The Industrial Pollution Projection System

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Most developing countries are faced with the problem of industrial pollution. Many of them have very little information on industrial pollutant emissions or on employment, value added, or output. The industrial pollution projection system is designed to convert the available data on industrial emissions into a profile of the associated pollution.
Summary findings

The World Bank's technical assistance work with new environmental protection institutions stresses cost-effective regulation, with market-based pollution control instruments implemented wherever feasible. But few environmental protection institutions can do the benefit-cost analysis needed because they lack data on industrial emissions and abatement costs. For the time being, they must use appropriate estimates.

The industrial pollution projection system (IPPS) is being developed as a comprehensive response to this need for estimates. The estimation of IPPS parameters is providing a much clearer, more detailed view of the sources of industrial pollution. The IPPS has been developed to exploit the fact that industrial pollution is heavily affected by the scale of industrial activity, by its sectoral composition, and by the type of process technology used in production.

Most developing countries have little or no data on industrial pollution, but many of them have relatively detailed industry-survey information on employment, value added, or output. The IPPS is designed to convert this information to a profile of associated pollutant output for countries, regions, urban areas, or proposed

new projects. It operates through sectoral estimates of pollution intensity, or pollution per unit of activity.

The IPPS is being developed in two phases. The first prototype has been estimated from a massive U.S. data base developed by the Bank's Policy Research Department, Environment, Infrastructure, and Agriculture Division, in collaboration with the Center for Economic Studies of the U.S. Census Bureau and the U.S. Environmental Protection Agency. This database was created by merging manufacturing census data with Environment Protection Agency data on air, water, and solid waste emissions. It draws on environmental, economic, and geographic information from about 200,000 U.S. factories. The IPPS covers about 1,500 product categories, all operating technologies, and hundreds of pollutants. It can project air, water, or solid waste emissions, and it incorporates a range of risk factors for human toxins and ecotoxic effects.

The more ambitious second phase of IPPS development will take into account cross-country and cross-regional variations in relative prices, economic and sectoral policies, and strictness of regulation.
IPPS

THE INDUSTRIAL POLLUTION PROJECTION SYSTEM

by

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Executive Summary

The World Bank's technical assistance work with new environmental protection institutions (EPI's) stresses cost-effective regulation, with implementation of market-based pollution control instruments wherever this is feasible. At present, however, few EPI's can do the requisite benefit-cost analysis because they lack data on industrial emissions and abatement costs. For the foreseeable future, appropriate estimation methods will therefore have to be employed as complements to direct measures of environmental parameters at the firm level. We are developing the Industrial Pollution Projection System (IPPS) as a comprehensive response to this need. Estimation of IPPS parameters is also giving us a much clearer and more detailed view of the sources of industrial pollution. In this paper, we report on our findings to date.

IPPS has been developed to exploit the fact that industrial pollution is heavily affected by the scale of industrial activity, its sectoral composition, and the process technologies which are employed in production. Although most developing countries have little or no industrial pollution data, many of them have relatively detailed industry survey information on employment, value added or output. IPPS is designed to convert this information to the best feasible profile of the associated pollutant output for countries, regions, urban areas, or proposed new projects. It operates through sector estimates of pollution intensity, or pollution per unit of activity.
We are developing IPPS in two phases. We have estimated the first prototype from a massive U.S. data base, developed by PRDEI in collaboration with the Center for Economic Studies of the U.S. Census Bureau and the U.S. Environmental Protection Agency. This data base was created by merging Manufacturing Census file data with US EPA data on air, water and solid waste emissions. It contains complete environmental, economic and geographic information for approximately 200,000 factories in all regions of the United States. The first prototype of IPPS spans approximately 1,500 product categories, all operating technologies, and hundreds of pollutants. It can separately project air, water, and solid waste emissions, and incorporates a range of risk factors for human toxic and ecotoxic effects. It can also project emissions of some greenhouse gases and several compounds which are hazardous to the ozone layer. Since it has been developed from a database of unprecedented size and depth, it is undoubtedly the most comprehensive system of its kind in the world.

We recognize, however, that this is only the beginning. Although much more detailed empirical research is needed on the sources of variation in industrial pollution, it is already clear that great differences are attributable to cross-country and cross-regional variations in relative prices, economic and sectoral policies, and strictness of regulation. The second phase of IPPS development will, therefore, have to be even more ambitious than the first. We are now undertaking an econometric research project which will use plant-level data from many countries to quantify the major sources of international and
interregional variation in industrial pollution. This project should help identify the policies which have reduced industrial pollution most cost-effectively under different conditions. By quantifying the effect of country- and region-specific policy and economic variables, it should also provide the basis for adjusting IPPS to conditions in a wide variety of national and regional economies.

We have learned a number of valuable things from first-phase development and application of IPPS:

- Industrial pollution problems vary substantially across countries, and across regions within countries. We have therefore estimated intensities for a large number of air, water and toxic pollutants. To illustrate, at the broadest level of pollutant aggregation, IPPS intensity estimates are available for the sum of all toxic pollutants released to all media (air, water, land). At the narrowest level, separate intensities have been estimated for air, water and land release of over 100 toxic pollutants.

- Complementary economic data for developing countries can be somewhat randomly available by variable and level of aggregation. We have therefore found it useful to estimate IPPS parameters at the 2-, 3-, and 4-digit levels of aggregation in the International Standard Industrial Classification (ISIC). At each ISIC level, we have estimated pollution intensities, or emissions per unit of activity, using all three economic variables which are commonly available: Value of output, value added and employment. For cases where extremely detailed data are available, we have also estimated sectoral parameters at the U.S. 4- and 5-digit SIC levels. In the latter case, the estimates include some information for over 1,000 industry sectors.
For individual pollutants, we find generally high correlations across intensities based on output value, value added and employment. At a purely 'mechanical' level, we therefore find little to distinguish the three sets of intensity measures as bases for pollution projection. However, basic economic reasoning does suggest that employment-based intensities may be preferable for pollution projection in developing countries. The logic is as follows: (1) Effective environmental regulation is thought to be quite income-elastic, although careful empirical work on cross-country data has yet to be done; (2) Sectoral pollution is thought to be quite responsive to effective environmental regulation in many cases; (3) Most cross-country econometric studies of sectoral labor demand find relatively high wage elasticities; (4) From (1)-(3), we can conclude that both sectoral pollution and sectoral labor demand will rise substantially as we move from richer (high-wage, high-regulation) to poorer (low-wage, low-regulation) economies. Since pollution and employment vary in the same direction, the variation in pollution intensity with respect to employment (P/E) may well be less than variation in pollution per unit of output. Very preliminary tests on U.S. and Indonesian sectoral data for water pollution provide support for this hypothesis, showing much higher variation for value-based intensities than for employment-based estimates.

We have uncovered what looks like an "iron law" of pollution intensity for all pollutants and levels of aggregation: Sectoral intensities are always exponentially distributed, with a few highly intensive sectors and many which have very low intensities. High-intensity sectors differ markedly across pollutants (see below), but the exponential pattern persists. The implication for applied work is clear: Pollution projections should always be done with the most disaggregated data available. The resulting gains in accuracy are often quite striking.

Although the phrase "pollution intensive" is commonly applied to industry sectors, it can be quite misleading. We find a very diverse pattern of sectoral intensity correlations across pollutants. Intensity correlations are sometimes high within similar classes (e.g., nitrogen
dioxide and sulphur dioxide among air pollutants; biological oxygen demand and suspended solids among water pollutants). Across classes, however, intensity correlations are sometimes quite low.

- IPPS parameters can be estimated differently, depending on the types of complementary data which are available. For the present purposes, we have used our U.S. factory sample to compute three basic types of indices. The first, or Upper Bound, estimates are computed from the subsample of factories which we have succeeded in matching between the EPA and Census data bases. Since no common ID codes are available, this has been a difficult process and inevitably entailed the loss of information from many plants. EPA files are kept only on firms which are significant pollutors, so we know that our matched sample provides an upward-biased estimate of general sectoral pollution intensity. Developing-country factories tend to be more pollution-intensive, however, so these estimates provide at least a partial correction.

- We have produced complementary Lower Bound estimates for U.S. plants by summing all EPA-recorded pollution by sector and dividing by all Census-recorded output or employment. This makes maximum use of the EPA sample (the Census data cover the whole population of firms), but implicitly counts pollution from all non-EPA-recorded firms as zero. This is an underestimate, so the Lower Bound intensities should be conservative. In both Upper and Lower Bound cases, we know that the presence of large outliers in the data can have an important impact on sector-specific results. As an alternative, we have computed pollution intensities for all plants separately using the subsample of matched data, and then estimated Interquartile Mean intensities. This eliminates the possible influence of outliers and provides a robust measure of central tendency. Each set of statistics can be useful in particular contexts, as discussed in the paper.

