Environmental Best-practice in Metals Production

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1 Introduction

Public policy to promote technical change and foster economic efficiency, rather than environmental regulation alone, is more likely to achieve sustained and competitive improvement in the long-term environmental management of our non-renewable natural resources. Three key issues are explored in this article.

The Relationship between Production Efficiency and Environmental Performance

There is growing evidence that technical change, stimulated by the 'Environmental Imperative', is reducing both production and environmental costs to the advantage of those dynamic companies that have the competence and resources to innovate. Such companies include mining enterprises in developing countries, as well as trans-national firms; but the evidence is strongest for large new investment projects and greenfield sites. In older ongoing operations, environmental performance correlates closely with production efficiency, and environmental degradation is greatest in operations working with obsolete technology, limited capital, and poor human resource management. The development of the technological and managerial capabilities to effect technical change in those organizations would lead to improved efficiencies in the use of energy and chemical reagents and in waste disposal, to higher metal recovery levels, and better workplace health and safety. This in turn would result in improved overall environmental management.

The Economic and Environmental Limitations of Regulation

Currently, the environmental performance of a mining enterprise is more closely related to its capacity to innovate than the regulatory regime within which it operates. Although international standards and stricter environmental regulation may not pose problems for the economics of new mineral projects, there could be major costs and challenges involved for older, and particularly inefficient, ongoing operations. Controlling pollution problems in many of these cases requires costly add-on solutions: water treatment plants, strengthening and rebuilding tailings dams, scrubbers, and dust precipitators, *etc*. Furthermore, in the absence of technological and managerial capabilities, there is no guarantee that such items of pollution control—environmental hardware—will be incorporated or operated effectively in the production process. In some instances such requirements are leading to shut-downs, delays, and cancellations as well as reduced competitiveness. When mines and facilities are shut-down the clean-up costs frequently get transferred to the public sector, which, particularly in developing countries, has neither the resources nor technical capacity to deal with the problem effectively. In most countries, perhaps with the exception of the USA, the lack of retrospective regulation means the pollutee-suffers-and-pays principle is alive and well. This is not in itself, however, an argument either against regulation *per se* or for the global diffusion of Superfund legislation. (The Superfund legislation enables blame for environmental damage to be apportioned to a selected one of many past mine owners and for that company to be charged an estimated cost for work which government contracts-in to clean up and rehabilitate the damaged site.)

The Case for an Environmental Management Policy

The implication of this analysis is that to ensure competitive and sustainable environmental management practices in metals production, governments need to embrace public policy which goes beyond traditional, incremental, and punitive environmental regulation. The latter, in the old 'environmental protectionist' mode, tends to treat the symptoms of environmental mismanagement (*i.e.* pollution), not the causes (*i.e.* lack of capital, skills, and technology and the absence of the capability to innovate). The challenge will be for governments to ensure that companies operating within their national boundaries remain sufficiently dynamic to be able to afford to clean up when operations cease and to innovate to improve economic efficiency and environmental management in the meantime. Governments need policy tools which enable them to predict 'corporate environmental trajectories' and pick up the warning signs of declining competitiveness and impending mine close-down to ensure sufficient resources are available for the environmental management of mine 'decommissioning'. Policy mechanisms need to be developed to promote technical change and to build up the technological and management capabilities to innovate and manage the acquisition and absorption of clean technology. The privatization of the state sector and the liberalization of investment regimes in many developing countries, such as Angola, Mozambique, Namibia, Botswana, Bolivia, Peru, and Chile, with their emerging emphasis on joint-ventures and inter-firm collaborative arrangements, provides new opportunities for the diffusion of both competitive and environmentally sound best-practice in metals production.

Public policy to promote technical change and, complementary to that, to improve economic efficiency, respects the interplay between the environmental and economic factors that constitute a sustainable development approach to the long-term environmental management of our non-renewable natural resources. Environmental regulation at best provides only one element of a public policy for environmental management.

2 The Limitations of Environmental Regulation and Challenge for Public Policy

Regulatory frameworks for safeguarding the quality and availability of land, water, and air degraded as a result of mining and mineral processing activities are growing in number and complexity. This has particularly been the case in the major mineral producing countries of North America and Australia, as well as Japan and Europe. The norm in environmental regulation is that governments set maximum permissible discharge levels or minimum levels of acceptable environmental quality. Such 'command and control' mechanisms include: Best Available Technology standards, clean water and air acts, Superfunds for clean-up and liability determination, and a range of site-specific permitting procedures which tend to be the responsibility of local government within nationally approved regulatory regimes. Such 'command and control' mechanisms tend to rely on administrative agencies and judicial systems for enforcement. Three issues are relevant regarding the appropriateness of industrialized country's environmental regulations to reduce environmental degradation and improve environmental management practices in metals production.

First, there is a trend away from a 'pollutee suffers' to 'polluter pays' principle. However, it remains the case that the polluter pays only if discovered and prosecuted, which requires technical skills and a sophisticated judicial system, and that may occur only after the pollution problem has become apparent and has caused potentially irreversible damage. This highlights the tendency of such environmental regulations to deal with the symptoms of environmental mismanagement (pollution) rather than its causes (economic constraints, technical constraints, lack of access to technology or information about better environmental management practices). This can be serious in some instances because once certain types of pollution have been identified, such as acid mine drainage, it is extremely costly and sometimes technically impossible to trace the cause, rectify the problem, and prevent its recurrence. Certain environmental controls may only work if incorporated into a project from the outset (*e.g.* buffer zones to protect against leaks under multi-tonnage leach pads and tailings ponds).

Second, Best Available Technology (BAT) standards may be appropriate at plant start-up, but their specified effluent and emission levels are not necessarily achievable throughout the life of the plant, because technical problems may arise and there may be variations in the quality of concentrate or smelter feed, *etc.*, if supply sources are changed. Moreover, there are serious implications for monitoring. It would be also erroneous for a regulatory authority to assume that standards are being met if a pre-selected item of technology has been installed. Ongoing management and the environmental practices at the plant are likely to be important determinants of 'best environmental practices'.

Third, related to points one and two above, BAT standards and environmental regulations of the command and control type tend to presume a static technology—a best technology at any one time. This tends to promote incremental add-on controls to respond to evolving regulation rather than to stimulate innovation. This acts as a disincentive to innovate by equipment suppliers, the mining companies and metal producers. Their innovation, which has required substantial research and development resources, may be superseded by some regulatory authority's decision about what constitutes BAT for their particular activity. BAT gives the impression of technology being imposed from outside the firm, not generated from within. The search for profit and cost-savings tends to be a more obvious instigating factor of technical change, and it might be argued that market-based mechanisms, a technology policy which is complemented by a regulatory framework, and a good corporate environmental management strategy, can better contribute to achieve that aim.

There has been growing interest in the use of market-based mechanisms, whereby the polluter is charged for destructive use by estimating the damage caused. An important justification for the use of market-based incentives is that they allow companies greater freedom to choose how best to attain a given environmental standard.[1] By remedying market failures or creating new markets (rather than by substituting government regulations for imperfectly functioning markets), it has been argued that market-based incentives may permit more economically efficient solutions to environmental problems. Two categories of incentives exist.[2,3] One set, based on prices, includes a variety of pollution taxes, emission charges, product charges, and deposit-refund systems. Another set is quantity-based, and includes tradeable pollution rights or marketable pollution permits. The most common of these measures relates to posting bonds up-front for the rehabilitation of mines on closure. This is standard practice now in Canada and Malaysia. There are also discussions taking place about a mercury tax in Brazil (see Cleary and Thornton's article earlier in this volume for further details) and a cyanide tax in the USA. Currently, no government has designed a systematic set of incentives for industry to innovate and develop new environmental technology.

There are two further areas where policy approaches can contribute to improved environmental management practices. First, the increasing conditionality of private, bilateral, and multilateral credit, which frequently requires both prior environmental impact assessment and the use of best practice environmental control technologies in new mineral projects. A growing number of donor agencies, in Germany, Canada, Finland, and Japan, for example, are also concerned with training in environmental management. Second, the attempts by some governments, particularly Canada, to promote research and development activities (jointly and within industry and academic institutions) to determine toxicity from mining pollution and clean-up solutions. For example, Canada has extensive government-funded research and development programmes to promote the abatement of acid mine drainage and of SO_2 emissions. There is considerable scope for expanding these approaches, as is argued in Section 4.

