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Alternative Forms of Mineral Taxation, Market Failure and the Environment

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Abstract

This paper examines the environmental effects of mineral taxes in a framework that recognizes the importance of rates and cumulative externalities and proposes an appropriate corrective tax. It concludes that mineral resources taxation should combine neutral taxes with a dynamic Pigovian type tax proposed in the paper. Such a tax resembles a specific tax plus an element that depends on the amount of remaining reserves. This resemblance means that, in practice, specific taxes may act as proxies for environmental taxes. The paper also points at complementarities and trade-offs between economic and environmental concerns that could arise in reforming mineral taxes.

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Summary

In recent years, a number of authors have examined the effects of mineral taxation on resource allocation, revenue yield and stability, conservation, and depletion dates. These studies have, however, assumed that mineral extraction involves no external effects (or environmental externalities) on other economic agents. As a result, they have not examined the nature of appropriate corrective taxes that may be required to ensure that mining firms take into account the social costs that they impose on others. Nor have they investigated the environmental effects that may be caused by various forms of taxes.

A notable exception is the paper by Schulze (1974), which explicitly incorporates the effects of cumulative environmental externalities in the firm's decisions and derives an appropriate corrective tax. Equally important, but not considered in the paper, are environmental externalities that depend on the current rate of mineral extraction. In addition, the paper does not examine the environmental effects of various taxes noted above within a framework that incorporates the cumulative environmental externalities that he develops.

This paper explores the environmental effects of various mineral taxes in a framework that assumes that extraction of minerals involves environmental externalities that depend on rates as well as cumulative amounts of extraction. It proposes an appropriate corrective tax for an extractive firm that generates such externalities. The results of the paper indicate that neutral taxes, such as the resource rent tax, need to be combined with appropriate corrective taxes, such as the one proposed in this paper, to ensure efficient resource allocation. In the absence of such corrective taxes, neutral taxes may perform worse (especially from an environmental point of view) than nonneutral taxes, such as specific taxes, because the latter partially offset the impact of environmental externalities on resource allocation. Finally, the paper finds that while changes in nondistortionary taxes have no impact on amounts of environmental externalities, changes in distortionary taxes do.

I. Introduction

Interest in taxation of mineral resources dates back to Gray (1914) and Hotelling (1931). In more recent years a number of authors, including Burness (1976), Levhari and Liviatan (1977), Fisher (1981), and Heaps (1985) have examined the effects of mineral taxation on resource allocation, revenue yield and stability, conservation, and depletion dates. Some of the important conclusions from these studies have been that taxes such as a Brown tax, a resource rent (with discount rate equal to investor's rate), and a pure profits tax (that allows no depletion allowances and provides only for economic depreciation allowances) are nondistortionary. The studies have also concluded that taxes such as a franchise tax, a specific tax on output, an ad valorem tax, or a property tax are distortionary. These studies have, however, investigated the effects of these taxes on the assumption that mineral extraction involves no external effects (or environmental externalities) on other economic agents. As a result, they have not examined the nature of appropriate corrective taxes which may be required to ensure that mining firms take into account the social costs that they impose on others. Nor have they investigated the environmental effects that may be caused by various forms of taxes. A notable exception is the paper by Schulze (1974) which explicitly incorporated the effects of cumulative environmental externalities in the firm's decisions and derived an appropriate corrective tax. Cumulative externalities are often important in mineral extraction, and are often related to previous amounts of extraction. They include tailings, risks of landbursts, or risks of landslides. Equally important, but not considered by Schulze, are environmental externalities that depend on the current rate of mineral extraction and often include road cuts, dust particles, air pollution, debris, or effluent discharge. In addition, Schulze did not examine the environmental effects of various taxes noted above within a framework that incorporates cumulative environmental externalities that he developed.

This paper examines the environmental effects of various mineral taxes in a framework that assumes that extraction of minerals involves environmental externalities that depend on both <u>rates</u> as well as <u>cumulative</u> amounts of extraction. The paper also proposes an appropriate corrective tax for an extractive firm that generates such externalities. The results of this paper indicate that neutral taxes, such as the resource rent tax need to be combined with appropriate corrective taxes, such as the one proposed in this paper, in order to ensure efficient resource allocation. In the absence of such corrective taxes, neutral taxes may perform worse (especially from an environmental point of view) than nonneutral taxes such as specific taxes because the latter taxes provide some partial offset to the impact of environmental externalities on resource allocation. Finally, the paper finds that while changes in nondistortionary taxes have no impact on amounts of environmental externalities, changes in distortionary taxes do.

The rest of the paper is organized as follows: Chapter II examines the various ways in which market and policy failures can affect environmental externalities; in Chapter III a framework for analyzing environmental externalities and an appropriate corrective tax are developed; the effects of various taxes on recoverable reserves, depletion dates, rates of environmental externalities, and cumulative amounts of environmental externalities are presented in Chapter IV; Chapter V concludes the paper; and Appendices I and II provide a mathematical appendix to Chapter III and an analysis of the effects of various mineral taxes in a selected number countries, respectively.

II. Extraction of Mineral Resources and Environmental Degradation

The extraction of mineral resources involves the use and degradation of environmental assets. When, in addition, there is market failure, including the presence of externalities or monopoly, the environmental degradation leads to inefficient allocation of resources. Some public policies provide explicit or implicit subsidies to certain inputs or outputs which may result in excessive use of environmental resources compared with what would obtain in their absence. When such policies are pursued in the presence of environmental externalities, this often exacerbates the extent of the externalities. Policymakers in many countries, including countries highly dependent on natural resources, have increasingly been concerned with the question of whether or not extraction rates of natural resources are sustainable. Concern has been expressed, for example, that in an effort to address balance of payments problems, devaluation of the currency for some countries which are highly dependent on extractive industries for their foreign earnings may lead to faster-than-sustainable rates of extraction. 1/ In this section, we attempt to answer the questions why and how the extraction of mineral resources can cause environmental degradation and how the rates of extraction of such resources can impact on the sustainability of a country's growth and development.

1/ While there may be some obvious cases where these policies may lead to unsustainable growth and development strategies, in general the net affect of the policies on sustainability are complex and often ambiguous.

1. Environmental externalities

Public concern with environmental degradation in mineral extraction can stem from two related sources. 1/ First, environmental degradation can arise from use of privately or publicly owned environmental resources without any spillover or external effects. For example, minerals often occur on land that could be used for recreational, agricultural, or other private or public purposes. In extracting mineral resources such land often has to be forgone and/or degraded, and rendered less suitable for other uses. Thus, trees often have to be cleared, top soil removed, and at the end of the extraction period a huge hole, and large amount of tailings may remain (unless the land is suitably reclaimed). To the extent that no external effects are involved in such cases, corrective public policy intervention is unwarranted except, perhaps, to provide incentives to firms involved with a view to encouraging them to employ extractive processes and technologies that are least environmentally degrading. 2/

Second, public concern over environmental degradation can stem from spillover effects from the extractive processes of firms into the environmental or other assets of some other economic agents or the public. For example, in coal and other mining operations, surrounding downwind areas, which are not owned by mining firms, are often subject to dust particles emanating from the mines. In addition, acid run-off in processes that use mercury, such as in gold mining, can adversely affect streams. In such cases, not only are privately owned environmental assets degraded by their owners, but the amount of environmental degradation tends to be excessive compared with what would obtain in the absence of spillovers.

These environmental externalities depend, among other things, on the type of mineral being extracted, on whether mining is onshore or offshore, and on the methods and technologies of extraction used. The major form of environmental externalities in onshore mineral extraction are surface water pollution, pollution of aquifers, land degradation, and air pollution. For example, during wet seasons, or when there is heavy rainfall, excess water

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1/ The terms environmental degradation, pollution, or environmental externalities are often used interchangeably and can be a source of confusion. In this paper the terms environmental degradation or pollution are used to refer to the use or consumption of any environmental assets or services thereof whether or not there are external or spillover effects. On the other hand, the term environmental externalities is used to refer to external effects associated with the use or consumption of environmental assets or services. All forms of environmental degradation may be of some concern to environmentalists. However, from an economic point of view it is the degradation associated with externalities that requires public policy intervention.

2/ Such incentives, if provided in competitive and efficient markets, could, however, drive a wedge, albeit one that gives rise to higher levels of environmental quality.

together with underdeveloped tailings and earth road cuts can result in waste streams which are high in suspended solids. As a result of the turbidity and sediment deposition the water courses of the mined areas often become serious problems. In addition, landslides, landslips, or landbursts could occur with adverse impact on surrounding land and habitats. In dry seasons (and in the case of coal mining in any season) the surrounding downwind area is polluted by sulfur dioxide, arsenic, or dust particles. 1/ The extent of these environmental externalities often depend on both rates at which extraction takes place, and cumulative amounts of mineral ores already extracted. Thus, the extent of road cuts and the waste emissions into streams or air often depend on the rates of extraction. On the other hand, the amount of tailings, and the risks of landslips or slides depend on cumulative amounts of mineral ore already extracted. 2/

In offshore mining, the major environmental externalities are also physical rather than chemical. Thus, in petroleum exploration and in mining, the construction of platforms, the installations of pipelines, or the debris and effluent produced during extraction can disturb the natural marine habitat and fishing activities which, however, often can be recolonized after mining ends. Where such operations are near coastlines, the turbidity and deposition of mud often depreciates the aesthetic value of the coastline and beaches. As in the case of onshore mining, the extent of these environmental externalities often depend on both rates and cumulative amounts of extraction.