IPPS has already been applied in several World Bank analyses, most notably in two recent World Bank publications:
Carter Brandon and Ramesh Ramankutty, *Asia: Environment and Development* (1993); and Richard Calkins, et. al., *Indonesia: Environment and Development* (1994). Inside the Bank, sector reports for Mexico, Malaysia and several Middle Eastern countries have also used IPPS-based estimates. IPPS has been used to produce the first comprehensive cross-country estimates of toxic pollution in *World Resources 1994-95* (Table 12.4) published by the World Resources Institute. Recent work on trade and the environment by the OECD has also been based on IPPS, most notably the paper by David Roland-Holst and Hiro Lee: "International Trade and the Transfer of Environmental Costs and Benefits" (OECD, December 1993).

During the next year, we anticipate very rapid movement on Phase II of IPPS development: adjustment to conditions in other economies. At the conclusion of Phase I, we can offer a massive database of pollution parameters which are immediately usable for environmental planning and analyses. Complete 2-, 3-, and 4-digit ISIC pollution intensities are available on diskette from the authors.
The Industrial Pollution Projection System

1. Introduction

The Industrial Pollution Projection System (IPPS) is a modeling system which can use industry data to estimate comprehensive profiles of industrial pollution for countries, regions, urban areas, or proposed new projects. It is apparent that there is a huge potential demand for IPPS among environmental and industrial planners, particularly those working on issues related to developing countries. Most developing countries have little or no reliable information about their own pollution. Rapid environmental progress in the near future will depend on estimating pollution with projection systems like IPPS.

IPPS has been developed to exploit the fact that industrial pollution is heavily affected by the scale of industrial activity, its sectoral composition, and the process technologies which are employed in production. Although most developing countries have little or no industrial pollution data, many of them have relatively detailed industry survey information on employment, value added or output. IPPS is designed to convert this information to the best possible profile of the associated pollutant output.

The prototype system has been developed from a database containing environmental and economic data for approximately
200,000 facilities in all regions of the United States. IPPS spans approximately 1,500 product categories, all operating technologies, and hundreds of pollutants. It can separately project air, water, and solid waste emissions, and incorporates a range of risk factors for human toxic and ecotoxic effects. It can also project emissions of some greenhouse gases and several compounds which are hazardous to the ozone layer. Since it has been developed from a database of unprecedented size and depth, it is undoubtedly the most comprehensive system of its kind in the world.

How applicable are US-based estimates to other economies? It is clear that many country-specific factors will affect the accuracy of prototype IPPS projections outside the US. For particular sectors such as wood pulping, average pollution intensity is likely to be higher in developing countries. However, the pattern of sectoral intensity rankings may be similar. For example, wood pulping will be more water pollution-intensive than apparel manufacture in every country. The present version of IPPS can therefore be useful as a guide to probable pollution problems, even if exact estimates are not possible.

Our present goal is to expand the applicability of IPPS by incorporating data from developing countries. The project is therefore moving into the stage of outreach and information sharing with developing countries. Over time, new evidence will be used to develop systematic adjustments for economies with different characteristics.
The objective of the present paper is to provide a critical account of the material and methodology used for the first-generation IPPS. Section 2 provides a brief assessment of the available databases. Section 3 describes our methods for estimating pollution intensities by combining US Manufacturing Census data with the US Environmental Protection Agency's pollution databases. Section 4 focuses on estimation of toxic pollution intensities weighted by human and ecological risk factors. Section 5 describes the media-specific pollution intensities developed for the US EPA's criteria air pollutants, major water pollutants, and toxic releases by medium (air/water/land). The results are critically assessed in the final section. The complete set of IPPS intensities is available from the authors on request.

2. Building Blocks for Plant Level Databases

In order to establish a reliable picture of industrial pollution, a large cross-sectoral sample of facilities is required. Perhaps the world's largest sample is available in the databases maintained by the US Environmental Protection Agency and the US Census Bureau. Five of the databases with the greatest potential for constructing useful estimates and projections of industrial pollution are described below.

2.1 US EPA Emissions Databases

The US EPA maintains a number of databases at the
national level that contain information on the environmental performance of regulated facilities across the US. Four are of particular relevance to the construction of pollution intensity indices: the Toxic Release Inventory, the Aerometric Information Retrieval System, the National Pollutant Discharge Elimination System, and the Human Health and Ecotoxicity Database.

2.1.1 The Toxic Release Inventory (TRI)

The 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: to provide communities with information about potential chemical hazards; and to improve planning for chemical accidents.

The TRI reporting requirements cover all US manufacturing facilities that meet the following conditions:

- they produce/import/process 25,000 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;
- 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. This was lowered to 50,000
pounds the following year and to 25,000 pounds in 1989. Under the 1987 definition, some 20,000 facilities filed TRI reports. These were subsequently reduced to 18,846 as a result of the de-listing of six major chemicals (see below), and increased again to 19,762 facilities following the lowering of the reporting threshold.

The list of chemicals covered by the TRI is subject to an on-going review by the EPA. In the first year of reporting (1987) 328 individual chemicals and chemical categories were included, but this was adjusted to 322 the following year when the EPA determined that six chemicals were not sufficiently toxic to warrant reporting. The exclusion of three chemicals in particular - sodium sulfate, aluminum oxide and sodium hydroxide - had a dramatic impact on overall TRI totals, since they were respectively the first-, second-, and sixth-ranked chemicals. As a result, the total amount of releases and transfers reported was cut by two-thirds. The pollution intensities calculated in this paper do not include the chemicals de-listed up to 1989.

The TRI chemicals are drawn from lists developed independently by the states of Maryland and New Jersey, and vary widely in toxicity. No non-toxic substances or other environmental parameters, such as chemical or biological oxygen demand (COD/BOD), are recorded. TRI facilities must report 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 the mass of the TRI chemical released (not the total volume of the waste stream containing the chemical) in each of a range of categories, including:

- fugitive or non-point air emissions;
- stack or point air emissions;
- discharges to streams or receiving water bodies;
- underground injection on-site;
- releases to land on-site;
- waste-water discharges to publicly-owned treatment works;
- transfers to off-site facilities for treatment, storage or disposal.

For the purposes of inter-media analysis these seven categories can be aggregated under the three standard headings of releases to air, land and water.

The national repository for TRI data submitted to the EPA is the TRI Reporting Center in Washington, D.C. The information is computer-accessible through the National Library of Medicine's TOXNET database. The National Technical Information Service of the US Government Printing Office is also able to provide the data on tape, disk, CD-ROM and microfiche.

2.1.2 Aerometric Information Retrieval System (AIRS)

AIRS is the management system of the US national database for ambient air quality, emissions, and compliance data. It is
divided into three subsystems:

- the Geographic/Common Subsystem, a database of necessary codes;
- the Air Quality Subsystem, containing ambient air quality data;
- the Air Facility Subsystem (AFS).

The AFS contains the emissions and compliance data mandated by the Clean Air Act that are provided by individual facilities monitored by the EPA and state agencies. There is some overlap with the TRI, because the AFS data include emissions of some chemicals listed in TRI, but the AFS also includes a number of additional substances and parameters. The most important are the US EPA's six criteria air pollutants: sulphur dioxide (SO₂), nitrogen dioxide (NO₂), carbon monoxide (CO), particulate matter (TP), fine particulates (PM10), and volatile organic compounds (VOC). Although air emissions data have been collected since 1973, we have only used the data from 1984 onwards. Access to information from years prior to this is more difficult.

2.1.3 National Pollutant Discharge Elimination System (NPDES)

The US EPA's NPDES database contains the self-monitored reports of facilities with NPDES permits for discharges of waste water. Both the permits and the monitoring are mandated by the Clean Water Act. Some 60,000 facilities file reports on monitoring that they perform on a monthly basis. 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, a measure of the amount of oxygen consumed in the biological processes that break down organic matter in water), Total Suspended Solids (TSS), 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.

2.2 The Human Health and Ecotoxicity Database (HHED)

The EPA's HHED contains a number of indices of toxicological potency. No single index is considered sufficient to characterize all the factors relevant to a chemical's toxic potential under different circumstances, so different indices have been developed for specific applications. For example the Reportable Quantity (RQ) index is designed to guide the reporting of accidental releases required under CERCLA, whereas the Threshold Planning Quantity (TPQ) index was developed to meet the emergency response planning requirements of SARA Title III, Section 2.

For the purposes of risk-screening the HHED aggregates the toxicity values for ten indices into three toxicological potency groups. Table 2.1 indicates the mapping of threshold figures onto toxicological potency groups for four of the ten indices. In a number of cases the differences in the criteria used to develop the indices cause the same chemical to be rated
in a different potency group according to the choice of index. For example, the RQ and TPQ potency categorizations may differ because TPQs are based on a chemical's potential for becoming airborne as well as its toxicity. Furthermore, a number of TRI chemicals have yet to be assigned an RQ and are not listed under any other index. Consequently these substances are listed in the HHED without being assigned a potency group ranking.