Environmental regulations designed specifically for mining and mineral processing have, until recently, been uncommon in developing countries, although most countries now have in place basic standards for water quality and,

1 OECD, 'Environmental Policy: How to Apply Economic Instruments', Paris, 1991.

2 D.C. O'Connor, 'Market based incentives', in 'Environmental Degradation from Mining and Mineral Processing in Developing Countries: Corporate Responses and National Policies', discussion document, ed. A. Warhurst, SPRU, 1991, Section 2, Ch. 5, pp. 189.

3 A. Warhurst, 'Environmental Management', Chapter 7, in 'Mining and the Environment: the Berlin Guidelines', Mining Journal Books, 1992.

less commonly, air quality. A few developing countries have recently adopted extensive regulatory frameworks—sometimes replicas of US models. This, for example, has been the case in Chile and, to a lesser extent, in Brazil. This growing concern about environmental degradation is occurring during a period of rapid liberalization in developing countries,[4] which finds expression in new policies to promote foreign investment, privatization schemes, and the availability of loan capital. These conditions also influence the regulatory regime of developing countries. Should the developing country pose less onerous environmental burdens on the potential investor to improve the terms of the investment by implying lower compliance costs or a greater assumption by the state of the environmental costs associated with mineral development projects? Should agreements be signed which release new investors from any liability for environmental damage caused by previous mine owners under less-restrictive regulatory regimes? Or will a clear and strict regulatory regime be more likely to facilitate credit flows from increasingly more environmentally conscious lending agencies? Developing countries, desperate for investment in their stricken mineral sectors, will need to determine what the market can stand and how such terms can be structured to reduce to the minimum the risk premium the investor will seek for a given tax or regulatory burden.

It is worth noting that surveys by Johnson[5] and Eggert[6] imply that environmental policy has not been a major factor in determining the investment strategies of international mining companies. However, more recently the industry press has been citing environmental regulations in Canada and the USA as a major factor causing the cancellation and delay of potentially large investment projects[7] and contributing to the shut-down of several mines. For example, in 1989, the Bharat Aluminium Company announced the closure of its bauxite mining project in the Gandhamardham Hills, Orissa State in India, because of strong environmental opposition by the local population.[8] Other projects such as Phelps Dodge, Copper Basin in Yavapai County (USA) have been withdrawn due to delays and excessive costs involved in project approval, while in 1991 the Kennecott Flambeau Mining Company finally received planning permits after twenty years of negotiation for the Grant Copper Mine in Wisconsin, which will operate for only six years.

However, environmental regulation alone is unlikely to solve environmental problems in developing countries due to endemic production inefficiencies. In particular, the approach of state-owned enterprises towards the environment reflects inefficient operating regimes, excess capacity, breakdowns and shut-downs, and poor management procedures, which contribute to worsen the polluting nature of effluents and emissions. Such inefficiencies make it very unlikely that environmental controls will be incorporated effectively.

[4] R. Brown and P. Daniel, 'Environmental issues in mining and petroleum contracts', IDS Bulletin, 1991, **22** (4).

[5] C.J. Johnson, 'Ranking countries for mineral exploration', Natural Resources Forum, August 1990, **14** (3), 178–186.

[6] R.G. Eggert, 'Exploration', in 'Public Policy and Competitiveness in the Nonferrous Metal Industries', eds. J.J. Landsber, M.J. Peck, and T.E. Tilton, 1992.

[7] *Min. J.* (*London*), 30 October, 1992.

[8] US Bureau of Mines, 'Bauxite, Alumina, Aluminium', Annual Report, 1989, p. 6.

Production inefficiency is endemic among many mining enterprises in developing countries, and problems of environmental degradation cannot be viewed independently of it. Moreover, obsolete technology is widely used without the modern necessary environmental controls and safeguards. For example, new concentrators and roasting plants tend to be totally computerized. Automatic ore assaying techniques give an extremely accurate picture of the chemical composition of the ore feed which has implications for the fine-tuning of pressure, heat, cooling, and specific environmental control systems. This, in turn, will facilitate the accurate prediction and monitoring of emissions. However, where these controls are missing and, in particular, where ore feeds are of variable composition (in terms of the sulfur, lead, and arsenic content) the pollutant content of emissions also varies. The inefficient use of energy and poor energy conservation practices also result indirectly in increases of environmental pollution through the excessive burning of fossil fuels. This is particularly the case in poorly lagged roasters and inefficiently operated flotation units and smelters which are very intensive in energy use. It might be further argued that command and control regulatory instruments are unlikely to result in a reduction of pollution since they cannot affect the capacity to implement technical change of a debt-ridden, obsolete, and stricken mining enterprise in the developing country context. Such a company might find it preferable to risk not being detected or convicted, to pay a fine, or to mask its emission levels, rather than face bankruptcy through investing in radical technical change.

In addition to the problems of inefficient production, there are further reasons as to why environmental regulations—particularly those of the 'command and control' and incremental 'paper tiger' nature[9]—do not improve environmental management, particularly in developing countries. These are discussed below.

Environmental regulations tend to be of the blanket-type which specify maximum levels of emitted substances, minimum levels of environmental quality, and best available technology standards. They do not tend to reflect the propensity of a particular operation to pollute, which in part depends on local site-specific conditions (geology, geography, and climate) as well as economic, infrastructure, and technology-related constraints. In a desert, tailings dams need not be as highly specified as in rainy climates; dust regulations may need to vary depending on topography, precipitation, and prevalent winds; the sub-strata of leach ponds might need to be of different composition, strength, and depth, depending on local geology or the existence of an impermeable level of clay. Since developing country regulations are often copied directly from the statute books of the industrialized countries (for example, there are instances in both the cases of Chile and Brazil) whose regulations are adapted to suit their circumstances, they may not be appropriate for the site-specific characteristics of mines in either tropical regions or deserts. They may result in unnecessary and costly adaptations on the one hand, or the lack of necessary control, on the other.

Command and control environmental regulations require intensive monitoring to ensure that they are enforced. However, the small and medium mine sector

[9] T. Panayotou, Q. Leepowpanth, and D. Intarapravich, 'Mining, Environment and Sustainable Land Use: Meeting the Challenge', Synthesis Paper No. 2, The 1990 TDRI (Thailand Development Research Institute), Year-End Conference, Jomtien, 8–9 December, 1990.

accounts for at least 25% of mineral production in many countries. Although these mines are individually relatively small polluters, collectively they account for a disproportionately large share. These mines are often located high in the Andes or in remote tropical rain forests and are almost impossible to monitor systematically. Indeed, as regulation becomes more sophisticated, such monitoring requires skills and human resources far beyond the technological and managerial capabilities of many developing countries and frequently beyond their budgets. Understanding the diverse range of toxicity and engineering issues behind regulatory aims also poses challenges even in the industrialized countries. The most knowledgeable regulators are often head-hunted by the mining companies.[10]

In a recent interview in Brazil, a spokesperson for one of the companies said that they were requested to monitor themselves and send effluent samples at intervals to an independent laboratory and to report any abnormal results. The State regulatory agency did not have the skills required to monitor the operation itself. Indeed, the skilled people involved in the environmental agencies tend to live and work in capital cities and infrequently travel into the politically dangerous and inhospitable mining regions. Moreover, the enforcement of command and control regulations depends on a system which admonishes with imprisonment and fines. This, in turn, requires a legal structure and judicial system far beyond the capacity of most developing countries. Compliance is also limited since fines are generally a fraction of the costs involved in remedial treatment and abatement technology. They are also only payable if the polluter is detected, and if convicted. Inflation and local currency devaluation, which are endemic in the developing country context, also eat into the value of such fines. The costs of environmental regulation enforcement are generally hidden from the public eye and regulatory agencies are not generally accountable as such. However, since different site-specific mining contexts often require individual regulation, perhaps for permit approval, this provides opportunities for bribery which is endemic in bureaucracies and industry in many developing countries.

Indeed the regulatory system does not demand that efforts are made to deal with the cause of environmental pollution once and for all. It simply deals with the symptoms—once they are reported. Even though there is a theoretical threat of mine closures due to non-compliance, most foreign mining companies know that their developing country host can least afford to lose the foreign exchange earnings from their activities. Therefore the risk of closure due to environmental non-compliance of this type is considered relatively low. Pollution rarely produces a one-off disaster—rather it is a constant crisis.

