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THE ECONOMIC SIGNIFICANCE OF POLLUTION CONTROL AND WORKER SAFETY COSTS FOR WORLD COPPER TRADE

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1. ABSTRACT

What is the relationship between strict environmental regulation in the industrialized countries and higher levels of global pollution? According to economic theory, the answer will depend upon cost parameters, and particularly upon the degree of responsiveness of production costs as they increase with control requirements. If, for example, an additional 10% increase in pollution control in a developed country causes a 20% increase in pollution control costs, then there will be an increase in global pollution if the developed country raises its standard. The process involves increasing the levels of uncontrolled production in developing countries, and increased export of copper and copper-intensive products to developed countries.

In the paper, theoretical discussion is complemented by a comparison of sulfur emission control, water pollution control, and worker safety practices at three pit mines and three smelters in Mexico and the United States. At the most advanced levels, environmental protection and worker safety practices cost 15¢ per pound of product copper.

This situation creates severe difficulties for controlling global pollution levels, and for international competition in copper trade. The paper concludes with a review of national and international responses to the problem.

2. INTRODUCTION

This paper proposes a model of trade and pollution control which has been generally rejected by economists studying the subject. The main conclusion now held is that pollution control and workplace safety policy in industrialized countries are unimportant economic factors in influencing the location of manufacturing or global pollution levels. Smith and Ulph [p. 328] end their extensive analysis of Asian development by observing

> "The general evidence suggests that the general resource allocation and macroeconomic effects of developed-country environmental policy are not so large as to have any significant impact on developing countries. Broadly, 'economic growth' in the developed world will not be retarded."

Similar conclusions were reached by the OECD Environment and Economics Conference [pp. 61-82], Ingo Walter [p. 100], and Jeffrey Leonard. Leonard, writing for the Conservation Foundation, noted that the location of metal processing and chemical manufacturing may be affected by U.S. regulation. However, he does not consider the impact that unilateral policies may have on global pollution levels to be important.

Edward Denison's examination of productivity factors places pollution abatement and worker safety and health in a minor position in explaining declining real national income per person employed in the United States [pp. 17, 18]. Denison notes that real national income per worker rose 2.46% annually from 1948 to 1973 but declined at a 0.22% rate from 1973 to 1981. The change between the two periods is primarily due to productivity loss on non-environmental factors.

Pollution intensive manufacturing is experiencing significant incentives for geographic redistribution of production and use. This is relevant to a broad spectrum of manufactured commodities, from agricultural produce grown with different pesticide regimes to metals processing using different air and water pollution emissions technologies.

Many U.S. critics of privately owned multinational corporations believe that U.S. producers move pollution intensive operations to other locations, but this is not the case. The geographic redistribution now taking place is indigenous to the producing countries, and is frequently state owned as well as privately owned.

The next section reviews relevant economic theory and explains how unilateral policies can affect production and trade. This is followed by a description of the current geography of production, consumption, and trade. Subsequent sections discuss costs in pollution control and workplace safety, an explanation of the apparent under-reporting of these costs, the contrasting benefits to industrialized and developing countries of unilateral action, and the current policy choices internationally.

3. ECONOMIC THEORY

Basic chemistry in copper has important economic implications in a theoretical context. In most of the world, copper is produced from ores which have an equivalent or greater amount of sulfur. Since airborne sulfur emissions are primarily sulfur dioxide (SO_2), two units of SO_2 may be emitted for each unit of product copper. Almost all of the emitted sulfur is as some stage transformed into H_2SO_4, sulfuric acid [Wilson, pp. 85-95]. Consequently, each unit of product copper is potentially associated with 3 units of sulfuric acid or other hazardous sulfate.

Figure 1, Part A shows two regional supply relationships. Each curve indicates the amount of refined copper that would be offered for sale at the price levels on the vertical axis. S_{IB}, for example, represents the supply function for the world's industrialized region producers before new sulfur regulations are implemented. S_D represents the supply response for developing country producers. Note that S_{IB} is to the left of S_D: at any price level, less quantity will be supplied by industrial region producers. In economic theory, the supply price is equivalent to the marginal or incremental cost of production for increasing quantities supplied.

