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World Development Report

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Background paper for World Development Report 1992

Economic Development, Environmental Regulation, and the International Migration of Toxic Industrial Pollution 1960-88

Robert E.B. Lucas
David Wheeler
and
Hemamala Hettige

Net displacement of toxic intensity toward developing countries may not have been inevitable in the last two decades. And toxic industrial migration seems to have been the result of restrictive trade policies in the developing countries themselves more than of regulatory cost differences between the North and the South.

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This paper — a product of the Office of the Vice President, Development Economics — is one in a series of background papers prepared for the *World Development Report 1992*. The *Report*, on development and the environment, discusses the possible effects of the expected dramatic growth in the world's population, industrial output, use of energy, and demand for food. Copies of this and other *World Development Report* background papers are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact the *World Development Report* office, room T7-101, extension 31393 (December 1992, 20 pages).

Several previous studies have asked whether environmental controls imposed in the industrial economies are diverting investments in pollution-intensive activities off-shore. Broadly, these studies conclude that direct investment does not appear to be stimulated by such regulations, partly because the cost of emission controls is generally a tiny fraction of operating costs.

Yet direct investment reflects only part of what may be happening to world production patterns. Technology transfers may occur with no simultaneous direct investment, and production may readily shift toward a different global distribution without either direct investment or technology transfer.

Lucas, Wheeler, and Hettige attempt a general test of the displacement hypothesis, developing time series estimates of manufacturing pollution intensity for a large sample of developed and developing countries between 1960 and 1988. Among their conclusions:

- As a result of shifts in industrial composition, total manufacturing emissions relative to GDP grow faster than GDP at lower levels of per capita income and slower than GDP at higher levels of income.

- This happens because manufacturing has a declining share of GDP at higher income levels, not because of any shift toward a cleaner mix of manufacturing activities.

- The more rapidly growing high-income countries have actually enjoyed negative growth in toxic intensity of their manufacturing mix.

- Stricter regulation of pollution-intensive production in the OECD countries appears to have led to significant locational displacement, with consequent acceleration of industrial pollution intensity in developing countries. The poorest economies seem to have the highest growth in toxic intensity. One cannot, of course, be certain of the causal connection.

- Pollution intensity has grown most rapidly in developing economies that are relatively closed to world market forces. Relatively closed, fast-growing economies experienced rapid structural transitions toward greater toxic intensity. The opposite seems to have been true for more open economies.

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Economic Development, Environmental Regulation and the International Migration of Toxic Industrial Pollution: 1960-1988

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David Wheeler
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Hemamala Hettige

Prepared as a Background Paper for the
World Development Report 1992

* This paper reports on work co-sponsored by the World Bank and the Center for Economic Studies, U.S. Bureau of the Census. The authors' affiliations are, respectively: Department of Economics, Boston University; Environment Department, World Bank; Industry/Energy Department, World Bank.

The World Development Report 1992, "Development and the Environment," discusses the possible effects of the expected dramatic growth in the world's population, industrial output, use of energy, and demand for food. Under current practices, the result could be appalling environmental conditions in both urban and rural areas. The World Development Report presents an alternative, albeit more difficult, path - one that, if taken, would allow future generations to witness improved environmental conditions accompanied by rapid economic development and the virtual eradication of widespread poverty. Choosing this path will require that both industrial and developing countries seize the current moment of opportunity to reform policies, institutions, and aid programs. A two-fold strategy is required.

- First, take advantage of the positive links between economic efficiency, income growth, and protection of the environment. This calls for accelerating programs for reducing poverty, removing distortions that encourage the economically inefficient and environmentally damaging use of natural resources, clarifying property rights, expanding programs for education (especially for girls), family planning services, sanitation and clean water, and agricultural extension, credit and research.
- Second, break the negative links between economic activity and the environment. Certain targeted measures, described in the Report, can bring dramatic improvements in environmental quality at modest cost in investment and economic efficiency. To implement them will require overcoming the power of vested interests, building strong institutions, improving knowledge, encouraging participatory decisionmaking, and building a partnership of cooperation between industrial and developing countries.

Other World Development Report background papers in the Policy Research Working Paper series include:

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Other (unpublished) papers in the series are available direct from the World Development Report Office, room T7-101, extension 31393. For a complete list of titles, consult pages 182-3 of the World Development Report. The World Development Report was prepared by a team led by Andrew Steer; the background papers were edited by Will Wade-Gery.

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Introduction

This paper is largely empirical. It examines how the structure of manufacturing production varies, both across countries and through time, in relation to the toxic emissions of component industries. Evidence is also presented on the connection between these variations and trade policy liberalization.[1]

Industrial emissions may be thought of as output multiplied by the pollution intensity of that output. In turn the pollution intensity of output derives from the mix of industrial products, the processes used to produce each of these goods, and the treatment of the resultant waste from these processes. It is important to establish at the outset that the present investigation addresses only the first of these elements -- the effect of product (or industrial) mix. This scope of analysis is dictated by the nature of the data available, which are described in section II. Yet this evidence does offer some interesting insights, for little systematic evidence currently exists in this sphere.[2]

Meanwhile section I discusses, in broad terms, some of the elements likely to affect the pollution intensity of industrial production, before turning to the results in section III.

I. Sources of Change in Pollution Intensity

1. Development and Private Comparative Advantage

In the absence of binding controls on the generation of environmental bads - including failure of private contractual arrangements to contain damaging effects - there will be over-production and over-consumption of environmentally harmful commodities. Free trade in such an unregulated context results in a distribution of production across countries founded on comparative private cost advantages without regard to environmental costs: the capacity or willingness of nations to withstand or accept environmental damage does not enter the trade calculus.