Environmental regulations often emerge contradicted by other economic and industrial policies. For example, several countries with tropical forests have recently introduced policies aimed at their conservation. At the same time countries such as Brazil, Ecuador, and Colombia have parallel economic policies to promote industrial investment, especially by foreign firms, in these remote areas. The example of the Government of Ecuador authorizing RTZ's mining investment in one of its national parks is one such case—it resulted in the latter company withdrawing to avoid controversy over the issue. Forest conservation

[10] EPA, 1991.

policies were also in place in Brazil in line with EV and World Bank loan conditions. However, despite the existence of these policies, smelters at Carajas, in Brazil, were fuelled by large amounts of charcoal from neighbouring forests.

Another recently discussed example of potentially contradictory policy issues revolves around the international Basel convention which restricts the inter-country transportation of toxic wastes. Since certain scrap metals fit theoretically into this category on account of their heavy metal content, this would undoubtedly restrict trade in scrap metal and metal recycling.[11] This is considered to contradict many of the new intentions of European and American governments to encourage the recycling of metal-containing materials at the expense of new primary production.

Command and control regulation tends to identify and deal with symptoms (pollution) of environmental mismanagement rather than causes (production inefficiency, human resource constraints, lack of technology, and lack of capital). It is also add-on and incremental in nature. Therefore, there is a tendency for it to emphasize end-of-pipe, add-on, and capital-intensive solutions (*e.g.* smelter scrubbers, mine water treatment plants, dust precipitators, *etc.*) for existing technology and work practices rather than promote alternative environmental management systems or technological innovation. Regulation may also, to a certain extent, presuppose a static technology. If regulation is incremental, technical change may be incremental, involving the addition of numerous new controls at relatively greater cost and with more overall resultant degradation than if a new, more radical change had been introduced in the first place. It may also oblige specific reductions in pollution, regardless of cost or local context. For example, regulation will refer to the chemical composition of an effluent in isolation from how that discharge rate and pattern may be influenced by natural site-specific precipitation, evaporation, or soil and geological conditions. In turn, this regulatory approach may get a more uncooperative response from industry which sees the rules always changing and their cost implications increasing. Furthermore, such regulation ignores the human resource elements of sound environmental management by emphasizing a specific pollution control technology rather than training, managerial approaches, and information diffusion.

3 Technical Change and Corporate Environmental Trajectories

Enterprise responses to environmental pressures have been characteristically slow, and reflect the regulatory regimes and public climate of either their home country or foreign countries of operation. Their response has also depended on the nature of their operations in terms of first, the mineral involved; second, the level of integration of mining and processing activities; third, the stage in the investment and operations cycle which its mineral projects have reached; and fourth, the internal economic and technological dynamism of the company, *i.e.* whether it has the financial, technical, and managerial capabilities to be an innovator or not.

[11] OECD, 'Environmental Concerns Related to Commodities: Scrap Recovery and Recycling of Non-Ferrous Metals and Environmental Policy Instruments: The 1989 Basel Convention', Paris, 15 October, 1990.

After a period of using rather 'static' technology, the mining and mineral processing industry is going through a phase of technical change as dynamic companies are innovating by developing new smelting and teaching technologies to escape economic as well as environmental constraints. Rapidly evolving environmental regulatory frameworks in the industrialized countries and the prospects of their application, reinforced by credit conditionality in the developing countries, are stimulating this trend. Changed technological and environmental behaviour in this context is evident particularly in the large North American and Australian mining companies, but is becoming increasingly apparent in developing country-based companies operating in, for example, Chile, Brazil, and Ghana. However, it seems to be the new operators and dynamic private companies which are changing their environmental behaviour, while both state-owned enterprises and small-scale mining groups in developing countries continue, with some exceptions, to face constraints regarding their capacity to change environmentally damaging practices.

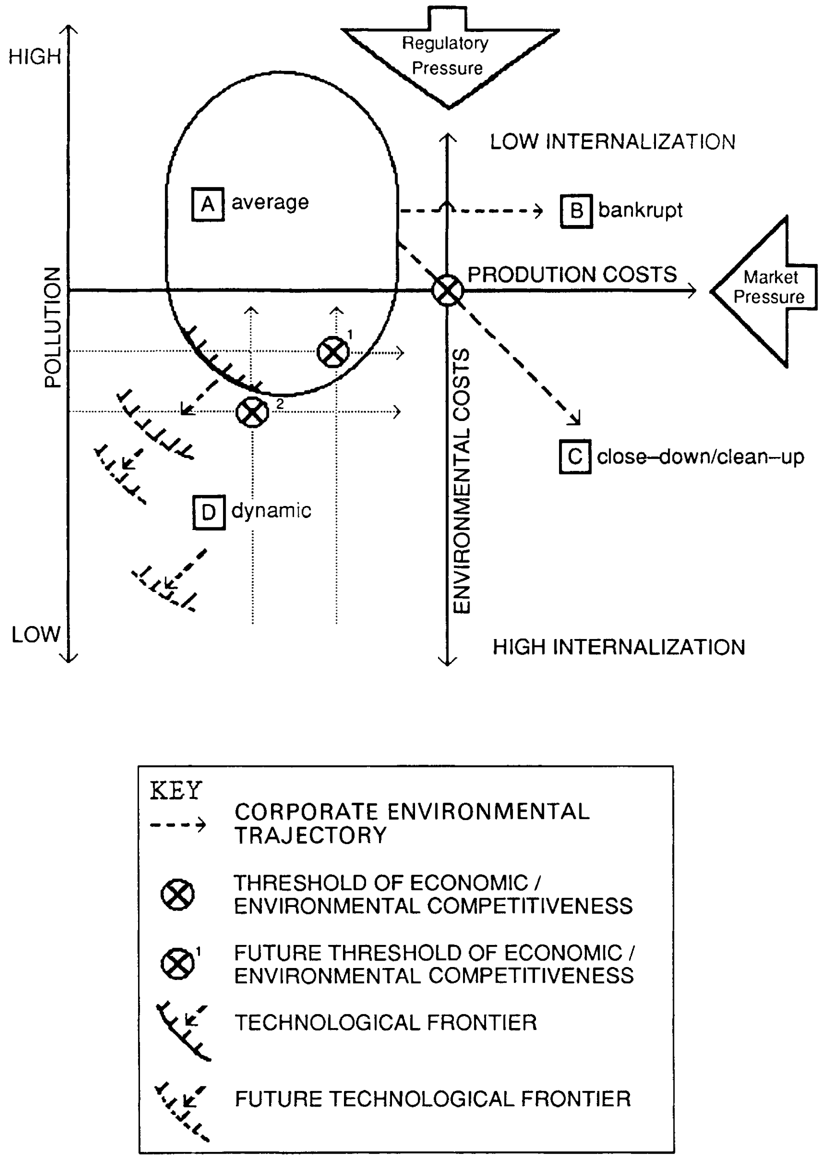
It is somewhat inevitable that only those companies which are dynamic and with new project development plans are in a position to invest in the research and development required to develop more environmentally sound alternatives, or to raise the capital to acquire them from technology suppliers. Nonetheless, after a long period of only conservative and incremental technical change, alternative process routes for mineral production are being developed which emerge as being more economically efficient as well as environmentally less hazardous. Furthermore, companies are beginning to sell their technologies, preferring to commercialize their innovations to recoup their research and development costs rather than sell obsolete technology and risk shareholders' scorn or retrospective penalties as environmental regulations are increasingly enforced by the developing countries. Some of those companies have pushed technology even beyond the bounds of existing regulations and as a consequence are seeking to increase regulation—particularly on a worldwide scale—because they can meet the requirements and use their new environmentally sound technologies to their competitive advantage.

There is evidence that improving the environmental management of a mining operation may not necessarily be detrimental to economic performance, and in some cases may even be of economic benefit. Furthermore, because environmental regulation is here to stay and bound to become more widely adopted, more stringent, and better enforced, who wins in the division of shares in the metals market will not be those companies that avoid environmental control (only later to be forced to internalize the high cost of having done so), but will be those companies that were ahead of the game, those that played a role in changing the industry's production 'parameters', and those that used their innovative capabilities to their competitive advantage.

The 'environmental trajectories' that different mining enterprises might take in response to environmental and market pressures are categorized in Figure 1. This diagram could be a planning tool for both companies and governments. It can help to evaluate the environmental and economic implications of applying different policies on corporate development.