Part B shows the world copper market. Q_{TB} is the total industry supply function for both regions, the sum of the two regional relationships. The downward-sloping customer demand function, Q_C, indicates that customer demand increases as market price declines. Market equilibrium is defined by the intersection of the upward-sloping supply function with the downward-sloping demand function, providing identical prices and quantities to customers and producers. The global equilibrium is at about 7.5 million metric tons (mmt) of world production, at a world price of about 66¢ per pound.

This market equilibrium price in Part B then defines the regional production levels in Part A: Q_{IB} is at 3.5 mmt, and Q_D is at 4.0 mmt. The higher marginal production cost for the industrial region reflects a considerable degree of sulfur control. This is about 67%, as discussed below. Consequently, global sulfur oxide emissions are at 10.3 mmt, 8 mmt from developing country producers, and 2.3 mmt from industrial country producers. Incidentally, Russian scientists Migdisov et al. [p. 118] estimate total global anthropogenic sulfur pollution emissions at 70 mmt, and they associate 10 mmt with sulfur emissions from metal processing.

Now suppose industrial regional countries tighten their sulfur control to 95% removal. In Figure 2, supply function S_{IG} reflects the higher cost of the new regulations control level. S_D for developing countries is unchanged. The new total supply function is Q_{TG}. The world demand function is unchanged at Q_C. Supply and demand are now in equilibrium at 76¢ per pound, and a world use level of 6.7 mmt. The dramatic change is the displacement of industrial

