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EVALUATION OF ECONOMIC BENEFITS OF RESOURCE CONSERVATION

by

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication, which addresses the issue of resource conservation, is one of the products of that research; a most vital communications link between the researcher and the user community.

The question of what value should be placed on resource conservation has been around for some time. If markets functioned perfectly, the value of conservation would be appropriately incorporated in the resource prices. But numerous forces act to distort prices from those which would be socially optimal. Moreover, it must be recognized that any socially optimal norm must necessarily be arbitrary when viewed in an intertemporal context. This report investigates the issue of price and quantity determinations for non-renewable resources and illuminates the difficulty of measuring biases given to prices by various forces acting over time.

Francis T. Mayo, Director
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ABSTRACT

This report addresses the issue of price and quantity determination for non-renewable natural resources in competitive markets. The issue of natural resource pricing is important in an overall evaluation of the social desirability of recycling, for the rate of recycling directly affects the quantities of virgin materials which are conserved. If through the action of the market mechanism conservation benefits are accorded a value which is less than the true value of these benefits to society, there would exist a rationale for greater governmental support of resource recovery and recycling.

A comprehensive review of the extensive literature on natural resource economics reveals that many forces may act to create a divergence between the socially optimal structure of prices and the prices which are determined in the market for natural resources. Unfortunately, for the purposes of this report, the forces act in varying directions and with varying intensities over time. It does not appear possible to establish analytically with any degree of precision the magnitude or even the direction of bias given to prices through the actions of supply and demand for natural resources.

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SECTION 1

INTRODUCTION

This report addresses one dimension of recycling--the economic evaluation of virgin materials which are conserved when industrial and consumer goods are recycled. Of key interest, then, is the value placed on undeveloped virgin natural resources. Do competitive markets for natural resources establish prices which correspond to the actual social value of the resource? If there are divergences between market prices and social values, can the differences be estimated?

The market evaluation of conservation is but one dimension of recycling. It is one factor which may lead to a difference between the amount society would like to recycle and the amount which is actually recycled. Some other factors which could have a similar impact on recycling but which will not be considered in this report include the relative amounts of pollution from primary and secondary industries, the pricing of solid waste disposal, and institutional factors such as freight rate policies and federal procurement policies.

Fears of increasing resource scarcity have led to recurrent demands for greater attention to resource conservation. For example, the Conservation Movement accepted as basic tenets that most resources were too cheap, were wastefully exploited, and would become exhausted soon, thereby depriving future generations of their use. More recently, attention has been directed to the virtues of energy conservation. Alarming statistics indicating imminent depletion of the world's petroleum resources have been used as a central argument to justify greater federal involvement in energy resource allocation and conservation.

This paper begins with a review of the history of resource conservation. Malthus [20], Ricardo [34], and other early economists offered some of the first views of the consequences of population growth and resource exploitation in a finite world. Later, the leaders of the Conservation Movement espoused the doctrine, along with supporting evidence, that resources were being exploited too rapidly. We will be interested in examining the accuracy of their forecasts of impending resource exhaustion and will search for explanations for the source of their errors. It will be shown that a variety of economic forces act to alleviate production and consumption constraints which otherwise would appear as resources are depleted. Lastly, we will be interested in the extent to which the forces of price sensitive demand, technological change, and substitution counteract the effects of resource depletion, thereby helping to ensure an adequate supply of exhaustible resources for use by future generations.

The conclusion that some resources will remain available for use by future generations, despite the cumulative effects of depletion since the arrival of man on this planet, does not in any way imply that the rate at which resources are being depleted is socially desirable. Although the world may not be in imminent danger of exhausting an essential resource, competitive market environments may lead to excessively high rates of consumption and lower standards of living for future generations.

The second section of the paper offers an analysis as to how the appropriate rate of resource depletion should be determined. From the perspective of economic efficiency, the competitive market system does a good job, subject to qualifications that when resources are exploited under conditions of free and open access or resource development is influenced by forces such as non-neutral taxation, externalities, uncertainty, and monopolistic control, some form of governmental regulation may be necessary. From the perspective of intertemporal equity among generations, one cannot be certain that the competitive market mechanism results in a desirable allocation of natural resources. Neither a single individual nor groups of individuals voicing their desires through the market will, in general, find it possible to devise resource consumption plans which are acceptable to those same individuals from every vantage point in time. One approach which has been advanced to help assure intertemporal fairness is that resource allocation decisions should be made by a congress of individuals operating from behind a veil of ignorance as to which generation each individual will belong. It is argued later, however, that this approach may not be very practical.

In the final section of the report, an attempt is made to be more specific as to the magnitude of the distortion in market prices created by each of several market forces. Because the effects of the seperate forces are to a degree offsetting and are uncertain in magnitude, it is not even possible to indicate the qualitative nature of the cumulative bias in natural resource prices, let alone make an explicit estimate of the size of the bias.

The appendix to this report contains a non-technical summary of the principal findings. This summary was delivered as a paper at the 107th Annual Meeting of the American Institute of Mining and Petroleum Engineers in March 1978.