The average mineral enterprise is competitive (*i.e.* to the left of the threshold of

Figure 1 Corporate environmental trajectories



economic competitiveness, X), although to a greater or lesser extent these enterprises produce environmental pollution and to a greater or lesser extent they have internalized the cost of the environmental degradation associated with their metal production, in response to the regulatory regime they are working within. (The threshold of 'environmental competitiveness' for a given regulatory context is also X and company operations in compliance have environmental trajectories in the quadrants below the horizontal axis.) However, market pressures—mainly a real decline in metal prices—combined with their economic inefficiencies, mean some of these companies are going bankrupt (a trajectory towards quadrant B).

They will leave a legacy of environmental pollution behind, and as in the case, for example, of COMIBOL (in Bolivia) and Carnon (in the UK), the burden of clean-up will fall on the state and society. Other companies will respond by innovating; moving into quadrant D; building into the new generation of technology both improved economic and environmental efficiencies (protecting themselves in the process from having to undertake relatively more costly add-on, incremental technical change and rehabilitation at later stages in their operation). Indeed, freed from the incumbent costs of retrofitting sunken investments, greenfield plants, in particular, display new levels of dynamism—the latest best-practice technology incorporates both improved economic and environmental efficiencies.

Nonetheless, there exists a growing group of companies which, if obliged to 'add-on' environmental controls in line with new regulations, would have to close down since the cost of the controls and clean-up required would render their operations uneconomic. The environmental trajectories of these companies is towards quadrant C. Currently, such examples are few, and it is difficult to differentiate between purely environmental factors and the range of other reasons as to why a company's cost curve starts increasing. However, as Figure 1 shows, that group would be expected to grow in number, since market and regulatory pressures combined will lower the threshold of economic and environmental competitiveness such that the average company will only survive in the new regime if it innovates. Even the previously dynamic companies will need to keep their environmental trajectories moving ahead of the encroaching threshold of economic/environmental competitiveness (X^1 and X^2).

Moreover, this implies a serious constraint on the regulatory process for two main reasons, which indeed distinguish mining companies from their manufacturing counterparts.

First, an implied close-down due to regulatory burden does not signal the end of environmental degradation. Pollution in metals production is not all end-of-pipe. Rather it heralds a new era—decommissioning, clean-up, and rehabilitation all pose significant environmental costs.

Second, in very few countries are bankrupt operators liable for the clean-up of their 'sins of the past'. The USA with its 'Superfund' liability laws, is an exception. Therefore, by moving the threshold of economic and environmental competitiveness, the overall extent of environmental degradation (particularly that without liability) increases. The policy challenge of the environmental imperative is therefore how to keep firms sufficiently dynamic to be able to afford to clean up their pollution and generate economic wealth.

Cleaning-up 'Sins of the Past' and Some Environmental Effects of Current Regulation

It is inevitable that those companies with long mining histories and extensive sunken investments in conventional mining and smelting facilities face the greatest technical, and therefore economic, challenges in cleaning-up their past facilities and reducing pollution from their ongoing operations. For example, some companies in central and south-west USA have found that dumps from past lead and copper mining operations have now created such serious acid mine drainage and toxic seepage that the government has placed them on its 'Superfund List' which obliges multi-million dollar sums being spent on their clean-up. The government then targets previous owners of the mine, often the richest, making them liable. If a company has already closed down a mine and written off the investment and perhaps is struggling in the current economic climate to manage a new project, it is clear that the costs of such a Superfund indictment, and the legal costs involved in answering it, can be quite crippling. For example, the Smuggler Mountain lead mining site in Colorado has a serious acid mine drainage and toxic seepage problem.[12] Its old lead and cadmium mine workings have apparently contaminated soils and ground-water in neighbouring residential areas, requiring a major clean-up operation, the secure repositioning of the toxic waste, and the establishment of monitoring mechanisms and pollution controls to prohibit further contamination. The cost of this project as estimated by EPA is currently US $4.2 million. Another Superfund listed mine site is the Silver Bow Creek Site in Butte Area, Montana, which for over one hundred years has been mined for silver, copper, gold, and zinc, resulting in severe water and soil contamination and the disruption of local ground and surface drainage water patterns. Currently, ground water is flooding the mine, becoming highly acidified in the process, and it is absorbing high concentrations of iron, manganese, arsenic, lead, cadmium, copper, zinc, and sulfate. This toxic seepage is currently threatening Silver Bow Creek, a major river in the region. The clean-up and remedial action is extensive and involves detailed diagnostic analysis and monitoring, water and tailings containment, water treatment, and soil treatment. Major mining companies and individuals, all past owners, are implicated, including Atlantic Richfield, AR Montana Corporation, and ASARCO. The clean-up cost is estimated to be in the region of several million dollars, to be confirmed once the precise plan of remedial action is determined. Another Superfund listed old mining site is that of Gregory Tailings in Colorado.[13] It was a gold mine, exploited during the late nineteenth century. Waste was placed in inadequate tailings dams and resultant leakages have contaminated local water supplies and soils with acidic waters containing copper, zinc, nickel, cadmium, and arsenic. The cost of the clean-up and water treatment has yet to be confirmed, but the strengthening of the tailings dam is estimated at over half a million dollars.

Although there may be economic opportunities associated with clean-up operations, such as the recovery of extra metal values from acid mine drainage, the commercialization of innovative water treatment methods, or the innovative use of tailings material, these may not be recouped by the mining company itself. Furthermore, companies which previously have had no links to the facility may be nervous of getting involved in case any liability is passed on to them.

This is one reason why some mining companies, which need to clean up their past operations, object to such retrospective regulation and suggest that such restrictions and control threaten their existence. An interesting and illustrative case is that concerning the respective responsibility of both government and industry for the management of mine closure and rehabilitation of old tin,

[12] EPA, 'Soil Clean-up of Smuggler Mountain Site', March, 1989.

[13] EPA, 'Gregory Tailings', July, 1986.

copper, and silver mining and smelting operations in Cornwall, UK. The observations that mine closure and rehabilitation were proceeding very inefficiently in the absence of an adequate regulatory framework have been borne out by the recent flooding of polluted acid mine water from the Wheal Jane mine near Truro, Cornwall (Warhurst, Mining and Environment Research Network Newsletter No. 2, April 1992). This highly acidic cocktail of dissolved metals, including copper, lead, cadmium, tin, and arsenic, entered the Carnon and Fal rivers at a rate of 2–4 million gallons a day and has spread throughout the surrounding estuary and coastal areas. The tourist industry and fisheries have been threatened and local well-water supplies destroyed.

Many have argued that legal responsibility for the mine discharge rests with the current owners, Carnon Consolidated (a management buy-out in 1990 from RTZ, which had bought it seven years previously from Consolidated Goldfields). However, the National Rivers Authority (NRA), the relevant UK regulatory body, publicly admitted that they were aware six months previously that this disaster could happen, but were unable to prevent it since their policy remit did not cover preventative action. The disaster occurred following the withdrawal of a government grant to the Wheal Jane mine which had always required pumping to prevent it from flooding. This meant that plans had to be shelved for turning the site into a golf course and leisure centre to help fund the pumping and maintenance costs at the mine of £100 000 per month. The consequent lack of finance forced Carnon Consolidated to turn off all the pumps on January 4, 1992. Since they had officially abandoned the mine, they denied responsibility for any ensuing flooding and pollution, a claim complicated by the fact that numerous underground shafts from other abandoned mines in the region also provided conduits for the polluted floodwater. The NRA had stated its intention to prosecute Carnon, but loopholes in the 1991 Water Resources Act meant there was no UK regulation to ensure that previous mine owners bear the financial liability for clean-up measures (unlike the Superfund legislation in the USA). Abandoned mines are specifically exempted from clean-up liability. Furthermore, the NRA itself has no remit or budget to treat pollution, particularly on this scale.

The NRA has opened an old dam to hold and treat the contaminated water. It is also analysing the potential of biotechnology to assist in the clean-up. For example, certain microbes bred in a slurry of cattle excrement have been shown to be metal-absorbing. Similarly, the creation of wetlands containing plants whose roots absorb metals is another possible long-term solution (see Cairns, Jr. and Atkinson's article for detail). However, such solutions are based on piecemeal research being undertaken in this area in different research institutions (*e.g.* the Colorado School of Mines in the USA, CANMET in Canada, and CETEM in Brazil) and none of these techniques has yet been proven commercially. The NRA is approaching the UK government to help pay for the clean-up, which may take decades and could cost over £1 million. The ultimate financial responsibility for mine clean-up in the UK may therefore lie with the tax-payer.