Table 2.1: Mapping of EPA Threshold Values onto Toxicological Potency Groups

<table>
<thead>
<tr>
<th>Toxicity Index</th>
<th>Toxicological Potency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group 1</td>
</tr>
<tr>
<td>Threshold Planning Quantity (TPQ)</td>
<td>1, 10, 100</td>
</tr>
<tr>
<td>-acute only (pounds)</td>
<td></td>
</tr>
<tr>
<td>Reportable Quantity (RQ) - pounds</td>
<td>1, 10, 100</td>
</tr>
<tr>
<td>Reference Doses (RfD) - mg/kg/day</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Water Quality Criteria (WQC) - mg/L</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

2.3 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) from 1973 to 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:

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

- the quantity and cost of material goods consumed;
- the quantity and value of product shipped;
- employment.

The product information collected by the CM (product quantity produced, product quantity shipped and product value shipped) is recorded at the 7-digit SIC level, which is so detailed that on average each facility reports under 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 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.

3. Pollution Intensity Index Construction

3.1. The Conceptual Goal

Access to the emissions, risk and economic data described above presents a unique opportunity to develop a comprehensive picture of the environmental and human health risks associated with industrial development. The US EPA's databases and the LRD contain samples of facility-level information of an unmatched size and detail, enabling a reasonable estimate to be made of the pollution associated with any given level of activity, in any specified industrial sector. Conceptually, such estimates can be presented as an index of "pollution intensity", expressed as a ratio of pollution per unit of manufacturing activity:

\[
\text{pollutant output intensity} = \frac{\text{pollutant output}}{\text{total manufacturing activity}}
\]

Initially, this project focused on the generation of all-media toxic pollution intensity indices from the data.
contained in the TRI and the LRD. This was combined with the HHED to develop additional risk-weighted indices. The TRI was chosen for analysis before the AIRS and NPDES databases, both because of its ready availability and because of the importance of toxic release information for the analysis of risk. The analysis draws only on the first year of TRI data (1987), chosen largely because it was a census year with consequently detailed LRD data.

In the next stage of the project the AIRS and NPDES databases, and the information on media-specific releases in the TRI, were used to construct a wide range of pollution output intensities by medium (air/land/water). In addition to disaggregating the toxic pollution intensities by medium, indices were obtained for the US EPA's six criteria air pollutants (SO₂, NO₂, CO, TP, PM10, VOC,) and two water pollutant indicators, (BOD and TSS).

3.2. Operational Complexities

Although pollution intensity estimation is conceptually straightforward, several practical problems had to be confronted in actual calculation of the indices. An understanding of their resolution is important if the indices are to be correctly interpreted and applied.
3.2.1 Merger of the EPA and LRD files.

The calculation of pollution intensity required merging the EPA and LRD data at the facility level. Unfortunately, no common code numbers link the same establishments within the EPA databases or between the EPA and LRD databases. This necessitated a complex matching process which used the facility names, addresses and SIC codes. Of some 20,000 plants reporting TRI information in 1987, about 13,000 were matched to the corresponding LRD data for that year. For medium-specific intensities, data from all 200,000 plants in the LRD, 20,000 plants in the TRI, 20,000 plants in the AIRS database, and 13,000 facilities in the NPDES were combined to the extent possible.

3.2.2 The Choice of a Numerator

A number of options existed for the choice of total pollutant risk to be used as the numerator. First, a decision had to be made regarding the choice of disposal medium. As noted above, the TRI data identify a range of releases and transfers, including emissions to air, water, land, underground injection, and off-site disposal in both landfill and public waste-water facilities. Initially pollution across all media was used, aggregating all releases and transfers of a given chemical from each facility.¹

¹In this regard, it is worth noting that there is little comprehensive analysis of the impact environmental regulation has had on total pollution at the plant level. Both regulation and research have generally focused on particular media, especially stressing releases to air and water. It is therefore unclear how much total "pollutant intensity" has been reduced in the US. Consider, for example, the
Second, a mechanism was needed to derive estimates of risk from the TRI data. Conceivably it would be possible to combine the TRI information on the quantity of particular chemical releases with the LRD data on quantity of inputs, thus developing a picture of cross-sectoral chemical input-output coefficients. While this might provide useful insight into the flow of specific chemicals within the economy, the wide range of environmental and health risks associated with different chemicals would restrict inter-sectoral comparisons of pollutant risk. A better alternative for the comparison of risks is provided by the multi-index categorization of toxic potency in the US EPA's HHED.

Our initial results indicated a high rank correlation between pollution risk intensity and pollution output intensity (see section 4.4). Therefore, subsequent work focused solely on medium-specific pollution output intensities (see section 5.3). These intensities were calculated at varying degrees of sectoral disaggregation, and with a number of different denominators, so that pollution projections could be made using the manufacturing data which are readily available in many developing countries.

3.2.3. The Choice of a Denominator

The LRD provides a number of options for the measure of manufacturing activity to be used as a denominator in calculating pollutant intensity. Four of the most obvious are:

implications of concentrating trace toxins from waste water into highly toxic solid waste for shipment to a landfill.
The most immediately appealing choice is physical volume of output, since pollution is associated with the volume of physical residuals from production. However, the use of physical output volume poses several practical difficulties. First, a wide range of units are used to report output quantities in the LRD even within a given sector, severely complicating inter-facility analysis. Second, 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 physical output volume in developing countries is generally very sparse.

Consequently, first-round estimation focused on shipment value as the measure of manufacturing activity for estimating toxic pollution risk intensities. Although this statistic has obvious relative price problems, particularly in the international context, it has the advantage of relatively complete coverage and the usual benefit of the dollar metric in allowing inter-sectoral comparison. Total output value was judged superior to value added because energy and materials inputs are critical in the determination of industrial pollution.

To allow the system to be applied in a wider range of circumstances, pollution intensities with respect to value added
and employment were also estimated in the second round of work.\(^2\) In addition, intensities were calculated for manufacturing sectors defined according to the 2-, 3- and 4-digit International Standard Industrial Classification (ISIC).

3.2.4 Alternative Estimates of Sectoral Pollution Intensities

The EPA data used in the study only cover facilities releasing pollutants in quantities over a threshold level of emissions. Consequently, pollution intensity estimates based on these data (as in Table 4.3) may be upwardly biased, by exclusion of cleaner facilities. To correct for this, alternative intensities were estimated, by grouping data from manufacturing facilities into three classes. Facilities reporting emissions to the EPA were classified as group (1) if they could be matched to the LRD, and group (2) if this was not possible. Those facilities which did not report emissions to EPA, but were in the LRD, were defined to be group (3).

The pollution intensities derived from group (1) data were presumed to give an "upper bound" estimate for each industrial sector because of their inherent upward bias. For the matched group an intensity estimate defined as the Upper Bound Weighted Mean (known as Upper-Bound (UB) hereafter) was calculated by weighting each plant's pollution intensity by its

\(^2\)We have noted in the Executive Summary, it is possible that employment-based intensities are more stable across countries than the value-based measures.
scale of activity\(^3\).

The Upper-Bound estimates can be heavily affected by the presence of some extreme outliers in the matched group. To eliminate this impact, Upper Bound Inter-Quartile Mean intensities (known as Inter-Quartile Mean (IQ) hereafter) were calculated for the matched group. This involved calculating the unweighted mean of the plant intensities after dropping those which are below the first quartile or above the third quartile.

The ratio of total EPA emissions reported in a sector (from groups (1) and (2)) to the total level of economic activity in that sector reported by the LRD (from all three groups) was calculated as the Lower Bound Weighted Mean pollution intensity (known as Lower-Bound (LB) hereafter). This intensity measure assumes an emissions level of zero for group (3) plants (those which report to the LRD but not to the EPA). To the extent that these facilities have some emissions, this LB estimate is biased downward\(^4\).

All three intensity measures were compiled with respect to each of the denominators - total value of output, value added and employment. We recommend the use of LB intensities (especially for non-toxic air and water pollutants) because of

---

\(^3\)This intensity is equivalent to: 
\[ \frac{\text{total pollution in group (1)}}{\text{total activity in group (1)}} \]

\(^4\)If the plants in the matched data set had lower than average sectoral pollution intensities compared to all the plants in the entire EPA dataset, IQ for those sectors could be lower than the LB.
the larger sample used for this measurement compared to the matched sample. However, depending on the circumstances in which the projections are made any one of the three measures may be used.