SECTION 2

HISTORICAL PERSPECTIVE ON CONSERVATION

The specter of increasing resource scarcity in industrial economies has long been a source of concern, both within and outside the economics profession. The economists Malthus, Ricardo, and Mill investigated some of the implications of increasing demands for resources in a finite world. Writing nearly 200 years ago, Malthus made a persuasive case that resource scarcity restrains economic growth. Malthus' model, which assumed fixed quantities of homogenous resources, was modified later by Ricardo to include resources of varying quality and productivity. Mill added to Ricardo's notion of scarcity noting that costs for individual mines will begin to rise before the mines are exhausted since "shafts must be sunk deeper, galleries driven further" [23, p. 188], etc. Mill also was one of the first to discuss aesthetic benefits from natural resources. In the late nineteenth century, the Conservation Movement flourished, partly because of a widely held conviction that the Nation's finite natural resources were being wasted and would soon be exhausted [4, ch. 4].

Members of the Conservation Movement offered what they felt was incontrovertible evidence that the Nation's physical resources were being wasted needlessly and depleted at rates which would lead to exhaustion of supplies in the proximate future. Although a closely reasoned economic analysis at that time might have reached quite different conclusions about the probability of impending economic calamities attributable to scarcity of natural resources, the arguments of those in the Movement did have a broad popular appeal. They argued, for example, that increasing scarcity was an inevitable consequence of the use of limited physical resources. The Conservation literature is replete with estimates of the size of the stock of many of the Nation's physical resources along with projections of the exhaustion dates for various future rates of consumption [e.g., 32, p. 43]. The inescapable consequences of resource use were thought to be aggravated by what was termed "waste." The Conservation literature identified several types of waste which could be avoided by "wise use." Some examples of needless waste included the flaring of natural gas from oil wells, the failure to obtain maximum productivity from renewable resources such as forests, cropland, and water, and the mismanagement of non-renewable resources (e.g., permitting mines to flood when useful ore remains).

An economic perspective on the issues discussed in the Conservation literature enables one to support some points and to refute others. Scarce resources are not necessarily being wasted when natural gas is flared. If the full costs of gas recovery exceed its market value, flaring is a welfare-maximizing policy for those making the decision. Recovery of the gas when done at an economic loss would be a true waste of resources. On the other hand, the development of common property resources often proceeds wastefully as there exist few or no incentives for individuals engaging in such resource development to consider their impact on the quality of the resource or the costs of other developers.

The views of the Conservation Movement that many renewable and non-renewable resources would soon be exhausted have been echoed by other subsequent writers. In nearly every instance, these predictions of resource exhaustion have proven to be highly inaccurate. Even when the predictions materialize, dire consequences fail to ensue. Some forty years ago, Leith, a well known geologist, warned that "depletion is further advanced than even mining men generally realize" [18]. At that time, Leith estimated that proven reserves of crude oil, lead, and zinc were only some 15 to 20 times as large as annual production rates. Lake Superior iron ore reserves had less than 20 years of supply remaining and copper reserves were about equal to 40 years of then current output. Forty years later, the predicted resource exhaustion had not occurred. In fact, rather than facing imminent exhaustion of these resources, the United States in the 1970's had ratios of known reserves to current output far in excess of those prevailing in the 1930's when Leith wrote. Domestic reserves of zinc equalled over 60 times the annual mine output of 1974, lead reserves over 80 times mine output for 1974, and copper reserves over 50 times 1974 mine output. The Lake Superior iron ores did become exhausted, but they were replaced by taconite, an iron-bearing rock not considered to be ore in Leith's time.

Modeling of the world economy by the Club of Rome represents a recent example of the continuing attempts to assess the impact of increased scarcity of physical resources [21]. As was characteristic of the Conservationist literature, the magnitude of proven reserves of various resources was compared with annual output and consumption to derive an estimate of the date of eventual exhaustion. Not surprisingly, limits of physical resources did place a limit to economic growth and in some scenarios signaled the impending collapse of the world economy. It should be noted that more recent modeling by these researchers has included some of the resource augmenting factors discussed in the next section and has reached more sanguine predictions as to the possibility of continued economic expansion with a fixed endowment of resources [22].

SECTION 3

ECONOMIC PERSPECTIVE ON RESOURCE SCARCITY

Several factors act to alleviate constraints which otherwise would appear as physical resources are consumed. Some of the more obvious of these factors include technical change, both induced and autonomous, substitution of inputs in production as input prices change, and reduced consumption in response to higher relative prices for final outputs. Many of the inaccuracies of previous forecasts of resource exhaustion can be explained by a failure to consider adequately some or all of the dynamic process through which supplies of physical resources are, in effect, augmented or enhanced.

Barnett and Morse investigated the extent to which the above factors have acted to offset the condition of increasing scarcity as resources are depleted. By equating increasing scarcity with rising costs of natural resource outputs in terms of the labor and capital used as inputs, Barnett and Morse were able to formulate empirically testable hypotheses on resource scarcity. With the notable exception of forest products, which have become noticeably more scarce over the past several decades, nearly all physical resources have become, by this definition, less scarce. This indicates that technical change and substitution (and possible economies of scale and imports) have in most cases compensated fully for the Ricardian scarcity which otherwise prevails as development proceeds over time from high grade to successively lower grade materials.

