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Policy Research

WORKING PAPERS

World Development Report

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Background paper for World Development Report 1992

Environmental Costs of Natural Resource Commodities

Magnitude and Incidence

Margaret E. Slade

What would happen to resource production, consumption, and revenue if the developing countries adopted the environmental standards set by the industrial countries, while at the same time the industrial countries increased their spending on environmental protection by the same fraction as the developing countries?

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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 (October 1992, 26 pages).

The carrying capacity of our natural environment is an important unpriced input to production. A consensus is growing that users should pay for the environmental damage that they cause. Although most people can accept this policy in principle, many are concerned with the magnitude and incidence of its associated costs and the disruptions that would be created during a transition period. Of particular concern is the burden that might be placed on the economies of developing countries. When the industrial world was developing, it was able to benefit from cheap natural-resource commodities. Is it fair to expect countries that are trying to imitate this pattern to pay more?

Unfortunately there are not reliable estimates of the effects of environmental protection costs on production, consumption, revenues, and foreign exchange. Slade explores these issues for the energy and nonfuel-mineral markets, sectors responsible for much of current industrial pollution.

Using a model, she examines the consequences of the developing world adopting the environmental standards of the industrialized world. She assumes: all producers incur clean-up costs; most adjustment is made through changes in prices and quantities, not through altered trade patterns; and the industrialized world increases its environmental expenditures by the same fraction as the developing world.

Slade finds that increased revenue resources will more than compensate the average developing country for the costs of pollution control, so no assistance or intervention would be required. This assumes, however, that capital markets are perfect, which is far from the case in many developing countries. These imperfections constitute the greatest obstacle to successful environmental regulation.

Loans or subsidies from North to South should be considered, says Slade. Developing country producers should be given access to credit in dollars, prices of imported pollution-abatement equipment could be reduced, or aid could be tied to the installation and maintenance of environmental capital.

Slade finds that environmental protection costs are small. Compliance costs of roughly three percent of product prices lead to changes in export revenues of less than one percent. The principal reason for this result is that mineral commodity demand and supply are inelastic in the long run.

As for the incidence of environmental costs, an environmental "tax" is on average progressive, because low-income countries are typically net exporters of mineral commodities, whereas high-income countries are net importers.

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Environmental Costs of Natural Resource Commodities: Magnitude and Incidence

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Prepared as a Background Paper for the
World Development Report 1992

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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.

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Nemat Shafik and Sushenjit Bandyopadhyay, "Economic Growth and Environmental Quality: Time Series and Cross-Country Evidence"

Anwar Shah and Bjorn Larsen,
(a) "Carbon Taxes, the Greenhouse Effect, and Developing Countries";
(b) "World Energy Subsidies and Global Carbon Emissions"

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(a) "Environmental Costs of Natural Resource Commodities: Magnitude and Incidence";
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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.

Table of Contents

I. Introduction

The carrying capacity of our natural environment is an important unpriced input to production. However, a consensus is growing that users should pay for the environmental damage that they cause. Although most people can accept this policy in principle, many are concerned with the magnitude and incidence of its associated costs and the disruptions that would be created during a transition period. Of particular concern is the burden that might be placed on the economies of developing countries. When the industrialized world was developing, it was able to benefit from cheap natural-resource commodities. Is it therefore unfair to expect countries that are attempting to imitate this pattern to pay more?

Unfortunately, we lack reliable estimates of the effects of environmental-protection costs on production, consumption, revenues, and foreign exchange. This paper explores these issues for the energy and nonfuel-mineral markets,[1] sectors that are responsible for a large element of currently generated industrial pollution.[2]

Unlike previous assessments, which look at unilateral adoption of standards and assess implications for the adopting country only[3], I assume that all producers incur clean-up costs. This means that most of the adjustment is accomplished through changes in prices and quantities rather than through changes in trade patterns. No new elasticities of supply and demand or environmental-protection costs for natural-resource commodities are estimated. Instead, information is gleaned from existing estimates, and used in a systematic fashion.

Background

Although environmental protection was a major concern in the 1970s, in the 1980s the interest of both private and public groups seemed to wane. However, and concern is again growing. Indeed, it is likely that environmental degradation will be a major public issue of the 1990s.

Pollution control in the U.S. provides one illustration of this pattern. In 1965, the Clean Air Act set national automobile-emissions standards for the first time. Other major legislation

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[1] The word mineral denotes any substance that occurs naturally in the Earth's crust and is extracted for Man's use. In this paper, we consider only mineral fuels and ferrous and nonferrous metals.

[2] For example, Jorgenson and Wilcoxen (1990) find that the petroleum refining, primary metals, and chemicals sectors account for over 55 percent of U.S. spending on pollution-abatement equipment.

[3] Examples include Walter 1971, den Hartog and Houweling 1976, Mutti and Richardson 1976 and 1977, Hollenback 1979, Pasurka 1984, Robison 1988, and Tobey 1990.

was passed in the late 60s and early 70s.[4] These early acts contain most of the guidelines under which U.S. environmental policy is conducted today. Under their mandate, firms incur substantial expenditures on environmental protection. When conservative politicians gained control of the government in the early 1980s, however, they began to question the efficacy of environmental legislation and to wonder if the burden was excessive. For example, in his 1981 State of the Union Address, President Reagan noted that *"we have no intention of dismantling the regulatory agencies, especially those necessary to protect the environment.... However, we must come to grips with inefficient and burdensome regulations -- eliminate those we can and reform the others."*[5] As a consequence, no major new legislation was passed for a decade.