2. Common resource problems

Two types of externalities are often associated with problems of common resources in the extraction and exploration of oil and natural gas. Even though not directly related to issues of environmental degradation, such externalities can have significant effects on the optimal rate of exploration and extraction of these resources and, therefore, indirectly on the amount of environmental degradation. 3/ First, is the case of external diseconomies that occur when drilling from a common pool. The

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1/ For a more detailed discussion of environmental degradation in mining operations see Higgins (1987), Lind (1987), Jaru-ampornporn (1987), and Malik and Yusof (1984).

2/ Although there are many descriptions of environmental damage in mineral extraction, none, to the best of our knowledge, have made the analytical distinction between the rate of and the amount of cumulative environmental degradation. As shown in Section III below, this distinction is important and calls for different corrective measures from those of standard static analysis.

3/ These common resource problems are, of course, not confined to nonrenewable resources. For example, the problems exist in ocean fishing where exclusive private rights are often not feasible in part because commercial species are migrants. For a detailed discussion of common resource problems, see Smith (1977).

basic problem in this case is that even though the pool is a common property each driller does not consider the effects of his drilling on others (and to the extent that he does, there is competitive drilling) and his private benefits exceed social benefits with the result that there is an excessive amount of drilling. Second, is the case of external economies that occur when the success or failure of an initial drill conveys valuable information (for which the initial driller is not compensated) to owners of neighboring plots of land: the result is that the amount of initial drilling will be less than optimal.

A Pigovian tax is required to "internalize" the negative externality in the first case, while a subsidy to the initial driller would compensate for the positive externality in the second case. If, in the first case, in addition to these common resource externalities, there are also environmental externalities related to the drilling process such as those described in Section 1 above, then, unless corrective measures are taken, there will be excessive environmental degradation over and above the amount that would result without the external diseconomy. Conversely, in the second case, the amount of environmental degradation will be less than the amount that would obtain in the absence of the external economy. In either case, two types of corrective measures are required: first, to correct for the externality arising from the common resource problem; and second, to correct for any environmental externalities involved in the drilling process.

3. Monopoly

Market structure can affect the extent and the amount of environmental degradation caused by an extractive firm primarily because it can influence the rate at which minerals are extracted and the cut-off points of extracting resources. For example, if amounts of environmental externalities from mineral extraction depend on rates of extraction and/or cumulative amounts of resource extracted, then amounts of environmental externalities will tend to depend on the elasticity of the demand function for mineral output as well as the nature of extraction costs. In particular, if the elasticity of the demand is constant and extraction costs are zero, then the rate of environmental externalities of a monopolist would be the same as that under competition. 1/ But in the more realistic cases where the elasticity of the demand increases over time (reflecting, among

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1/ This follows from the fact that under the stipulated assumptions the equilibrium rate of output for a monopolist requires that $MR_t = MR_{t+1}/1+r$, where MR_t is the marginal revenue at time t, and r is the interest rate. With a constant demand curve, $MR_t = \beta P_t$, where $1/1-\beta$ is the elasticity of demand. It follows that the equilibrium rate of output for a monopolist implies a price such that $P_t = P_{t+1}/1+r$, which is also the equilibrium condition under competition. For further discussion of an extractive monopolist firm, see Stiglitz (1976).

other things, development of substitutes), 1/ or where extraction costs are positive, the optimal extraction rate for a monopolist during earlier periods (and, hence, the rate of environmental degradation) will tend to be lower than that of firms under competition. In other words, a monopolist pursues a more conservationist policy which at earlier periods means a lower rate of environmental externalities than under competition. At some point, however, the reverse may be true because a monopolist, like firms under competition eventually exhausts the resource (assuming that costs are independent of the cumulative level of extraction). Therefore, the total cumulative environmental externalities are the same under both market conditions. The situation is more complicated in the more general case where extraction costs depend on cumulative amounts of extraction. In such a case the resource is not necessarily exhausted and, therefore, cumulative amounts of environmental damage tend to be lower for a monopolist compared with that of competitive firms. 2/

4. Other

The absence of a full set of efficient markets, including markets for trading into the future and markets for trading risks means that a competitive economy will not lead to an efficient intertemporal allocation of natural resources and an efficient bearing of risk. Two problems arise in respect of the absence of futures markets. First, the absence means that individuals with different expectations about future scarcity of natural resources than indicated by the market have no way of capturing the benefit of their expectations if the benefits are realized beyond their lifetimes. Therefore, they may have no incentive to enter the markets for natural resources. Second, there may be important inefficiencies and externalities

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1/ Obviously if, over time, perfect substitutes are developed, the monopolist at that time faces a demand curve equivalent to that under competition. The text statement implicitly assumes that such substitutes are not perfect.

2/ In addition, a monopolist may, because of size, have easier access to capital markets than individual competitive firms. If this means that the cost of capital, or the discount rate, is lower for the monopolist than for firms under competition, this would further strengthen the bias in favor of conservation by the monopolist. At the same time, in some countries, monopolists may face a significantly larger probability of nationalization than competitive firms. Such fear of nationalization would induce a monopolist to extract resources at a faster rate than in its absence. It should be stressed, however, that the fact that a monopolist may pursue a more conservationist policy than firms under competition does not mean that from a social welfare point of view the rate of extraction by a monopolist is preferred to that of firms under competition. On the contrary, to maximize welfare, a subsidy may be required to induce the monopolist to produce at the level of a competitive industry. In all cases, however, corrective measures should be imposed to "internalize" environmental externalities.

associated with the generation of information on future demand and supplies of mineral resources. Thus, expenditure by individuals in generating such information is either excessive, owing to unnecessary duplication, or insufficient, because the information may be a public good. 1/

The absence of markets for trading risk may mean that owners of reserves of mineral resources may be unable to insure themselves against risks of price fluctuations. Since, under conditions of uncertainty, rates of extraction of mineral resources are, in part, determined by the individual's attitude toward risk, and to the extent that risk aversion is the prevalent behavior of owners of such resources, rates of resource extraction of mineral resources would tend to be excessive compared with the rates which would obtain under risk neutrality. 2/

To the extent that the absence of futures and risk-trading markets leads to excessive rates of extraction of mineral resources, this may also lead to higher rates of environmental externalities than would obtain with a full set of efficient markets. In this context, tax and other nontax policies may need to correct for the excessive rate of extraction caused by the absence of these markets as well as correcting for environmental externalities associated with the extraction process. 3/

5. Policy failures

In cases where mining and exploration activities are associated with environmental externalities, some tax and/or nontax policies may aggravate environmental degradation by encouraging excessive rates of extraction through granting of explicit or implicit subsidies to mining and exploration activities. The total effect on the environment in such cases often reflects two factors: (a) the amount of environmental externalities that would have occurred in the absence of this policy-induced behavior but often goes uncorrected; and (b) the additional amount of environmental externalities that may be generated by the effects of these policy measures which are over and above amounts that would have occurred in their absence.

Some countries have often provided generous tax incentives for investment in mineral resources. Such incentives have often included income

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1/ See Section 2 above.

2/ To see this point, consider a case in which the risk premium of a risk-averse individual is added to the risk-free interest rate. A risk-averse individual would discount the future more heavily than a risk-neutral individual. This means that the rate extraction of a resource would be higher for the risk-averse individual than for a risk-neutral individual.

3/ It is important to point out that corrective taxes in this case would internalize environmental externalities that would be aggravated by the effects of absence of futures and risk-trading markets. The corrective taxes would not be attempting to solve the general problems of the absence of futures and risk-trading markets.

tax holidays (over many years), unlimited loss carry-overs beyond the tax holiday periods, exemptions especially of capital goods from domestic sales taxes and import duties, and generous depletion and depreciation allowances. 1/ Granting tax holidays for investments in mineral sectors serves to lower before-tax required rates of return on investment in the sectors compared with those in other sectors not benefiting from tax holidays giving rise to higher rates of investment, greater rates of mineral extraction and environmental externalities than would be the case without such incentives. Similarly, granting exemptions from sales taxes and import duties on capital goods provides implicit subsidies on equipment, including heavy machinery, which has been especially associated with environmental degradation in mining. Tax laws in a number of countries also provide depletion allowances far in excess of cost recovery and grant more generous investment allowances than provided to other sectors. 2/ These tax provisions lead to resource misallocation with the result that rates of extraction and, hence, rates of environmental degradation may exceed levels that would obtain in their absence. The tax incentives also tend to encourage degrees of capital intensity which, in some labor surplus countries, frustrates implementation of labor-intensive policies that would help in poverty alleviation and reduce the stress on environmental resources.

6. Sustainability

In recent years there has been increasing interest in, and concern with, the issue of whether or not rates of exploitation of natural (including mineral) resources are sustainable. It is, therefore, important to examine how, and to what extent tax policies may affect sustainability of rates of extraction of mineral resources. Analysis of sustainability is, however, complicated by the large number of definitions of the concept and by the absence of a consensus on an appropriate definition. For example, sustainable growth and development is sometimes defined in terms of nondeclining output, consumption, or utility or in terms of achieving minimum levels of consumption. 3/ Sustainability of rates of natural (including mineral) resource extraction, which is related to, but necessarily derived from, sustainability of overall economic growth and development, is often defined in terms of nondeclining resource stocks, or

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1/ The provision of these incentives, while prevalent among developing countries, are not limited to such countries. The United States, for example, provides generous tax incentives particularly for the oil industry through depletion allowances. For a detailed discussion of tax incentives provided by some developing countries, see Gillis and Beals (1980), and the United States Government (1990).

2/ For a detailed discussion of taxation of nonrenewable resources, see Church (1981), and for a survey of mineral resource taxation for a selected group of countries, see Appendix II.