Although Barnett and Morse found that costs for extractive outputs, in terms of labor and capital inputs used in their production, had remained stable or fallen between 1870 and 1960, one could argue quite persuasively that in the long run the relative price of extractive products will increase [36]. For one thing, the availability of certain minerals apparently changes surprisingly little as the grade of ore mined is lowered [6]. Even with technological improvements in mining and processing, the supply curve for some of these minerals may be highly inelastic. Another factor suggestive of higher prices for extractive outputs is the substantial energy requirement of most mining operations. Energy prices appear to have reversed a long-run secular decline and to have begun a steep upward climb relative to general economy-wide price indexes.

If the relative prices of many of the extractive outputs do begin to advance, as a consequence of further scarcity of mineral deposits which cannot be compensated by falling mining and processing costs, the same factors which have led to stable or falling relative prices for extractive products in the past should act to restrain the upward pressure on resource prices. Rising resource prices help to render profitable the mining of low grade ores. Rising resource prices also may induce changes in technology to permit greater output of consumption and investment goods per unit of resource input. The exhaustion of certain mineral ores may induce the development of technologies capable of extracting minerals from other, previously unexploited, ores and stimulate more intensive research for new deposits. Rising resource prices may stimulate greater recycling, thereby reducing the requirements for primary ores. Finally, higher prices for final products attributable to rising resource prices may induce consumers to substitute services and other goods which use few physical resources as inputs for resource intensive goods. In addition to these factors, there is an upper limit on the price of a given resource whenever there exists an abundant though more expensive substitute. Nordhaus [25] has termed this a "backstop technology."

Experiences of the domestic steel industry provide ample support for the pervasiveness of these factors. In the 1950's, as the Lake Superior iron ores were nearing exhaustion, technologies were developed to pelletize taconite ores for use as a feedstock to blast furnaces. The electric furnaces as a facility for producing steel came into widespread use during the 1960's, a period of relative abundance of scrap steel (the principal input). Steel, itself, represents a technological improvement over iron. Because of a higher strength to weight ratio, steel has replaced iron as the dominant metal in consumption and investment goods. This substitution has permitted an increase in the output of consumption and investment goods per unit of iron ore input.

As Goeller and Weinberg [10] argue, iron, or steel, and aluminum as substitutes for other, scarcer minerals may constitute the most important resources for the backstop technologies. Taconite ores presently being mined as an iron-bearing mineral contain about 27 percent iron and 51 percent silica, or about 3.4 times the average crustal abundance of iron. Some bauxite presently being mined for aluminum production contains concentrations of aluminum at about 2.2 times its average crustal abundance. These figures indicate that supplies of iron and aluminum ore may be viewed as relatively abundant.

One key question, which remains unanswered, is the price at which various minerals will be replaced by the backstop technologies. Although coal liquefaction does not represent a complete backstop for oil, coal certainly is far more abundant than oil. Nordhaus estimated that coal liquefaction would represent an economically viable alternative to oil at seven or eight 1970 dollars per barrel, a price approximately equal to the present price of crude oil. One true backstop technology for most uses of oil is solar energy; another might be the breeder reactor. The price at which solar energy would substitute for oil as fuel varies from below the present price of oil, for some uses such as heating in sunny climates, to prices considerably higher than present oil prices for other uses (propelling vehicles, for example).

The relationships between resource use, resource prices, and the backstop technologies are examined in more detail in the next section.

SECTION 4

INTERTEMPORAL RESOURCE ALLOCATION

This section of the report reviews the economic concepts and models which have been used to analyze how a private free enterprise economy determines the rate at which exhaustible resources will be depleted. The fundamental question is whether the owners of exhaustible resources have the incentives to develop resources at a socially optimal rate. To answer this question, one must first define what is meant by socially optimal. The Pareto test has long been used as a criterion of optimality, but this has been in reference to the allocation of inputs and outputs at one point in time. To apply such a test in an intertemporal context, one must assign weights to consumption in different time periods. Whether these weights should be constant across time or decline into the future is an ethical question, one which cannot be resolved through positive analysis. Therefore, any comparison of private resource development with a norm which is deemed to be socially optimal will be arbitrary, given that the criterion for intertemporal optimality depends upon arbitrarily determined standards.

Initially, the discussion will focus on the model first developed by Hotelling [14]. In this model, exponentially declining weights are given to future social values. Later, it is shown that such a weighting system can result in massive transfers of wealth and income among generations. Finally, we explore some alternative criteria for resource allocation among generations.

MARKET ALLOCATION

Initially this discussion will consider resource allocation decisions which are made by resource developers. The fundamental differences between open access exploitation and the development by a sole owner have long been recognized. If access to a resource is shared, the incentives which are perceived by individuals will differ from those which are experienced by society. Typically resource development under open access is premature and excessive from the viewpoint of society as a whole. Assignment of property rights forces resource developers to make a continuing comparison between the value of the resources if extracted and processed today and the future values which the same resource would command if development were postponed.