Environmentalists in the UK are pressing for the law to be changed so that companies which abandon mines are liable for any resulting pollution. However, it has been suggested that such a change would make life difficult for British Coal. The NRA has already analysed pollution from rising waters in old coal mine workings which are polluting rivers in South Wales and Yorkshire. They have established that the capital costs of treating the ten worst cases in Yorkshire are estimated at more than £10 million, and indeed as long ago as 1981 the Royal Commission on coal and the environment (the Flowers Report) recommended that the costs of remedial action for existing mines abandoned by the National Coal Board are met by central government. However, the tightening of UK laws to ensure that the bills for such pollution are paid by previous owners could have serious implications for the current government's plans to privatize the coal industry.

Similar pollution liability issues are also being faced by governments in developing countries currently engaged in privatizing their state mines—Bolivia, Peru, and Chile are cases in point. In Peru, for example, the legacy of past pollution, particularly from toxic tailings along the river below CENTROMIN's La Oroya and Cerro Pasco facilities, was preventing the government from selling those enterprises since the cost of clean-up rendered the investments uneconomic and unattractive to foreign capital. It was therefore agreed that the investment contract for buying these operations would protect the foreign partner from liability for previous environmental damage. They would start with a 'clean slate', as it were, with generous lag-times regarding the introduction of new environmental controls to reduce ongoing pollution. This means that the economic burden for clean-up falls on the state but, in developing countries, that means on society. Where capital is scarce cleaning up pollution problems from past decades affecting remote rural communities is of low priority.

This poses a policy dilemma. If the government does not waive liability for past pollution, the privatization schemes, vital to the future of the economy, will not succeed since foreign partners would not be interested relative to other available investment opportunities in mining. Moreover, international companies are particularly wary of falling prey to new retrospective liability laws and punitive tariffs in their import markets, particularly given the enormity of the clean-up involved. The responsibility for clean-up therefore lies formally with the state. Should loan-conditionality put pressure on the government to clean-up using precious capital resources? Should clean-up funds be established and incentives provided to prompt local industry to develop technical solutions? Should aid programmes provide technical assistance and training in clean-up? Should new investors be taxed for old pollution? Clearly the optimal outcome would be for government and donors combined to provide incentive programmes for local firms to seize the commercial opportunities available. Nuñez[14] clearly documents the extensive range of local capabilities which could be harnessed.

While 'Superfund' in the US may theoretically be successful, given that one is targeting local investors and traceable companies, it may be more difficult to target and litigate against previous mine owners (prior to nationalization) in developing countries. Searching out the foreign investors responsible for the many old and abandoned mines may be difficult since most have long since returned home, and local miners have limited resources, which makes the task of determining liability and enforcing clean-up a daunting one.

[14] A. Nuñez, 'Environmental Management in a Heterogenous Mining Industry—The Case of Peru', Paper presented at the second workshop to the Mining and Environment Research Network, Sussex, September 1992.

Companies which are being forced through environmental pressures to deal with pollution problems in their existing operations have been observed to react both defensively and in innovative fashion, depending on the challenges posed. For example, depending on the level of enforcement of the regulatory regime, some mining companies, particularly those operating in the developing country context, may prefer to pay financial penalties and fines for affected water and air quality. These may amount to less than the cost and effect involved in remedial action, such as water treatment, and considerably less than the costs involved in innovation or the incorporation of pollution controls. In some instances, as discussed above, the state pays those remedial costs itself and it is clear that it may be subsidizing the profit of foreign mining companies at the expense of environmental degradation. Sometimes that trade-off is influenced by the state's absolute dependence on the foreign company as a source of foreign exchange and government revenue.

Indeed, a number of mining companies perceive environmental regulation as imposing a cost burden on their operations that threatens their profitability. They may then enter into negotiations with the state to arrive at a 'stay of execution' or to devise a plan for implementing controls. However, as regulation becomes increasingly strict, backed up by more sophisticated monitoring devices and data processing, companies are being pushed to take remedial action in both the industrialized and developing countries. Data from the USA suggests trends that may be followed elsewhere. According to a US Congressional Report, sulfur dioxide emission controls have resulted in 'substantial capital expenditure' for US copper smelters and increased operating costs due to 'add-on' acid plants.[15] Present levels of environmental control entail capital and operating costs of between 10 and 15 cents per pound (*i.e.* 27–40¢ kg^{-1}) of copper. However, the USA has lost substantial smelting capacity. It has been reported that eight out of sixteen smelters operating in the US in the late 1970s have closed permanently, 'most because the capital investment to meet regulations was unwarranted given current and anticipated market conditions'.[16]

Moreover, the evidence from studies in the USA shows that environmental compliance does not distort significantly the economics of new mineral projects, but does place a considerable cost burden on ongoing facilities for either retrofitting or clean-up on mine and plant closure. The US Bureau of Mines has estimated direct 'environmental' operating costs for smelting facilities with emission controls. Retrofit capital costs were estimated to be of the order of $150 million per facility or 5.6 cents per pound (15¢ kg^{-1}) of copper produced.[17] According to Coppel[15] the overall cost penalty, including capital invested, to the producer for implementing the new smelter and sulfur dioxide capture facilities was estimated to be 7.5 cents per pound (20¢ kg^{-1}) after deductions of 1.3 cents per pound (3.5¢ kg^{-1}) of acid credit. The operating costs for individual smelters ranged from 10 to 15 cents per pound (27–40¢ kg^{-1}) of copper, and the average

[15] N. Coppel, 'Worldwide minerals and metals investment and the environment, 1980–1992', unpublished report for RTZ Corporation Plc, August, 1992.

[16] Copper Technology and Competitiveness, Office of Technology Assessment, Congress of the US, 1988, p. 16.

[17] US Bureau of Mines, 'Copper', Annual Report, 1990, p. 28.

operating cost in 1987 was 12.3 cents per pound (33¢ kg^{-1}). Of this amount, 26% or 3.2 cents per pound (8.6¢ kg^{-1}) was calculated by the US Bureau of Mines to be the cost burden of compliance with environmental, health, and safety regulations.

It is highly like that regulation in developing countries will follow a similar pattern. An interesting example is the ALCAN bauxite mine and alumina plant in Jamaica. Foreseeing impending environmental regulation and responding to public concerns in its home country of Canada, ALCAN supported a local university department to develop an innovative solution to the disposal of the red mud sludge from its bauxite mining operations. Previously, the sludge was dumped in a large catchment pond, but toxic seepages into surrounding soils and groundwater had been reported. The university developed a process called red-mud stacking which involved sun-drying of much of the moisture content of the sludge and stacking of the material into much less obtrusive piles, which indeed as bricks may have further use within the plant site.[18] A similar technology was introduced by ALCAN at the Vaudrevil alumina plant in Quebec in 1989.[19]

However, this technology neither seems to offer a solution to the toxic seepage of previously dumped slurries nor is it a solution to pollution *per se*. It appears to replace water pollution by dust pollution which is less stringently regulated against. Moreover, a change in the production process to facilitate the recovery of caustic soda from the 'mined' dry mud stacks means that a greater amount of that chemical is discharged than in the previous disposal method. This means that the dust pollution, plus overflows from those parts of the dry mud stacks which become water-logged during tropical rain showers, may cause a greater toxic hazard than previous low level seepages.

Dynamic Innovators—Technical Change to Improve Environmental Management

Although some mining companies resist the application of environmental regulation to their existing operations, a growing number of dynamic innovative companies are making new investments in environmental management because they see an evolution toward stricter environmental regulation. Free of the encumbrance of sunken investments in pollutant-producing obsolete technology or with significant resources for research, development, and technology acquisition, they have chosen either to develop more environmentally sound alternatives or to select new improved technologies from mining equipment suppliers, who are themselves busy innovating. Increasingly, these new investment projects are incorporating both improved economic and environmental efficiencies into their new production processes, not just in terms of new plant or items of technology, but also through the use of improved environmental management practices. Some examples of these are discussed below in three categories: smelter emissions, gold extraction, and waste management.