FIGURE I. WORLD SULFUR MARKET BEFORE NEW REGULATIONS, MILLION METRIC TONS

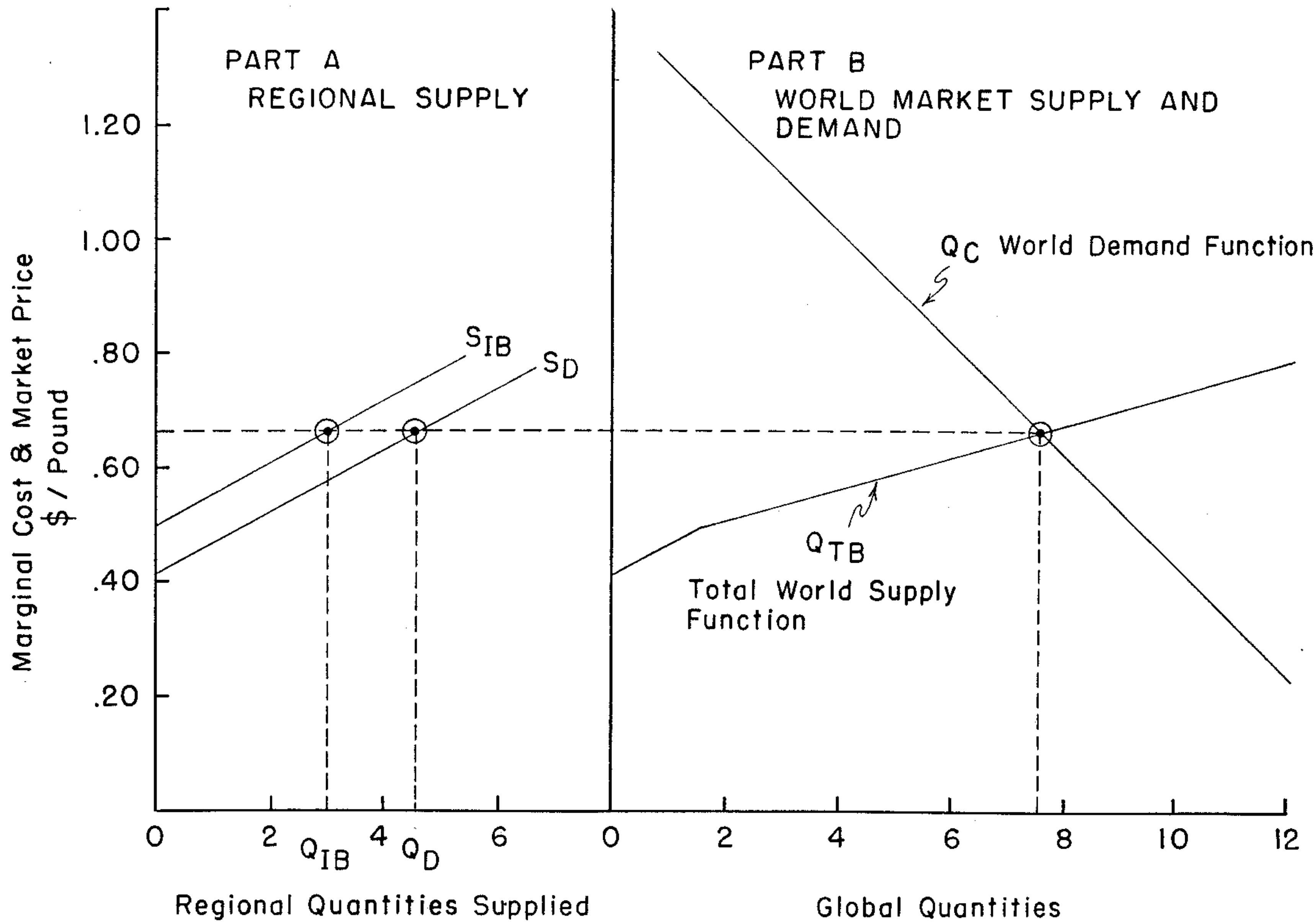
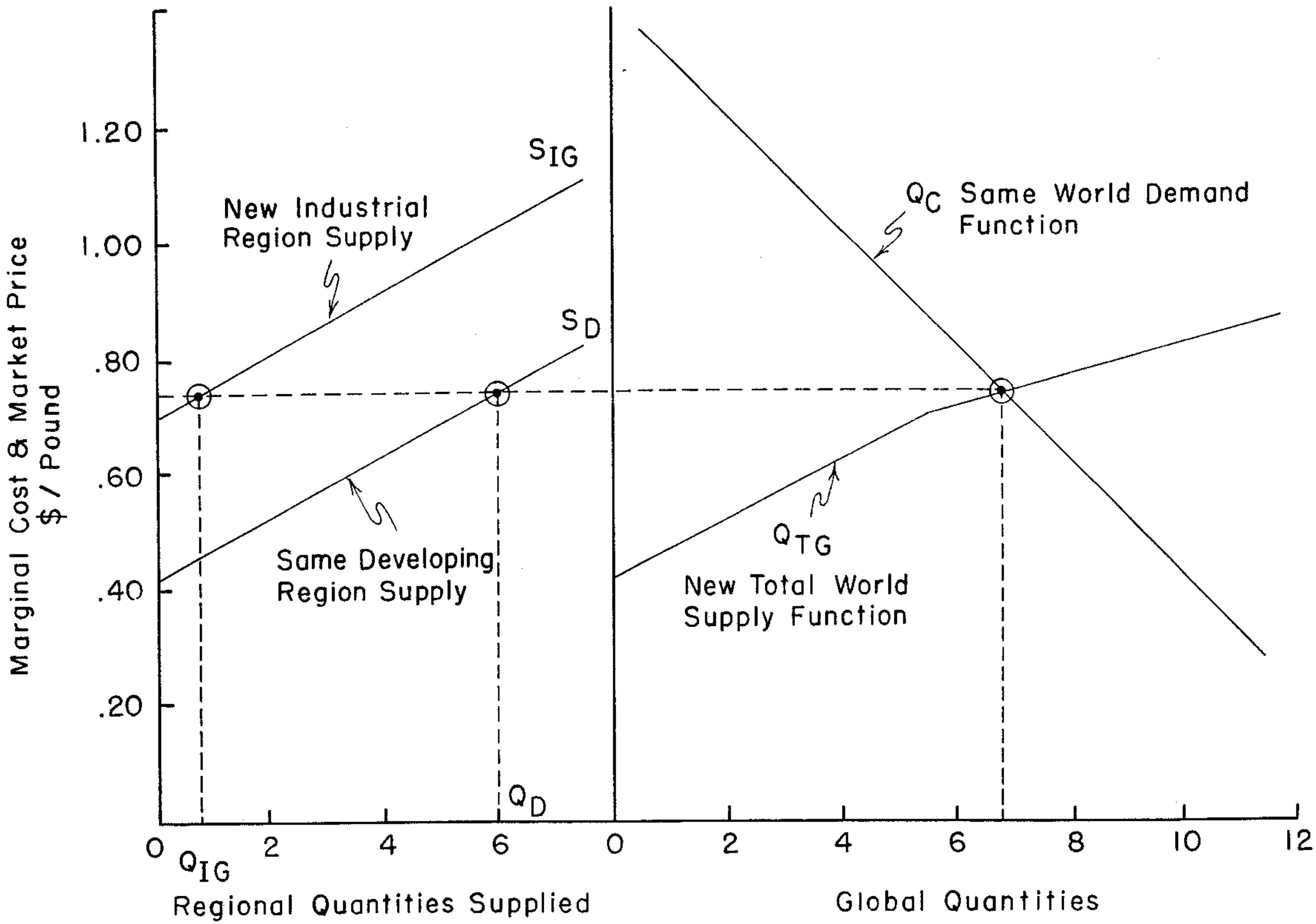