3.2.5. Remapping US Facilities to 4-digit ISIC

Having matched the TRI data to the LRD information at the facility level, it was necessary to select a suitable level of aggregation of industrial activity for international comparisons of pollutant intensity. The 4-digit ISIC level, comprising about 80 sub-sectors, was selected, since it is the most detailed and comprehensive level of reporting used by UNIDO.\footnote{Pollution intensity estimates were also derived for other levels of disaggregation: 2-digit, 3-digit and 4-digit US Standard Industrial Classification (SIC) sectors, which have respectively 9, 39, and 1500 sub-sectors.}

A standard US Department of Commerce concordance was used to assign a 4-digit ISIC code to each sector. Difficulties arose in dealing with those facilities reporting under more than one 5-digit SIC code when the facility's SIC codes matched more than one ISIC classification. The standard procedure for dealing with this problem was to assign each facility the 4-digit ISIC code with the greatest shipment value. Although this was generally 80% or more of the total shipment value, this approach inevitably lent some inaccuracy to the final estimates of pollutant intensity.
4. Construction of a Toxic Pollution Risk Intensity Index

4.1. Calculation of Risk-Weighted and Unweighted Releases and Transfers

This section describes how toxic pollution intensity weighted by risk was calculated using the TRI, HHED and LRD databases. This measure enables the comparison of inter-sectoral environmental and health-related risks. Using the multi-index categorization of HHED, each chemical's rating under each index was assigned to one of three toxicological potency groups, Group One being the most hazardous (see Table 2.1). Each of the indices is also assigned to one of four higher levels of aggregation as follows:

- acute human health and terrestrial ecotoxicity;
- chronic human health and terrestrial ecotoxicity;
- acute aquatic ecotoxicity;
- chronic aquatic ecotoxicity.

For our purposes two of these categories were chosen to characterize pollutant intensity, these being acute human health and terrestrial ecotoxicity and acute aquatic ecotoxicity. Human and terrestrial ecotoxicity are distinguished from aquatic ecotoxicity because of the significant variation between the toxicological potency of many chemicals to mammalian and fish life. Chronic toxicity was ignored, largely because the evidence for low-dose, long-term effects is contentious. Since the HHED contains more than one index within each of these categories, the most hazardous toxicological potency rating was selected as a
A difficulty arose 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 adopted in this study 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, two forms of weighting were used to test the sensitivity of the results. First, the EPA toxicological potency ratings were simply reversed, giving a linear weighting scale from 1 to 4. Four weights were used, although there are only three toxicological potency ratings, because those TRI chemicals yet to be assigned a toxicological rating (see section 3.2.2 above) were grouped together with the lowest weighting. Second, an exponential weighting was used for the four groups, rising by orders of magnitude from 1 to 1,000. This methodology generated four measures of risk-weighted releases and transfers for each facility:

- linear acute human health and terrestrial ecotoxicity;
- exponential acute human health and terrestrial ecotoxicity;
- linear acute aquatic ecotoxicity;
- exponential acute aquatic ecotoxicity.

In addition, two TRI totals unweighted for risk were calculated for each facility:
• total quantity of TRI chemicals released or transferred;
• total quantity of metals released or transferred.

A separate figure was calculated for metals and their compounds because of the specific risks associated with their accumulation in the environment and concentration as they are passed up the food-chain. The TRI metals are listed in the Annex and follow the same definition as those in "Toxics in the Community" (1989), published by the US EPA.

With each facility assigned a 4-digit ISIC code and six TRI release and transfer parameters, sectoral totals for each parameter were calculated by summing across all facilities falling within the same ISIC category.

4.2. Scaling by Shipment Value to Give Pollution Intensity

The final element in the creation of risk-weighted measures of pollutant intensity was the scaling of all six TRI parameters by shipment(output)value. This was achieved by summing facility shipment values within the 4-digit ISIC sectors in the matched TRI-LRD dataset, and dividing the result into the TRI totals. This produced the Upper Bound (UB) estimates discussed in the previous section. Of the six pollutant intensity estimates for each sector, four are dimensioned as risk-weighted pounds of TRI chemicals released and transferred per $1000 of gross output, and two are unweighted pounds of TRI chemicals per $1000 of output. It should be noted that this set of six sectoral pollutant intensity indices is probably unique. Not only is the TRI
database relatively new and unique in itself, but the massive plant-level matching undertaken in this study has not previously been possible.

4.3. Results

As an indication of results obtained using the methodology described above, Figure 4.1 charts the linearly-weighted acute human and terrestrial ecotoxicity index across the seventy-four 4-digit ISIC codes for which TRI data are available. The units of the pollution index are linearly risk-weighted pounds of TRI releases and transfers per $1,000 of shipment value. Table 4.1 presents the same information, together with the ISIC sector names.

Figure 4.1 clearly illustrates the extreme sectoral variation in pollutant intensity, ranging from Fertilizers and Pesticides (ISIC 3512) with 105.3 risk-weighted pounds of TRI releases and transfers per $1,000 of product shipped, to Soft Drinks and Carbonated Water (ISIC 3134), with only 0.22 pounds per $1,000. Despite a few surprises, such as the fifteenth ranking of the Musical Instruments sector, Table 4.1 generally confirms the intuition that the most intensive sectors in terms of toxic waste per dollar of output are industrial chemicals, plastics, paper and metals. The middle-ranked sectors are associated with consumer products such as electrical appliances, textiles, and cleaning preparations, followed by the high shipment value (and consequently relatively low intensity) machine-tool industry, with the food and drink sectors filling
the least intensive rankings. The shape of the distribution of pollutant intensities is also of interest. Almost perfectly exponential, it provides some hope that problems associated with toxic releases can be 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 impact on the total level of releases and transfers. Nor does the index incorporate any abatement cost considerations.6

Table 4.1: Four Digit ISIC Codes and Descriptions in Descending Order of Linear Acute Human Toxic Intensity Index (Risk Weighted Pounds/1987 US $ Million Output Value)

<table>
<thead>
<tr>
<th>Four Digit ISIC Description</th>
<th>ISIC Code</th>
<th>Linear Acute Human Toxic Intensity</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>FERTILIZERS &amp; PESTICIDES</td>
<td>3512</td>
<td>105.30</td>
<td>1</td>
</tr>
<tr>
<td>INDUSTRIAL CHEMICALS EXCEPT FERTILIZER</td>
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<td>TANNERIES AND LEATHER FINISHING</td>
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<td>3</td>
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<td>SYNTHETIC RESINS, PLASTICS MATERIALS, &amp; MANMADE FIBRES</td>
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<td>PAPER &amp; PAPERBOARD CONTAINERS &amp; BOXES</td>
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<td>PLASTICS PRODUCTS, N.E.C.</td>
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<tr>
<td>PRINTING &amp; PUBLISHING</td>
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<td>14.93</td>
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<tr>
<td>PULP, PAPER &amp; PAPERBOARD ARTICLES</td>
<td>3419</td>
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<td>9</td>
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<tr>
<td>NONFERROUS METALS</td>
<td>3720</td>
<td>13.23</td>
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</table>

<table>
<thead>
<tr>
<th>Four Digit ISIC Description</th>
<th>ISIC Code</th>
<th>Linear Acute Human Toxic Intensity</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRON AND STEEL</td>
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<td>TOBACCO MANUFACTURES</td>
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<td>WINE INDUSTRIES</td>
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<td>TIRES AND TUBES</td>
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<td>0.74</td>
<td>65</td>
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<td>BAKERY PRODUCTS</td>
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<td>CONFECTIONERY PRODUCTS</td>
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<td>MEAT PRODUCTS</td>
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<td>71</td>
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<td>MALT LIQUORS AND MALT</td>
<td>3133</td>
<td>0.37</td>
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<td>GRAIN MILL PRODUCTS</td>
<td>3116</td>
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<td>73</td>
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<tr>
<td>SOFT DRINKS &amp; CARBONATED WATER</td>
<td>3134</td>
<td>0.22</td>
<td>74</td>
</tr>
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</table>
4.4 Variation Across Indices

Sectors may have very different toxic significance, depending on the toxic index or weighting employed. To test this, Table 4.2 presents Pearson rank correlation coefficients for all six indices. Correlations are very high for the five all-toxic measures. The linearly-weighted human (LinHum) and aquatic (LinAq) indicators have rank correlations of .99 with total toxic intensity (TotTRI), while correlations of the latter with exponentially-weighted human (ExpHum) and aquatic (ExpAq) indicators are respectively .88 and .80. The pairs of linear/exponential indices for humans and aquatic life are also highly correlated. The high correlation (.91) between the two human indicators is illustrated in Figure 4.2.

The implications of exponential weighting can be seen in a comparison of Figure 4.3 and Table 4.3 (ExpHum) with Figure 4.1 and Table 4.1 (LinHum). Although the same exponential distribution of values is observed for both measures and the two most intensive sectors are the same [Fertilizers and Pesticides (ISIC 3512), followed by Industrial Chemicals Except Fertilizer (ISIC 3511)], a number of other sectoral rankings have shifted. For example the Iron and Steel sector (ISIC 3710) rises from eleventh place in the linearly weighted index to fourth place in the exponentially weighted index, while Paper and Paperboard Containers and Boxes (ISIC 3412) falls from fifth to twelfth place.
These undeniable differences between the linearly and exponentially weighted rankings indicate that some caution is warranted when the indices are applied. However, the results do show that total toxic intensity is a good proxy for all the total toxic measures.