As nations develop, the range of commodities in which they have a private comparative cost advantage in trade obviously shifts. These shifts may arise from accumulating capital available per worker, from improvements in the state of know-how and worker skills, or from enhanced ability to exploit natural resources. Even if there were no environmental regulation in wealthier economies, free trade under these conditions might well lead to disproportionately rapid growth of industrial pollution in developing countries. Rising manufacturing emission

1. See, in addition, the earlier study by Lucas, "Toxic Releases by Manufacturing: World Patterns and Policies," also prepared as a Background Paper for the World Development Report 1992 and available in the Policy Research Working Paper Series. This includes various toxic emissions data and regressions that are not included in the present study.

2. See, however, Grossman and Krueger (1991).

intensity with income might simply reflect a shift toward comparative advantage in manufacturing generally, and of more capital intensive (smokestack) industries, which also happen to be particularly pollution intensive.

2. Environmental Regulation

The standards required by environmental regulations vary substantially across countries for several reasons:

(a) **World income inequality**: The desire for a cleaner environment is presumably a normal good, in the sense that demands for tighter standards rise with income. The lower income countries would then be less concerned to avoid local environmental damage, as were the advanced nations at an earlier stage in their growth.

(b) **Environmental absorptive capacity**: Being able to locate industries with emissions harmful to humans far from densely populated areas presumably has its attractions. On the other hand, some sparsely populated regions exhibit particularly fragile eco-systems, diminishing their capacity to withstand toxic releases.

(c) **Regulatory capability**: Differences in the ability to enforce regulations may explain some of the observable gaps in legislated norms and in the strictness of enforcement.

In principle, regulating environmental damage and taxing emissions can be used to internalize the external costs stemming from various forms of pollution. To be effective, such instruments must alter the costs of production and hence comparative cost advantages in trade. If the externalities inherent in environmental damage are appropriately contained, then trade will take place according to the social comparative advantage of nations, an advantage defined by a balance of environmental and other costs. But since both private costs and environmental costs differ from country to country, one would not expect to see an even spatial distribution of toxic emissions in an optimally regulated world. Indeed, rising incomes may well cause worsening emission levels, as cost advantage shifts toward pollution intensive industries. This trend may then be overtaken at higher income levels by electoral demands for a cleaner environment and perhaps enhanced capacity for enforcement.

3. Economic Policy Regime

Industrial development has traditionally been viewed as damaging to the environment. Since environmentalists have joined most economists in associating liberal economic regimes with more rapid industrial growth, they have tended to look askance at openness. However, this view neglects the possibility that more open economies might follow a less pollution-intensive industrial development path. If openness were to decrease pollution intensity, then its negative environmental impact via aggregate growth would certainly be mitigated, and might even be reversed.

The labor cost advantage of developing economies, if allowed free rein in the market, would enhance the prospects of many l:_ht assembly activities with modest environmental impacts. Protection, on the other hand, is often focused on relatively capital- and pollution-intensive sectors such as chemicals and steel.

4. Towards Testable Hypotheses

The previous discussion identifies three forces which may have significantly affected the worldwide incidence of industrial pollution: development-related changes in private comparative advantage; environmental regulation in the wealthier economies; and differences in economic policy regimes. From this we distill three lines of analysis for further examination.

(i) **Development and sectoral composition**: The patterns of pollution intensity of manufacturing production in relation to level of economic development, as measured by income per capita, are explored. In particular, it is frequently asserted that pollution exhibits an inverse U-shaped relationship with per capita income: in other words, pollution is believed to first rise faster than output at low levels of income, then to rise more slowly than output after some critical income threshold.[3]

(ii) **OECD environmental regulation and displacement**: Since it is difficult to proxy for the strictures and implementation of OECD environmental regulations, direct tests of any resultant production relocation are difficult to undertake. Nonetheless, at a minimum, broad differences in trends across differing time periods may be examined to ascertain whether production relocation of dirtier industries has been more rapid during episodes of enhanced OECD environmental regulation.

(iii) **LDC economic policy and pollution intensity**: Has actual import protection among the developing countries promoted or discouraged production of dirtier industrial products? This is examined here by posing the question: Have periods of trade liberalization led to more or less rapid growth in pollution intensive industries among LDCs?

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3. Although there are many assertions that such a pattern prevails there is little systematic evidence either to support or refute this presumption. See, however, Grossman and Krueger (1991) who indeed find such an inverse-U pattern in a cross country study of urban air pollution.

II. Data: Sources and Issues

1. Data Sources

For the purposes of this study, four primary data sources are drawn upon to derive a measure of manufacturing output's pollution intensity in some 80 countries over the period 1960 to 1988.[4]

The first data source is a sample of 15,000 plants, drawn from the US Environmental Protection Agency's (EPA's) Toxic Release Inventory (TRI) for 1987. First mandated by amendments to U.S Superfund legislation in 1986, the TRI records air, water, underground and solid waste releases of 320 toxic substances by each reporting plant.

For the second data source, the US Census Bureau has provided output data, drawn from the 1987 Census of Manufactures, for each of the 15,000 EPA sample plants. After matching plant-level observations and translating from U.S. five digit SIC identifiers to ISIC codes, the aggregate toxic releases per unit of output are calculated for each of 37 ISIC industry categories.

The third data source provides information about the toxic risk of different pollutants; three toxic intensity measures per unit of output are considered. The first is simply total pounds released of all 320 toxic substances -- whether atmospheric, effluent or solid -- per dollar's worth of output. In Table 1, this measure is labeled Total Release Intensity. However, this measure neglects the fact that some emissions are of greater concern than others. We have therefore developed alternative risk measures using the EPA's Human Health and Ecotoxity Database (HHED), which contains several measures of toxicological and carcinogenic potency for each substance.