Today, there is considerable evidence of a rebirth of worldwide concern with environmental degradation. For example, the European Association of Environmental and Resource Economists was created in 1990; its North American counterpart was founded in the 70s. The culmination of this new awareness is the United Nations Conference on the Global Environment and Development, perhaps the largest international congress ever. Although at the time of writing it remains unclear what the precise results of UNCED will be, it seems at least possible that some form of international-environmental agreement may eventually be reached.

This paper aims to assess some of the consequences of such an agreement, and in particular, its potential effect on the incomes and output of less developed countries. Many nonindustrial economies are still highly dependent on exports of primary commodities as sources of foreign revenue. UNCTAD (1991) estimates this dependence at 70 percent or more for those countries recognized as least developed. For this reason, changes in net-export revenues by income class and geographic region are assessed in this paper.[6]

Organization of the Paper

The next section deals with the magnitude and incidence of environmental-compliance costs and their consequences for developing countries, both net producers and net consumers. A simple partial-equilibrium competitive-market model is used for this purpose. As the model is very simple, it is not apt to be highly accurate. I therefore adopt a pessimistic approach; in other words, when a choice must be made, a high-cost/low-adjustment alternative is selected. In this way, I hope to come up with an upper bound on potential disruptions.

The data are of two kinds. First, a data bank of previous estimates of elasticities of

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[4] These include the Air Quality Act of 1967, the National Environmental Policy Act of 1969, the Federal Water Pollution Control Amendments of 1972, the Toxic Substances Control Act of 1976, the amendments to the Solid Waste Disposal Act of 1976, and the Clean Water Act of 1977.

[5] This quote is taken from Pasurka (1984).

[6] Net-export revenues will of course be negative for net-importing counties.

supply and demand, and environmental-compliance costs for particular commodities, is compiled. These data are used to estimate worldwide changes in production and consumption of specific fuel and nonfuel-mineral commodities. Second, detailed data on population, GNP, and mineral production and consumption by country, are used to attribute worldwide changes in production and consumption to specific regions and income groups.

A final section summarizes and conclud . To anticipate results, the estimated magnitude of worldwide changes is not large. Contrary to popular belief, many poor countries may benefit from international environmental regulation. Nevertheless, disruptions could be severe for some countries, especially in the short-term.

II. The Magnitude and Incidence of Compliance Costs

1. The Assumptions

All models rely on a set of simplifying assumptions whose realism is suspect. It is therefore important to make these assumptions transparent so that readers can form their own judgements as to the validity of the exercise.

First, I assume that producers incur all environmental compliance costs (hereafter ECC). In 1972, the OECD agreed to a polluter-pays principle under which the full cost is born by the user. From an economic point of view, this is the only sensible policy. Environmental costs are real costs and, just like wages, should be paid by the producer. Nevertheless, other schemes have been suggested. For example, Mutti and Richardson (1977) compare the polluter-pays principle to a scheme where costs are fully subsidized and the subsidy is financed through a uniform-value-added tax. The presumed advantage of the second scheme is that the burden of compliance is borne equally by all sectors. However, this is precisely its disadvantage. Competitive markets allocate resources efficiently only if full marginal costs are paid by each producer. For this reason, a polluter-pays principle is adopted here.

Second, I assume that all markets are competitive and that, with the exception of ECC, all costs are fully and accurately accounted for. These assumptions, which are made for tractability, may not be realistic. Imperfections in input and output markets are discussed by Slade (1991a), who concludes that, at least in developing countries, factor-market distortions such as unemployment and capital constraints are potentially large. In particular, in less developed countries there are often systematic forces that cause the shadow price of labor to be less than the market wage.[7] On the other hand, if the domestic currency is overvalued, the social-opportunity cost of imported capital exceeds the official financial cost. Thus, capital and labor-market distortions tend to offset each other, thereby mitigating the effect of either in isolation. Monopoly power, in contrast, is apt to be of less concern. This is true because most mineral commodities are sold in world markets so that local producers have little price power. Moreover, there are few mineral markets remaining where the number of producers is very small.

[7] For a discussion of these issues, see Little and Mirrlees (1974).

Third, the analysis is partial-equilibrium in nature. A general-equilibrium approach might be preferable. There are, however, at least two defenses of the partial approach in addition to its simplicity. First, although in theory Marshalian demand curves hold all other prices constant, in practice econometric estimates of demand typically include only prices of the most important substitutes. This means that some general-equilibrium responses are embodied in the estimated long-run elasticities. Second, when models are constructed with general-equilibrium refinements, estimated displacement costs are lower than those produced by partial-equilibrium models (Mutti and Richardson, 1977). In other words, feedback from other sectors tends to mitigate the impact of ECC. My estimates therefore err on the high side.[8]

Fourth, the analysis deals only with the private costs of protection. If this were a cost-benefit study, I would attempt to estimate social costs.[9] The object, however, is to forecast changes in resource revenues with an emphasis on net exports. Given that prices and quantities are determined in markets, only costs that are actually incurred matter for the purposes of this analysis. Moreover, the analysis is strictly positive; I do not consider the welfare implications of the changes that are forecast.