FIGURE 2. NEW INDUSTRIAL REGION REGULATIONS AND GLOBAL MARKET, MILLION METRIC TONS



country producers. Their production level is 0.7 mmt. Q_{IG} market share is now 10%, compared to 40% before the new regulations.

This theoretical analysis has purposefully been constructed to give this result: global sulfur oxide emissions are higher. For the industrial region, 95% control on 0.7 mmt copper production means 0.07 sulfur oxide emissions. The developing country sulfur oxide emissions are 12 mmt for the Q_D production level of 6 mmt copper. Total world sulfur oxide emissions are 12.1 mmt.

In this exercise, a further tightening of industrial region sulfur emission control is associated with 1) a rise in global emissions, 2) a rise in world prices, 3) falling world output, and 4) a severe contraction in production in the control region and displacement by uncontrolled region producers.

The economic studies summarized above generally do not perceive these characteristics of the impact of regulations on copper production.

4. WORLD PRODUCTION AND TRADE

Forty-seven western market economies have been identified as producing or consuming copper. Seventy-five to eighty-five percent of refined consumption and mine, smelter, and refined production is accounted for by 15 countries. In Table 1, these countries are divided into two groups, developing countries with GNP per capita less than $2150 and industrialized countries with GNP exceeding $6500. The table includes all countries with at least 200 thousand metric tons of refined consumption or production at any stage.

The developing country group shares several characteristics: low GNP per capita, very little refined consumption, significant mine and smelter production, state ownership, and low levels of sulfur control for smelter operations. The exception is South Korea, which has very little mine and smelter production but uses significant refined copper, and has a relatively high level of sulfur control. Excluding South Korea, the developing country producer group exports 97% of its mine production.

The industrialized group includes two major producers, but is primarily an importer. Excluding the U.S. and Canada, the industrial group imports 99% of its copper.

The industrial group companies are primarily or wholly privately owned, and of the five studied by Maxim, three have sulfur control exceeding 85%. Canada is an exception, controlling 26% of its potential copper-based sulfur emissions, as is Australia with no control.

Table 1. MAJOR PARTICIPANTS IN THE WORLD COPPER MARKET

	Mine Production	Smelter Production	Refined Production	Refined Total Consumption	Approx. S Control
Developing Country Producers					
Chile	1356	1089	884	26	12%
Peru	385	354	227	37	3%
Zaire	502	469	227	3	3%
Zambia	520	544	510	7	35%
S. Korea	2	113	152	207	50%
Philippines	226	134	130	5	0%?
Group Total	2991	2703	2130	285	
Market Total	6472	6910	7327	7338	
Percent	46%	39%	29%	4%	
Without S. Korea	46%	37%	27%	1%	
Industrialized Country Consumers					
Australia	261	175	193	124	0%
German F.D.	1	247	414	754	95%
Canada	730	494	500	223	26%
Belgium	0	115	413	310	?
France	0	7	44	398	?
U.S.	1106	1138	1436	1906	85%
Japan	43	933	936	1231	95%+
Italy	0	0	64	362	?
U.K.	1	0	125	347	?
Group Total	2142	3109	4125	5655	
Percent	33%	45%	56%	77%	
Without Can., Aust.	18%	35%	47%	72%	
Total Percent, 15 countries	79%	83%	82%	81%	

Note: Table includes all market economy countries with at least 200 thousand metric tons at one or more stages. Developing countries all have per capita GNP not exceeding $2150. Industrial countries all have per capita GNP exceeding $6500. Sources are World Bank, World Bureau of Metal Statistics, and Maxim.