One of these is an ordinal measure of human toxicity risk, ranging from category 1 (mild) through 4 (very serious). Our second measure of toxic intensity uses these risk factors in a linear weighted sum of toxic releases per dollar's worth of output. The implicit assumption is that the HHED risk scale is inherently linear, with one pound of emission with risk factor 4 as damaging as four pounds of releases with risk factor 1. This may not be a reasonable approximation; in consequence, we have also constructed a third weighted index, which assumes that the HHED risk factors are exponential (1, 10, 100, 1000), instead of linear. In Table 1, the latter two measures are labeled Linear and Exponential Intensities. One feature of the three intensity measures in Table 1 is particularly significant for our analysis: their simple (unweighted) correlation is very high across the 37 ISIC categories (See Table 2). Little is lost, therefore, by focusing on one index, and we have chosen to work with the total (unweighted) toxic intensity.

4. For full technical details, see Martin, Wheeler, Hettige, Stengren (1991).

Table 1 Toxic Release Intensities by Manufacturing Industries.

Industry	ISIC Code	TOTAL lbs. per Million 1987 US Dollars	RISK-FACTOR WEIGHTED Linear	Exponential
Food Products	3110	781.6	1418.0	20776.7
Beverages	3130	205.1	387.1	4647.5
Tobacco	3140	489.0	977.9	5308.9
Other Textile Production	3210	3502.2	6289.7	51086.7
Spinning, Weaving	3211	3106.7	7400.0	154381.3
Wearing Apparel	3220	1744.8	3341.8	17515.8
Leather & Products	3230	15380.7	25762.0	268922.3
Footwear	3240	2277.7	3324.0	11695.0
Wood Products	3310	4399.4	9247.0	137294.6
Furniture, Fixtures	3320	5366.8	10056.8	61291.0
Other Paper Prods.	3410	8741.7	16897.6	98109.5
Pulp, Paper	3411	6225.9	11720.6	116899.8
Printing, Publishing	3420	7513.9	14931.6	109252.0
Other Industrial Chem.	3510	52260.3	105302.7	966600.0
Basic Ind. Chem.	3511	32254.6	54922.9	609770.9
Synthetic Resins	3513	14002.9	26436.7	544602.8
Other Chemical Prods.	3520	3563.8	6582.8	58049.0
Drugs and Medicines	3522	3966.7	7416.5	42819.7
Petroleum Refineries	3530	3757.9	7669.5	78634.6
Petroleum & Coal Prods.	3540	2544.1	4777.4	29444.3
Rubber Products	3550	2934.2	5385.5	26305.2
Plastic Products n.e.c.	3560	9335.0	17310.5	175559.9
Pottery, China, etc.	3610	3614.5	5479.4	29164.7
Glass & Products	3620	1481.2	2893.2	43583.8
Non-Metal Prods. n.e.c.	3690	3853.8	5920.2	44194.1
Iron and Steel	3710	7642.8	12931.9	349897.7
Non-Ferrous Metals	3720	9334.3	13234.7	151219.2
Metal Products	3810	4592.5	9103.6	166930.2
Other Machinery n.e.c.	3820	1596.2	2840.5	39165.8
Office & Computing Mach.	3825	303.3	452.4	3163.4
Other Electrical Mach.	3830	1797.3	3195.2	38967.4
Radio, Television, etc.	3832	1808.3	3137.4	29207.4
Transport Equipment	3840	1007.8	2085.8	28055.7
Shipbuilding, Repair	3841	2546.5	3743.2	17426.9
Motor Vehicles	3843	666.9	1188.4	15733.1
Professional goods	3850	887.6	1576.5	16127.0
Other Industries	3900	2706.8	4679.0	42682.7

Table 2 Correlation Coefficients: Industry Toxic Intensity

	Linear Weights	Exponential Weights
Total	0.995	0.944
Linear Weights	-	0.941

The fourth data source is the U.N. annual sectoral output series for each reporting country during the period 1960-1988.[5] To create annual toxic intensity estimates for each sample country, the Total Toxicity Intensity measures from Table 1 are applied to ISIC sector shares. These national intensity estimates form the basis for section III's analysis of the sources and probable environmental consequences of changing sectoral composition.

2. The Assumption of Constant Sectoral Intensities

As noted in the introduction, this paper does not attempt a comprehensive analysis of changes in international industrial pollution. Constant, U.S.-based, output intensities are adopted because there is no choice -- international data on within-sector process mix and abatement choices have not yet been collected. Nevertheless, the following estimates will have first-order validity if there is rough stability in the *relative* pollution intensity of sectors across countries and over time. Such an assumption of fixed toxic intensity embodies at least three elements:

- The application of observed US emission intensities to other countries assumes similar technologies and enforcement standards across countries. For instance, to the extent that lower income countries have more pollution-intensive techniques for given industries than does the US (whether because of the state of know-how, differing regulations, or greater difficulty in enforcement), the measures generated here understate toxic outputs from lower income nations. On the other hand, if emissions per unit of output are roughly similar no matter where the product is produced, then the measures will provide a reasonable approximation.

- Closely related to the above is an issue arising from the level of disaggregation available in the industrial data. The application of US intensities to other countries assumes either that the pollution intensities of various products within an industry group are not too dissimilar or that the mix of products within each industry is essentially the same across countries.

- Emissions are assumed to relate to an industry's output rather than, for instance, to value added. This may not be an unreasonable assumption; the limited availability of data on international value added prevent any systematic evaluation.