3/ See Pezzey (1989) for an exhaustive survey of sustainability definitions.

maintaining intact the stock of capital, defined to include the initial stocks of man-made and natural resource stocks. 1/ Those advocating for constancy of natural resource capital stocks tend to emphasize the irreversibility of such stocks and the limited degree of substitutability between natural resources and man-made capital. The significance of irreversibility and limited substitutability assumes greater importance in cases where natural resources have values both as production inputs and/or as final consumption goods.

In the case of extraction of mineral resources by an individual country, the issue of sustainability may be somewhat less complicated for two reasons. First, mineral resources contribute to welfare only indirectly as inputs in production of goods and not directly as final consumption goods. 2/ This means that the amount of mineral resources of an individual country does not, in itself, enhance welfare except through the production process. Therefore, imposing a sustainability constraint on the rate of extraction of mineral resources for an individual country may be unnecessary because if, and when, the resource is exhausted, the country can always use substitutes or import from other countries. 3/ Second, the critical issue as regards mineral resources of an individual country is less to do with the preservation of the resources than to ensure that the competitive rents from the resources extracted are invested in a way that maintains the capital stock (defined to include natural resources stocks) intact. Viewed in this way, sustainability of mineral resource extraction for an individual country should be addressed as a macroeconomic and investment issue rather than as a tax policy, micro or sectoral issue.

This section has shown that the presence of environmental externalities, monopoly, common resource problems, policy failures, and absence of a full set of efficient markets for trading risks can affect the rates and amounts of environmental externalities in mineral extraction through their effects on a mining firm's rate of resource extraction. In the next section we present an analytical framework for designing corrective taxes suitable for addressing these environmental externalities. The framework is also used for evaluating the effects of various mineral taxes on rates and amounts of environmental externalities in Chapter IV. Specifically, the framework incorporates environmental externalities that depend on rates of mineral extraction as well as on cumulative amounts of minerals extracted.

1/ See Solow (1974).

2/ The exception is ornamental minerals such as gold and diamonds.

3/ While this may be true for a single or group of economies, it may not be true for the world economy as a whole. For the world economy, sustainable use of mineral resources would be achieved if the world price system functioned efficiently, which, aside from the effects of the interest rate, would cause the price of the minerals to rise in line with the rate at which the global supply of minerals are being exhausted in relation to global demand. See Solow (1974).

III. Mineral Resource Extraction, Environmental Externalities, and Corrective Taxes

A number of studies have examined the behavior of a mining firm and the effects of mineral taxation on rates of extraction, recoverable reserves, grade selection, or depletion dates under the assumption that a firm's mining activities have no external effects on other economic agents. 1/ An important exception is the paper by Schulze (1974) who incorporated cumulative environmental externalities in his model. He concluded that if the amount of resource extracted causes negative externalities, and if corrective measures were not taken to "internalize" the externalities, then competitive markets would lead to higher-than-optimal rates of exploitation of a nonrenewable resource.

In effect, Schulze analyzed one important class of environmental externalities such as underdeveloped tailings, landslides, landslips, or landbursts all of which are, in one way or another, associated with the cumulative effect of extraction on the environment. His study, however, ignored other environmental externalities, including earth road cuts, debris and effluent discharge, dust, and air pollution (from smoke or dust particles) associated with rates of extraction which are equally or, in some cases, even more significant than cumulative amounts of externalities. Indeed so important is this latter class of externalities that much of the static analyses on externalities has focused on them to the exclusion of cumulative externalities. 2/ In addition, while recognizing the importance of cumulative environmental damage, Schulze's analysis ignored the impact of cumulative mineral extraction on the firm's extraction costs. His analysis is, therefore, appropriate for those special cases where extraction costs do not depend on cumulative amount of extraction even though environmental externalities do. Clearing of forests and park land

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1/ Burness (1976) analyzed the effects of resource taxation under the assumption that the costs of resource extraction are not affected by the cumulative amount of extraction--an assumption that leads to the conclusion that resources are completely exhausted at the terminal period. Gordon (1967), Levhari and Liviatan (1977), and Heaps (1984) among others, have incorporated the effects of cumulative extraction in their models and modified earlier results. For example, as against the standard Hotelling conclusion that a flat rate severance tax always prolongs the depletion date of a mine, Levhari and Liviatan show that the impact of the tax is ambiguous primarily because, on the one hand, the tax reduces the total cumulative amount extracted and, on the other, it increases the rate of extraction. These studies have not, however, incorporated the effects of environmental externalities in their models. At the same time, other studies, including those by Anderson (1972), Smith (1977), and Vousden (1973) have examined the importance of environmental externalities, resource conservation, and of other environmental issues in the context of macroeconomic growth models.

2/ See Baumol and Oates (1988).

(which have scenic and recreational values) for agricultural, human settlements, or other economic uses may represent such cases: production costs (i.e., costs of clearing) need not increase with the amount of forest already cleared; however, the scenic and recreational value diminish with the amount of forest already cleared. In many of the real world cases, especially in mining, it is likely that both extraction costs and environmental damage are affected by cumulative amounts extracted.

In this chapter we analyze the effects of both types of environmental externalities discussed above under the assumption that a firm's costs of extraction depend on cumulative amounts of extraction. We then derive an appropriate Pigovian type of tax that addresses these environmental externalities. This extension is important for two reasons. First, it suggests that the nature of corrective taxes for extractive industries may be different from those of other industries and from those which have been suggested in the literature. 1/ Second, it provides a framework for evaluating some existing types of mineral taxes which are implemented primarily for revenue and other fiscal reasons but which in fact may act as proxies for corrective taxes for environmental externalities.

Assume that an extractive firm producing current output q(t) at time t inflicts environmental externalities on other economic agents, the extent of which depends on the rate of output as well as the cumulative output from time 0 to time t so that $dx(t)/dt = q(t)$. The total cumulative output x(T) at the termination of production cannot exceed $\bar{x}$, the total stock of mineral reserves in situ at time 0. Total production cost C(q, x) and amounts of environmental externalities D(q, x) are increasing functions of the rate of output and of cumulative output. If the firm sells its current output at price P(t), its current profits after paying an appropriate Pigovian tax to compensate society for environmental externalities that it causes are

$$\Pi = Pq - C(q, x) - D(q, x).$$

The objective of the firm is to maximize V, the present value of current and future profits net of corrective taxes for environmental externalities which the government requires the firm to pay or

$$\max V = \int_0^T \alpha(t)\{Pq - C(q,x) - D(q,x)\}\, dt \qquad (1)$$

1/ The analysis may, however, be relevant for cases beyond extractive industries. For example, it would seem to apply to cases discussed by Pearce (1976) where, beyond a certain level, economically optimal waste emissions into an environmental medium diminishes the medium's assimilative capacity and this in turn increases marginal environmental damages.

subject to

$$\dot{x}(t) = q(t) \tag{2}$$

$$x(0) = 0;\ x(T) \leq \bar{x}, \tag{3}$$

where $\alpha(t) = e^{-rt}$, r is the rate of interest, q is the control variable, and x is a state variable. Carrying out the maximization and after some manipulation it can be shown that 1/

$$P(t) = C_q(t) + D_q(t) + \alpha(T-t)[P(T) - C_q(T) - D_q(T)] + \int_t^T \alpha(s-t)[C_x(s) + D_x(s)]ds. \tag{4}$$

We shall use this equation to examine a number of special cases. First, ignoring all types of environmental externalities and the effects of cumulative output on costs of extraction, equation (4) reduces to

$$P(t) - C_q(t) = \alpha(T-t)[p(T) - C_q(T)], \tag{5}$$

which implies the Hotelling result that marginal profits should increase at the rate of interest. Alternatively this result can be interpreted as requiring that marginal profits at time t are equal to discounted marginal profit in any future period. Under these assumptions the mine is exhausted, $x(T) = \bar{x}$, and output at the terminal point is zero, $q(T) = 0$. These are, however, very restrictive assumptions for real world mining firms.

Second, when extraction costs of the firm increase with cumulative output but extraction does not involve any environmental externalities, equation (4) becomes

$$P(t) - C_q(t) = \alpha(T-t)[P(T) - C_q(T)] + \int_t^T \alpha(s-t)C_x(s)]ds. \tag{6}$$

As noted by Gordon (1967), and Levhari and Liviatan (1977), equation (6) indicates that when the effects of cumulative output on extraction costs are taken into account, the Hotelling rule that marginal profits must increase at the rate of interest no longer holds. Specifically when extraction costs increase with cumulative output ($C_x > 0$), then marginal profits will increase at less than the rate of interest. This result follows from the fact that under these assumptions an increase in current output at time t gives rise to additional extraction costs (represented by the last term on the right-hand side of equation (6)) from time t through to the terminal period, T. In other words, an extractive firm facing a cost function which increases with cumulative output must take into account not only the current costs of extraction, and the fact that its production plans are subject to a

1/ See Appendix I.

resource constraint, but also the effects of current output on extraction costs from the current to the terminal period. Since marginal profits at the terminal time, are zero $\{(P(T) - C_q(T)\} = 0$, and positive for all other times, $\{P(t) - C_q(t) > 0\}$ for all $t < T$, it follows that marginal profits for an extractive firm decline as the rate of extraction proceeds.