Smelter emissions. **Inco Ltd.**: At one time one of the world's highest cost nickel producers, Inco was until recently the greatest single point source of environmental pollution in North America. This was due to its aged and inefficient reverberatory

[18] D. R. Kelly, Personal Communication, Alcan International Ltd., Montreal, 1990.
[19] US Bureau of Mines, 'Bauxite, Alumina, Aluminium', Annual Report, 1989, p. 6.

furnace smelter technology which spewed out excessive tonnages of SO_2 emissions. Inco Ltd. had reached the limit of improving the efficiency of this obsolete technology through incremental technical change at the same time as the Ontario Ministry of the Environment began an intensive SO_2 abatement programme to control acid rain. These factors prompted Inco to invest over 3000 million Canadian dollars (C$) in a massive research, development, and technological innovation programme.[20]

Under the Canadian acid rain control programme, Inco is required to reduce SO_2 emissions from its Sudbury smelter complex from its current level of 685 000 to 265 000 tonnes per year by 1994: a 60% reduction. To achieve this, Inco plans to spend C$69 million to modernize milling and concentrating operations and C$425 million for smelter SO_2 abatement. The modernization process will include replacement of its reverberatory furnaces with a new innovative oxygen flash smelter, a new sulfuric acid recovery plant, and an additional oxygen plant. By incorporating two of these flash smelters the company plans to reduce emissions by over 100 000 tonnes per year in 1992, and by 1994 to achieve the government target levels of 175 000 tonnes per year. Other environmental benefits include a cleaner, safer workplace environment.[21]

Inco is now one of the world's lowest cost nickel producers and again, like other dynamic companies that are responding to environmental regulation through innovation, Inco is seeking to recoup research and development costs through an aggressive licensing effort in other copper and nickel processing countries. More than 12% of Inco's capital spending during the last ten years has been for environmental concerns.[15]

Kennecot—Utah, USA: A new smelter project has recently been launched by Kennecott Corporation (RTZ) with the dual aims of setting a new standard for the cleanest smelter worldwide and improved cost efficiencies in processing its ore. Advantages include the capture of 99.9% of sulfur off-gases (previous levels were 93%). Sulfur dioxide emissions will be reduced to a new world best-practice level of approximately 200 pounds (*i.e.* 75 kg) per hour, less than one twentieth of the 4600 pounds (1716 kg) per hour permissible level for Utah's current clean-air plan. The investment is US $880 million, resulting in 3300 new construction jobs and the investment of US $480 million in local companies through project development contracts.

The proposed Garfield smelter will expand the concentrate processing capability to the level of mine output (about 1 million tonnes of copper concentrate per year) at more than half previous operating costs. It represents the first-time application of oxygen flash technology to the conversion of copper matte to blister (details are based on an excerpt from a Kennecott Corporation press release, March 11, 1992). The two-step copper smelting process consists of smelting furnaces which separate the copper from iron and other impurities in a molten bath, followed by converting furnaces where sulfur is removed from the molten copper. A new technology known as flash converting will then be utilized in the second step of the process at the new smelter. This unique technology was developed by Kennecott in co-operation with Outokumpu Oy, a Finnish

[20] R. Aitken, Personal Communication, Inco Ltd., 1990.
[21] *Min. J.* (*London*), 23 February, 1990.

company and a leader in the supply of smelting technology. Essentially the new technology eliminates the open air transfer of molten metal and substitutes a totally enclosed process of producing molten metal. 'Flash converting' has two basic effects: first, it allows for a larger capture of gases than the current open-air process; second, it allows the smelter's primary pollution control device—the acid plant—to operate more efficiently. The smelter will include double-contact acid plant technology.

There will be other environmental benefits from the new smelter as well. Water usage will be reduced by a factor of four through an extensive recycling plan. Pollution prevention, workplace safety, and hygiene and waste minimization will be incorporated into all aspects of the design. In addition, the smelter will generate 85% of its own electrical energy by recovering energy as steam from the furnace gases and emission control equipment. This eliminates the need to burn additional fossil fuel to provide power. The new facility will require only 25% of the electrical power and natural gas now used per tonne of copper produced.

The copper refinery's planned modernization and expansion modifications include major electrical system changes, material handling system improvements, and new electro-refining cells. In addition, a new state-of-the-art precious metals refinery will be built. The refinery will be able to process the entire output of the new smelter.

Gold Extraction. **Homestake's McLaughlin Gold Mine, California**: The McLaughlin gold mine, opened in 1988, is perhaps the best example of a new mine and processing facility which has been designed, constructed, and operated from the outset within the bounds of what is probably the world's strictest environmental regime. Environmental efficiency is built into every aspect of the gold mining process, in terms of innovative process design criteria, fail-safe tailings and waste disposal systems, and extensive ongoing mine rehabilitation and environmental monitoring systems. The mining operation therefore combines innovative technologies with 'best practices' in environmental management. The most interesting conclusions drawn by the author from site visits and discussions with the firm's environmental officers is that most of these environmental management initiatives have not resulted in any substantial extra cost, and indeed many of these procedures have apparently improved the efficiency of the mine, affecting positively the economics of the overall operation.

For example, before the mining operation began, an extensive environmental impact analysis and survey were undertaken. All plant and animal species were identified and relocated, ready for rehabilitation on the completion of mining operations. The survey also measured in detail prior air, soil, and water quality characteristics and flow patterns to provide the baseline for future monitoring programmes. Assaying was undertaken not just of the gold ore, but also of the different types of gangue material and waste, so that waste of different chemical compositions could be mined selectively and dumped in specific combinations to reduce its acid mine drainage generating capacity. Local climate conditions were evaluated to determine the frequency of water spraying needed to reduce dust, and evaporation rates were evaluated to control the water content and flood risk potential of tailings ponds. The tailings ponds themselves are constructed on specially layered impermeable natural and artificial filters, with high banking to prevent overflow, and with secondary impermeable collecting ponds in the rare case of flooding.

Unlike other mining projects where rehabilitation is seen as a costly task to be undertaken at the end of a mining operation, often when cash flows are lowest as ore grades decline, at Homestake rehabilitation began immediately and is an ongoing activity. Not only does this serve to spread expenditure more evenly over the life of the mine, but it enables the more efficient utilization of truck and earth moving capacity as well as of relevant construction personnel. This means that as soon as work piles have reached a certain pre-determined dimension, soils (previously stripped from the mine area and stored) are laid down and revegetation is begun. Although mining has been under way for only three years, extensive areas of overburden and waste have already been successfully revegetated—immediately reducing environmental degradation and negative visual impacts. In addition to these inbuilt environmental control mechanisms, Homestake Mining Company has sophisticated environmental monitoring procedures in place. This means that seepages, emission irregularities, wildlife effects, and vegetation effects can be detected and rectified immediately, which in the long-term reduces the risk of expensive shut-down in operations, costly court cases (*e.g.* if water toxicity results), and the need for treatment technologies.

Waste Treatment. In the minerals industry, considerable waste is produced in the form of overburden, marginal ore dumps, tailings, and slags. Much of the toxicity associated with that waste is a direct result of the loss of either expensive chemical reagents, or metal values. Currently, public policy has not taken up the challenge to promote and direct research and development in the area of waste reduction and treatment innovations. One interesting area is the application of biotechnology to waste treatment[22]

Water Treatment at Homestake's mine at Lead (S. Dakota, USA): Homestake Gold Mining Company turned regulatory pressure to clean up a cyanide seepage problem to its advantage. Its own research staff developed a proprietary biological technique to treat the effluent which led to the recovery of local fisheries and water quality in the mine's vicinity at Lead, North Dakota, USA.[23] It is now actively commercializing the technology which could be widely applied at other gold leaching plants.

Water Treatment at Exxon's Mine, Los Bronces (Chile): A mining project in Chile, Los Bronces, is to be expanded into one of the largest open-pit copper mines in the world and consequently required the stripping of very large tonnages of overburden and low-grade ore. Before mine development, the Chilean government warned Exxon that it would be imposing financial penalties for the water treatment costs on account of expected acid mine drainage from the overburden of low-grade ore dumps into the Mantaro River, the source of Santiago's drinking water. This threat became the economic justification for a

[22] A. Warhurst, 'Metals Biotechnology for Developing Countries and Case Studies from the Andean Group, Chile and Canada', Resources Policy, March, 1991, pp. 54–68.