In fact most existing empirical work assumes rough constancy in relative cross-sectoral pollution intensity, invariably identifying the same sets of "heavy polluters" (e.g. metals, cement, pulp and paper, chemicals) and "light polluters" (e.g. most light assembly, food

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5. Some of these data are published in the United Nations Industrial Statistics Yearbook. These data are deflated using the GDP deflator for each country, since specific deflators for each manufacturing sector are generally unavailable.

products, instruments). This assumption is largely based on two sources: (a) case-oriented engineering estimates of intensities in the few air and water pollutants which have been conventionally regulated in the OECD economies since 1975; and (b) reported annual total output- or investment-based intensities of expenditure on pollution abatement and control. In an appendix to this paper some partial evidence is reviewed on the plausibility of rough constancy in sectoral intensities, which suggests that this assumption may not be too misleading, at least as a first approximation. Thus the following analysis retains the assumption of fixed toxic intensity that is common to almost all prior work.

III. Toxic Intensity of Industrial Production: Economic Development, Time Trends and Trade Policies

In this section some proximate determinants of variations in industrial toxic intensity are explored. The results are presented in two parts: first, the pattern with respect to income per capita and through time, and second, the role of trade policy.

1. Levels of Development and Time Trends

The visual evidence in Figures 1.A[6] and 1.B brings out two important points:

- Across countries, an inverse U relationship does indeed hold between GDP per capita and total estimated toxic releases from manufacturing relative to GDP. This is shown in Figure 1.A (and is confirmed in unreported regression analysis).[7] This does not, of course, necessarily imply that every country must follow a pattern of rising toxic intensity of production as development proceeds, followed by declining intensity at more advanced stages of development: the time path for individual countries need not follow the cross country pattern. It should also be emphasized that this pattern does not necessarily imply a decline in aggregate toxic releases at higher levels of GDP, only that toxic releases per unit of production fall among higher income countries.

- However, Figure 1.B exhibits no tendency for intensity of manufacturing toxicity per unit of manufacturing output to decline among high income countries. Thus, the declining portion in the inverse U relationship just noted is a result of

6. The measure on the vertical axis in Figure 1.A is pounds of toxic emissions per 1000 US 1987$ of GDP in each country.

7. See the earlier study by Lucas, "Toxic Releases by Manufacturing: World Patterns and Trade Policies," also prepared as a Background Paper for the World Development Report 1992 and available in the Policy Research Working Paper Series.

the declining fraction of GDP accounted for by industrial output, and **not** of any shift toward a less toxic mix of industries within manufacturing.

We have also conducted a more detailed regression analysis for pooled cross-section time-series data, based on the following equation:

$$\ln N_{it} = a_0 + (b_1 + b_2 Y_{it})t + (b_3 + b_4 Y_{it})Y_{it}$$

where N_{it} = Toxic Intensity (country i, period t)
Y_{it} = Real income per capita ($US 1987)
t = Time

This specification allows for possible variations of trend intensity growth (b_1), both with income (b_2) and over different periods: 1960-73; 1974-79; and 1980-88. The latter permits one test of

FIGURE 1.A

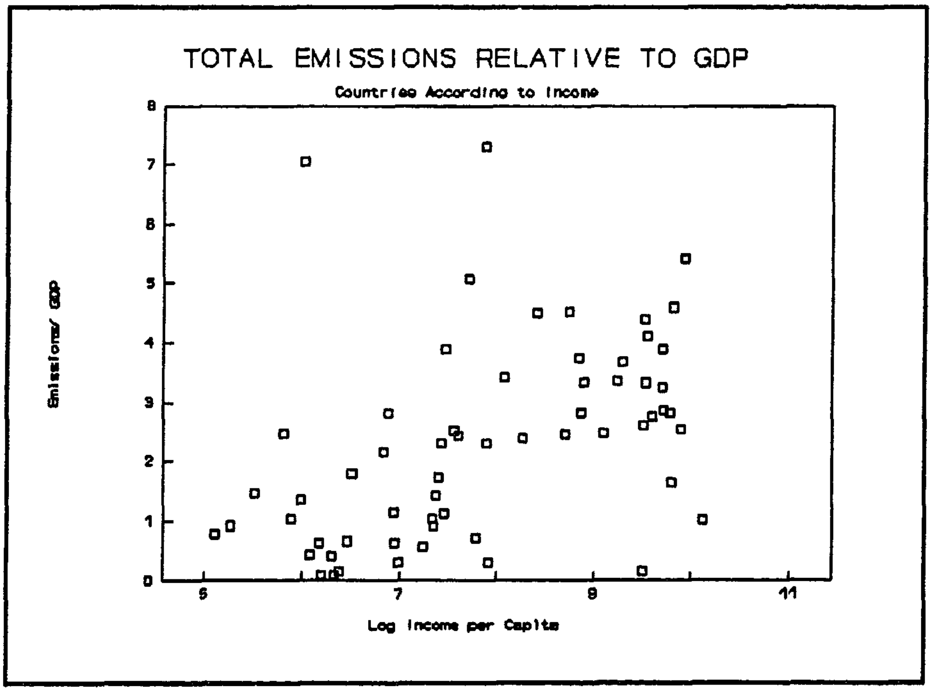
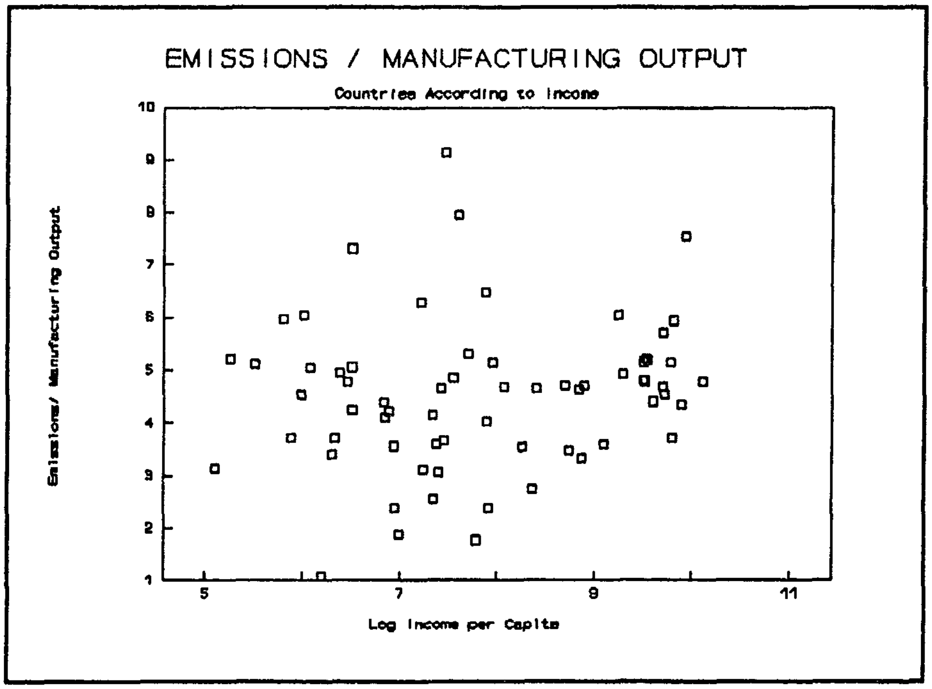