Finally, if there are environmental externalities for which the extractive firm is made to pay, this will affect marginal profits in two ways. First, current environmental externalities will affect the level of marginal profits but not their rates of growth. Second, cumulative environmental externalities will reduce rates of growth of marginal profits over time. To see this, assume that extractive costs are not affected by cumulative output but that there are negative current (but no cumulative) environmental externalities. Under these assumptions equation (4) becomes

$$P(t) - C_q(t) - D_q(t) = \alpha(T - t)[P(T) - C_q(T) - D_q(T)]. \qquad (7)$$

Since $D_q(t) > 0$ for all $q(t) > 0$, comparing equation (7) with equation (5) establishes the point that the level of marginal profits is reduced by current environmental externalities. However, their rates of growth remain r, the rate of interest. On the other hand, if we assume negative cumulative (but no current) environmental externalities, equation (4) can be written as

$$P(t) - C_q(t) = \alpha(T-t)[P(T) - C_q(T)] + \int_t^T \alpha(s-t)[C_x(s) + D_x(s)]ds. \qquad (8)$$

Since $D_x(t) > 0$ for all $q(t) > 0$, it follows that rates of growth of marginal profits in equation (8) are less than in equation (6). This result says that a mining firm that is made to pay for cumulative environmental externalities will reduce its rate of extraction, in part because of the burden of future tax liabilities (equal to the cumulative environmental damage) that will be imposed on account of the entire profile of cumulative environmental externalities in the future caused by an increase in current extraction.

Other effects of imposing a corrective tax that takes into account both current and cumulative externalities are (1) increasing the cutoff point for mineral extraction and, therefore, reducing the amount of recoverable reserves; 1/ and (2) slowing down the rate of extraction of minerals. Since these effects are offsetting, their net impact on depletion dates is ambiguous.

It is well known that one difficulty encountered in implementing environmental taxes in practical situations is due to the complexity of computing such taxes, mainly because of the large amount of information

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1/ The cutoff point for mineral extraction refers to a point where extraction ceases, or the point when marginal profits are zero.

required for their design. This difficulty has often been discussed in the context of environmental taxes analyzed within a static framework when only rates of environmental externalities are taken into account. 1/ The analysis here shows that the problem of computing environmental taxes may be considerably more complex when cumulative externalities are also taken into account.

The appropriate corrective tax when current and cumulative externalities are present is given by

$$\tau(t) = D_q(t) + \int_t^T \alpha(s-t) D_X(S) ds. \tag{9}$$

The complexity involved in computing an optimal environmental tax, or what we refer to as a dynamic Pigovian tax, arises from (a) the difficulty in obtaining information required for computing marginal current environmental externalities, $D_q(t)$, at each point in time, and cumulative externalities $D_X(t)$; and, even more so, (b) the fact that to compute the tax at time t involves computing the present value of all future marginal cumulative externalities arising from a unit increase in cumulative output. This latter element, represented by the last term on the right-hand side of equation (9), cannot be assumed to be constant over time since

$$\lim_{t \to T} \tau(t) = D_q(T). \tag{10}$$

That is, the second term on the right-hand side of equation (9) approaches zero as the terminal period is approached. In other words, a dynamic Pigovian tax reduces to its static equivalent as terminal production is approached.

It is interesting to note that a dynamic Pigovian tax discussed above has similarities with taxes designed primarily for revenue and other purposes other than correcting for environmental externalities. The first term on the right-hand side of equation (9) is, for example, similar to a specific tax on output. The second term, which declines over time, is similar to a sliding specific tax that is imposed on remaining reserves of an extractive firm and vanishes when mining stops. The fact that these taxes are similar to a dynamic Pigovian tax may be important for policy purposes because it may provide some economic justification for output taxes which are otherwise condemned as being distortionary.

To sum up the discussion in this chapter: if, as discussed in Chapter II, mineral extraction involves environmental externalities that depend on both rates and cumulative amounts of environmental externalities, then an appropriate corrective tax has two elements--one that depends on

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1/ See Baumol and Oates (1988) for a suggested way of getting around this problem.

current rates of extraction, and the other that depends on cumulative output. The first element of the tax is similar to a specific tax on mineral output. The second element declines over time and vanishes when mining stops and is, therefore, similar to a sliding specific tax imposed on the remaining amount of reserves. The results of this chapter indicate that in a mining world where environmental taxes such as the one discussed in this paper or any other are rarely imposed, but specific taxes are popular with governments, such taxes may, in fact, have a redeeming feature.

IV. Mineral Resources Taxation, Environmental Degradation, and Sustainable Growth

In the previous chapter we discussed a dynamic form of the Pigovian tax that needs to be imposed on an extractive firm in order to achieve efficient resource allocation by "internalizing" two types of environmental externalities (current and cumulative externalities) which are often associated with mining. Currently, few governments, if any, impose such a tax to correct for environmental externalities, but this could change as interest in improving and maintaining environmental quality increases. However, as noted in the last chapter and discussed below, certain forms of taxation imposed primarily for revenue and other purposes, and often condemned as being distortionary, have similar resource allocation effects as a dynamic Pigovian tax.

Governments often have four main objectives in taxing mineral resources. First, they often seek to maximize tax revenues from this source. Second, they often desire to ensure that mineral taxes be neutral, that is, that they should have no definite compensatory effects on allocative decisions of firms other than the need to "internalize" externalities such as discussed in the previous section. Third, some governments will wish to minimize variability and uncertainty of tax revenues from mineral resources. Finally, some governments may place great importance to the timing of tax revenues and, therefore, attempt to avoid delays in receipt of tax revenues from mineral resources. 1/ Beyond these objectives, a significant amount of discussion on mineral taxation in the literature has focused on the issues of particular concern to conservationists and environmentalists, such as the effects of mineral taxation on rates of extraction, on recoverable reserves, and on depletion dates. Interest in these issues dates back to Gray (1914) and Hotelling (1931) and is motivated, in part, by conservationists' concern that extraction of mineral resources in free markets may be too rapid and could be inconsistent with sustainable economic growth and development. While interest in resource conservation is also the concern of many environmentalists, the existing literature on mineral tax policy has

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1/ For a discussion of the objectives of mineral resource taxation, see Garnaut and Clunies-Ross (1983).

generally ignored another of their concerns--the direct and/or indirect effects of mineral taxes on environmental externalities.

In this chapter we review the effects of various forms of mineral taxes on rates of extraction, recoverable reserves, and depletion dates. In addition, making use of the framework developed in the previous chapter (in which current and cumulative environmental externalities are recognized as significant aspects of mineral extraction), we examine the effects of such taxes on both current and cumulative environmental externalities. Specifically, we examine the effects of profit taxes, resource rent taxes, franchise taxes, severance taxes, and property taxes on current and cumulative environmental externalities. Consistent with the analysis in the previous section and studies by Levhari and Liviatan (1977), Conrad and Hool (1981), Heaps (1985), among others, we shall generally assume that firms in the mining sector operate under resource constraints, and that costs of extraction increase with cumulative extraction. 1/ The effects of these various forms of mineral taxation on recoverable reserves, depletion dates, and current and cumulative environmental externalities are summarized in Table 1.

1. Profits tax

In comparative static analyses it is well established that imposing a pure profits tax does not change allocative decisions of a firm. This conclusion is also true for an extractive firm facing a resource constraint whether or not costs increase with cumulative output. 2/ Such a tax, therefore, has no effect on rates of extraction and on current and cumulative amounts of environmental externalities, on recoverable reserves, and on resource depletion dates. Under the assumption that a firm imposes environmental externalities on other economic agents, as assumed in this paper, a combination of such a pure profits tax and a dynamic Pigovian tax would result in efficient resource allocation.

In practice, however, a pure profits tax is difficult to compute particularly in mining. In addition to the difficulties of computing economic depreciation, imposing a pure profits tax on a mining firm faces additional problems posed by the treatment of depletion allowances and exploration and development costs. Granting depletion allowances under a profits tax, for example, often induces firms to shift production toward early periods. For example, imposing a profits tax with provision for cost depletion allowances (i.e., a fixed nominal value for each unit of output)

1/ The results reported in this chapter could, of course, be obtained formally by analyzing each of the taxes noted above in the model developed above. The approach followed in this chapter is to examine the effects of such taxes on rates of extraction and recoverable reserves from previous studies and to relate these directly to rates and amounts of environmental externalities.

2/ See, for example, Burness (1976).

Table 1. Summary of the Economic and Environmental Effects of Various Forms of Mineral Taxation

Tax	Recoverable Reserves	Rate of Extraction	Reserve Depletion Dates	Rate of Environmental Externalities	Cumulative Environmental Externalities
<u>Profits tax</u>					
Flat rate with no depletion allowances	Zero	Zero	Zero	Zero	Zero
Flat rate with cost depletion allowances	Increased	Increased	Ambiguous	Increased	Increased
Flat rate with percentage depletion allowances	Increased	Zero, increased, or decreased depending on prices rising at rate equal, less, or greater than interest rate	Ambiguous	Zero, increased, or decreased depending on prices rising at rate equal, less, or greater than interest rate	Increased
Flat rate with "excessive" depreciation, investment, and exploration allowances	Increased	Increased	Ambiguous	Increased	Increased
Progressive rate with no depletion allowances	Increased	Reduced	Extended	Reduced	Increased
Rate increasing over time	Reduced	Increased	Advanced	Increased	Reduced
Rate decreasing over time	Reduced	Reduced	Ambiguous	Reduced	Reduced
<u>Resource rent tax</u> 1/	Zero	Zero	Zero	Zero	Zero
Resource rent tax with interest rate less than the investor's	Reduced	Reduced	Ambiguous	Reduced	Reduced
Resource rent tax with interest rate greater than investor's	Increased	Increased	Ambiguous	Increased	Increased
<u>Brown tax</u>	Zero	Zero	Zero	Zero	Zero
<u>Franchise tax</u>	Reduced	Increased	Advanced	Increased	Reduced
<u>Taxes on output</u>					
<u>Per unit output tax</u>	Reduced	Reduced	Ambiguous	Reduced	Reduced
Flat rate 2/					
Rate increasing at a rate less than rate of interest	Reduced	Reduced	Ambiguous	Reduced	
Rate increasing at a rate greater than rate of interest	Reduced	Increased	Advanced	Increased	Reduced

Table 1. Summary of the Economic and Environmental Effects of Various Forms of Mineral Taxation (concluded)

Tax	Recoverable Reserves	Rate of Extraction	Reserve Depletion Dates	Rate of Environmental Externalities	Cumulative Environmental Externalities
Rate equal to the rate of interest	Reduced	Unchanged	Advanced	Unchanged	Reduced
<u>Ad valorem tax</u>					
Flat rate	Reduced	Zero, reduced, or increased, depending on prices rising at rate equal, greater, or less than interest rate	Advanced except when prices rising less than interest rate, when it is ambiguous	Zero, reduced, or increased, depending on prices rising at rate equal, greater, or less than interest rate	Reduced
<u>Property taxes</u>	Increased	Increased	Ambiguous	Increased	Increased

1/ Assumes that the interest rate that is used in discounting the net cash flow of the extractive firm is equal to that of the firm. It is also assumed that the cash flow patterns of mineral projects undertaken by the firm exclude those in which a cumulative positive net-cash flow in earlier years is followed by subsequent negative net cash outflow. If any of these assumptions are not satisfied, the tax is no longer neutral.