Fifth, I assume that ECC are uniform across regions and that trade patterns remain unaffected by compliance. Given the first part of this assumption, the second is not overly unrealistic. Even when unilateral standards are assessed, only small changes in trade patterns are found (see Dean, 1991, for a summary). Equalizing abatement costs, however, has been criticized on the grounds that it fails to take account of the reallocation of pollution-intensive industries to regions with large environmental endowments (Pearson 1987). A counter argument is that changes in trade patterns resulting from nonuniform standards are, in fact, small.

Finally, I have been unable to find ECC data for countries other than the United States. The pattern of expenses is therefore assumed to be similar in other regions.

2. The Model

The model used to assess changes in production, consumption, and revenues is very simple. When compared to models used to assess the greenhouse effect, most of which are very large dynamic-general-equilibrium or multi-sector-macro models,[10] this approach may seem overly simplistic. Simplicity, however, can be a virtue: all assumptions are transparent and the model can be understood by policy makers who are not academic economists.

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[8] As is discussed in subsection IIc, the estimates of ECC used here include both direct and indirect components. Moreover, they are constructed under the assumption of full-cost passthrough. The estimated ECC themselves therefore are upper bounds.

[9] For a discussion of the differences between social and private environmental costs, see Hazilla and Kopp (1990).

[10] For a survey of these models see Hoeller, Dean, and Nicolaisen (1990).

We begin with *long-run* demand and supply equations for *world* consumption (Q_d) and production (Q_s) of a commodity. These equations are used to determine a world price. Long-run elasticities are used, because it is the long-run implications of environmental regulation that are of primary concern. The choice of aggregate demand and supply equations, however, is not so simple and deserves further comment.

Most mineral commodities are fairly homogeneous and are sold in world markets. A single-price assumption therefore seems reasonable. Nevertheless, when disaggregate demand and supply equations are available, one must decide whether to construct world demand and supply by adding up regional demands and supplies, or by using aggregate equations. The latter alternative is selected for several reasons. First, disaggregate equations are only available for a few commodities, and a symmetric treatment seems preferable. Second, the data that are available for poorer regions are less reliable than data for industrial economies. Last and most important, when several regional-elasticity estimates are available, the variation in estimates for a given region is at least as great as the variation across regions.[11] Furthermore, no consistent pattern of high and low-elasticity regions emerge from the estimates. Consequently, even if the estimated elasticities are accurate on average, it is unwise to put much faith in a single number.

Assume that demand and supply equations are linear in logarithms (constant elasticity), so that[12]

$$Q_d = a P^e, \qquad e < 0 \tag{1}$$

and

$$Q_s = b P^h, \qquad h > 0 \tag{2}$$

In (1) and (2), e and h are long-run elasticities of demand and supply respectively. Equations (1) and (2) can be inverted to yield

$$P = a Q_d^{1/e}, \qquad a := [1/a]^{1/e}, \tag{3}$$

and

$$P = MC = b Q_s^{1/h}, \qquad b := [1/b]^{1/h}, \tag{4}$$

where MC stands for marginal cost.

If markets clear, (3) and (4) can be equated and solved for Q as follows

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[11] For example, Fisher et al. (1972) find that the long-run elasticity of copper supply for Zambia is "*far* greater" (italics theirs) than the short-run elasticity, whereas Wagenhals (1984) finds that the two are statistically indistinguishable.

[12] Constant-elasticity supply (demand) equations are exact if the aggregate long-run technology of production (use) is translog. In (1) and (2), the prices of substitutes and complements, which are assumed to be constant, are included in a and b.

$$Q^d = a/b, \qquad d := -1/e + 1/h, \qquad Q := Q_s = Q_d \tag{5}$$

or

$$Q^* = [a/b]^{1/d} \tag{6}$$

In (6), * denotes a long-run-equilibrium value. Finally, long-run-equilibrium price can be obtained from either (3) or (4) and (6) as

$$P^* = a^{1+m}\, b^{-m}, \qquad m := 1/de \tag{7}$$

Suppose now that environmental regulations are implemented that raise the marginal cost of producing this commodity by r percent. The inverse-supply equation (4) then becomes

$$P' = MC' = b(1 + r)\, Q_s^{1/h}. \tag{8}$$

In the new equilibrium, prices and quantities are

$$Q'^* = \left[a/(b(1+r))\right]^{1/d} = Q^*(1+r)^{-1/d} \tag{9}$$

and

$$P'^* = a^{1+m}\, b(1+r)^{-m} = P^*(1+r)^{-m}. \tag{10}$$

Finally, revenues from the sale of the commodity change from P*Q* to

$$P'^*Q'^* = P^*Q^*(1+r)^{-(1+md)/d} \tag{11}$$

Given estimates of long-run world elasticities of supply and demand for a commodity (e and h) and estimates of ECC for that commodity (r), equations (9)-(11) can be used to estimate changes in world price, production, consumption, and revenues. Worldwide changes are then allocated to different countries by means of the assumption that, since all marginal costs (prices) have increased by the same amount, production (consumption) is reduced in every region by the same fraction.[13] In other words, if P'^*_i and Q'^*_{ij} are post-agreement prices and quantities in country i, where j = s or d, then

$$P'^*_i = P'^* \tag{12}$$

and

$$Q'^*_{ij} = (1+r)^{-1/d} Q^*_{ij} \qquad j = s,d \tag{13}$$

where Q^*_{ij} is a pre-agreement quantity in country i.