Private Profit Maximizing Behavior

When natural resources are privately held, the owners are free to determine that path of extraction which maximizes their private welfare. The basic dynamic model of the mine assumes that a mine owner seeks to maximize the present value of profits subject to the obvious constraints that production each year be non-negative and total production not exceed the initial quantity of minerals in the deposit. It is assumed that future prices are known with certainty, that the true magnitude of all reserves is public knowledge, and that there are no externalities. Given these assumptions, the dynamic optimization problem can be solved to produce the following fundamental results:

(1) When output is unaffected by the stock of resources remaining, the value of the resource in place must increase at the market rate of interest. As Solow [37] and others have suggested, this must hold in order that resource owners will be indifferent between producing today and holding minerals in place for sale at a later date. Equilibrium in the market for mineral assets must produce this result; otherwise resource owners would have incentives to alter their rates of production. If resources in place increase in value at rates less than the going rate of interest, resources owners have an incentive to accelerate their rate of extraction and invest the proceeds elsewhere. If the value of minerals in place increases at rates in excess of the going return on capital, resource owners would cut back on current output, raising current prices relative to future prices until the rate of return is brought into equality with the interest rate.

(2) The price of extracted minerals equals marginal extraction cost plus marginal user cost. That is, minerals are supplied by a competitive mining industry at a price equal to the sum of extraction costs on the last units removed and an amount equal to the value of minerals in place (the marginal user cost). Because price depends on both marginal extraction and user costs, it is to be expected that changes in technology, the rate of new discovery, and demand would affect price.

(3) The first two results can be combined to yield the proposition that the optimal time profile for extraction proceeds from high-grade, low-cost, to low-grade, high-cost deposits. High-cost producers cannot serve the market when low-cost deposits are known to exist. At a price level which supports production from high-cost resources, the low-cost producer would have a strong incentive to undercut the price. More fundamentally, prices could not be high enough initially to sustain production from the high-cost sources because at those prices, user cost on both grades of desposits could not continue to rise at the same rate of compound interest. High-grade deposits would increase in value more slowly than the going rate

of interest, thereby stimulating production from high-grade sources. These concepts have been developed more rigorously by Heal [13].

A more formal and precise development of these basic results is given in the appendix. Having established the basic results under profit maximization in a dynamic context, we now turn to the maximization of social value.

Maximization of Social Value

Hotelling and others [14, 35, 41, 43] have investigated the conditions which maximize societal welfare. Generally speaking, social values are assumed to be the sum of producer and consumer surpluses. The critical question is how social values in different periods are to be weighted. Is a unit of consumption today worth more, less, or the same as a unit next year or one hundred years from now? As noted in the introduction to this section, Hotelling assumed that present and future social values could be compared by discounting future values at the market rate of interest. This convention dates at least as far as the work of Irving Fisher in the late nineteenth century. More recently, Koopmans [16] has lent further theoretical support to the notion that it is quite rational for existing members of society to discount future values.

The maximization of social welfare is thus defined as the maximization of the present value of producer and consumer surpluses, with all future values discounted at the market rate of interest. When the objective function is expressed in functional form and the indicated operations performed, it can be shown that the equilibrium conditions are identical to those for private profit maximization. In this way, it has been demonstrated that the decisions of profit maxmizing individuals are entirely consistent with the intertemporal maximization of aggregate social welfare.

Two aspects of the demonstration that profit maximization leads to a socially optimal allocation of resources across time deserves further discussion. First, the demonstration requires that a number of assumptions regarding production be satisfied. Some of these assumptions include (1) competition must prevail, (2) there must be no uncertainty, and (3) there must be no distortions between private and social cost (such as caused by taxation or externalities). The second important aspect which should be noted is that maximization of the present value of profits, or equivalently, the present value of producer and consumer surpluses, can result in significant impacts on the distribution of income and wealth over time. We will discuss this latter point in the next few pages and reserve consideration of the first point until later.

DISTRIBUTIONAL CONSIDERATIONS

Several economists have questioned the desirability of permitting market forces to determine resource allocation over long time spans. Essentially, these arguments share a common theme, that when decisions involve transfers of wealth among generations the best course of action will vary depending upon one's perspective in time. It is as if we were evaluating a project with undiscounted future benefits and costs as illustrated in Figure 1. From the perspective of t_o, a present value calculation which discounts future benefits and costs may indicate a positive value for net present benefits. Using t_o as the vantage point for its calculations, the market process signals that the project should be undertaken. If one were to compute the present value of future benefits and costs at a later date, say t_1, the calculations would show present costs exceeding present benefits and market forces would signal to decision makers that the project should not be undertaken. The immediate gains from undertaking the project at date t_o are followed by net costs to succeeding generations.