2/ A flat rate per unit of output tax is equivalent to a once-and-for-all downward shift in the demand curve: the cutoff point at which marginal profits equal zero implies lower rate of output; total cumulative output is lower as the result of an imposition of the tax.

effectively raises output price by a constant amount (equal to $\tau\theta/1-\tau$, where τ is the constant rate of the profits tax, and θ is the fixed dollar allowance per unit of output when profits are positive). 1/ The effects of the tax on output are the opposite of a per unit output tax and, therefore, could be conceived as a per unit of output subsidy to the firm. Therefore, the tax induces mining firms to increase rates of extraction, and increase current as well as cumulative environmental externalities. Recoverable reserves are also increased by such provisions of a profits tax. The effects of the tax with such depletion allowance provisions on depletion dates are ambiguous since both rates of extraction and recoverable reserves increase. If, on the other hand, extraction costs are independent of cumulative output, the tax would have no effect on recoverable reserves and amounts of cumulative environmental externalities while reserve depletion dates would be advanced to the present.

Imposing a profits tax with provisions for percentage depletion (i.e., a fixed proportion of the current value of output regardless of actual cost) effectively raises price (by $\tau\theta/1-\theta$, where θ is a fixed proportion of output) and has the same qualitative effects as a negative ad valorem tax (subsidy). 2/ As can be seen from Table 1, the effects of the tax are the opposite of those of an ad valorem tax discussed in 5(b) below.

The tax structures of many countries provide for accelerated depreciation (well in excess of economic depreciation), immediate expensing of all exploration costs, and investment tax incentives aimed at stimulating capital accumulation and/or at providing an offset to high degrees of uncertainty usually associated with mining. Imposing a profits tax under these conditions has similar qualitative effects as, for example, the effects of the tax with cost depletion provisions. To see this, assume that accelerated depreciation is proportional to output. The effect of imposing a profits tax under this assumption is to effectively raise output price in a similar way as discussed under cost depletion above.

Some countries have imposed progressive profits taxes with a view to capture "windfall" returns or to capture higher proportions of rents accruing in mineral resource exploitation. Often such tax provisions have a base rate and a growth component which depend on the level of profits. Such a tax lowers rates of extraction and, therefore, rates of environmental externalities; it increases amounts of recoverable reserves and, therefore, cumulative amounts of environmental externalities. Since recoverable reserves increase at the same time as rates of extraction are lowered, reserve depletion dates are extended by imposing such a tax.

The above results assume a profits tax rate which is fixed over time.

1/ For a derivation of this result, see Conrad and Hool (1981).

2/ For similar conclusions and derivations of this result, see Conrad and Hool (1981).

If rates of the tax increase (decrease) over time, then rates of extraction and environmental externalities are faster (slower), recoverable reserves and cumulative environmental externalities are reduced, and reserve depletion dates are advanced (ambiguous) (see Table 1).

A dynamic Pigovian tax should still be imposed even when a profits tax contains provisions that make the tax distortionary. However, the choice between such a tax package and other distortionary tax packages, such as a specific tax on output combined with a dynamic Pigovian tax is no longer clear cut.

2. Resource rent tax

A resource rent tax seeks to tax the net present value of a mining firm as it is realized. Under the tax, when a firm's net cash flow is negative, no tax is applicable, and a negative cash flow is accumulated at a government chosen interest rate until such time as there is a positive cumulative net cash flow when the tax is applied at a flat rate. 1/

A resource rent tax will not affect a firm's allocative decisions provided (a) the government chosen interest rate is the same as the firm's discount rate; and (b) the cash flow pattern of a firm excludes cases in which the accumulated net cash flow in earlier years is followed by subsequent negative net cash flow with no further positive net cash flow. If the government chosen interest rate is lower than the firm's discount rate the firm's tax liability is higher than would be the case under assumption (a). In this case, recoverable reserves and rates of mineral extraction are lower than would be the case under assumption (a). Similarly, current and cumulative amounts of environmental externalities would be lower than would the case under assumption (a). The impact on resource depletion dates is, however, ambiguous. The case in which the chosen interest rate is higher than the firm's rate is the reverse of that when it is lower.

If assumption (b) does not hold, that is if the firm's cash flow is characterized by a positive net cash flow in earlier years and subsequent negative net cash flow thereafter, the firm's tax liability would be higher than that indicated under the assumption. The effects of a resource rent tax on resource allocation under these conditions is to reduce recoverable reserves and rates of mineral extraction compared to what obtains under assumption (b); the effect on resource depletion dates is again ambiguous. At the same time, current and cumulative amounts of environmental externalities would be reduced to below what obtains under assumption (b).

The fact that a resource rent tax is based on cash flow rather than income, means that no distortions arise from application of the tax because of depreciation rules that differ from economic depreciation. Even though

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1/ For a detailed discussion on tax see Garnaut and Clunies-Ross (1975).

the choice of an appropriate interest rate is crucial, and not simple, this tax has many desirable properties and has been recommended as the appropriate form of taxing mineral resources. It has been applied in Papua New Guinea and Tanzania. 1/

A combination of a resource rent tax that satisfies conditions (a) and (b) noted above and a dynamic Pigovian tax would be preferred to a package that includes a specific tax on output. However, when conditions (a) and (b) are not satisfied, the resource rent tax also becomes distortionary and its superiority over a specific tax on output cannot be assumed a priori.

3. The Brown tax

Under a Brown tax all cash flows generated from the mining operations of a firm would be subject to a flat rate tax. Unlike a resource rent tax according to which a firm would accumulate net negative cash flows, under a Brown tax the firm receives negative taxes (subsidies) when net cash flow is negative. The tax has one major advantage over a resource rent tax: there is no need to choose an interest rate as there are no accumulated negative net cash flows. Its major disadvantage is that it entails great revenue risk to governments where, as is often the case, cash flows from firms' mining operations are uncertain. 2/

Apart from its effect in reducing risk, the Brown tax is completely neutral and, therefore, its impact on all the variables of interest in this paper is zero. In the presence of environmental externalities as described in this paper, this tax combined with the dynamic Pigovian tax would be the economist's ideal mineral resource tax. 3/

4. The franchise tax

A franchise tax (which can be conceived as a lump-sum tax that is imposed in each time period) is similar to a lump-sum tax in static analysis, except that in the dynamic context the tax depends on time. Thus, while in static analysis it is well known that a lump-sum tax does not change a firm's allocative decisions, the effects of a franchise tax for an extractive firm is to increase rates of extraction, reduce recoverable reserves, and advance depletion dates. 4/ As regards environmental degradation, the effects of a franchise tax is to increase rates of environmental externalities while reducing cumulative amounts of environmental externalities over the life of a mine. The difference in the effects of the lump-sum tax in static analysis and the franchise tax in

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1/ See Garnaut and Clunies-Ross (1983).
2/ For a detailed comparison between a Brown and a resource rent tax, see Garnaut and Clunies-Ross (1983).
3/ Perhaps because of its significant revenue risk to governments, many governments do not seem to favor the tax.
4/ See Burness (1976).

dynamic analysis is, of course, due to discounting. Since the nominal value of the franchise tax paid is the same in each period irrespective of the level of output, an extractive firm can minimize the present value of its tax liability by reducing the number of periods in which extraction takes place through accelerating extraction from the future toward the present. In this sense the tax is avoidable and, strictly speaking, not a lump-sum tax.

If extraction costs are independent of amounts extracted (the Hotelling assumption) then at the terminal period the mine is exhausted. Under this assumption the tax has no impact on recoverable reserves (since they will always be exhausted). Similarly, cumulative amounts of environmental externalities are the same with or without the tax, even though their time pattern would be different. The effects of the tax on rates of extraction and, therefore, on rates of environment externalities, and on depletion dates are the same as under the assumption of costs which increase with cumulative extraction.

From an economic point of view, a franchise tax loses the neutrality appeal of a lump-sum tax in static analysis. Making a judgment on the desirability of the tax is more complex when environmental and conservationists' concerns are taken into account. For example, under the assumption of extraction costs which increase with cumulative amounts of extraction, rates of environmental externalities are higher with than without the tax. At the same time, amounts of cumulative environmental externalities are lower with than without the tax. Similarly, while conservationists may be concerned that the tax increases rates of extraction, they will be pleased that amounts of reserves left in situ are greater in the presence of the tax than in its absence. If extraction costs are independent of cumulative extraction, the effects of the tax pose no such dilemmas since cumulative amounts of environmental externalities and recoverable reserves are the same with or without the tax. Rates of environmental externalities are higher, and depletion dates are advanced to the present, with the tax than without it.

