD, 1991). The need to reduce the high ambient concentrations of criteria pollutants has led to regulatory controls over industrial emissions that are in many cases more stringent than the national average (SCAQMD, oral communication).

A more subtle explanation for the error in the IPPS estimates of the SCAQMD emissions is related to the way in which the IPPS pollution-intensity coefficients were calculated. As I explained in Chapter 3, the IPPS coefficients are size-weighted average pollution intensities. Consequently, the pollution intensities of the largest plants in each ISIC sector of the World Bank team's sample have a greater influence on the IPPS coefficents than the pollution intensities of the smallest plants. If there is a systematic relationship between plant size and pollution intensity, then the size-weighted coefficients will misrepresent the average pollution intensity of samples with a different mix of plant sizes. Unfortunately, the data available did not allow me to compare the SCAQMD mix of plant sizes with those in the World Bank team's sample.

For the sake of completeness, I note that it is also possible that the error in the IPPS estimates is partially attributable to errors in the recording of SCAQMD emissions. In the previous section I identified significant differences between the national emissions reported in AIRS and those presented in the "National Air Quality and Emissions Trends

Report". This indicates that errors in the officially recorded emissions cannot be discounted.

Further Work

The analysis that I have presented in this chapter has raised some important issues regarding the use of the IPPS indices. In particular, it is essential that further effort be devoted to uncovering the true sources of the disparity between the IPPS estimates and the national and SCAQMD reports. A likely conclusion is that there is too much variation in the factors affecting pollution intensity at the four-digit ISIC level of aggregation to place much confidence in a single estimate of the sector's pollution intensity. In order to improve the accuracy of the IPPS estimates, further work is needed to identify and control for the sources of variation. Although substantial effort would be required to examine all sources of variation in all sectors, there is hope that significant improvements in the IPPS estimates can obtained by focusing future work on a few important sources of variation in the most pollution-intensive sectors of production. The exponential distribution of pollution intensities illustrated in Figures 4.1-4.4 indicates that the pollution load from a set of manufacturing plants is highly dominated by production in the most pollution-intensive sectors. Analysis of the key sources of variation that I suggest below should focus first on these critical sectors.

One of the major problems with the current set of IPPS coefficients is that each four-digit ISIC sector covers a number of production processes, each with a different level of pollution intensity. The existing sample of matched EPA/DOC data could be used to test the improvement in IPPS estimates at more detailed levels of aggregation, ultimately down to the seven-digit level of SIC product classification. At this level of product definition, there is only limited variation in production technologies. This approach will raise two problems. First, it will not be immediately possible to generate more detailed disclosable pollution-intensity estimates for a large number of more finely defined sectors. Using the existing IPPS sample of matched EPA/DOC data, any increase in the number of sectors reduces the number of plants in each sector, meaning that fewer sectoral indices pass the Bureau of Census disclosure requirements. Nevertheless, improvements in the IPPS estimates with nondisclosable data can be tested on the premises of the Bureau of the Census, and disclosable estimates can be developed for those sectors with a larger number of plants. Second, the four-digit ISIC categorization was justified as an appropriate level of aggregation on the basis that this is the most common degree of aggregation for economic data from developing nations. The immediate ease of application of IPPS would be substantially curtailed if it became necessary to develop and apply IPPS indices at a more finely detailed level of industrial classification. There is some hope, however, that the dominant effect of a few highly pollution-intensive sectors may mean that substantially improved estimates can be obtained with more detailed classifications from a relatively few key sectors.

At a sufficiently detailed level of product definition there is only limited variation in the available production technologies. Variation in pollution intensities is therefore primarily determined by end-of-pipe pollution-control measures. The inclusion of this source of variation would greatly improve the accuracy of IPPS estimates, but raises two difficulties. First, how to relate information regarding pollution-control measures to emission intensities, and second, how to determine what degree of pollution-control is employed by the facilities being modeled. The first issue is more easily solved than the second, as extensive data are available on the effectiveness of pollution-control technologies. For example, the World Health Organization's Rapid Assessment procedure (World Health Organization, 1989) provides "Penetration Factors" for a number of different stages of waste control for both emissions to air and effluent discharges, expressed as a percentage reduction of the uncontrolled release. Alternatively, the Pollution Abatement and Control Expenditures (PACE) data collected by the DOC could be used in a regression analysis to relate pollution-control costs to pollution intensity.

Determination of the degree of pollution control employed by a set of manufacturing plants to be modeled using IPPS is more difficult. Such pollution-control data are not widely available in developing countries, although it is generally assumed that the degree of control is less than in most industrialized nations. One approach to dealing with this problem is suggested by the Industrial Efficiency and Pollution Abatement Project (IEPA), commissioned jointly by the World Bank and the Indonesian Ministry of Industry in 1991 (World Bank, 1991). This data collection study surveyed a number of key polluting sectors to determine the degree of pollution control, broadly categorized as "Western Standard", "Below Western Standard" and "None". Clearly, a trade-off has to be made between the accuracy of the adjusted IPPS estimates and the resources expended in data collection.

Although process technology and end-of-pipe pollution controls are likely to account for much of the variation in pollution intensity within the four-digit ISIC sectors, additional factors may play some role. In particular, there may be some effect due to plant size and age. This hypothesis can be tested relatively easily with a regression analysis of the production and investment data recorded in the LRD. The most difficult aspect of the test will be to control for the effect of differences in process technology and end-of-pipe controls.

The suggestions I have made above represent a substantial program of further work aimed at improving the accuracy of the IPPS estimates, but I believe that the potential of such a system to improve the quality of environmental decision-making for developing countries justifies the additional investment of time and resources.

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GLOSSARY OF ABBREVIATIONS

AFS - AIRS Facility Subsystem

AIRS - Aerometric Information Retrieval System

ASM - Annual Survey of Manufactures

BOD - Biological Oxygen Demand

CES - Center for Economic Research

CO - Carbon Monoxide

COD - Chemical Oxygen Demand

DOC - Department of Commerce

CM - Census of Manufactures

EPA - U.S. Environmental Protection Agency

HHED - Human Health and Ecotoxicity Database

IPPS - The Industrial Pollution Projection System

ISIC - International Standard Industrial Classification

LRD - Longitudinal Research Database

NO_2 - Nitrogen Dioxide

NPDES - National Pollutant Discharge Elimination System

PCS - Permit Compliance System

PT - Particulates

REMI - Regional Economic Models Incorporated

SCAQMD - South Coast Air Quality Management District

SIC - Standard Industrial Classification

SO_2 - Sulfur Dioxide

TRI - Toxic Release Inventory

TSS - Total Suspended Solids

UNIDO - United Nations Industrial Development Organization

VOC - Volatile Organic Compound

WHO - World Health Organization