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[13] Regional elasticities, when available, are not used at this stage for the same reasons that they were not used in calculating P* and Q*.

3. The Data

Elasticities:

Table I shows estimated long-run demand and supply elasticities for ferrous and nonferrous metals and energy. Entries marked "world" are taken from aggregate production or consumption equations; those marked "averages over regions" are aggregated from several regional equations. Models that pertain to a single country or region are not included.

From the metals' data, a consistent picture emerges. Perhaps the most striking fact is that demands and supplies are inelastic in the long run. Elasticities are greater than one for only two entries. Moreover, for no group does an average of the elasticities shown in the table exceed one. Also notable is the fact that variation in estimated elasticities for a single commodity (eg., copper supply) is at least as great as variation across commodities. Finally, variation in estimated supply elasticities is greater than variation in demand estimates.

Part E of Table I shows aggregate-energy-demand elasticities. Most energy commodities are valued for their thermal content. As a result, an energy aggregate is more meaningful than a metal aggregate. Moreover, the demand for individual energy commodities is more elastic than is aggregate-energy demand. The reason is that most of the substitution that occurs when a single price changes, involves switching between various types of energy. However, we wish to consider the situation where the prices of all energy commodities increase simultaneously. Aggregate elasticities are therefore more apt to be accurate.

Somewhat surprisingly, estimates of energy-demand elasticities are less plentiful than estimates for metals. Even though whole books have been devoted to the subject of energy demand, most of these consider only the U.S. (Halvorsen 1978, Bohi 1981) or are static (Halvorsen 1978, Pindyck 1979). Very few dynamic-econometric studies of world-energy demand have been made. Therefore, although no single-country or single-region models are considered, I include studies that assess many countries or many models of the same country.

With respect to energy supply (Table I, part F), the situation is even worse. Most econometric studies of energy supply treat exploration, production, and refining separately and make no attempt to integrate the various phases. It is perhaps for this reason that it is difficult to identify anything that might be called an energy-supply elasticity.[14]

The elasticities that are used in the analysis are contained in Table II. In general, I have chosen the group averages, suitably rounded to avoid the appearance of spurious accuracy. The one exception is copper supply -- the long-run supply elasticity obtained by Fisher et al. (1972) is so out of line with other estimates that I use a value that is only somewhat larger than an average that excludes their study.

[14] This should not be regarded as a complete explanation. After all, metal production also has several phases, yet many metal-supply elasticities have been estimated.

TABLE I:
ESTIMATED ELASTICITIES

IA: Nonferrous-Metal Long-Run Demand Elasticities

Commodity	*Period*	*Demand Elasticity*	*Source*	*Comments*
Aluminum	1965-77	-0.45	Hojman (1981)	OECD
Copper	1950-67	-0.51	Fisher et al. (1972)	Average over consuming regions
Tin	1955-75	-0.72	Chhabra et al. (1978)	Average over regions and uses
Zinc	?	-0.47	Behrman (1975)*	World
Average Nonferrous		-0.54		

Found in Adams and Behrman (1978)

1B: Nonferrous-Metal Long-Run Supply Elasticities

Commodity	*Period*	*Supply Elasticity*	*Source*	*Comments*
Aluminum	1965-77	0.07	Hojman (1981)	World
Bauxite	1965-77	0.45	Hojman (1981)	World
	?	0.40	Berhman (1977)**	World
Copper	1950-67	4.65	Fisher et al. (1972)	Average over producing regions
	1953-68	1.10	Banks (1974)	Average over producing regions
	?	0.10	Behrman (1977)**	World
	?	0.87	Pobukadee (1980)**	Average over producing regions
Tin	1955-75	0.90	Chhabra et al. (1978)	Average over producing regions
	?	0.18	Behrman (1975)*	World
Zinc	?	0.08	Behrman (1975)*	World
Average Nonferrous		0.88		
Excluding Fisher et al.		0.46		

* Found in Adams and Behrman (1978)

** Found in Adams and Behrman (1982)

IC: Ferrous-Metal Long-Run Demand Elasticities

Commodity	*Period*	*Demand Elasticity*	*Source*	*Comments*
Iron and Steel	?	-0.81	Hashimoto (1979)	OECD
	1961-84	-0.48	Priovolos (1987)	Average over consuming regions
Average Ferrous		-0.65		

ID: Ferrous-Metal Long-Run Supply Elasticities

Commodity	*Period*	*Supply Elasticity*	*Source*	*Comments*
Iron and Ore	1961-84	0.24	Priovolos (1987)	Average over consuming regions
	?	0.30	Behrman (1977)**	World
Nickel	?	0.91	Adams (1974)*	Average over consuming regions
Average Ferrous		0.49		

* Found in Adams and Behrman (1978)
** Found in Adams and Behrman (1982)

IE: Aggregate-Energy Long-Run Demand Elasticities

Commodity	*Period*	*Demand Elasticity*	*Source*	*Comments*
Aggregate Energy	Various	-0.36	Energy-Modeling Forum (1980)	Average of elasticities from 17 US models
	Cross section by country	-0.85	Seale et al. (1991)	Average over 51 countries developed and developing
	1970-85	-0.27	Ibrahim and Hurst (1989)	Average of elasticities for 6 developing countries
Average Energy		-0.49		