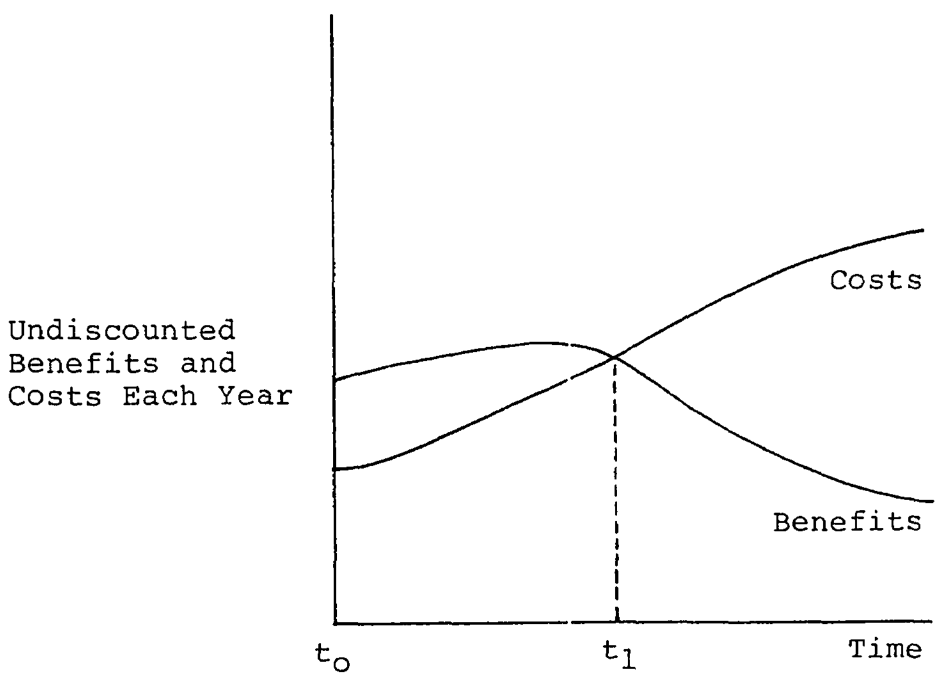

Figure 1. Time profile of benefits and costs.

One important refinement of present value maximization by members of existing generations has been offered by Arrow and Fisher [3]. They show that in situations where decisions are basically irreversible and the magnitude of future benefits and costs is uncertain, waiting to make a decision can often increase the magnitude of the expected net benefits when waiting reduces the uncertainty of benefits and costs. In the example of Figure 1, one can take the benefit and cost values as expected values, assuming that there is a wide band of uncertainty about each expected value. Any delay in decision-making will, in this example, increase the likelihood that the computed value of expected net benefits will be negative.

A related finding was first offered by Strotz [40]. He showed that the plan (specifically a consumption plan) which is optimal for an individual from one vantage point, often will not be optimal (in the sense of present value maximization for that individual) from another vantage point. Page [26, 27, 28] has argued that this so-called "dynamic inconsistency" should give present members of society further pause for thought when they selfishly maximize net present benefits of projects which have the potential for large intertemporal transfers of wealth. The arguments of Strotz and Page appear to have limited bearing upon economic decision-making by members of the present generation. Economists have attempted repeatedly to tackle questions of wealth and income distribution, and by now have apparently reached a consensus that economics, per se, has little to offer in the way of guidance. Nonetheless, when the use of nuclear power, fluorocarbons, and pesticides by members of the present generation threatens a massive transfer of wealth away from members of future generations, a basic appeal to intertemporal fairness dictates that we proceed with great caution. Moreover, the tremendous uncertainties associated with the estimates of future costs for these projects may, according to the Arrow-Fisher analysis, necessitate delays in such investments if expected net present benefits are to be maximized.

The typical decision to deplete a particular nonrenewable resource deposit does not involve such a clearcut transfer of wealth among generations. Occasionally, these decisions may involve the irreversible loss of scenic natural environments. In such a case, one may appeal to the Arrow-Fisher [3] argument that the present value of benefits can often be increased by postponing the development decision and attempting to resolve the uncertainties which accompany estimates of future benefits and costs. In most other situations, the decision by members of the present generation to develop a non-renewable natural resource has both plusses and minuses with respect to the welfare of future generations. Assuming net present benefits of development, such decisions increase the income of the present generation and, assuming a positive marginal rate of saving out of income, such development decisions also increase the wealth of future generations unless some resource essential to future income is exhausted. When prices for non-renewable resources dictate development today, this is because capital which embodies the resource is more productive than is the resource in its undeveloped state.

If all resources (including natural environments) are priced correctly in the market place, the typical development decision should benefit future as well as present generations. In those cases where resource development is expected to enhance the welfare of the present generation, but damage the interests of future generations, an alternative to market-determined allocations may be deemed desirable.

The next few pages explore one possible alternative to market-determined allocations.

ALLOCATIONS FROM THE ORIGINAL POSITION

The original position provides an alternative to market determinations for resource allocation both over extended time horizons and at one point in time. In contrast to decisions by members of existing generations, which in a competitive market setting are consistent with the maximization of these individuals' self-interest, decisions in the original position result from the thought experiment of soliciting a consensus from hypothetical individuals who are unaware of the generation they will be born into and the abilities they will possess.