Overall, there appears to be a general pattern of a developing country group which produces about half of world copper ore and concentrates but does not process refined copper. Simultaneously, an industrial country group uses refined primary copper, but as a group, imports concentrate, blister, and refined copper from the developing country group. The two industrial group exporters, Canada and Australia, sell most of their exports to other industrialized region members.

Since the industrial group also imports embodied copper in imported electronic and automotive goods, the table understates copper imports. For example, the U.S. imported 5.7 million vehicles in 1985, representing about 75,000 tons of copper [MVMA, p. 73].

Over time, there is a tendency for world consumption to increase, for industrial region use of imported primary and refined copper to increase, and for mine and smelter production in the developing region to replace production in the industrialized region.

If direct use of scrap is included, the 9 industrialized region countries use 2.1 mmt of the world's 2.6 mmt recycled in 1985. Viewing the 10.0 mmt total consumption of refined and direct scrap use, the industrial region used 76%.

The terms "developing" and "industrial region" are used here to differentiate national income levels, production, consumption, trade patterns, and sulfur recovery. Geographically, major mine producers are on five continents, and major consumers are on three continents. Every continent except Antarctica is part of the world market.

5. COST IMPACT OF PROTECTION STANDARDS

Protection standards have two kinds of cost impact. First, productivity is lowered because production labor and management are undertaking pollution control and workplace safety activities instead of producing copper. Second, company expenditures on protection increase costs directly. Both cost influences can be described with cost and production functions:

$$Q = \alpha_0 L^{\alpha_1} K^{\alpha_2} E^{\alpha_3} M^{\alpha_4} (1-S)^{\beta}. \tag{1}$$

This is a production function where copper output Q depends upon labor L; capital K; electrical and fuel energy E, ore material M, and sulfur and other protection activities S. All the α parameters are positive. Now consider labor productivity, the ratio of Q/L:

$$(2) \qquad \frac{Q}{L} = \alpha_0 L^{\alpha_1 - 1} K^{\alpha_2} E^{\alpha_3} M^{\alpha_4} (1-S)^{\beta}.$$

Note that the derivative of productivity with respect to control is negative. Higher environmental protection levels mean lower productivity levels. This is so, even assuming that α_1, the elasticity of production with respect to labor is constant. In fact, slight upward trends in efficiency in all other parameters can be masked by increases in sulfur removal S.

In mine operations, for example, labor expended in watering for dust control, or maintaining tailings dams, or in safety training programs, is all labor removed from production, and necessarily reduces conventional productivity measures. Similarly, labor operations in sulfur emission control and in plant safety training reduce conventional productivity rates.

More obviously, expenditures on equipment for air and water pollution control increase cost simultaneously with the reduction in conventional productivity measures associated with the operation of this equipment. Maxim reports Dorenfeld's analysis of smelter costs for sulfur removal by retrofitting old plants. The cost per pound of copper increases exponentially by a factor of 4.5 as sulfur control rises from 0% to 98%, and cost increases by 23¢ per pound product copper.

Several options can reduce the cost of sulfur control. A flash smelter uses sulfur oxidation as an energy source, reducing input energy requirements and concentrating SO_2 gas.

Of course, the availability of a market for sulfuric acid reduces the net cost of sulfur removal. Japan is apparently a prime example of sulfur markets being exploited successfully by copper producers. However, copper production facilities which are in direct competition with geologic sulfur or oil desulfurization cannot count on significant byproduct markets, particularly if smelter production is at a considerable distance from sulfuric acid markets.

Leaching and electrowinning offers another technology for reducing sulfur control costs from smelting. The sulfuric acid byproduct from smelting forms the basis for the leach solution for hydrometallurgy. This option seems to be increasing in use.