The effects of a franchise subsidy are the converse of those of a franchise tax. That is, providing a franchise subsidy will reduce rates of mineral extraction, and rates of environmental externalities while postponing depletion dates; and (when costs increase with cumulative extraction) the subsidy will increase recoverable reserves and cumulative amounts of environmental externalities.

5. Taxes on output

Taxes on mineral output can be grouped into three categories: (a) fixed payment per unit of gross output; (b) fixed payment per unit of certain quality of output; and (c) fixed proportion of the price of a mine's output. Mineral taxes on output can also be applied on sliding scales which may reduce tax payments to zero as extraction costs reach a certain threshold, after a number of years of extraction, or when extraction stops.

Specific or ad valorem taxes (often referred to as duties) are quite popular forms of taxing minerals or petroleum, primarily because of their administrative simplicity. In static analysis the general conclusion is that the taxes induce extractive firms to restrict output and they encourage high grading--that is, extraction of high grade ores by-passing lower grade ores. However, as shown below, in dynamic analysis, when stocks of resource ores are given, the effects of these taxes vary depending on specific assumptions about the nature of the tax. For simplicity only two forms of the taxes are examined here--specific and ad valorem; that is, we ignore the distinction between a specific tax based on gross value and that based on certain quality of output. 1/

a. Specific taxes

The effects of a specific tax on output at a rate, τ, on an extractive firm operating under a resource constraint depends, in part, on how τ, and its rate of change, is related to r, the rate of interest. Imposing a flat rate per unit output tax on an extractive firm reduces rates of extraction and amounts of recoverable reserves but its effects on depletion dates is ambiguous. The tax reduces the rate of extraction because the marginal tax liability is constant for each period but (with a positive interest rate) the present value of future marginal tax liabilities is smaller than that for the present period. Therefore, other things remaining the same, an extractive firm can increase its net present value by postponing production into the future. Recoverable reserves are reduced because the tax increases the cutoff point--that is, the point where marginal profits are zero. The effects of the tax on reserve depletion dates is ambiguous as they depend on the relative effect of the tax on reducing rates of extraction and its effect in increasing amounts of reserves left in situ. The tax is a favorite for environmentalists and conservationists because it reduces both rates and amounts of cumulative environmental externalities while increasing amounts of reserves left in situ.

If extraction costs are independent of amounts extracted, so that reserves are always exhausted, then the effect of the tax is to extend depletion dates. All the other effects of the tax are the same as those discussed under the assumption of costs which increase with cumulative extraction.

The effects of the tax when rates change over time depend on whether the rate of change of the tax is greater, equal, or less than the rate of interest. If the rate of increase of the tax is greater than the rate of interest ($\dot{\tau}/\tau > r$), then rates of extraction are increased, recoverable reserves reduced (assuming increasing costs), and reserve depletion dates advanced. Rates of environmental externalities are increased while

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1/ For an analysis that makes the distinction between a specific tax based on gross value and that based on certain quality of output, see Conrad and Hool (1981).

cumulative amounts of externalities fall because with nominal marginal tax liabilities increasing at a rate greater than the rate of interest, the firm can increase its net present value by reducing its tax liability through shifting extraction to the present which is less heavily taxed in real (i.e., present value) terms. If extraction costs are independent of amounts extracted then reserves will be exhausted with or without the tax, and the effect of the tax on cumulative amounts of environmental externalities is zero.

If the rate of the tax increases at rates equal to interest rate ($\dot{\tau}/\tau = r$), then the tax has no effect on rates of extraction but recoverable reserves will be reduced so that reserve depletion dates are advanced. Rates of environmental externalities are unchanged by the tax while cumulative amounts of environmental externalities are lower. The effects of the tax (assuming extraction costs are independent of cumulative output) are the same as when the tax rate increases at a rate greater than the rate of interest. The effects of the tax when the tax rate increases at rates lower than the rate of interest are similar (and for similar reasons) to the effects of a flat rate tax.

As already noted, a combination of a specific tax on output with a dynamic Pigovian tax is inferior to a package that combines a dynamic Pigovian tax with the neutral taxes noted above. However, in practice, the conditions for neutrality of, in particular, a profits tax or a resource rent tax are not satisfied which means the choice between these taxes and specific taxes has to be based on other grounds. In addition, dynamic Pigovian taxes, or any other corrective taxes are rarely imposed and this further complicates judgment between specific taxes and, even a Brown tax. This is because without an appropriate corrective tax a Brown tax would lead to excessive rates of mineral extraction. At the same time, a specific tax on output if combined with a sliding element that depends on amounts of remaining reserves is similar to a dynamic Pigovian tax and would have similar qualitative effects in internalizing environmental externalities. In our view specific taxes should be explicitly designed to internalize environmental externalities while a resource rent tax, profits tax, or a Brown tax should be designed to capture resource rents. In other words, these taxes should be viewed as complementary rather than substitutes.

b. Ad valorem taxes

The effects of an ad valorem tax at rate τ differs from that of a specific tax primarily because tax liability in this case varies with output price rather than output. Generally, the effects of the tax on rates of extraction are the opposite of the effects of those of changes in prices. For example, the effects of a once-and-for-all increase in price (assuming extraction costs are independent of the amount extracted) is to increase rates of extraction and rates of environmental externalities, while advancing depletion dates. 1/ The effects of an ad valorem tax, on the other hand, is to reduce rates of extraction, and environmental externalities, and to advance depletion dates. The effects of the tax on rates of extraction and on environmental externalities remain the same when extraction costs increase with amounts extracted. At the same time, under the same assumption the tax reduces recoverable reserves and cumulative amounts of environmental externalities while its effects on resource depletion dates are ambiguous.

The effects of continuously increasing output prices depend on whether the rate of increase in prices is greater, equal, or less than the rate of interest. For example, resource extraction would cease if prices were rising faster than the rate of interest since the resources would be more valuable in situ than on the market. On the other hand, extraction would be shifted forward into the future if prices were rising at a slower pace than the rate of interest. 2/ The effects of imposing an ad valorem tax when prices are rising faster than the rate of interest would be to induce (if the rate is sufficiently high) the firm to carry out some extraction in the current period (instead of postponing all production into the future). If, on the other hand, the tax is imposed when prices are increasing at a slower rate than the rate of interest, the effect is to shift extraction into the future. In either case (if extraction takes place) the effect of the tax is to reduce recoverable reserves and cumulative amounts of environmental externalities while resource depletion dates are advanced in the first case and are ambiguous in the second.

6. Property taxes

In principle this tax is imposed on the remaining mineral reserves at the end of each period. A particular case of the tax is one in which the tax is imposed on the capitalized value of the firm or on the present value of all the assets of a mining firm. In practice the base of the tax can vary substantially from this because it is difficult to estimate the value of reserves or the capitalized value of a mining firm, and because mining firms tend to report exploration costs as proxies for the base of the tax. 3/ Because the base of the tax declines over time, the nominal value of a constant rate property tax also declines over time. The effect of the tax is, therefore, to induce faster rates of extraction and higher rates of environmental externalities than would be the case in its absence, since, other things remaining the same, faster extraction rates reduces the firm's tax liabilities. In this sense the tax has the opposite effects of an ad valorem tax discussed above.

1/ See, for example, Levhari and Liviatan (1977).

2/ See, for example, Levhari and Liviatan (1977).

3/ For a more detailed discussion of the property tax see, for example, Burness (1976).

A property tax increases recoverable reserves and cumulative amounts of environmental externalities. To appreciate this result it is useful to remember that since total available reserves are fixed, the firm can reduce its tax liabilities at the terminal point by extracting beyond the nontax cutoff point because it receives the equivalent of a negative ad valorem tax on each unit extracted. The effect of the tax on depletion dates is, however, ambiguous because, on the one hand, it induces higher rates of extraction, while on the other, it increases recoverable reserves. The tax is not welcome by both environmentalists (because it increases both rates and cumulative amounts of environmental externalities) and conservationists (because it shifts extraction from the future to the present, and reduces the reserves left in situ).

The above discussion suggests that there are complementarities as well as trade-offs between mineral tax policies and environmental concerns. There are also considerable uncertainties about the effects of certain mineral taxes on the environment and related issues. From a tax policy point of view an ideal mineral resource tax may be a Brown tax, a neutral resource rent tax, or an income tax with true economic depreciation, and true depletion allowance provisions. Such taxes have the advantage that they raise revenues in a nondistortionary manner. That is, in the absence of environmental and other externalities, such taxes lead to least amount of distortions in respect of rates of extraction, recoverable reserves, and depletion dates.

However, environmentalists may point to the fact that the resulting rates of extraction may not be sustainable and prefer taxes that would reduce the rates of extraction, recoverable reserves, and extend depletion dates compared to the ones resulting from those indicated by the above-mentioned neutral taxes. From this perspective, specific and ad valorem taxes may be considered more environmentally friendly taxes than the more neutral taxes referred to above. 1/

If mining operations are associated with environmental externalities of the nature analyzed in this paper, then economists' and environmentalists' concerns coincide at least up to the point of urging imposition of a dynamic Pigovian tax discussed in this paper. Fiscal economists, in addition, would point at the complementarity of such taxes between economic efficiency, environmental protection, and improving fiscal management for governments strapped for budgetary resources. Furthermore, in the absence of environmental taxes, distortionary taxes such as specific taxes which are common in mining sectors of some countries can be seen in more favorable light in cases where mining operations inflict environmental externalities. Even though the rates of such taxes may not equal rates dictated by dynamic

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1/ However, as noted in Chapter II above, sustainability or conservation in the extraction of mineral resources should, ideally, be considered as a macroeconomic and investment policy issue rather than a micro or sectoral policy issue.