Table 4.2: Rank Correlation Analysis for Six Indices of Pollution Intensity

Pearson Rank Correlation Coefficients

<table>
<thead>
<tr>
<th></th>
<th>TotTRI</th>
<th>LinHum</th>
<th>ExpHum</th>
<th>LinAq</th>
<th>ExpAq</th>
<th>TotMet</th>
</tr>
</thead>
<tbody>
<tr>
<td>TotTRI</td>
<td>1</td>
<td>0.99</td>
<td>0.88</td>
<td>0.99</td>
<td>0.8</td>
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<tr>
<td>LinHum</td>
<td>0.99</td>
<td>1</td>
<td>0.91</td>
<td>0.99</td>
<td>0.83</td>
<td>0.49</td>
</tr>
<tr>
<td>ExpHum</td>
<td>0.88</td>
<td>0.91</td>
<td>1</td>
<td>0.89</td>
<td>0.82</td>
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<tr>
<td>LinAq</td>
<td>0.99</td>
<td>0.99</td>
<td>0.89</td>
<td>1</td>
<td>0.84</td>
<td>0.45</td>
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<tr>
<td>ExpAq</td>
<td>0.8</td>
<td>0.83</td>
<td>0.82</td>
<td>0.84</td>
<td>1</td>
<td>0.23</td>
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<tr>
<td>TotMet</td>
<td>0.51</td>
<td>0.49</td>
<td>0.46</td>
<td>0.45</td>
<td>0.23</td>
<td>1</td>
</tr>
</tbody>
</table>

Key:
- TotTRI - Total pounds of TRI substances released
- LinHum - Linearly weighted acute human toxicity
- ExpHum - Exponentially weighted acute human toxicity
- LinAq - Linearly weighted acute aquatic toxicity
- ExpAq - Exponentially weighted acute aquatic toxicity
- TotMet - Total pounds of TRI metallic compounds released

Table 4.2 also shows that the total toxic measures have much lower rank correlations with intensity in releases of bioaccumulative metals. The rank correlations do not rise above 0.51 and fall as low as 0.23. Clearly, the metals-generating sectors are not a random draw from all toxic
sectors. Applications should therefore distinguish between general toxic releases and releases of bioaccumulative metal compounds.
Figure 4.2 - Plot of Sectoral Ranks for Linearly Weighted Acute Human Toxicity against Sectoral Ranks for Exponentially Weighted Acute Human Toxicity
Table 4.3: Four Digit ISIC Codes and Descriptions in Descending Order of Exponential Acute Human Toxicity Intensity Index (Risk Weighted Pounds/1987 US$ Million Output Value)

<table>
<thead>
<tr>
<th>Four Digit ISIC Description</th>
<th>ISIC Code</th>
<th>Exponential Acute Human Toxicity Intensity</th>
<th>Rank</th>
</tr>
</thead>
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<tr>
<td>FERTILIZER &amp; PESTICIDES</td>
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<td>966.60</td>
<td>1</td>
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<tr>
<td>INDUSTRIAL CHEMICALS EXCEPT FERTILIZER</td>
<td>3511</td>
<td>609.77</td>
<td>2</td>
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<tr>
<td>SYNTHETIC RESINS, PLASTICS MATERIALS, &amp; MANMADE FIBRES</td>
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<td>544.60</td>
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<tr>
<td>IRON AND STEEL</td>
<td>3710</td>
<td>349.90</td>
<td>4</td>
</tr>
<tr>
<td>TANNERIES AND LEATHER FINISHING</td>
<td>3231</td>
<td>318.93</td>
<td>5</td>
</tr>
<tr>
<td>FABRICATED METAL PRODUCTS</td>
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<td>212.82</td>
<td>6</td>
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<td>STRUCTURAL METAL PRODUCTS</td>
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<td>201.71</td>
<td>7</td>
</tr>
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<td>PLASTICS PRODUCTS, N.E.C.</td>
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<td>175.56</td>
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<tr>
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<td>154.38</td>
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<tr>
<td>NONFERROUS METALS</td>
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<tr>
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<tr>
<td>PULP, PAPER, &amp; PUBLISHING</td>
<td>3411</td>
<td>116.90</td>
<td>13</td>
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<tr>
<td>PRINTING &amp; PUBLISHING</td>
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<td>109.25</td>
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<td>75.92</td>
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<td>75.45</td>
<td>19</td>
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<td>OILS AND FATS</td>
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<td>72.28</td>
<td>20</td>
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<td>21</td>
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<td>FURNITURE &amp; FIXTURES, NONMETAL</td>
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<td>61.29</td>
<td>23</td>
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<td>JEWELRY AND RELATED ARTICLES</td>
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<td>25</td>
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<tr>
<td>Four Digit ISIC Description</td>
<td>ISIC Code</td>
<td>Exponential Acute Human Toxicity Intensity</td>
<td>Rank</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-----------</td>
<td>------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>ELECTRICAL APPARATUS AND SUPPLIES, N.E.C.</td>
<td>3839</td>
<td>57.62</td>
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<tr>
<td>NONMETALLIC MINERAL PRODUCTS, N.E.C.</td>
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<td>56.60</td>
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<td>MUSICAL INSTRUMENTS</td>
<td>3902</td>
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<td>28</td>
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<tr>
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<td>51.90</td>
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<td>MADE-UP TEXTILES EXCEPT APPAREL</td>
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<td>PAINTS, VARNISHES, &amp; LACQUERS</td>
<td>3521</td>
<td>46.29</td>
<td>31</td>
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<td>SPORTING AND ATHLETIC GOODS</td>
<td>3903</td>
<td>44.92</td>
<td>32</td>
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<td>GLASS AND GLASS PRODUCTS</td>
<td>3620</td>
<td>43.58</td>
<td>33</td>
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<td>DRUGS AND MEDICINES</td>
<td>3522</td>
<td>42.82</td>
<td>34</td>
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<td>39.96</td>
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<td>38.03</td>
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<td>METAL &amp; WOOD WORKING MACHINERY</td>
<td>3823</td>
<td>30.30</td>
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<td>FURNITURE &amp; FIXTURES OF METAL</td>
<td>3812</td>
<td>30.10</td>
<td>39</td>
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<td>MISC. PETROLEUM &amp; COAL PRODUCTS</td>
<td>3540</td>
<td>29.44</td>
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<td>RADIO, TV, &amp; COMMUNICATION EQUIPMENT</td>
<td>3832</td>
<td>29.21</td>
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<tr>
<td>POTTERY, CHINA, &amp; EARTHENWARE</td>
<td>3610</td>
<td>29.16</td>
<td>42</td>
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<td>AIRCRAFT</td>
<td>3845</td>
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<td>45</td>
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<tr>
<td>WATCHES AND CLOCKS</td>
<td>3831</td>
<td>19.48</td>
<td>47</td>
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<td>19.71</td>
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<td>CEMENT, LIME, AN PLASTER</td>
<td>3692</td>
<td>18.47</td>
<td>49</td>
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<td>WEARING APPAREL</td>
<td>3220</td>
<td>17.52</td>
<td>50</td>
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<td>SHIPBUILDING AND REPAIRING</td>
<td>3841</td>
<td>17.43</td>
<td>51</td>
</tr>
<tr>
<td>ENGINES AND TURBINES</td>
<td>3821</td>
<td>17.13</td>
<td>52</td>
</tr>
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<td>FOOD PRODUCTS, N.E.C.</td>
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<td>17.07</td>
<td>53</td>
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<tr>
<td>DISTILLED SPIRITS</td>
<td>3131</td>
<td>16.80</td>
<td>54</td>
</tr>
<tr>
<td>PROFESSIONAL &amp; SCIENTIFIC EQUIPMENT</td>
<td>3851</td>
<td>16.21</td>
<td>55</td>
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<tr>
<td>BAKERY PRODUCTS</td>
<td>3117</td>
<td>15.96</td>
<td>56</td>
</tr>
<tr>
<td>WINE INDUSTRIES</td>
<td>3132</td>
<td>15.88</td>
<td>57</td>
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<tr>
<td>Four Digit ISIC Description</td>
<td>ISIC Code</td>
<td>Exponential Acute Human Toxicity Intensity</td>
<td>Rank</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-----------</td>
<td>------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>MOTOR VEHICLES</td>
<td>3843</td>
<td>15.73</td>
<td>58</td>
</tr>
<tr>
<td>PHOTOGRAPHIC AND OPTICAL GOODS</td>
<td>3852</td>
<td>15.37</td>
<td>59</td>
</tr>
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<td>SUGAR FACTORIES &amp; REFINERIES</td>
<td>3118</td>
<td>14.62</td>
<td>60</td>
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<tr>
<td>FOOTWEAR</td>
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<td>11.70</td>
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<tr>
<td>PREPARED ANIMAL FOODS</td>
<td>3122</td>
<td>9.35</td>
<td>62</td>
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<tr>
<td>AGRICULTURAL MACHINERY &amp; EQUIPMENT</td>
<td>3822</td>
<td>9.24</td>
<td>63</td>
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<tr>
<td>RAILROAD EQUIPMENT</td>
<td>3842</td>
<td>8.46</td>
<td>64</td>
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<td>GRAIN MILL PRODUCTS</td>
<td>3116</td>
<td>8.14</td>
<td>65</td>
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<tr>
<td>STRUCTURAL CLAY PRODUCTS</td>
<td>3691</td>
<td>7.90</td>
<td>66</td>
</tr>
<tr>
<td>CARPETS AND RUGS</td>
<td>3214</td>
<td>7.18</td>
<td>67</td>
</tr>
<tr>
<td>CONFECTIONERY PRODUCTS</td>
<td>3119</td>
<td>5.53</td>
<td>68</td>
</tr>
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<td>TOBACCO MANUFACTURES</td>
<td>3140</td>
<td>5.32</td>
<td>69</td>
</tr>
<tr>
<td>SOFT DRINKS &amp; CARBONATED WATERS</td>
<td>3134</td>
<td>5.26</td>
<td>70</td>
</tr>
<tr>
<td>MEAT PRODUCTS</td>
<td>3111</td>
<td>5.04</td>
<td>71</td>
</tr>
<tr>
<td>OFFICE, COMPUTING, &amp; ACCOUNTING MACHINERY</td>
<td>3825</td>
<td>3.16</td>
<td>72</td>
</tr>
<tr>
<td>TIRES AND TUBES</td>
<td>3551</td>
<td>2.89</td>
<td>73</td>
</tr>
<tr>
<td>MALT LIQUORS AND MALT</td>
<td>3133</td>
<td>1.99</td>
<td>74</td>
</tr>
</tbody>
</table>
Figure 4.3 - Exponentially Weighted Acute Human Toxic Intensity Index
This section describes three major extensions of the IPPS indices introduced in sections 3 and 4. First, Upper Bound (UB) estimates are broadened to include Lower Bound (LB) and Interquartile Mean (IQ) estimates. Second, the intensity estimates are extended to value added and employment as denominators. Finally, intensities for toxic pollution by medium (air, water, land) and many non-toxic air and water pollutants are developed. Box 1 provides brief descriptions of all pollutants incorporated in IPPS.