FIGURE 1.B



the possibility that stricter OECD environmental regulation in the mid-late 1970's had a significant overall impact on the international location of pollution-intensive industries. The responsiveness of toxic intensity with respect to income (b_3) is also permitted, in this specification, to vary with income itself (b_4).

Table 3 reports fixed-effects estimates of this equation for the period 1960-1988, with one dummy variable included per country. When intensity is defined as industrial emissions divided by GDP, the rise in intensity with respect to rising income at least tapers off at higher income levels. On the other hand, when intensity is defined as pollutants per unit of manufacturing output, this is definitely not the case (indeed, the relationship in equation (2) goes the other way).

To summarize, these results imply:

- that there is no transition to lower toxic intensity in manufacturing at high incomes. The toxic intensity of GDP declines only because the manufacturing share in GDP declines beyond a certain level of income.

- that growth in toxic intensity has been far more rapid in developing countries.

Table 3 **Pooled Annual Data Across Countries: Fixed Effects Regressions**
Dependent Variables: Logarithm (Toxic Emissions/ Manufacturing Output or GDP)

Toxic Emissions Relative To:

	Manufacturing Output			GDP	
	(1)	(2)	(3)	(4)	(5)
Time trend	9.206	9.901		27.396	
	(12.15)	(12.21)		(17.94)	
Trend: 1960-73			4.598		17.895
			(3.04)		(6.03)
1974-79			4.629		17.982
			(3.07)		(6.08)
1980-88			4.637		17.973
			(3.09)		(6.10)
Income per capita	0.886	0.666	0.870	2.483	2.310
	(4.06)	(2.82)	(3.99)	(5.76)	(5.38)
Income squared		0.001		-0.001	-0.001
		(2.39)		(2.66)	(2.50)
Income * Trend	-0.450	-0.350	-0.442	-1.260	-1.173
	(4.11)	(2.98)	(4.03)	(5.89)	(5.51)
No. country dummies	80	80	80	73	73
No. observations	1517	1517	1517	1395	1395
R squared	0.79	0.79	0.80	0.93	0.93

T-statistics in parentheses.

2. Trade Liberalization and Toxic Intensity of Manufacturing

In order to explore the consequences of alternative trade regimes for the local toxic intensity of manufacturing production, we have adopted a price level distortion index recently developed by David Dollar (1990) for the period 1973-1985.[8] For present purposes, Dollar's sample of 95 developing countries is divided into seven rank groups: rank 1 LDCs exhibit the least distortion from international price norms; rank 7, the highest. The OECD economies are not included in Dollar's sample. Two approaches are therefore adopted for the OECD countries: (a) assigning a Dollar rank of 0 to these cases, and; (b) omitting the OECD countries from the sample.

The average annual rate of growth in total toxic intensity relative to manufacturing output within each country is regressed upon Dollar's index of trade openness.[9] More precisely, country growth rates in toxic intensity are regressed upon the growth rate in per capita income within countries over the relevant time interval, the logarithm of the per capita income at the beginning of each interval, and the Dollar index interacted with the growth in per capita income. The estimated equations also incorporate a measure of the share of export earnings derived from fuel exports (in an attempt to capture any impact of related toxic-intensive sectors), but in the balance this has no apparent effect.

One interpretation of any differences between the three decades is as follows: the 1960's provide a pre-environmentalist control, while the 1970's and 1980's may provide evidence about short- and long-run adjustments in the wake of stricter OECD regulation. Table 4 presents the estimated results for the three decades.

For the 1960's, when almost no environmental regulations had yet been imposed by the various countries, the regression has no explanatory power; from these data we are unable to detect any significant general trend in toxic intensity change. There is no impact for either initial income or income growth during the 1960s.

In the 1970's and 80's, however, the situation changes sharply. The implications of the results for these two decades are perhaps most readily seen from the tableau marked as Table 5.