IF: Aggregate-Energy Long-Run Supply Elasticities

Commodity	*Period*	*Supply Elasticity*	*Source*	*Comments*
Aggregate Energy	?	0.2 - 0.8	World Bank (1990)	Not clear if this is an econometric estimate
Average Energy		0.5		

TABLE II:
PARAMETERS USED IN THIS STUDY

Commodity	*Demand Elasticity*	*Supply Elasticity*	*Comments*
Nonferrous Metals	-0.55	0.50	Supply average excludes Fisher et al. (1972)
Ferrous Metals	-0.65	0.50	
Aggregate Energy	-0.50	0.50	
Average Over All Commodities	-0.57	0.50	
Commodity	*EEC per Dollar of Output (%)*		*Comments*
Metals	2.7		ρ
Energy	3.7		ρe
Average	3.2		

Environmental Compliance Costs:

At least three agencies have estimated U.S. ECC: the Bureau of the Census, the Bureau of Economic Analysis (both of which are within the Department of Commerce), and McGraw-Hill Inc. Survey methods used differ along several dimensions including unit of analysis and sample size. For example, the Bureau of the Census surveys plants or establishments, whereas the Bureau of Economic Analysis and McGraw-Hill survey firms. McGraw-Hill's sample is by far the smallest (approximately 350 compared to 20,000 for the Census and 15,000 for the BEA). Given these differences, it is not surprising that there are differences in the estimates. However, for most industries, these differences are not large. More important, no one source is systematically higher or lower than the other two. I have chosen to base my analysis on the estimates produced by the Bureau of the Census because they are more widely employed in previous research. For example, Pasurka (1984), Robison (1985 and 1988), and Jorgenson and Wilcoxen (1990) all use Census data.

The raw data, which come from *Pollution Abatement Costs and Expenditures* (various years) consist of operating and maintenance costs (operating expenses, depreciation, and interest on loans). These are the direct costs of environmental regulation; they do not include indirect costs that result from paying higher prices for inputs whose production is also subject to regulation. Kopp and Portney (1981) note two factors that might lead to an upward bias in the Census estimates of direct costs. First, there is a sample-selection bias; firms that respond to a survey are likely to be those spending considerable amounts on pollution abatement. Second, there is a joint-cost problem. When production and abatement costs are difficult to separate, the temptation is to err towards large pollution-control expenditures. However, an upward bias in ECC is consistent with our pessimistic approach.

I have chosen to use estimates of ECC for 1977 because it is perhaps the year of highest relative expenditures (ECC/GNP). For example, the U.S. Council on Environmental Quality (1990) estimates that the ratio of ECC expenditures (capital plus operating) to GNP was 2.0 percent in 1977. The same ratio fell to 1.8 percent in 1982 and remained at that lower level in 1987. Pasurka (1984) translates these dollar expenditures into direct-abatement costs per dollar of output for various sectors. For energy and metals, these percentages are contained in the column marked "Direct Cost" in Table III. They average slightly more than 1.5 percent.

Indirect costs, however, are more significant. They arise because other sectors must also comply with environmental regulations. Pasurka (1984) and Robison (1985) have used input-output models of the U.S. economy to estimate these indirect costs. Their estimates can be found in the column marked "Direct Plus Indirect Cost." Estimated total costs are on average about 40 percent higher than direct costs.

The estimates of total ECC made by the two authors are not directly comparable, partly because different levels of aggregation were used. In keeping with the pessimistic approach, I select the largest entry in the "direct plus indirect" column for each sector. In other words, 3.7 is used for the percent increase in the energy sector (r_e) and 2.7 for ferrous and nonferrous metals (r_m). These are shown in the second half of table II.

There are several additional reasons why these might overestimate true ECC. Two reasons relate to the input-output structure of the models used to obtain them. With an input-output model, all cost increases are passed on in the form of higher prices. In other words, markets are assumed to be competitive and supply elasticities to be infinite. In

TABLE III:
1977 ENVIRONMENTAL-COMPLIANCE COSTS PER $ OF OUTPUT (%)

Sector	*Direct Cost*	*Direct and Indirect Cost*	*Source*
Ferrous and Nonferrous-Metal and Coal Mining	1.94	2.67	Pasurka (1984)
Petroleum and Natural Gas, All Stages	2.21	3.69	Pasurka (1984)
Iron-Ore Mining		0.59	Robison (1985)
Petroleum Refining		1.34	Robison (1985)
Ferrous-Metal Refining	1.29	2.35	Pasurka (1984)
Nonferrous-Metal Refining	0.73	2.00	Pasurka (1984)
Iron and Steel Refining		2.17	Robison (1985)
Copper Refining		2.40	Robison (1985)
Nonferrous Refining, Other than Copper		1.85	Robison (1985)
Average	1.54	2.12	

addition, the production function that underlies an input-output model is of the fixed-coefficient variety. This means that substitution does not occur in response to changes in relative prices.

A third reason for overestimation, in contrast, arises from the sectoral focus of our study. The Census data include all expenditures to eliminate air, water, and solid-waste pollution. Since we are concerned only with indirect costs due to pollution abatement in the energy and metals sectors, our estimates might be substantially exaggerated. However, this does not seem likely. Jorgenson and Wilcoxen (1990), for example, find that only one sector, namely motor vehicles, is hit as hard by environmental regulations as primary metals and energy.