Pigovian taxes analyzed in this paper, their imposition provides partial offsets for, otherwise, uncorrected environmental externalities.

The above discussion also points to some uncertainties concerning the effects of various taxes on depletion dates which complicates attempts to rank some of the taxes on the grounds of environmental friendliness. Consider, for example, a comparison between a flat rate per unit of output tax and a progressive profits tax with no depletion allowances (Table 1). Imposing either tax reduces rates of environmental externalities. On the other hand, imposing a specific tax reduces cumulative amounts of environmental externalities while a progressive profits tax increases them. However, this does not necessarily imply that a specific tax is more environmentally friendly because its effect on depletion dates is ambiguous while a progressive tax extends them. Similar difficulties arise in ranking a franchise tax and a property tax (see Table 1).

We have analyzed these taxes as if they were alternatives. In practice the taxes are often implemented as a package. An assessment of the net effects of such packages would shed more light on their effects in actual cases. However, such an assessment is beyond the scope of this paper. At the same time, however, it seems that one package that could simultaneously address the economists' quest for nondistortionary taxes and environmentalists' and economists' concerns with environmental externalities could be either a Brown tax, a neutral resource rent tax, or a pure profits tax on one hand, and a specific tax on output which incorporates a sliding specific tax on output that reduces to zero at the terminal period on the other. For this reason, (distortionary) specific taxes on mineral output may in fact improve resource allocation at the same time as they protect the environment.

V. Concluding Remarks

This paper has examined the effects of mineral taxes on the environment from two perspectives. First, an appropriate framework for environmental taxes (the dynamic equivalent of the Pigovian taxes in static analyses) that is suitable for mining firms was developed. The framework takes into account the fact that mining firms face resource constraints, their extraction costs may increase with cumulative extraction, and the fact that mining activities are often associated with two forms of environmental externalities--one that depends on the rate at which mineral extraction takes place, and the other which depends on the cumulative amount of mineral extraction. Second, the paper examined the effects of various forms of mineral taxes that are often imposed to achieve several fiscal objectives (including revenue generation) but not specifically directed toward correcting for environmental externalities. The effects of the taxes examined, which are of particular interest to conservationists, include those on rates of extraction, depletion dates, and amounts of reserves left in situ. In addition, we have examined the effects of such taxes on rates and cumulative amounts of environmental externalities. On the basis of this examination we can make the following conclusions:

1. Changes of both a Brown tax, or a neutral resource rent tax (in which the rate of interest used in discounting the net cash flow is equal to a mining firm's discount rate) have neutral effects on the environment. That is, the taxes neither aggravate nor ameliorate environmental externalities. As is well known, a Brown tax or a neutral resource rent tax are the preferred forms of taxing mineral resources. However, in the presence of environmental externalities, these taxes need to be supplemented with environmental taxes (of the form discussed in this paper) if economic efficiency as well as environmental protection are to be achieved. Despite their economic appeal, there are not many countries which have implemented mineral tax packages that combine a Brown or resource rent tax with the type of environmental taxes discussed in this paper.

2. Many countries have environmental regulations governing the operations of mining firms and few impose appropriate environmental taxes that internalize the two forms of environmental externalities discussed in this paper. No doubt this partly reflects governments' preference for a command and control approach to use of economic instruments to control environmental degradation. But this may also reflect the considerable complexity and extensive information requirements associated with the design and implementation of appropriate environmental taxes for mining firms. The absence of applied research on practical designs of environmental taxes may be a further impediment in efforts to implement these taxes. With increasing research and understanding of the nature of environment taxes in mining, regulations could be replaced by environmental taxes in the future.

3. Even though usually imposed largely for revenue purposes, and often condemned as distortionary, per unit taxes on mineral output have similar qualitative effects in restraining environmental externalities as static Pigovian taxes. This is not to suggest that these taxes are a perfect substitute for static Pigovian taxes, let alone the dynamic version discussed in this paper. They are not. This is in part because rates of such taxes which are often based on revenue and other fiscal considerations are likely to differ markedly from those based on the need to "internalize" environmental externalities. However, if environmental externalities are significant and they are related to rates of mineral extraction, then, in the absence of any environmental taxes, per unit of output taxes could be viewed as proxies for static Pigovian taxes. If these taxes are supplemented by taxes on remaining reserves, then they resemble, at least in form, the dynamic Pigovian tax. Viewed in this light, these taxes in practice may be less distortionary than often suggested in theoretical analyses. These taxes are environmentally friendly as are: a profits tax with the rate decreasing over time; a resource rent tax with the rate of interest less than the investor's discount rate; and a per unit of output tax with a rate increasing at a rate less than the rate of interest. If, in a reform package, these taxes are replaced by a Brown tax, or a neutral resource rent tax, then it may be necessary to implement appropriate

environmental taxes as part of the reform package otherwise environmental degradation would worsen after the tax reform.

4. There is complementarity between economic and environmental objectives when taxes, such as a flat rate profits tax with provision for cost depletion, a flat rate profits tax with provisions for "excessive" depreciation allowances, a resource rent tax with an interest rate which is greater than the investor's discount rate, or a property tax, are replaced by a Brown tax or a neutral resource rent tax. In such cases the tax substitution reduces environmental damage at the same time as it improves resource allocation. Because these taxes are distortionary and environmentally damaging they should be the first target for elimination or reduction in a reform package in which economic and environmental considerations are important.

5. The complementarity or trade-off between economic and environmental concerns are less clear for the rest of the other taxes--a flat rate profits tax with percentage depletion, a franchise tax, a per unit of output tax with a rate greater than the rate of interest, and a flat rate ad valorem tax. Specifically, replacing such taxes with a Brown tax, or a neutral resource rent tax will improve resource allocation, but the effects on the environment may be mixed. For example, elimination of a franchise tax would increase the rate of environmental degradation at the same time as it reduces the cumulative environmental externalities: the environmental impact of eliminating a flat rate, an ad valorem tax, or a flat rate profits tax with percentage depletion are even less certain.

The Dynamic Pigovian Tax

In this appendix we derive the results discussed in Chapter III.

Current profits of an extractive firm after it pays an appropriate Pigovian tax to compensate society for the environmental externalities that it causes are:

$$\Pi = Pq - C(q, x) - D(q, x) \tag{1}$$

where P(t) is price of output at time t, q(t) is current output at time t, C(q, x) are total production costs (which depend on the rate of output and cumulative output x), and D(q, x) is the amount of environmental externalities which depend on the rate and cumulative output.

The objective of the firm is to maximize V, the present value of current and future profits net of corrective taxes for environmental externalities or

$$\max V = \int_0^T \alpha(t)\{Pq - C(q,x) - D(q,x)\}\, dt \tag{2}$$

subject to

$$\dot{x}(t) = q(t) \tag{3}$$

and

$$x(0) = 0;\ x(T) \leq \bar{x}, \tag{4}$$

where $\alpha(t) = e^{-rt}$, r is the rate of interest, q is the control variable, and x is a state variable.

The necessary conditions for a maximum are that

$$\dot{\lambda} = \alpha(t)(C_x + D_x) \tag{5}$$

$$\lambda = \alpha(t)(P - C_q - D_q), \tag{6}$$

where λ is a co-state variable and H is the Hamiltonian 1/

1/ $\dot{x}(t) = \frac{dx(t)}{dt}$, $\dot{\lambda} = \frac{d\lambda(t)}{dt}$, and C_x is a partial derivative with respect to x.

$$H = \alpha(t)\Pi - \lambda q. \tag{7}$$

Since this is a case in which the firm chooses the terminal period, T, and the terminal cumulative output, x(T), the transversality conditions require that

$$Pq(T) - C[q(T), x(T)] - D[q(T), x(T)] = q(T)[P - C_q(T) - D_q(T)], \tag{8}$$

and that

$$P - C_q(T) - D_q(T) = 0. \ \underline{1}/ \tag{9}$$

In other words, at the terminal period, T, the rate of output is such that average cost (including the compensation for environmental externalities) should equal to marginal costs (condition equation (8)), and price must be equal to marginal cost plus the marginal environmental externalities (condition equation (9)). Integrating equation (5) yields

$$\lambda(t) = \alpha(T-t)[P(T)-C_q(T)-D_q(T)]+\int_t^T \alpha(s-t)[C_x(s) + D_x(s)]ds, \tag{10}$$

and combining equation (10) with equation (6) yields

$$P(t) = C_q(t) + D_q(t)+\alpha(T-t)[P(T)-C_q(T)-D_q(T)]+\int_t^T \alpha(s-t)[C_x(s) + D_x(s)]ds. \tag{11}$$

which is equation (4) in the text.

1/ Since x(T) and T are not given, we need (two) conditions for determining them. Equation (8) is the condition for determining the optimal terminal period, T, and equation (9) is the condition for determining the optimal cumulative amount of extraction, X(T). For an analysis of this and other cases in which X(T) or T may be given, see Takayama (1974).

Survey of Mineral Resource Taxation and Environmental Impact

In Chapter II we pointed out that environmental degradation is often caused by the existence of environmental externalities, and aggravated by policy failures, including tax provisions that may encourage rates of environmental degradation or cause unsustainable rates of exploitation of mineral resources. In this appendix we examine mineral tax provisions of a selected number of countries with a view to analyzing their possible effects on recoverable reserves, rates of extraction, depletion rates, and rates and cumulative amounts of environmental externalities. Evidently, these are not the only policy failures that can have negative effects on the environment: others include exemptions or preferential treatment of some inputs of the mining industry. The sample of countries included in this survey is illustrative rather than representative of countries which tax mineral resources. Statements made about the likely effects of various taxes in this appendix must be treated with great caution in large part because the evaluation is not based on detailed empirical examination of the various taxes.