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8. Briefly, Dollar's index uses the Summers and Heston price index for a constant basket of commodities across countries. Under free trade, such a basket of tradeable goods ought to have the same price everywhere. Departures from unity may then be interpreted as a consequence of some form of trade barrier. In practice some nontradeables enter the basket of commodities. Dollar attempts to control for this latter difficulty by regressing the raw index on measures of factor endowments (presumed to affect relative prices of nontradeables across countries). The residual from these regressions is then adopted to form the purged index.

9. The annual growth rates are first estimated by fitting a regression of intensity upon time within each of three time intervals: 1960-69; 1970-79; 1980-88. The trend growth rate is estimated this way only for countries with at least five observations available within each time period, so the sample size varies slightly from decade to decade.

Table 4 Impact of Income Growth, Level of Development, Openness to Trade and Fuel Status on the Growth Rate of Toxic Intensity, by decade

Dependent Variable: Growth Rate in Toxic Emissions/ Manufacturing Output

	Including OECD Countries			Excluding OECD Countries		
	60's	70's	80's	60's	70's	80's
Intercept	-0.071 (0.78)	0.053 (2.39)	-0.030 (1.19)	0.03 (0.19)	0.094 (2.39)	-0.067 (1.60)
Growth in per capita income	0.096 (0.19)	-0.596 (1.63)	-1.71 (2.72)	-0.008 (0.30)	-0.696 (1.57)	-1.96 (2.1)
Ln (initial per capita income)	0.008 (0.60)	-0.005 (1.80)	0.006 (1.65)	0.001 (0.01)	-0.012 (2.0)	0.012 (1.9)
Fuel share in exports	-0.046 (0.32)	-0.021 (0.834)	-0.003 (0.14)	-0.010 (0.06)	-0.031 (1.09)	-0.016 (0.51)
Dollar's index interacted with income growth	-	0.223 (1.92)	0.589 (3.10)	-	0.297 (2.10)	0.664 (2.37)
No. observations	25	56	55	19	44	39
R squared	0.03	0.18	0.19	.01	0.22	0.22

T-statistics in parentheses

This tableau has three dimensions:

Three income levels are represented:
- Low ($150)
- Middle ($1800)
- High ($22000)

Two annual growth rates are shown:
- Slow (1%)
- Fast (6%)

And two level's of Dollar's index are depicted:
- Open (1)
- Closed (6)

Table 5 Percent Change in Total Toxic Intensity Relative to Manufacturing Output

LOW INCOME COUNTRIES

Per Capita Income Growth	Policy Regime: Open 70s	Open 80s	Closed 70s	Closed 80s
Slow	2.4	-1.2	3.5	1.8
Fast	.6	-6.7	7.2	10.9

MIDDLE INCOME COUNTRIES

Per Capita Income Growth	Policy Regime: Open 70s	Open 80s	Closed 70s	Closed 80s
Slow	1.2	.4	2.3	3.3
Fast	-.1	-5.2	6.0	12.4

HIGH INCOME COUNTRIES

Per Capita Income Growth	70s	80s
Slow	-.1	1.9
Fast	-1.9	-3.7

The fundamental importance of policy emerges strikingly in these results. Fast-growing closed economies experienced very rapid change toward toxic intensive structures in both the 1970s and 1980s, with acceleration in the latter decade for both low- and middle-income developing countries. In contrast, fast-growing open economies experienced essentially toxic-neutral structural change in the 1970s and a strong shift toward less-toxic structure in the 1980s. The same trends are evident in slower-growing economies, but less pronounced. This evidence leads us to a strong qualification of our earlier conclusions:

> **While developing countries as a whole had greater toxic intensity growth in the 1970s and 1980s, trends for individual countries depended heavily on the growth rate of income and the policy regime. The story of "toxic displacement" seems to have been focused in relatively closed, fast-growing economies.**

IV. Summary and Conclusions

Several previous studies have asked whether environmental controls imposed in the industrialized economies are diverting investments in pollution intensive activities off-shore.[10]

10. Dean (1991) offers a very useful survey of this material.

In broad terms these studies reach a negative conclusion: direct investment does not appear to be stimulated by such regulations, in part because the cost of emission controls is generally a tiny fraction of operating costs. Yet direct investment reflects only a portion of what may be happening to world production patterns; technology transfers may occur with no simultaneous direct investment, and production may readily shift toward a different global distribution without either direct investment or technology transfer.

In this paper, a very general test of the displacement hypothesis has been attempted. Time series estimates of manufacturing pollution intensity for a large sample of developed and developing countries during the period 1960-1988 have been developed. The results derived from these data may be summarized in terms of the three lines of analysis set out in section I.4.

• **Development and sectoral composition:**

(a) As a result of industrial composition shifts, total manufacturing emissions relative to GDP grow faster than GDP at lower levels of income per capita, then, at higher levels of income, grow less quickly. In other words, an inverse U-shape is confirmed between industrial pollution intensity and income.

(b) The decline observed in total industrial emissions relative to GDP at higher income levels, is a result of the declining share of manufacturing in GDP, rather than of any shift toward a cleaner mix of manufacturing activities. The pooled cross-country time series estimates reveal no tendency for toxic intensity of manufacturing itself to exhibit an inverse U-shape. On the other hand, the data do indicate that the more rapidly growing high income countries have actually enjoyed a negative growth in toxic intensity of their manufacturing mix. To what extent the latter result is a reflection of more rapid introduction of cleaner technologies in more rapidly growing economies cannot be discerned, but it is certainly a potential explanation.