Although clearly not the originator of the concept of an original position, Rawls [33] has developed a rich exposition of decision-making from this perspective. Rather than debate what is a fair allocation of resources given one's present position in life and society, Rawls suggests that a fair resolution of distributional issues can be had by resorting to what he terms the "veil of ignorance" in an original position. From this position of ignorance as to one's eventual position in society, preferences, abilities, and the like, one is asked to evaluate alternative allocations of resources. Rawls concludes that from this original position one would opt to reallocate within a generation until an equal share is available to all. The Rawlsian utility function, which places liberty above all else in importance, and the generalized difference principle, which is that societal welfare within a generation is increased only by increasing the welfare of the least well-off member of society, are of less interest to us than is the basic concept of decision-making from the original position.

The generalized difference principle, subsequently termed the "maximin principle" (maximizing welfare at its minimum level), has been severely criticized by economists. This principle implies that any benefit to the worst-off member of society outweighs any loss to other individuals, provided the latter do not become the worst-off in the process. As Arrow has noted, by this principle one would support the use of medical procedures which serve to keep terminally ill patients alive, even if the procedures were so expensive as to reduce the rest of the population to poverty levels. Apparently Rawls was aware of this problem with the strict interpretation of maximin, for he developed the modification of "close knittedness" of society through which individuals consider not only their own welfare but also the welfare of others in evaluating their own level of satisfaction. Some inequality in the distribution of resources is to be tolerated, particularly if the inequality can be shown to produce incentives for improved performance from the most able members of society.

The maximin principle represents a basic alternative to the utilitarian approach of welfare economics. The fact that a fundamental alternative to utilitarian welfare economics has surfaced has sparked inquiry into the feasibility of using maximin as an intertemporal allocation rule; in fact, he specifically rejected it because "there is no way for later generations to improve the situation of the least fortunate first generations." Despite such a disclaimer by Rawls, the implications of maximin have been investigated in some detail. For example, Solow [38] shows that the maximim criterion calls for equal consumption in all generations. With stationary technology there would be zero net saving and with technological progress there would be, of necessity, negative net saving.

Rather than use maximin as an intergenerational savings criterion, Rawls argued that as each "generation cares for its immediate descendants, as fathers care for their sons, a just savings principle . . . would be adopted." The economic implications of this principle were investigated by Dasgupta [7]. He interpreted the savings rule as a Nash equilibrium where each generation's strategy consisted in the choice of its own savings rate. Compared to the savings implied by the Utilitarian principles, the Rawlsian savings rule was found to be Pareto inefficient. That is, some members of society could be made better off while none were worse off if one were to deviate from the Rawlsian savings plan.

Finding a fair and defensible rule for allocating resources across generations is a problem which has attracted only limited attention from economists. Generally, it is conceded to be more difficult than the problem of allocating resources within one time period, and the latter problem has not been solved completely. As Rawls has noted,

> the question of justice between generations . . . subjects any ethical theory

> to severe if not impossible tests . . .
> I believe that it is not possible, at present anyway, to define precise limits on what the rate of savings should be. How the burden of capital accumulation and of raising the standard of civilization is to be shared between generations seems to admit of no definite answer.

Two economists, Vickrey [42] and Harsanyi [11, 12], predate Rawls in the use of a construct which removes men from their station in life as a perspective for making ethical judgments. Vickrey focused on the question of optimality of an income distribution. Building upon ideas of Ramsey, von Neuman, and Morgenstern, that choice in risky situations can be described as the maximization of expected utility, Vickrey argued that from a position of ignorance as to their station in life, individuals would want to maximize the sum of expected utilities accruing to members of society. If there are n members of society and the utility accruing to the ith individual is U_i, the value of a particular distribution is $1/n\ (\Sigma U_i)$. The expectation for an individual is maximized by making the sum of utilities as large as possible.

Vickrey established the connection between utility and the distribution of income by assuming that the marginal utility of income declines with increasing income. If one could treat the aggregate amount of income to be distributed as independent of the distribution income, the sum of utilities would be maximized with an equal share for all. But the distribution of income can affect the incentives for production and in turn the total aggregate income. Therefore, Vickrey suggests that some degree of inequality is needed to create the incentives which would maximize the sum of expected utilities, which in turn maximizes the expected utility of an individual in the original position. Rawls and Vickrey are very close to agreement in how one would distribute fairly a given quantity of income among members of one generation.

Extending Vickrey's model to cover more than one generation is quite difficult. One then needs to be concerned with the rate of savings, for savings have a profound effect on future incomes. In its barest form, the intertemporal version of Vickrey's model would say that one should maximize the sum of all present and future utilities, thereby maximizing the expected utility of an individual in the original position. Depending upon how severely the marginal utility of income declines with increasing income, this approach appears to suggest that savings should be made as high as possible, constrained only by that minimal level of consumption necessary for survival.

The principal difficulty with the criterion of maximizing the sum of future utilities is that it would require great sacrifices by the present generation and would benefit individuals not yet born. It seems obvious that the present generation would be unwilling to agree to such a proposition. Because the future promises to be wealthier than we are, we may anticipate that they will view our failure to save more as justifiable. It does appear though, that when the present generation engages in activities which can be expected to make future generations far poorer, future generations will not view our actions kindly.