These factors (leaching, profitable sulfuric acid markets, flash smelting) can all reduce the cost impact of sulfur control. However, review of protection practices at U.S. operations leads to the conclusion that advanced practices add 15¢/lb to product cost for air and water pollution control, and for worker health and safety protection. Tables 2 and 3 list the major elements of these costs. The calculations are based upon actual recorded equipment expenditures for air and water pollution control equipment, and actual annual operating costs for worker health and safety at actual sites.

In some instances operating and management personnel under-report these costs. Environmental practices established before the current period are often viewed as standard operating procedure rather than as environmental or workplace protection. The focus on costs is generally on the costs of implementation of current or proposed procedures. In addition, the loss in conventionally defined productivity is often overlooked.

6. BENEFITS TO THE INDUSTRIAL REGION OF UNILATERAL POLICIES

The implementation of protection practices in the industrial region has to date been of considerable public benefit. Sulfur, particularly, is clearly identified as toxic to humans and to the natural environment. Much of the cost of worker safety and environmental protection arises from the isolation of sulfur compounds from the workforce and from the air and water environment. [See Wilson, Ch. 4 for a summary.]

In earlier periods, sulfur and particulate pollution was a major health hazard in the Eastern United States. A general interpretation of Freeman's literature review is that each million tons of sulfur and particulate emissions has caused, in round numbers, one thousand premature deaths in the United States. The apparent historical maximum of sulfur oxide emissions occurred in 1973 with 28 mmt. This declined to 21 mmt in 1985. With current levels of metal processing and fuel use, the United States Environmental Protection Agency estimates that sulfur oxide emissions would be 33 mmt. The copper industry contributed to this reduction, reducing emissions from 3 mmt in 1970 to 0.7 in 1985.

It would be tempting to extrapolate the Freeman generalization to the reduction in emissions from copper production. This would mean that premature fatalities have been reduced by 2,000 persons because of the reduction in copper-derived sulfur emissions. However, population densities in the copper areas in the Western U.S. are much lower than in the East, and it seems

Table 2. ENVIRONMENTAL PROTECTION ACTIVITIES AND EQUIPMENT

a. air and water pollution for coal burned for power generation
b. bag house on crusher
c. berms for chemical storage
d. covered conveyor
e. primary convertor hoods
f. fugitive emission hoods
g. gas collection fans, electricity
h. hazardous waste control
i. meteorological data and forecasting for possible pollution emergencies
j. monitors for air and water quality
k. PCB control
l. storm catchment reservoir for 10 year storm
m. tailing reservoir
n. tall stack
o. waste oil control and monitoring
p. water discharge plans and monitoring
q. water recycle zero discharge
r. water spray for dust control
s. wet scrubbers
t. professional environmental protection personnel
u. Federal and State reports and meetings

Table 3. WORKPLACE HEALTH AND SAFETY PROTECTION COSTS

a. personal safety equipment: protective jacket, hardhat, glass, respirator, boots
b. roll cages and cabs on vehicles
c. clean work places
d. lights
e. minimum train crews
f. hearing testing, protection, and monitoring
g. plant air testing
h. radiation monitoring
i. respirator testing
j. training programs
k. mine and industrial safety personnel
l. mine and industrial safety reports and meetings

certain that a given quantity of sulfur oxide emitted from a tall stack at a Western smelter has less health impact than the same emission level in the East directly affecting ambient air in a nearby community.

Epidemiological data on pollution health impact in developing countries is limited. It is reasonable, however, to assume that current uncontrolled industrial emissions in developing country urban areas have at least the same impact that such previous policies caused in the United States.

Czechoslovakia may be the current world leader in sulfur pollution impact. Brown coal burned in Bohemia and the German Democratic Republic has 50 percent ash and 10 percent sulfur. The forest devastation there is well known. The Ore Mountain forest, previously spruce, fir, and beech, is wholly destroyed. This is an area 60 km long and 2-5 km wide. Reforestation efforts have yet to be successful because pollution deposition remains high. More significantly, unpublished data show much higher miscarriage rates and significantly higher rates of respiratory illness and retarded child development.

The elimination of these health and environmental problems constitute a significant benefit for the industrial regional countries. At current sulfur emission and deposition levels, it is unclear whether a significant problem remains. The forest stress in the Eastern United States is believed to be due to vehicle emissions rather than sulfur deposition [NAPAP, pp. 3-15].