All the countries in the sample impose some form of income tax on income from mining, and for a few of them (Botswana, Zambia, and Zimbabwe) this is the only mineral tax imposed. Many more combine the income tax with a specific (including in the case of Malaysia an export tax) or an ad valorem tax. None of the countries in this sample imposes a Brown tax, a resource rent tax, a franchise tax, or a property tax. 1/ This observation is consistent with earlier ones that have concluded that specific and ad valorem taxes are the most popular special taxes in mining. Also, none of the countries in the sample have any corrective taxes such as a dynamic Pigovian tax discussed in Chapter III. This is also consistent with earlier observations (see Church (1981)) and possibly reflects the preference of governments to use direct regulation rather than economic instruments of control to address environmental problems.

On the whole it would appear that Australia's income tax possibly distorts allocative decisions of mining firms. This is primarily because of the provision of cost depletion (which is unlikely to represent true economic depletion) and the provision of depreciation allowances (which also do not represent true economic depreciation). Corporate income is taxed at the rate of 31 percent. The concept of depletion for wasting assets is based on costs. Until the end of 1990, profits from gold mining were exempt from income tax. Expenditures on exploration or prospecting for minerals are fully deductible in the year incurred. Capital expenditures incurred in setting up or in carrying on mining operations are deductible by equal amounts over the estimated life of the mine. There is an option to deduct

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1/ This does not mean that such taxes are not implemented in some countries. For example, the resource rent tax has been implemented in Papua New Guinea and Tanzania see Garnaut and Clunies-Ross (1975).

expenditures on machinery and equipment by way of ordinary tax depreciation (straight-line method at a rate based upon the expected life or declining-balance method at 150 percent of straight-line rates).

Specific taxes on petroleum, some condensates of naturally occurring liquefied petroleum gas, coal, and on uranium tend to offset the stimulative effects of the income tax on these minerals. Production of crude oil and some condensate and naturally occurring liquefied petroleum gas are subject to a domestic levy while an export levy is imposed on coal and uranium. There are also cash bids for offshore petroleum exploration permits or production licenses.

In Canada the tax on income from mineral resources also possibly increases rates of extraction and environmental externalities (including cumulative environmental externalities) primarily because provisions for depreciation allowances (the depletion allowances were phased out in 1989) may be different from true economic depreciation. 1/ But this stimulative effect is possibly offset by various severance taxes imposed by the provinces. Corporate income is taxed at the federal and provincial levels. The federal rate inclusive of a surtax is 38.8 percent; the provincial rates vary from 2.5 percent to 17 percent; the provincial abatement is 10 percent, so that the combined tax rates vary from 28.8 percent to 45.8 percent. Capital cost allowances are computed on a pool basis with relatively few separate classes of property. Annual allowances generally are determined by applying a prescribed rate to each class on a declining-balance basis. The rate for most machinery and equipment is 70 percent.

A federal resource tax allowance, equal to 25 percent of resources profits after deducting operating expenses and capital cost allowances, but before deducting interest, exploration, and development expenses, and depletion, is provided. The depletion allowance earned as a percentage of eligible expenditures on exploration and development of mineral resources available in addition to the deduction for the expenditure itself was phased out by reducing the rate at which it can be earned from 16.66 percent to zero for expenditures after 1989.

In Norway, where depreciation allowances on plant, machinery, and equipment are at 30 percent on a reducing-balance basis, and there are other special provisions, the effects of the income tax may increase rates of extraction and, hence, amounts of environmental externalities. At the same time, a progressive severance tax has the opposite effect so that the net impact is uncertain. Corporate income is taxed at the rate of 50.8 percent (state: 27.8 percent, municipal aggregate: 23 percent). Companies engaged

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1/ Assessing the impact of mineral taxation in Canada is complicated by the fact that the sector is subject to a federal income tax and various taxes at the provisional level. However, in the case of Ontario and Quebec, two large mineral producing provinces, Boadway, et al. (1987) have concluded that the federal income tax and the various principal taxes distort resource allocation.

in exploration for exploitation of submarine petroleum and related activities, including pipeline transport of petroleum, are subject to the following special factors: (1) the gross income and the value of stocks of petroleum is assessed according to norm prices as determined quarterly by a board appointed by the Ministry of Energy; (2) deductions for ordinary depreciation may be claimed up to a maximum of 16.67 percent per annum; and (3) deductions are subject to a petroleum revenue tax at the rate of 30 percent on net income which exceeds 6.67 percent of the cost of depreciable assets which have been put into ordinary use for these activities and which were acquired before the beginning of the relevant year. The rate of the ad valorem royalty depends on production and a national net worth tax is imposed at the rate of 0.3 percent of a value of the property.

The effects of Bolivia's income tax on income from mining are uncertain because the tax is based on presumed net income calculated as the difference between receipts at official prices and presumed operating and sales costs. The relationship between net income so computed and pure profits is unclear. Its severance tax on domestic sales and exports, however, tends to reduce rates of extraction and, hence, environmental externalities. Thus, oil output is subject to a 24 percent domestic sales tax and a 27.35 percent tax on exports. In addition, 11 percent of sales in both domestic and export markets are paid to regional development corporations. 1/

Botswana's income tax would appear to be stimulatory because of its cost depletion and depreciation allowance provisions which are, in all likelihood, more generous than true economic depletion and/or depreciation. The corporate income tax rate is at 40 percent but there are special tax (and royalty) arrangements with mining companies. Dividends paid to resident shareholders are deductible from company profits. The tax makes provisions for cost depletion allowances. Mining capital allowances are ascertained by dividing the residual capital expenditure by the minimum of ten and the estimated number of whole years during which mining operations may be expected to continue.

In Chile, there is no provision in the income tax for allowance for depletion but provision for depreciation allowances are on a straight-line basis rather than true economic depreciation: its effects are, therefore, uncertain. The income tax is levied at 10 percent on retained earnings and 32.5 percent on distributions. There are no depletion allowances for mineral resources and depreciation is by straight-line method with rates calculated on the estimated useful life of the assets--that is, 20 years for heavy machinery and 7 years for trucks. Alternatively, the income of miners may be imputed by applying a factor on net sales which depends on the world price of the respective metal. A surtax of 40 percent on the share of the state in profits applies to state enterprises. In addition, there are fees on mining licenses and a one time payment for rights of exploration of

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1/ In practice, these rates are subject to negotiations and depend on international prices, the company's cash flow, and its investment program.

0.5 percent to 4 percent of monthly tax units (UTM) depending on extent of the land. The mining concessions cost 10 percent of one UTM per hectare per year.

The income tax in Jamaica would seem to be stimulatory as regards mineral resources (except bauxite) and oil primarily because of the provision of a 20 percent initial investment allowance and depreciation allowances which more than likely exceed economic depreciation. The effects of the presumed income tax on bauxite, on the other hand, are uncertain while the effects of the severance tax tend to reduce rates of extraction and environmental externalities, and reduce recoverable reserves and cumulative amounts of environmental externalities.

With provisions for depreciation allowances of 8 to 20 percent on a straight-line basis, initial investment allowances of between 12 and 20 percent, and depletion allowances based on various costs (including the cost of mineral rights, prospecting, and development costs), the Malaysian income tax tends to increase rates of extraction and environmental externalities, and tends to increase recoverable reserves and cumulative amounts of environmental externalities. At the same time, the effects of the ad valorem export tax on oil, and the progressive ad valorem tax on tin are much more uncertain even though they tend to reduce recoverable reserves and cumulative amounts of environmental externalities. Thus, the corporate income tax is levied at 35 to 45 percent on profits from petroleum operations with the initial allowance for plant and machinery invariably at 20 percent, and the annual allowance in general ranging between 8 to 20 percent on a straight-line method. In the mining industry the initial allowance is 20 percent for earth-moving plant and heavy equipment, 12 percent for dredges, and 10 percent for mining and quarrying plant and machinery. The types of expenditures which qualify for depletion of allowances include the following: the cost of the site, the cost for acquiring mineral rights, and the cost of land used for mining works; all expenditures connected with searching for and discovering or testing deposits or winning access thereto--independent of success; and all management and development expenditure before commencement of actual production is included under this category.

Export taxes are also imposed on tin and crude oil. The export duty is levied on tin at a price level exceeding M$26,400 per ton which is estimated to be the cost of production. Rates increase from 20 percent to 50 percent. In addition to an export duty, a tax for research and development called "cess" is also levied on the export of tin. A 25 percent ad valorem export duty is levied on the gazetted value of crude oil minus 10 percent for royalty and a maximum of 20 percent for cost of the oil exported. The amount of this duty can be expended against gross income in computing taxable petroleum income.

The Zambian income tax on minerals tends to increase extraction rates and environmental externalities as well as increase recoverable reserves and cumulative amounts of environmental externalities. Corporate income is taxed at the rate of 40 percent, and depreciation allowances for plant, machinery, and equipment are at 30 percent on a reducing balance. There are special provisions for capital expenditure relating to mining operations. There are also provisions for remission of income tax paid by new mining companies or for the exemption of a mining company from payment of the tax. Parastatal companies (i.e., companies with both government and private sector participation, as well as 100 percent government-owned companies) are required to pay 15 percent of the Government's equity holding in these companies, or normal company income tax, whichever is greater.

The Zimbabwean income tax has similar effects to those of the Zambian tax primarily because of its provision of an (optional) initial investment allowance of 100 percent on investment in mining. At the same time, the effects of the 5 percent depletion allowance are uncertain. Corporate income is taxed at a rate of 50 percent. An optional special initial allowance of 100 percent is available for capital expenditure on mines. The depletion allowance is 5 percent on the gross sale proceeds of minerals produced.

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