The relationships between intertemporal and intratemporal resource allocation was addressed recently by Mishan [24]. He argued that the failure of economics to provide reasonable criteria for intratemporal allocation need not preclude the analysis of intertemporal distributional issues. For intratemporal allocations of income, Mishan considers two plausible perspectives. One is that the income distribution is generated by random chance, that chance encounters, the friends one has, and the abilities one is born with, largely determine one's income. From this perspective, an equal distribution within a generation would be deemed just. On the other hand, one may argue plausibly that income is the fruit of one's efforts and, therefore, to encourage that effort, incomes should be distributed according to effort. Both views have merit, but unfortunately economic criteria do not enable one to decide which is more important. The distributional question is essentially an ethical problem to be resolved from the original position.

For intertemporal allocations, Mishan argues that no matter which view one has on a just income distribution, one is led to advocate an equal share for each generation. Clearly, those who believe that variation in income is generated by random chance would advocate an egalitarian distribution across generations. Those who believe that income should be distributed according to effort would be led to the same conclusion, Mishan argues, because the effort by each generation is probably constant, at least as a first approximation.

In his commentary, Fisher [8] pointed out that an equal distribution for the members of each generation has the same deficiencies noted by Solow for the maximin criterion. That is, income would be constrained for all time by the low income level of the first generation. Fisher argued that one may escape this unhappy dilemma if one postulates benevolence toward future generations. If each generation attempts to "make the world a better place for its having been there," one can have rising incomes over time as the equal incomes which are roughly proportional to effort by each generation are augmented by the benevolence motive.

Despite the progress which has been made to date in assessing the basic issue of fairness to existing and future generations, the original position and related constructs face formidable obstacles before they can truly be deemed workable as tools for intertemporal resource allocation. No matter how hard we may try to place ourselves in the original position, the fact remains that we are members of a current generation and have established tastes, preferences, and abilities. Any decisions we make would no doubt reflect these inherent sources of bias.

SECTION 5

DIVERGENCE OF PRICES FROM OPTIMALITY

ASSESSMENT OF MARKET FORCES

This section is directed to the assessment of the nature and magnitude of deviations between actual market prices and a "socially optimal" norm. While we have reviewed two methods for deriving the "socially optimal" norm, the original position method appears to be so severely limited in practicality that we must use Hotelling's definition of optimality. That is, we must maximize the present value of producer and consumer surpluses. Using this as the criterion for social optimality, Hotelling demonstrated that the price and consumption patterns which result from the competitive exploitation of resources by profit-maximizing firms are optimal, from the viewpoint of society, provided certain assumptions are satisfied. The assessment here centers upon establishing the direction and magnitude of biases in market price which result when Hotelling's strict assumptions are relaxed to reflect real-world considerations of taxation, monopolies, externalities, and uncertainty.

Most of the literature relevant to this problem investigates a somewhat different question, that of the impact of various market forces on the rate of resource depletion. Knowing that resources are being depleted too fast or too slowly does not tell one immediately that prices today are either too low or too high. For example, when development is stimulated by a force such as uncertain tenure of ownership, resources are extracted and consumed at an earlier date than would be deemed socially optimal. Initially, prices for the mineral will be depressed as production exceeds the optimal rate. Later, however, when the deposit is exhausted, less of the mineral will be available than would be socially optimal, and prices may well be higher than would prevail under an optimal plan. Later, we attempt to deal more fully with this problem of assessing impacts on the time profile of prices. Below, we review the literature on production biases caused by various market forces.

Taxation

The extractive sector which develops natural resources is subject to an unusually large number of taxes and tax deductions including depletion allowances, expensing of exploration and development outlays, bonus bidding for lease rights, production royalty payments, and severance taxes, as well as ordinary sales, income, and property taxes. Some of these taxes and tax subsidies are easily incorporated into an economic model of production from a mineral deposit. For example, Sweeney [41] and Peterson [29] have shown that lump sum and pure profits taxes would not distort production decisions. Included in this category would be bonus bids, as well as ideal income taxes. Among those forces which may accelerate production are depletion deductions and expensing of exploration and development (though the latter has not been analytically demonstrated in the literature). When property taxes are based on the value of mineral remaining in the ground, they too can accelerate production. Forces which serve to slow the pace of mineral extraction include royalty payments and severance taxes.

Monopoly

The effects of monopolistic ownership of resources on the time profile of production were first analyzed by Hotelling. He showed that monopolistic control of resources served to delay production, in essence concluding that the monopolists may be doing more to promote the interests of conservation than the Conservation Movement was ever able to do. Subsequent investigation by others has revealed that monopolists do not always maximize the present value of their profits by holding resources off the market. Sweeney [41] and Lewis [19] have shown that certain patterns of demand growth and certain configurations of stable demand curves can lead the monopolist to extract at a faster rate than would a competitive group of owners. On the other hand, Stiglitz [39] and Peterson and Fisher [31] have concluded that the most likely effect of monopolistic control over resource exploitation is to slow the rate of extraction. To date, there has been no analysis of the impacts of oligopolistic resource development on resource prices and production rates.