Production and Consumption:

The World Bank collects data on GNP, population, and production and consumption of the principal fuel and nonfuel-mineral commodities for nearly 200 countries.[15] Countries are classified by geographic region and income level.[16] These data are used to attribute worldwide changes in output and revenues of mineral commodities to geographic regions and income groups. First, however, a preliminary analysis is useful.

Table IV provides summary statistics for 1987 by income class.[17] The low-income group of countries is the largest with 2.8 billion people. The middle-income group has 1.4 billion, and the high group is the smallest with 0.8 billion. GNP per capita ranges from $15,829 for the highest class to $285 for the lowest. (Note that the income of the middle group is much closer to that of the low group than it is to the high.) Finally, each group's per-capita consumption of nonferrous metals, steel, and energy differ sharply.

The second part of Table IV contains figures on net supply (production minus consumption) of individual commodities and commodity aggregates by income group. Although net supply cannot be equated with net exports, for storable commodities such as metals, these numbers are reasonable proxies for the numerical difference of exports and imports.[18] The table shows that middle-income countries are net producers of both nonferrous metals and energy, whereas high-income countries are net consumers. In contrast, net supplies for low-income countries are not large. The situation is very different, however, with respect to steel; here, high-income countries are net producers and low-income countries are net consumers.

Table V contains the same summary statistics. In this table, however, instead of income groups, countries are organized into eight geographic regions. North America and Western

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[15] Not all data are available for every country.

[16] Detailed documentation for these data can be found in *World Tables* (1990).

[17] 1987 was chosen as the base year because it is the most recent year for which the data are complete.

[18] For the same reason, net supplies do not sum to zero.

TABLE IV:
SUMMARY STATISTICS BY INCOME CLASS, 1987

IVA: GNP and Per-Capita Consumption

Variable	*Low-Income Group*	*Medium-Income Group*	*High-Income Group*	*Units*
GNP	804	1,772	12,648	10^9 US $ (1980)
Population	2.823	1.374	0.799	10^9 people
GNP per capita	285	1,290	15,829	$
Per-Capita Consumption of				
Energy	314	2,018	4,988	tons oil equiv. / 10^3 people
Steel	34,217	221,013	402,834	tons/10^6 people
Nonferrous Metals	977	8,598	30,355	"

IVB: Production Minus Consumption

Variable	*Low-Income Group*	*Medium-Income Group*	*High-Income Group*	*Units*
Aluminum	151	899	-1,105	10^3 tons
Copper	570	1,204	-1,931	"
Lead	-51	-31	-9	"
Tin	35	47	-100	"
Zinc	-118	178	45	"
Total Nonferrous	587	2296	-3101	"
Steel	-24,014	4,498	27,790	"
Electricity	0.6	-0.4	1.0	10^6 tons oil equiv.
Liquid Fuels	85	477	-527	"
Natural Gas	25	51	-68	"
Solid Fuels	-4	24	-15	"
Total Energy	106	551	-608	"

TABLE V:
SUMMARY STATISTICS BY GEOGRAPHIC REGION, 1987

VA: GNP and Per-Capita Consumption[a]

Variable	*North America*	*Latin America*	*Western Europe*	*Eastern Europe*	*Middle East/N. Africa*	*Sub-Sahara Africa*	*Asia*	*Pacific*
GNP	4.93	0.72	4.99	0.24	0.50	0.22	1.07	2.56
Population	0.27	0.42	0.44	0.41	0.22	0.48	2.39	0.36
GNP per capita	18,286	1,710	11,226	2,247[b]	2,265	455	447	7,029
Per-Capita Consumption								
Energy	77.5	9.9	30.8	45.5	12.6	2.7	4.4	12.4
Steel	42.6	7.9	28.6	52.9	6.7	2.3	5.2	22.5
Nonferrous Metals	3.7	0.5	2.2	1.8	0.2	0.08	0.2	1.2

a Units are the same as in table IVA.

b Excludes Czechoslovakia and the Soviet Union.

VB: Production Minus Consumption[a]

Variable	*North America*	*Latin America*	*Western Europe*	*Eastern Europe*	*Middle East/N. Africa*	*Sub-Sahara Africa*	*Asia*	*Pacific*
Aluminum	-80.7	4,067	-562.8	490.8	249.8	256.3	236.6	-1,324
Copper	-306.1	934.0	-1,444	224.7	23.2	796.0	-150.5	-235.9
Lead	-44.0	99.3	-111.0	-52.7	-17.0	14.1	88.4	-69.3
Tin	-35.7	21.4	-31.9	-23.4	-0.5	1.6	58.5	-8.1
Zinc	-256.0	69.8	117.0	0.3	-27.0	70.3	281.7	-151.0
Total Nonferrous	-722.5	5,191	-2,033	639.7	228.5	1,138	514.7	-1,788
Steel	-19,065	6,901	27,801	5,933	-8,234	-1,256	-23,837	20,031
Electricity	-0.8	-3.8	-0.5	6.3	0.0	-0.07	-0.4	1.0
Liquid Fuels	-278.7	104.3	-379.6	118.2	616.6	61.9	-35.4	-173.5
Natural Gas	6.8	4.2	-47.6	27.7	19.4	0.2	5.1	-7.7
Solid Fuels	54.7	-2.5	-68.2	16.9	-4.1	29.6	42.5	-63.9
Total Energy	-217.9	102.3	-495.9	169.1	631.9	91.6	11.8	-244.1

a Units are the same as in table IVB.