An additional consideration is the level of sectoral disaggregation to be used for IPPS, which could have been constructed at the enormously detailed seven-digit SIC used in the LRD. However, given that measures of corresponding economic activity in developing countries are most widely available at the four-digit ISIC level, the project has remained focused at this level of aggregation.
BOX 1: MAJOR AIR, WATER AND TOXIC POLLUTANTS

Industrial emissions to air and water pose a variety of hazards to human health, ecosystems, and economic activity.

Air Pollutants

- **Total Suspended Particulates (TP) and Fine Particulates (PM10):** Particulates are fine liquid or solid particles such as dust, smoke, mist, fumes or smog found in air emissions. In heavy concentrations, airborne particulates interfere with proper functioning of the human respiratory system. High levels of ambient TP in urban/industrial areas are therefore associated with greater morbidity and mortality from respiratory diseases. Particulate coatings on leaves inhibit plant growth. High TP concentrations may also force the use of high-cost filtration equipment by manufacturers. Fine particulates (PM10) are less than 10 micron in diameter. They pose the greatest respiratory hazard.

- **Sulphur Dioxide (SO₂):** Sulphur dioxide is a heavy, pungent, colorless, gaseous air pollutant formed primarily by fossil fuel combustion. It is associated with morbidity and mortality from respiratory disease. In addition, SO₂ is a prime source of the acid rain which has damaged huge forest tracts in the OECD and several transitional socialist economies. Acid rain and runoff have raised the acidity in numerous lakes beyond the point where indigenous fish species can survive. Acid rain also degrades concrete, mortar, marble, metals, rubber and plastics.

- **Nitrogen Oxides (NOₓ):** Nitrogen dioxide (NO₂) and nitric oxide (NO) are oxides of nitrogen, often collectively referred to as "NOₓ." The primary source of NO is thermal combustion of fossil fuels, which emits NO. Higher combustion temperatures, sometimes recommended to reduce emissions of Volatile Organic Compounds (VOCs), are associated with higher production rates of NOₓ. NOₓ emissions have important ecological impacts, since they are integral to the formation of acid rain and tropospheric ozone. Inhalation of concentrated NOₓ damages the respiratory tract, resulting in a range of effects from mild reductions in pulmonary function to life-threatening pulmonary edema.

- **Carbon Monoxide (CO):** Carbon Monoxide is a colorless, odorless, and tasteless poisonous gas produced by incomplete fossil fuel combustion. CO binds with hemoglobin in human blood 200 times faster than oxygen. Thus, the blood's ability to carry oxygen to tissues is significantly impaired after exposure to only small concentrations of CO. High doses of CO can result in heart and brain damage, impaired perception and asphyxiation, and low doses may cause weakness, fatigue, headaches and nausea.

- **Volatile Organic Compounds (VOC):** The term volatile organic compounds, describes a class of thousands of substances used as solvents and fragrances. VOCs are particularly important in the petrochemical and plastics industries. Human exposure to VOCs is mainly via inhalation,
although some VOCs appear as contaminants in drinking water, food, and beverages. Many VOCs are suspected carcinogens. Acute effects from industrial exposures include skin reactions and central nervous system effects such as dizziness and fainting. Recently, sick-building syndrome (SBS) and multiple chemical sensitivity (MCS) have been linked to the relatively low (part per billion) concentrations of VOCs which are more typical of ambient environments. In addition, VOCs may form photochemical oxidants which have been identified as eye and lung irritants.

**Water Pollutants**

- **Biological Oxygen Demand (BOD):** Organic water pollutants are oxidized by naturally-occurring micro-organisms. This 'biological oxygen demand' removes dissolved oxygen from the water and can seriously damage some fish species which have adapted to the previous dissolved oxygen level. Low levels of dissolved oxygen may enable disease causing pathogens to survive longer in water. Organic water pollutants can also accelerate the growth of algae, which will crowd out other plant species. The eventual death and decomposition of the algae is another source of oxygen depletion as well as noxious smells and unsightly scum. The most common measure for BOD is the amount of oxygen used by micro-organisms to oxidize the organic waste in a standard sample of pollutant during a five-day period (hence, '5-day BOD').

- **Suspended Solids (SS):** Small particles of non-organic, non-toxic solids suspended in waste water will settle as sludge blankets in calm-water areas of streams and lakes. This can smother plant life and purifying micro-organisms, causing serious damage to aquatic ecosystems. The loss of purifying micro-organisms enables pathogens to live longer, raising the risk of disease. When organic solids are part of the sludge, their progressive decomposition will also deplete oxygen in the water and generate noxious gases.

**Toxic Pollutants**

- **Toxic Chemicals:** Many chemicals in industrial emissions are poisonous to humans, either on immediate exposure or over time, as they accumulate in human tissues. Humans can ingest severely damaging or fatal quantities through repeated exposure, or by consuming plants or animals in which these compounds have accumulated. Toxic chemicals may cause damage to internal organs and neurological functions; can result in reproductive problems and birth defects; and can be carcinogenic. Quantities and length of exposure necessary to cause these effects vary widely. Benzene and asbestos are known carcinogens linked to leukemia and lung cancer.

- **Bioaccumulative Metals:** In bioaccumulation, relatively low concentrations of contaminants in air, water, soil and plants become far more concentrated further up the food chain. Some metals can be converted to organic forms by bacteria, increasing the risk that they will enter the food chain. Bioaccumulative metals are particularly dangerous because they are dissipated very slowly by natural systems. They may cause both mental and physical birth defects. Metals can also become rapidly oxidized and converted to soluble form when sediment is exposed to oxygen. Some of the metals which are commonly measured and particularly dangerous are mercury, lead, arsenic, chromium, nickel, copper, zinc and cadmium.
5.1 Alternative Estimates of Sectoral Pollution Intensities

The impact on industrial sector rankings of different intensity measures is best illustrated by their rank correlation coefficients. As described in section 3.2.4, a range of intensity measures can be calculated for each industrial sector. Table 5.1 presents the rank correlation coefficients across these measures for toxic air pollution intensity.