It is likely that a significant amount of current U.S. sulfur deposition originates at smelting operations in Mexico and Canada, a relationship which further underlines the transnational nature of copper markets and pollution control. This is, of course, because sulfur may travel hundreds of miles before deposition. It would be interesting to know if Nacozari and Cananea contribute more to sulfur deposition in Arizona and New Mexico than do U.S. sources.

Finally, it may be observed that unilateral industrial region policies benefit consumers by providing imported copper products (and products from imported copper) at lower prices than would be the case if policies were implemented internationally.

7. BENEFIT TO DEVELOPING REGION

As compensation for the health and environmental damage from sites without controls, developing region producers gain greater sales, greater profit per unit output, and greater employment. Consider again the theoretical production function Eq. (1). Assume it applies in a general way to both developing and industrial region production. Of course, the same technology and equipment is in use around the world: pit and underground mines, comminution, flotation, truck and conveyor transport at mines and smelters, reverbatory, flash or other smelting methods, tall stacks, hydrometallurgy where it is used, etc. Except for the current absence of sulfur control, the Nacozari operation resembles its U.S. neighbors.

However, because of historical or infrastructure causes, the α production parameters may for a period of years be lower for developing country producers. In addition, maintenance supplies and equipment may need to be imported. Even with lower wage rates, developing region producers without access to byproduct sulfur markets or uses may not be able to compete with other producers and simultaneously control sulfur.

In other cases, the absence of controls simply translates into a greater market share and unit profit.

8. CONCLUSIONS: THE POLICY CHOICES

There are two types of policies, unilateral and international. At the international level, the obvious option is to consider minimum world standards for environmental sulfur release per unit of product copper. The recent United Nations Environment Programme initiative on chlorofluorocarbons shows that such global agreements can be undertaken. Historically, such standards have been promulgated by agencies representing affected populations and interest groups. Perhaps it is possible that trade and professional associations affiliated with production may develop initiatives. The Sulfur Oxide Technical Seminar at the International Conference Copper 87 might be followed in later years by sessions on control policy.

Another international policy relates to developing region financing by the World Bank, which is supported by industrial region countries. The Bank might consider financial inducements to the low-income developing region producers. Such inducements could be variable interest rates linked to degree of sulfur control, or partial grants for purchase of capital equipment used in pollution control.

One caveat is necessary about international policies: the role of the Soviet Union and China needs to be accepted by both industrial and developing regions. Although copper trade is currently small between Russia and China and the market economies, there is no reason to suppose that this will be true in the long run. China, Russia and Eastern Europe are major producers and consumers, using one-fourth of world primary production and consumption. They must participate in any international agreements on emissions.

In the absence of international agreements, the question arises as to whether unilateral national policies can have positive results. The current U.S. policy requires high levels of sulfur control and worker safety for U.S. producers regardless of byproduct use, and accepts copper imports without consideration of sulfur emission control. The benefit of this policy has previously been significant emission reduction, safer workplaces, and continued availability of low cost copper through imports. The economic cost has been loss of economic activity from closed facilities.

However, as Canadian and Mexican metal processing replaces U.S. production, their transborder emissions play an increasing role in deposition within the U.S. As was explained above, unilateral policies can be associated with elevated global pollution levels. It was suggested that unilateral policies can cause such global increases. More correctly, it is the unilateral initiative in the absence of international policies which can have perverse effects.

A second unilateral policy could be to provide financial support for pollution intensive industry such as copper which is in competition with unregulated developing country producers. Such assistance could be in the form of tax credits, or tax exempt bonds for pollution control, or direct funding. In the current U.S. economic climate such policies seem improbable.

Finally, an industrial region tariff based upon pollution standards could be implemented. It might include workplace safety standards. Likely candidates for a pollution import tariff would include metals, metal products, chemicals, and chemical products such as produce. If the tariff equaled 50% of the avoided protection costs, this might be 5¢-10¢ per pound for copper.

The changes in world copper markets reflect the broad flow of growth in the world economy. Consumer products and production technologies are not identical but sufficiently similar to be viewed as common. A rational approach to health and environmental problems requires the same international perspective which is evident in the Copper 87 Conference. The alternative is a future world economy, including China and Russia, in which price competition is derived from pollution control avoidance.

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