Europe are the wealthy, industrialized areas. The Pacific is mixed, containing industrialized countries such as Japan as well as less developed countries such as Indonesia. The middle-income regions are Latin America, Eastern Europe, and the Middle East/North Africa. The poorest areas are Asia and Sub-Sahara Africa.

The table shows that GNP per-capita ranges from $18,286 in North America to $455 in Sub-Sahara Africa and $447 in Asia, respectively. With one exception, per-capita consumption of metals and fuels is closely related to GNP per capita. The exception is Eastern Europe, which consumes more of all commodity groups than its income level would predict. In fact, per-capita steel consumption is actually higher in Eastern Europe than in North America.

The second part of table V shows a similar pattern to the one revealed by the breakdown by income classes -- wealthy regions are net consumers of everything, middle-income regions are net producers, and poor regions produce nonferrous metals and energy, and import steel. There are exceptions. For example, Middle East/North Africa is a net consumer of steel whereas the Pacific countries are net producers. More important, although the pattern is similar to that shown in Table IV, the finer geographic detail allow us to identify potential problems not earlier apparent. Asia's heavy dependence on imported steel, for instance, suggests that it might be hard hit by price increases.

4. A Conceptual Experiment

The following conceptual experiment can now be conducted. Let the industrialized world be called "North." North is assumed to have high per-capita income and moderate environmental standards.[19] Less developed countries ("South"), are assumed to have lower incomes and standards. We then ask what will happen to resource production, consumption, and revenue if South adopts the standards set by North while, at the same time, North increases its expenditures by the same fraction as South. That is to say, suppose that current ECC are r percent of total costs in the North and zero in the South. We are trying to assess the consequences of new environmental legislation that causes total (production plus environmental) costs in the energy and metals sectors of both regions to increase by r percent. Raising everyone's costs means that standards continue to be more stringent in the regions that are more able to pay.

The model developed earlier and the data just described can be used to perform this experiment. After the numbers contained in table II are substituted for the parameters, we apply equations (9)-(13) to each commodity and each geographic region or income class. The results are contained in table VI.

Several conclusions can be drawn from this table. First, the numbers are small. Price changes average about 1.5 percent; the comparable figure for quantities is -0.8. Moreover, with

[19] We assume that all "Northern" countries have the same standards as the U.S. Robison (1988) concludes that Canadian ECC are roughly equivalent to those in the U.S. Moreover, Western Europe, which is not a major producer of most mineral commodities, probably has moderate standards. Assessing current levels of ECC for each region, however, is not important as long as all countries increase expenditures by the same fraction.

TABLE VI:
FORECAST CHANGES

VIA: % Change in Price and Aggregate Production

Commodity	*Price*	*Quantity*
Nonferrous Metals	1.28	-0.70
Ferrous Metals	1.17	-0.75
Energy	1.83	-0.90

VIB: %Change in Export Revenues

		By Income Class		
	Low	*Medium*	*High*	
	2.55	0.88	-0.98	

By Region							
North America	*Latin America*	*Western Europe*	*Eastern Europe*	*Middle East/North Africa*	*Sub-Sahara Africa*	*Asia*	*Pacific*
-0.79	0.78	-1.03	0.83	0.93	0.88	-0.47	-1.11

one exception, changes in export revenues are close to one percent in absolute value. These numbers seem insignificant, when compared to the year-to-year fluctuations metal and energy markets frequently experience. Petroleum and tin prices, for example, both more than halved between 1985 and 1986, and aluminum prices nearly doubled between 1986 and 1988.[20] Two of these changes were temporary fluctuations, but the tin price collapse has endured. Moreover, in the 1970s energy prices experienced large increases that were sustained for many years.

The second conclusion is that an environmental "tax" is on average progressive. Where mineral-commodity revenues increase in low and medium-income countries by approximately 2.5 and one percent respectively, in high-income countries, in contrast, they decline by about one percent.[21] Similarly, the three regions with highest income per capita, North America, Western Europe, and the Pacific, increase expenditures on mineral commodities, whereas in the three middle-income regions, higher prices more than compensate for sales reductions, and export revenues rise. The fate of the poorest regions, however, is mixed. Net exports increase in Sub-Sahara Africa. The Asian countries, in contrast, must spend more for the energy and steel that they import. Nevertheless, their export revenues fall by only one half of one percent.

To check whether these conclusions are strongly dependent on the period chosen for the analysis, the same calculations are performed for the years 1986 and 1988 also. In addition, a coarser geographic breakdown is assessed using 1987 data, and 1987 prices are replaced with average prices for the 1986-1988 period. Naturally, the numbers change. These changes, however, are surprisingly small. The findings are therefore robust, and the qualitative predictions survive the sensitivity analysis.

The situation seems quite rosy. Not only are the magnitudes associated with environmental protection small, but the burden of protection is borne by those who can best afford to pay. However, a word of caution is in order. Environmental regulation could cause hardship for some low-income countries. On average, increased energy and nonferrous-metal revenues more than compensate for the higher expenditures that poor countries must incur for purchases of iron and steel. Unfortunately, some low-income countries are poorly endowed with every sort of mineral and must buy all of their resource requirements at higher prices. Identifying individual countries that are most disadvantaged, however, requires a finer geographic breakdown of mineral production and consumption.[22]

5. The Initial Investment

Given that increased revenue resources will more than compensate the average LDC for

[20] For an analysis of metal-price instability, see Slade (1991b).