[23] D. Crouch, Personal Communication, McLaughlin Mine, CA, 1990.

bacterial leaching project at the mine. Indeed, the feasibility of this bacterial leaching project was particularly illustrative of the profitability of leaching copper from waste at the same time as prohibiting otherwise naturally occurring pollution (acid mine drainage). Over a billion tonnes of waste and marginal ore below the 0.6% copper cut-off grade are expected to be dumped during the project's lifetime. The waste would have an average grade of 0.25% copper and would therefore contain a lucrative 2.5 million tonnes of metal worth approximately US $\$3.5 \times 10^9$, at 1985 prices.[24] The study demonstrated that with a 25% recovery, high quality cathode copper could be produced profitably, at 39 cents per pound (*i.e.* 105¢ kg^{-1}), by recycling mine and dump drainage waters through the dumps over a twenty-year period. This was shown to have the double advantage of both extracting extra copper and avoiding government charges for water treatment. At the same time both investment and operating costs were less than two-thirds of estimated costs for a conventional water treatment plant, which would not have had the benefit of generating saleable copper. The Los Bronces mine thus demonstrates the potential economical benefits of building environmental controls into mine development.

In conclusion, these few examples suggest that dynamic companies are not closing down, re-investing elsewhere, or exporting pollution to less restrictive developing countries; rather they are adapting to environmental regulatory pressures by innovation and by improving and commercializing their environmental practices at home and abroad.

4 Policy Implications for Mineral Producing Countries

Technical Change and the Environmental Trade-off

Evidence suggests that, at least during the 1980s, environmental policies have not been a major factor in determining where a mining company will target exploration and subsequent investment activities. Geological potential remains of primary importance, which is not to underestimate that in some cases the approval and permitting process is a major cost of compliance. (Johnson[5] ranked corporate criteria in selecting countries for exploration. See also Eggert.[6]) This would suggest that developing countries are not seen as pollution havens and that the industrialized countries' environmental regulations are not stifling new mining investment. Indeed, there are currently several new gold projects in the process of development in California, which has probably the world's strictest environmental regulatory regime. Although environmental policies may not negatively influence the investment activities of dynamic adaptive mining companies, the latter still seek to play a role in determining the detail and focus of relevant legislation so that new regulatory frameworks also reflect, as far as possible, their corporate interests. During preliminary fieldwork by the author in North America and Europe it became evident that this task was an important function of many of the companies' newly appointed environment vice presidents,

[24] A. Warhurst, 'Employment and Environmental Implications of Metals Biotechnology', World Employment Programme Research Working Paper, International Labour Organization (ILO), Geneva, March 1990, WEP 2–22/SP.207.

directors, and environmental affairs representatives. For example, the Environmental Vice President of Inco sits on Canada's high level Environment and Economy Committee, and the Environmental Director of Homestake Mining Corporation sits on the Environmental Committee of the American Mining Congress—which works closely with the US Environmental Protection Agency and lobbies government for tariffs on metal imports originating from countries with poor environmental performance.

If one understands the new environmental pressures being placed upon the mining industry in the industrialized countries in the context of hard-won survival following a prolonged period of low metal prices, which gave significant market advantages to their lower cost competitors in the developing countries, then it is possible to understand the recent lobbying by some firms for industry-wide international environmental standards. Although international standards may not pose too much of a problem for the economics of new mining projects in the developing countries, our analysis suggests there could be major costs incurred by any older ongoing operations. Controlling the latter's pollution problems would in most cases require major water treatment plants, strengthening and rebuilding tailings dams, add-on scrubbers, and dust precipitators, *etc*.

The imposition and strict regulation of international environmental standards could make some developing countries' mineral production uneconomic, thus swapping one social cost (environmental pollution) for another (unemployment, poverty, and indeed clean-up, given the absence of liability laws). This is not to dispute the need for improved environmental controls, particularly in the developing countries, but rather to show the complexity of the process by which the underlying power structure of the industry can help to determine the environmental agenda.

Most planned mines (including existing mine expansions) and available reserves are located in the developing countries. Furthermore, after a period of mineral production monopolized by state-owned mining companies (with some exceptions), many developing countries are now embarking upon a phase of liberalization and have promulgated a number of laws and incentives to promote foreign investment. In many cases those investments are being partly financed by credit which is conditional upon good environmental practice and prior environmental impact analysis. The upshot is that this trend in technical change may be to the benefit of the developing countries in that it may enable them to reduce the trade-off between higher environmental costs and lower production costs. This may mean that at least in the case of new mineral projects there may be a wider range of more environmentally sound and economically efficient technologies available to them.

Indeed, new flexible-scale, lower-cost, less-hazardous hydrometallurgical (leaching) alternatives to conventional smelting may further be to the advantage of developing countries, improving value-added from their mineral production. For example, processing right up to the stage of a final saleable metal product can be undertaken at the mine site—while in conventional process routes a smelter will require feed from at least ten large mines for full capacity utilization, and ore may have previously been exported to foreign smelters with consequent loss of by-products and entailing charges for the treatment of pollutant elements.

However, this new prospect of environmental security may have its own costs which require careful analysis. For example, depending how technology transfer agreements are drafted and managed, such new 'environmentally friendly' investment may herald indebtedness, bankruptcy of local equipment suppliers and engineering firms, and the loss of employment, *etc*., reinforced by aid conditionality. On the other hand, smelting, concentration, and leaching innovations are being developed by international companies, such as Outokumpu, Mitsubishi, Kennecott, Inco, Cyprus Mines, and Homestake, which are adapted to new and prospective regulations in the industrialized countries. These trends may oblige developing countries for both economic and environmental reasons to export only semi-processed minerals or raw materials, reinforced by credit conditionality, new international regulatory agreements, and trade tariffs imposed on imports of metals produced not using a pre-determined 'Best Available Technology'.

Technology Policy for Environmental Management

Environmental behaviour correlates most closely with a company's capacity to innovate, rather than its size, origin, scale, and scope of operations or ownership structure. For example, government policy over time has resulted in a failure by state enterprises to re-invest capital in human resource development, repairs and preventative maintenance, research and development, and technology development. Managers became bureaucrats rather than entrepreneurs.[25] This factor, combined with cumulative inefficiencies, a poor waste management strategy leading to metal and reagent losses, and scarce resources, means that environmental mismanagement is endemic. It is a structural problem and one not readily solved by recourse to regulation, punitive tariffs, or even the simple act of purchasing an environmental control technology. The cases of COMIBOL (Bolivia) and MINEROPERU and CENTROMIN in Peru bear witness to this, as does the case of private companies such as Carnon Consolidated in the UK. However, CODELCO and ENAMI, the state enterprises of Chile, have invested in developing their innovative capabilities both within the industry and through historically close links with local research and development institutions and universities. Although new regulations currently pose a significant technological challenge to these companies, efforts are being made to develop the required human resources and to implement substantial technical change. For example, CODELCO is now at the forefront of metals biotechnology and has made considerable investments in new solvent–extraction/electrowinning technology. In addition, ENAMI is planning to replace its reverberatory furnaces with modern flash-smelting technology at an estimated cost of $300 million, 'largely motivated by the need for environmental improvements'.[15,26] Environmental degradation from small 'garimpeiro'-type operations is also related to the miners' incapacity to innovate through a lack of access to capital, technology, skills, and information. Scale further complicates the choice of optimal low-waste, high metals-recovery technology. With few exceptions, however, it is the private

[25] R. Jordan and A. Warhurst, 'The Bolivian Mining Crisis', Resources Policy, March, 1992.
[26] US Bureau of Mines, 'Copper', May–June, 1991.

sector which has so far shown itself to be most innovative and therefore most capable of improving environmental management. In several cases improved environmental management would have been brought about irrespective of regulation due to market pressures to introduce new, more efficient, low-waste technical change.

This is not an argument against regulation but rather to recommend a more sophisticated public policy approach through first, the definition of regulatory goals—something to aim at—and second, an informed technology policy to guide and stimulate those companies along the fastest, more efficient route to achieving those goals.

This technology policy could include a detailed technology-transfer strategy, tax relief on research and the training of engineers and managers in environmental technology, government grants for collaborative inter-industry and university–industry research projects, and information dissemination programmes regarding the moving technological and regulatory frontiers. It requires training for regulators so that they are informed disseminators of information about environmental technology. Finally, it requires the provision of new lines of credit—in banks and donor agencies—to promote investment in the development, commercialization, acquisition, and improvement of environmental control technologies.