Table 5.1: Rank Correlation Coefficients Between Different Intensity Measures: Toxic Air Pollution Intensity With Respect to Total Value of Output

<table>
<thead>
<tr>
<th>Type of Measurement</th>
<th>Upper Bound</th>
<th>Inter-Quartile Mean</th>
<th>Lower Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Bound</td>
<td>1.00</td>
<td>0.79</td>
<td>0.82</td>
</tr>
<tr>
<td>Inter-Quartile Mean</td>
<td>0.79</td>
<td>1.00</td>
<td>0.72</td>
</tr>
<tr>
<td>Lower Bound</td>
<td>0.82</td>
<td>0.76</td>
<td>1.00</td>
</tr>
</tbody>
</table>

The toxic air correlations are quite high, as are the corresponding correlations for toxic land pollution (not shown). For water and non-toxic air pollution, however, the results are not so clear. The water pollution intensity measures are not very robust for a few sectors because of the presence of large outliers in the EPA database. The rankings differ considerably across intensity measures, with correlation coefficients typically around 0.5. The presence of extreme outliers suggests reliance on LB or IQ estimates. For water pollution LB estimates may be optimum for most uses, because
they are based on the largest sample of available data and provide the most conservative estimate. Outliers also haunt the AIRS data for some criteria air pollutants, like fine particulates. Therefore, for PM10, LB is the most conservative intensity estimate available.7

5.2 Different Measures of Activity

Medium-specific intensities were calculated for each of the following measures of activity:

- total value of shipment (TVS) in millions of 1987 US $;
- value added (VA) in millions of 1987 US $;
- total employment (TE) in thousands of persons.

The advantages and disadvantages of each measure have already been discussed in section 3.2.3. By developing all three, we provide more options for areas where data are scarce. Table 5.2 shows that the intensity rankings are almost perfectly correlated in any case. Therefore, the choice of measure should be driven by the availability, reliability, coverage and detail of the corresponding production data. The more disaggregate the available information, the more robust the intensity measure will be, irrespective of which scaling variable is used.

7The LB air pollution intensity estimates incorporate all the AIRS observations in the numerator; total activity levels from the 1987 LRD were used in the denominator.
Table 5.2: Rank Correlation Coefficients Between Intensity Measures Using Different Scales of Activity: Lower-Bound Toxic Water Pollution Intensity

<table>
<thead>
<tr>
<th>Scale of Activity</th>
<th>Total Value of Shipments</th>
<th>Value Added</th>
<th>Employment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Value of Shipments</td>
<td>1.00</td>
<td>0.99</td>
<td>0.98</td>
</tr>
<tr>
<td>Value Added</td>
<td>0.99</td>
<td>1.00</td>
<td>0.98</td>
</tr>
<tr>
<td>Employment</td>
<td>0.98</td>
<td>0.98</td>
<td>1.00</td>
</tr>
</tbody>
</table>

5.3 Medium-Specific Intensities

Medium-specific indices are useful for two reasons. First, they provide a better indication of the ecological stress and health risks imposed by pollution than estimates which do not distinguish the medium of discharge. Second, they allow analysis of the extent to which inter-medium substitution of waste disposal is possible within a given sector, an important consideration in comprehensive pollution control.

Current development of IPPS has drawn on plant-level pollution information from all of the previously mentioned US EPA pollution data bases: Toxic Release Inventory (TRI), Aerometric Information Retrieval System (AIRS) and National Pollutant Discharge Elimination System (NPDES). Using the corresponding economic data from the LRD, intensities have been calculated for 14 different pollutants. These intensities, calculated as pounds of pollutant released per unit of production in each industrial sector, are listed in Table 5.3.
Full sets of intensities by three-digit or four-digit ISIC sector are available from the authors upon request.

Table 5.3: **Pollution Intensities in IPPS**

1. **Toxic and Bio-Accumulative Pollution Intensities by Medium:**
   1. Toxic Pollution to Air
   2. Toxic Pollution to Water
   3. Toxic Pollution to Land
   4. Bio-Accumulative Metal Pollution to Air
   5. Bio-Accumulative Metal Pollution to Water
   6. Bio-Accumulative Metal Pollution to Land

2. **Criteria Air Pollution Intensities:**
   7. Sulphur Dioxide (SO2)
   8. Nitrogen Dioxide (NO2)
   9. Carbon Monoxide (CO)
   10. Volatile Organic Compounds (VOC)
   11. Particulates less than 10 um in diameter (PM10)
   12. Total Particulates (TP)

3. **Water Pollution Intensities:**
   13. Biological Oxygen Demand (BOD)
   14. Total Suspended Solids (TSS)

*Since all risk-weighted indices are highly correlated with total toxic intensity, we have standardized on the latter. See Section 4.4.*
5.3.1 Total Toxic Pollution Intensities by Medium

Extreme sectoral variation in toxic pollution intensity within each medium is indicated by Figures 5.1 and 5.2, which focus on sectors with output-based intensities greater than 3000 lbs/$1 million (US 1987). As before, pollution intensities by medium show an exponential distribution when arranged in descending order. However, it is clear that there is little correspondence between the most pollution-intensive sectors across media (see Figure 5.2). For example, Pulp, Paper, and Paperboard (3411) is relatively intensive in toxic water and air pollution; Iron and Steel (3710) is prominent in land and water; Textiles n.e.c. (3219) is mostly air pollution intensive.
Figure 5.1- Toxic Pollution Intensity by Medium for Selected Sectors
Figure 5.2 - Toxic Pollution Intensity by Medium for Selected Sectors

Total Toxic Pollution Intensity

Toxic Water Pollution Intensity
Figure 5.2 - Toxic Pollution Intensity by Medium for Selected Sectors

Toxic Air Pollution Intensity

Toxic Land Pollution Intensity
The results displayed in Table 5.4 confirm that there is little correlation between the rankings of sectors discharging toxics by water and air. In fact, when Inter-Quartile Mean intensities are compared, the air rankings are negatively correlated with land and water rankings. These low correlations also suggest that inter-medium substitutability may be a second-order problem for toxic waste.

Table 5.4: Rank Correlation Coefficients Between Toxic Pollutants by Different Media: Lower-Bound Toxic Pollution Intensity with Respect to Value Added

<table>
<thead>
<tr>
<th>Discharge Medium</th>
<th>Air</th>
<th>Land</th>
<th>Water</th>
<th>All Media</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>1.00</td>
<td>0.70</td>
<td>0.32</td>
<td>0.93</td>
</tr>
<tr>
<td>Land</td>
<td>0.70</td>
<td>1.00</td>
<td>0.60</td>
<td>0.87</td>
</tr>
<tr>
<td>Water</td>
<td>0.32</td>
<td>0.60</td>
<td>1.00</td>
<td>0.46</td>
</tr>
<tr>
<td>All Media</td>
<td>0.93</td>
<td>0.87</td>
<td>0.46</td>
<td>1.00</td>
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</tbody>
</table>

There are, however, a few industries which are highly toxic pollution intensive in all three media (See Table 5.5). These are Industrial Chemicals Except Fertilizer (3511), Plastics and Man-made Fibers (3513), Tanneries and Leather Finishing (3231), and Non-Ferrous Metals (3720). The least toxic pollution-intensive manufacturing sectors with respect to air, water and land are food-processing industries such as Bakery Products (3117), Grain Mill Products (3116), Fish Products (3114); and other industries such as Wearing Apparel (3220).
### Table 5.5 Toxic Pollution Intensity by Medium
(Pounds/1987 US $ Million Output Value)

<table>
<thead>
<tr>
<th>Four Digit ISIC Description</th>
<th>ISIC Code</th>
<th>By Air Lower-Bound</th>
<th>Inter Quartile</th>
<th>By Land Lower-Bound</th>
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5.3.2 Metals Intensities

As previously mentioned, metals pose a particularly serious problem because they bioaccumulate. The natural distribution of metals is progressively altered by industrial activity, giving rise to focal concentrations. The potential consequences for exposed populations were demonstrated by
Japan's Minamata crisis in the 1960's: Hundreds of people were killed or severely damaged by poisonous levels of industrial mercury in fish. Separate attention to metals is clearly warranted, since the rank correlations of metals intensity with the toxic intensity measures are low (See Table 4.2). Separate IPPS intensities for toxic metal emissions to air, water and land are presented in Table 5.6.

As expected, Non-Ferrous Metals (3720), and Iron and Steel (3710) have very high metals intensities. Other sectors whose toxic intensity is high are also metals-intensive (e.g., Industrial Chemicals Except Fertilizer (3511); Tanneries and Leather Finishing (3231)). In contrast, Fertilizer & Pesticides (3512), Synthetic Resins and Plastics (3513) and Pulp and Paper (3411) are toxic-intensive but not particularly metals-intensive.