• **OECD environmental regulation and displacement:**

It is frequently asserted that stricter regulation of pollution-intensive production in the OECD countries has led to significant locational displacement, with consequent acceleration of industrial pollution intensity in developing countries. All our results are consistent with this hypothesis. Both sets of estimates suggest that the poorest economies have the highest toxic intensity growth. The estimated toxic intensity elasticity of income growth for a typical (midrange-distortion) LDC economy was apparently negligible in the 1960's, positive in the 1970's, and even higher in the 1980's. Of course, one cannot be certain of a causal connection between these decadal patterns and the roughly concurrent shifts in OECD environmental policies. The results are nonetheless suggestive of a strong contributory effect.

• **LDC economic policy and pollution intensity:**

Pollution intensity has grown most rapidly in developing economies that are relatively closed to world market forces. Relatively closed, fast-growing economies experienced very rapid structural transitions toward greater toxic intensity. The opposite seems to have been true, however, for more open economies.

More work on this issue clearly needs to be done, but the results in this paper suggest that net toxic displacement toward the LDCs may not have been inevitable during the past two decades. Restrictive trade policies imposed by the developing countries themselves may even have been the main stimulus to toxic industrial migration, rather than regulatory cost differences between the North and South.

It is hoped that these results will suggest future directions for analysis; much remains to be done. For instance, although the present results suggest that more liberal trade policies among the developing countries have focused manufacturing production on a cleaner mix of industries, we still lack evidence of the effects of freer trade policies on the choice of production technique, on waste disposal, on toxicity of consumption activities and environmental harm from changes in agriculture. Moreover, this paper has focused on the global distribution of toxic emissions rather than upon changes in the global aggregate. It is too early to draw any sweeping conclusions about the connections between protectionist trade policies and environmental effects, but it is hoped that this paper has at least suggested some empirical foundations for the debate.

APPENDIX

This appendix presents four types of evidence relating to the international and intertemporal constancy of toxic intensity for different industries.

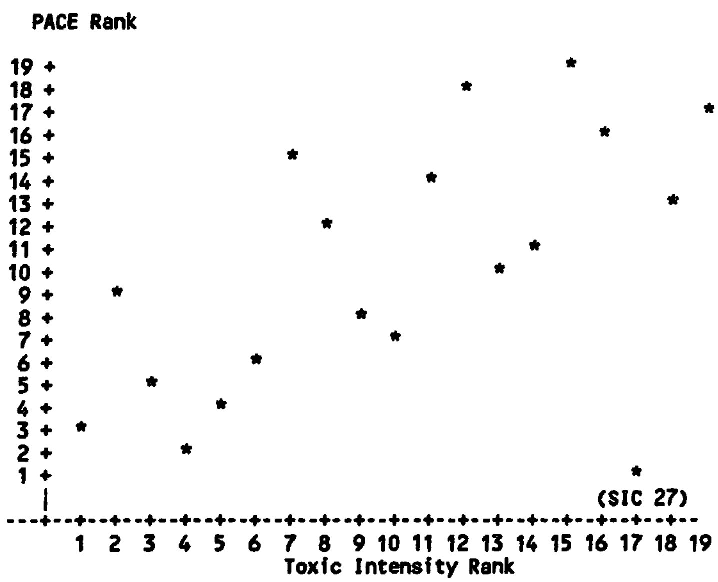
1. Constancy Across Measures of Pollution Intensity

The analysis in the text uses the US Environmental Protection Agency's Toxic Release Inventory (TRI) data. Since these data are not available before 1987 (and then only for the U.S.), no international or intertemporal series is available for cross checking. Useful indirect evidence can be obtained, however, by checking the intersectoral correlation between the TRI data and the US data on Pollution Abatement and Control Expenditures (PACE). Figure A.1 is a scatter plot of ranks for 19 2-digit industries according to: (a) the percentage of new plant and equipment expenditures absorbed by pollution abatement and control; (b) the linear weighted toxic pollution intensity of the industry. In this graph there is a clear outlier -- SIC 27 (printing and publishing) -- which exhibits high emissions according to the TRI data but very low pollution abatement expenditures. If this exception is excluded, then pollution intensity (whether total, linear or exponentially weighted) is quite highly correlated with pollution abatement expenditures. (See Table A.1).

Table A.1 Rank Correlations: PACE Expenditure Intensity (1986) and Measures of Toxic Pollution Intensity (19 2-Digit SIC Sectors)

	Printing and Publishing (SIC 27):	
Toxic Intensity	Excluded	Included
Unweighted	.72	.55
Linear Human	.76	.55
Exponential Human	.74	.64

Figure A.1 PACE Expenditure Intensity Rank (1986) vs. Linear Weighted Toxic Pollution Intensity Rank (1987) (19 2-Digit SIC Sectors)