Another factor which reinforces the need for trained and informed environmental regulators relates to their ability to determine corporate environmental trajectories as a response to regulation. Figure 1 provides a planning tool which would enable regulators to plot corporate environmental trajectories against changing thresholds of economic competitiveness and environmental compliance over time. For example, it is suggested that fast changing 'incremental' regulation would tend to promote add-on incremental technical change—pushing cost-curves upwards rather than down. As a consequence, and evidence of this is slowly emerging, many mining companies, particularly those with large sunken investments, are on a trajectory heading towards close-down and certainly reduced competitiveness. With the growth of market and regulatory pressures that group of companies heading towards bankruptcy, close-down, project delay, or cancellation is also likely to grow in number. At the same time, the clean-up problem posed by the closing-down of those companies would also be expected to grow in scale and severity, as evidence drawn for Peru[14,27] and Bolivia[28] demonstrates. Given the difficulties involved in retrospective clean-up legislation in terms of cost assessment, litigation, and technical complexity, it would seem desirable for government to avoid such a scenario. This could be done on the basis of sound prediction and planning, either through imposing a levy on operators as the mine nears exhaustion/abandonment (whichever is sooner) to cover clean-up and rehabilitation, or through promoting tax and other incentives for the required investment in clean-up. For new investments, reclamation bonds, or equivalent mechanisms can promote environmental management from the outset, and a carefully planned waste management

[27] C. Morgan, 'The Privatisation of State Industries—Guidelines on Environmental Liabilities: Third Newsletter of Mining and Environment Research Network', December, 1992.

[28] Loayza (1992).

programme from the start of operations will assist in spreading the costs and reducing potential hazards.

The 'polluter pays principle' only holds if the polluter can survive in order to pay. The capacity to innovate, including capabilities in environmental management, is one key factor in determining a firm's ability to survive, grow, and continue to generate wealth from metals production.

The Role of Technology Transfer in an Environmental Management Policy

Technological and managerial capabilities are not required just to deal with new and emerging technologies, they are also vital to an environmental management strategy using existing technology due to pervasive inefficiencies. Technology transfer and technology partnership through joint venture arrangements is one way to overcome these constraints, particularly in the developing country context, although such strategic alliances are emerging in all the major mineral producing countries. Recent examples of collaborative partnerships in innovation include: Outokumpu and Kennecott, Outokumpu and CODELCO, Cyprus Mines and Mitsubishi, and Comalco, Marubeni Corporation of Japan, and, the Chilean power company, Endesa.

However, there is a need to broaden the common concept of technology transfer to achieve the desired result of a real transfer of environmental management capability. Traditionally technology transfer has meant a transfer of capital goods, engineering services, and equipment designs—the physical items of the investment, complemented by training in the skills and know-how for operating the plant and equipment. Such transfers are often restructured in scope to match the 'step-increments' involved in add-on regulatory–response technical change.

New forms of technology transfer will need to go further to embrace: first, the knowledge, expertise, and experience required both to operate and manage technical change of an incremental and radical nature; and second, the human resource development and organizational changes involved in an overall approach to improve efficiency and environmental management throughout the process route, plant, and facility.

Many trans-national companies play a major role in the mining industry, usually contributing significant managerial and engineering expertise in joint ventures and subsidiaries. They usually limit their contribution in the light of the costs, capabilities, and work involved to fulfil the immediate needs of the specific investment project or physical item of technology transfer. Empirical research on other sectors demonstrates considerable potential to increase those contributions without adversely affecting corporations' strategic control over 'proprietary' technology.[22,29,30] What is required is a strategy of technology and enterprise targeting and a clear set of technology transfer objectives and financial

[29] A. Warhurst, 'Technology Transfer and the Development of China's Offshore Oil Industry', *World Development*, 1991, **19** (8), pp. 1055–1073.

[30] M. Bell, 'Continuing Industrialisation, Climate Change and International Technology Transfer', A report proposed in collaboration with the Resource Policy Group, Oslo, Norway. SPRU Report, December, 1990.

mechanisms to cover the extra costs involved over and above the investment and basic training budget.

There already exists a developed market and a range of commercial channels through which mine operators can purchase capital goods, engineering services, and design specifications; however, the market for knowledge, expertise, experience, and accelerated training programmes is less mature. Bilateral and multilateral agencies and development banks can play a major role in improving this situation. Such an approach was at the heart of the strategy of China's National Offshore Oil Corporation (CNOOC) which targeted specific major oil companies and required them under technology transfer agreements to transfer the capabilities to master selected areas of technology.[29] Another interesting example is the Zimbabwe Technical Management Training Trust. It was founded by RTZ in 1982 with the aim of training South African Development Community (SADC) professionals in technical management and leadership. It effectively combines academic and on-the-job training in both home and overseas operations, providing possibilities for accelerated managerial learning by being exposed to on-the-job problem-solving situations with experienced colleagues in a range of challenging technical scenarios. Although smaller in scale, this is a similar strategy to that designed by CNOOC to ensure that its trainees worked alongside experts, in different trans-national oil companies, in situations which ensured a 'mastery' of the technology rather than the knowledge of how to create it. RTZ absorbs the entire cost of the training and related MSc scholarship programme at the City of London Business School.

It would be quite feasible to build similar in-depth training programmes, concentrating on human resource development in environmental management, into many of the proposed and prospective mineral investment projects throughout the world. Investors and technology suppliers could be selected in part on the basis of their proven environmental management competence and their willingness to transfer it. It cannot be over-emphasized that all technology transfer and training has a set of costs for the supplier and these must be covered to ensure optimal results. The danger of not budgeting for these costs would be to resort back to a training programme in operational skills rather than in technology 'mastery' skills. The corporate partners, the government, donor agencies, or development banks could assist in finance. However, negotiating power regarding the precise objectives and scope of the programmes would be greater if governments, organizations, or firms contributed financially. This paper suggests that it is the capacity to effect technical change, not just the skill to operate an item of environmental control technology, which will ultimately determine the success with which firms build up competence in environmental management.

Moreover, referring back to our case study examples of best practice environmental management, the technical changes introduced illustrate the myriad of intangible practices which constitute sound environmental management. Of relevance to technology transfer policy is the fact that it is not the utilization of one specific technique, but rather a combination of technology, managerial approaches, work-place practices, and regulatory and monitoring frameworks, which explains the parallel achievements of improving economic efficiency and environmental performance. Most of this capacity would not be secret or proprietary to the firm. It is more a question of knowing what to ask for and then being prepared to pay the cost of the resources, time, and effort required for its transfer. This reinforces the need for mining enterprises to build up a range of technological and managerial capabilities as well as workers' skills. This also explains why in the developing country context the simple act of acquiring a new item of technology or an add-on piece of pollution control will not automatically lead to an expected increment of pollution reduction. The transfer of environmental technology does not lead to a transfer of environmental management capabilities unless training and broader human resource development programmes are built into the investment and an overall approach to improve efficiency and good housekeeping at the plant site is adopted. In the developing country context such change is best brought about when stimulated by donor agency requirements supported by credit, government commitment, and the participation in the investment project of a partner with proven competence in environmental management elsewhere.

A further public policy implication suggested by the preceding analysis is the need for a two-tier environmental management policy. There is one set of challenges for the on-going minerals industry, which must encompass the findings above regarding production inefficiency and its environmental consequences and the clean-up requirements on mine shut-down and plant decommissioning. Another set of challenges concerns the policy need to build environmental management into investment and expansion projects from the outset, which requires negotiation at the earliest stage with operators, equipment suppliers, and credit sources.

The public policy challenge is, therefore, how to keep firms sufficiently dynamic to be able to afford to clean up their pollution and generate economic wealth through innovation and sustainable environmental management practices. The achievement of improved production efficiency and environmental management, particularly in developing countries, will in turn be dependent upon the extent to which far-reaching technology transfer and training clauses are built into the joint ventures and new investment arrangements which characterize the industry, and whether banks, donor organizations, and governments demonstrate responsibility by providing the appropriate lines of credit and technical assistance in support of such objectives. Environmental regulation would be one element of that policy and would provide the goal posts for site-specific best practice in environmental management; and, technology policy to promote technical change through technology transfer and human resource development would lie at its heart.

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