Table 5.6: Toxic Metal Pollution Intensity by Medium
(Pounds/1987 US$ Million Output Value)

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<th>Four Digit ISIC Description</th>
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<th>By Air</th>
<th>By Land</th>
<th>By Water</th>
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<td>22.19</td>
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<td>0.00</td>
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<td>528.66</td>
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<td>99.01</td>
<td>1.45</td>
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<td>3.43</td>
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<td>90.69</td>
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<td>1.12</td>
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<td>73.06</td>
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<td>MOTORCYCLES AND BICYCLES</td>
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<td>4.56</td>
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<td>16.51</td>
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<td>PHOTOGRAPHIC AND OPTICAL GOODS</td>
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<td>0.07</td>
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<td>1.27</td>
<td>0.21</td>
<td>0.00</td>
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<td>JEWELRY AND RELATED ARTICLES</td>
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<td>0.26</td>
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<td>0.24</td>
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<td>4.26</td>
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<td>0.31</td>
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<td>3999</td>
<td>7.70</td>
<td>82.68</td>
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</table>

5.3.3 Air Pollution Indicators

The major air pollution intensities compiled in this paper can be grouped into 5 distinctly different categories. The first group, consisting of SO2, NO2, CO and total Particulates,
exhibit consistently high rank correlations (see Table 5.7). The sector rankings for volatile organic compounds (VOCs), PM10, total toxic air pollution and toxic metals are correlated neither with each other nor with any of the other air pollution intensities, so they form distinct categories.

Table 5.7 **Rank Correlations between Major Air Pollutant Intensities: Inter-Quartile Mean Intensities per Unit of Total Output**

<table>
<thead>
<tr>
<th>Inter-Quartile Intensity</th>
<th>SO2</th>
<th>NO2</th>
<th>CO</th>
<th>TP</th>
<th>PM10</th>
<th>VOC</th>
<th>All Toxics by Air</th>
<th>Toxic Metals by Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO2</td>
<td>1.00</td>
<td>0.89</td>
<td>0.8</td>
<td>0.85</td>
<td>0.65</td>
<td>0.58</td>
<td>0.21</td>
<td>0.27</td>
</tr>
<tr>
<td>NO2</td>
<td>0.89</td>
<td>1.00</td>
<td>0.86</td>
<td>0.81</td>
<td>0.67</td>
<td>0.56</td>
<td>0.19</td>
<td>0.24</td>
</tr>
<tr>
<td>CO</td>
<td>0.8</td>
<td>0.86</td>
<td>1.00</td>
<td>0.76</td>
<td>0.63</td>
<td>0.62</td>
<td>0.28</td>
<td>0.33</td>
</tr>
<tr>
<td>TP</td>
<td>0.85</td>
<td>0.81</td>
<td>0.76</td>
<td>1.00</td>
<td>0.75</td>
<td>0.59</td>
<td>0.17</td>
<td>0.10</td>
</tr>
<tr>
<td>PM10</td>
<td>0.65</td>
<td>0.67</td>
<td>0.63</td>
<td>0.75</td>
<td>1.00</td>
<td>0.45</td>
<td>0.15</td>
<td>0.08</td>
</tr>
<tr>
<td>VOC</td>
<td>0.58</td>
<td>0.56</td>
<td>0.62</td>
<td>0.59</td>
<td>0.45</td>
<td>1.00</td>
<td>0.57</td>
<td>0.47</td>
</tr>
<tr>
<td>All Toxics</td>
<td>0.21</td>
<td>0.19</td>
<td>0.28</td>
<td>0.37</td>
<td>0.15</td>
<td>0.57</td>
<td>1.00</td>
<td>0.53</td>
</tr>
<tr>
<td>Toxic Metals by Air</td>
<td>0.27</td>
<td>0.24</td>
<td>0.33</td>
<td>0.18</td>
<td>0.08</td>
<td>0.47</td>
<td>0.53</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Figure 5.3 displays high-intensity sectors for all the air pollutants analyzed in this paper. In group 1 (SO₂, NO₂, CO and Total Particulates), high intensity sectors include: Cement, Lime and Plaster (3692), Pulp, Paper and Paperboard (3411), Iron and Steel (3710), Miscellaneous Petroleum and Coal products (3540), and Structural Clay Products (3691). Toxic Air and VOC intensities are high in: Synthetic Resins, Plastics and man-made Fibers (3513), Textiles n.e.c. (3219), and Industrial Chemicals except Fertilizer (3511). Inter-quartile intensities of PM10 are recorded in only three of the four-
digit ISIC sectors. This reflects the relatively small matched sample for this pollutant compared to the other air pollutants. The lower bound intensities for PM10 however, are more robust and exhibit a pattern similar to that of Total Particulates.

Table 5.8: Air Pollution Intensity for Selected Air Pollutants
(Pounds/1987 US$ Million Output Value)

<table>
<thead>
<tr>
<th>Four Digit ISIC Description</th>
<th>ISIC Code</th>
<th>SO2</th>
<th>NO2</th>
<th>CO</th>
<th>VOC</th>
<th>PM10</th>
<th>TP</th>
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</thead>
<tbody>
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<td>MEAT PRODUCTS</td>
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<td>197</td>
<td>499</td>
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<td>56</td>
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<td>73</td>
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<td>3113</td>
<td>736</td>
<td>375</td>
<td>72</td>
<td>136</td>
<td>5</td>
<td>73</td>
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<td>FISH PRODUCTS</td>
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<td>173</td>
<td>76</td>
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<td>2</td>
<td>2</td>
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<td>OILS AND FATS</td>
<td>3115</td>
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<td>3360</td>
<td>750</td>
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<td>GRAIN MILL PRODUCTS</td>
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<td>128</td>
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<td>16</td>
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<td>6428</td>
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Figure 5.3: Air Pollution Intensity for Selected Sectors
5.3.4 Water Pollution Indicators

The main water pollutants in IPPS have similar sector rankings. Rank correlations between BOD intensity, TSS intensity and Toxic effluent are all 0.6 or more, with the exception of the correlation between metals and other pollutants (see Table 5.9). Pulp, Paper and Paperboard Industries (3411), Non-ferrous Metals (3720), Industrial Chemicals except Fertilizer (3511) and Distilled Spirits (3131) are high in both BOD and TSS intensities (see table 5.10).

Table 5.9  Rank Correlations between Major Water Pollution Indicators: Lower-bound Intensities

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<th>Lower Bound Intensity</th>
<th>BOD</th>
<th>TSS</th>
<th>Toxics by Water</th>
<th>Toxic Metals by Water</th>
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Figure 5.4 - Water Pollution Intensity for Selected Sectors

BOD Intensity

Total Suspended Solids Intensity

ISIC Codes

ISIC Codes
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6. Critical Assessment and Plans for Further Work

6.1. Sources of Bias

The methodology used in this study contains several possible sources of bias. The imposition of thresholds for reporting pollution to the EPA causes two obvious sampling biases, the net outcome of which is unclear. First there is no record of the cleanest plants, which will tend to move Upper Bound calculations toward overestimates of average sectoral pollutant intensities. In an effort to correct for this bias, the Lower Bound intensities assign all non-reporting facilities a pollution intensity of zero. The second bias arises because there may be a number of small facilities with very high pollutant intensities which do not reach the reporting thresholds. The Lower Bound estimates falsely assign these plants a zero pollution intensity. An attempt was made to avoid both sources of bias by calculating Inter-Quartile Mean estimates of intensities.

The differences between the Upper Bound, Lower Bound and the Inter-Quartile Mean estimates highlight the difficulty of selecting an appropriate level of sectoral aggregation. At the four-digit ISIC level, the confidence interval defined by the Upper and Lower Bound estimates will be wider than if more finely detailed decomposition is used. But the more detailed the data required, the less likely they are to be readily available.

Beyond the unavoidable inaccuracies of estimating pollution intensities at the four-digit level, a further bias may arise out of the standard procedure used to aggregate the 5-digit US-SIC data to
the 4-digit ISIC level. Under this procedure, those facilities with US-SIC codes that matched 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 other activities. This approximation might lead to some overstatement of pollutant intensities, since there are frequently scale economies in pollution control for individual activities. However, this problem is probably minimized by the random occurrence of different assignments.

6.2. International Applicability

Cross-country variations in regulatory, economic and technological conditions clearly impose limitations on the international applicability of the pollutant intensity indices derived in this study. To the extent that pollution control measures merely move waste from one medium to another, the estimates of total toxic pollution intensity will be more robust than medium-specific intensities. Nevertheless, high waste disposal costs provide strong incentive for waste minimization, so US pollution intensities are likely to be lower than in less-regulated settings.

Even if there is considerable international variation in the absolute level of sectoral pollutant intensities, the relative ranking of intensities across sectors may be expected to remain more constant. Thus, one might reasonably expect the Fertilizers and Pesticides sector to be found near the top of all national rankings of toxic release intensity indices, and the Soft Drinks & Carbonated
6.3. Plans for Further Work

Clearly there remains huge scope for further development of IPPS. We are now assembling plant-level databases from several developing countries. Our future econometric work will quantify the effects on pollution intensity of national or regional differences in regulatory regimes, factor prices and availability of technology. Using these estimates, we will develop simple procedures which can adjust IPPS parameters for conditions in developing countries.
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