[21] In all cases where revenues are reduced, they were negative to begin with. This means that "reduced revenues" means spending more for imports rather than receiving less for exports.

[22] Data on production and consumption are missing for many of the poorer countries.

the costs of pollution control, no assistance or intervention should be required. This assumes, however, that capital markets are perfect, which is far from the case in many developing countries. These imperfections constitute perhaps the most substantial obstacle to successful environmental regulation.

In addition to increased marginal costs, considerable fixed costs are involved. Because the technology is imported, these costs will be incurred in foreign exchange. Unfortunately, the shadow price of foreign exchange can be extremely high, especially for countries experiencing balance-of-payments difficulties.

In light of the transboundary externalities involved, loans or subsidies from North to South should be considered: LDC producers could be provided with access to credit in dollars, prices of imported pollution-abatement equipment could be reduced, or aid could be tied to the installation and maintenance of environmental capital. The design of optimal credit and subsidy schemes is beyond the focus of this paper. Nevertheless, if environmental agreements are to be successful, it is a subject that merits serious consideration.

III. Summary and Conclusions

The model used here is very simple. The conclusions reached are probably valid in terms of qualitative predictions and relative magnitudes. As good point estimates of environmental-compliance costs and their ramifications, they probably are not.

The spirit of the conclusions drawn might be trusted for several reasons. First, the pessimistic approach necessitated choosing high-cost, difficult-adjustment scenarios. Second, the conclusions reached are not sensitive to the period of analysis or to the exact geographic breakdown of the regions. Rather, the most sensitive parameters in the model are the mineral-commodity prices. This is true, not because small changes in prices lead to radical differences in estimates, but because commodity prices are infamously volatile, both in relative and absolute terms. Large changes in relative-mineral-commodity prices could therefore cause some countries to switch from net-exporting to net-importing positions. Nevertheless, the seven geographic regions analyzed are fairly large and consequently not prone to sign reversals.

Our two main findings relate to the magnitude, and the incidence, of environmental-protection costs. We saw that the magnitudes involved are small. Compliance costs of roughly three percent of product prices lead to changes in export revenues of less than one percent. The principal reason for this result is that both demands and supplies of mineral commodities are inelastic in the long run. Moreover, this empirical regularity shows up in virtually every econometric-commodity model examined.

With respect to incidence, we saw that an environmental "tax" is on average progressive. This is true because low-income countries are on average net exporters of mineral commodities, whereas high-income countries are net importers. Our second finding, however, should be interpreted with caution. While it is true on average, it is unlikely to be true for every low-income country. In fact, a program that is on average progressive could lead to substantial hardships for the mineral poor.

The conclusions reached are therefore somewhat more optimistic than those of other studies. Jorgenson and Wilcoxen (1990), for example, find ECC-related reductions in U.S.

mineral industry output of more than five percent.[23] There are two reasons why the Jorgenson-Wilcoxen simulated impacts are much larger than those found here. First, they analyze unilateral adoption of environmental regulations within the North-South paradigm; polluting activities, such as metal refining, consequently gravitate towards regions that are less stringently controlled. Second, the U.S. is a net importer of all major metals and most fuels. The inevitable consequence is higher import dependence, coupled with larger per-unit expenditures on imported-mineral commodities.

Some of the assumptions underlying the model may not be realistic. For example, all minerai industries are assumed to be competitive. For this reason, regulation does not cause profit rates to change. To the extent that industries are imperfectly competitive, however, resource rents will be generated and environmental controls will cause shifts in these rents across geographic regions and income classes.

A full-employment assumption also underlies the model. As a result, factors released from mineral industries can find employment in other sectors, and no deadweight loss is created. To the extent that unemployment exists, however, the predicted reduction in output of mineral commodities will exacerbate the situation. Moreover, the opportunity value of the released workers might be closer to zero than to the market wage.

A possible problem with the analysis arises because mineral production is a vertically integrated process. This leads to various anomalies. For example, Western Europe is a net producer of zinc, in spite of the fact that it mines little zinc ore. Most of its zinc production comes from custom smelters. In a similar vein, Japan is a net producer of steel but mines little iron ore. Unfortunately, keeping track of imports and exports at every stage of production requires better data than are available.

Finally, no attempt was made to evaluate the benefits of environmental regulation. Nevertheless, given that the costs are not prohibitive, benefits would have to be comparably small if they were not to outweigh the costs.

Suppose that benefits do in fact exceed costs. Global environmental controls should then be adopted. Unfortunately, this leads to a new set of difficult economic problems, including the issue of enforcement. Although national governments have legal authority to force firms within their boundaries to comply with environmental regulation, there is no global agency with comparable powers. The implication is that, if environmental legislation is to be successful, it must be self-enforcing. In the terminology of game theory, the desired outcome -- compliance -- must be a Nash equilibrium of the regulation game. The trick is to choose the rules of the game so that selfish behavior on the part of national governments coincides with the cooperative solution. Design of such schemes, however, is the subject of future research.

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[23] These reductions are due to historic ECC. In other words, costs increases of the same magnitude as those that we examine.

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