2. Constancy Across Countries in the OECD

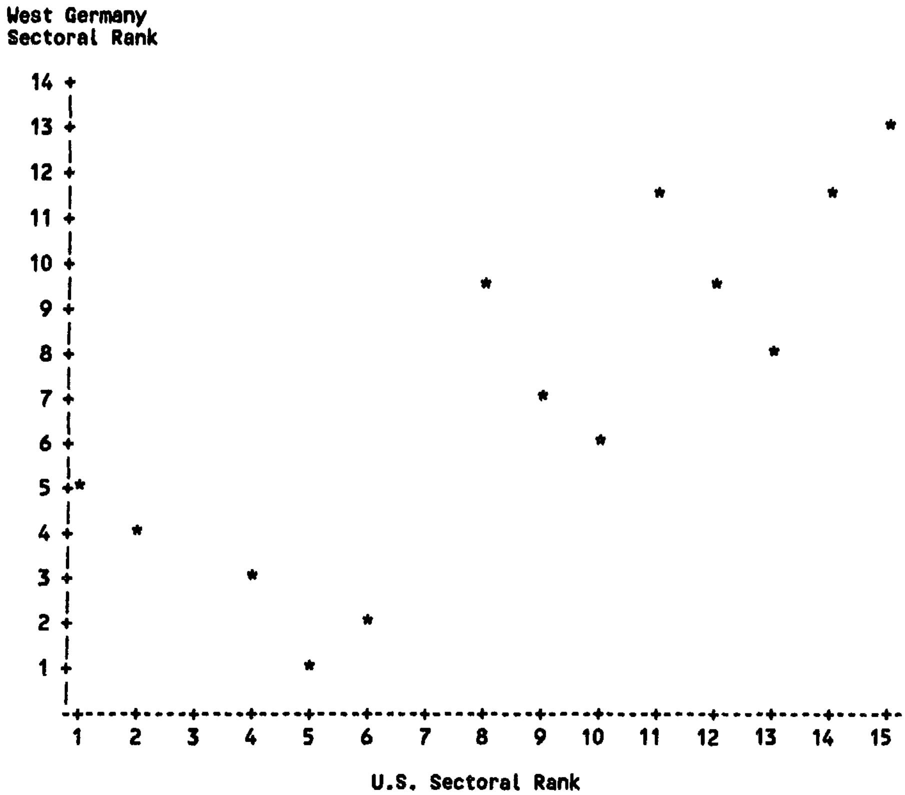
Figure A.2 plots the rank of 13 industries in West Germany during the mid-1970s and the US for 1975, according to pollution abatement expenditures relative to new investments in plant and equipment. The raw data underlying this graph are presented in Table A.2. There is a clear positive association in sectoral ranking across the two countries, and in fact the rank correlation is 0.8. Comparable data for other countries (and especially for the LDCs) are not available. However, this two country comparison suggests that industries needing substantial abatement controls in one country also require expensive controls in another, despite differences in emphasis on the various pollutants and media of release in the two countries.

Table A.2 Percent of New Plant and Equipment Expenditures on Pollution Control, mid-1970's

	U.S.	West Germany*
Nonferrous metals	24.1	8.4
Paper	16.8	9.6
Stone, clay, glass	14.3	--
Iron, Steel	13.5	10.7
Petroleum	11.8	19.9
Chemicals	10.9	11.1
Electric power	9.7	--
Electrical machinery	5.8	1.9
Lumber, furniture, instruments, misc.	5.3	2.4
Food, beverages	5.2	3.2
Textiles	4.6	1.5
Rubber	4.0	1.9
Motor vehicles	3.9	2.0
Apparel, leather, tobacco, printing/publishing	2.8	1.5
Machinery, except electrical	1.8	1.3
Fabricated metals	--	.5

*West German data are averages for the period 1971-77
Sources: Tietenberg (1988), drawn from various US Surveys of Current Business; OECD (1985)

Figure A.2 Sectoral Pollution Abatement Expenditure Intensity Rankings, West Germany vs. United States



3. Constancy Over Time in the U.S.

In the U.S., sectoral Pollution Abatement Control Expenditure data have been collected since the 1970's. Table A.3 presents correlations for PACE expenditure intensities (PACE divided by total shipment value) in 1974, 1980, and 1986.[11] The correlations are very high and show no sign of decreasing over time. We conclude that, in the U.S. at least, sectoral "heavy polluters" have retained their identity since 1970.

Table A.3 Correlations: Sectoral PACE Expenditure Intensities (19 2-Digit SIC Sectors)

	1974	1980
1980	.94	
1986	.94	.94

4. Process and Abatement Considerations

Economists generally assume that sectoral technology mix will be different in developing

11. Our thanks to Hamid Alavi for generously making these data available to us.

countries, and that pollution abatement equipment will not be installed in the absence of formal regulation. Empirical work on the technology question from an environmental perspective has only recently begun, and survey evidence on abatement choices is practically nonexistent. A few recent studies, however, raise some doubts about the conventional wisdom.

A twenty-five year analysis of international diffusion for wood pulping technology by Wheeler and Martin (1991) finds that developing countries with open trade policies exhibit no lag in adoption of the newest and cleanest technology. Huq and Wheeler (1991, forthcoming) report survey results for a small sample of pulp and fertilizer plants in Bangladesh. The combination of public ownership and aid dependency in this extremely poor economy has led to technology adoption which is largely dictated by prevailing norms in donor countries. Although formal regulation is almost entirely lacking, many large, polluting Bangladeshi enterprises have already instituted monetary compensation and first-level effluent treatment in response to strong pressure from neighboring communities.

There is at present no strongly persuasive evidence about the environmentally relevant direction of departures from typical OECD technology mix in developing countries. Wheeler and Huq (1991, forthcoming) find rapid adoption of the newest, least polluting (electric arc) steel technology in many developing countries. This, coupled with newcomer avoidance of the highly-polluting open hearth process, which remained important in many OECD countries during the 1970's, implies average pollution intensities which may be quite close to typical OECD intensities, even allowing for significant differences in abatement. Thus Wheeler and Martin (1992, forthcoming) find that slower average adoption of new clean pulping technology by developing countries is almost exactly counterbalanced by slower average decline in the oldest technology (mechanical pulping), which is also quite clean.

5. Conclusion

This evidence, although admittedly sparse, nonetheless suggests that an assumption of constant relative toxic intensities within industries, both across countries and though time, may not be too egregious: the adopted measures of toxic intensity are highly correlated with PACE expenditure intensity; for the U.S. and West Germany aggregate sectoral PACE expenditure intensities are highly correlated; within the U.S., PACE expenditure intensities have very high intertemporal correlations; and case study evidence suggests a number of reasons why LDC technologies are not necessarily more pollution intensive, as often presumed.

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