Uncertainty

Although Sweeney claims that the effects of uncertainty on the production decisions of the natural resource sector are still largely unresolved, there is substantial agreement that one general impact is the acceleration of production from known deposits. At least three important cases of uncertainty have been discussed: uncertain tenure of resource ownership, uncertain price (demand) expectations, and uncertainty over future technology and factor costs. To this list could be added uncertainty over future taxes and royalties which may be levied on output. Assuming resource owners are risk averse, each source of uncertainty will, other things equal, create an incentive to accelerate the rate of production.

Perhaps this effect is most clearly illustrated in the case of uncertain tenure of ownership. A profit-maximizing firm operating a mineral concession in a politically volatile region has a tremendous incentive to extract ore at a rate far in excess of that which would maximize profits on a similar domestic deposit. One common method of accelerating mineral production on these foreign concessions is to extract and process only the highest grade ores. This often has the effect of rendering uneconomic much of the lower grade ore which would have been mined had tenure been more certain.

A second probable impact of uncertainty has been noted by Peterson and Fisher. In their view, uncertainty would diminish incentives for exploration, leading to smaller reserve holdings, especially relative to production rates. The related problem of optimization in exploration has been addressed recently by Gilbert [9]. Preliminary results show that private firms may invest excessive amounts (from society's view) to eliminate uncertainty over the quality and quantity of mineral deposits available for development.

Kay and Mirrlees [15] sketched a preliminary analysis of the likely effects of uncertainty over future prices on production decisions of resource owners. In their view, current prices for resources whose exhaustion is not imminent should approximate the marginal cost of extraction. Because resources cannot be sold at prices which fall short of extraction costs, at least in the long run, the general level of resource prices is more likely to exceed than to fall short of the true marginal cost of extraction. If prices are too high, this is just another way of saying that production is delayed relative to the socially optimal path (that which would maximize the present value of producers' plus consumers' surpluses).

Externalities

The interest of the economics profession in the problems of environmental externalities dates at least as far back as Pigou's smoke nuisance example. Only relatively recently have natural resource economists examined in any detail mineral exploration and production for evidence of such market failures. Peterson [30] investigated two sources of externalities to the petroleum industry. His results, which apply equally to other extractive industries, indicate that the discovery of a new oil-producing site typically involves two externalities, a so-called "Easter egg" externality and an information externality. By removing one more "Easter egg" from the field of search, each new discovery raises the cost of finding new deposits. Since the unclaimed mineral deposits have no market price (at least on open access federal lands in the U.S.), scarcity value is reflected only in the expenditures individual economic units must incur in order to find each new deposit. Such common property resources become overdeveloped because of a divergence between private and social costs of acquiring additional resources.

The information externality arises when the spatial orientation of deposits is such that the discovery of one deposit conveys valuable information to those searching for deposits on nearby lands. If the value of the information cannot be recovered by those making the initial discovery, insufficient expenditures will be forthcoming in the resources sector (private cost exceeds the social cost for new discoveries). Another externality in exploration, which may produce too much information, arises when firms are permitted to perform their own independent evaluations of properties prior to leasing. Expensive exploratory programs are duplicated as each firm attempts to gain an advantage in the ultimate bidding for lease rights.

Under the General Mining Law of 1872, which governs hardrock mineral development on U.S. federal lands, the actions of individual mining operators to protect their own interests serve to increase development costs for all [1]. One example of this is the absence of a comprehensive claim reporting system, the result being thousands of cases of overlapping and conflicting claims.* In developing such properties, a claimant bears the risk that another claimant will seek to invalidate his rights in court. Such uncertainties over title to a property should serve to inhibit development. These uncertainties differ importantly from those faced by the owner of an operating mine. In the latter case, fears of higher taxes, expropriation, and the like definitely serve to hasten the rate of extraction. A second example of inefficiency in mineral development, especially common now that lower grade deposits are being mined in large-scale, capital intensive operations, is the difficulty of amalgamating several small claims into large properties under one owner. Individual claim owners have an incentive to hold out for all of the potential gains from consolidation under the present system and this often serves to block development. This implies that properties which would be developed under alternative systems for the disposal of mineral rights on public lands (e.g., a leasing system) are not developed under the discovery system of the 1872 law. In turn, these inefficiencies under the present system of mineral development lead to higher costs for the mining industry and a slower rate of extraction than would occur in a system free of such externalities.

Yet another form of externality, one which is perhaps more obvious to all, are the residuals which are produced in mining, smelting, and refining operations. These residuals are left in

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* It should be noted that a comprehensive claim reporting system is called for in the Federal Land Policy and Management Act of 1976. How well it will work in practice remains an unknown.

the form of tailings, discharges into the atmosphere, and on occasion, discharges into waterways. When such discharges impose costs on other economic units and these costs are not paid by the mineral firm making the discharges, there is said to exist an externality. Again, social costs of production exceed private costs of production. In such situations, the quantity of output exceeds that which is socially optimal.

Finally, as noted earlier, the environment serves as a source of valuable amenity services. Typically, private resource developers are not rewarded by the market when they preserve scenic natural environments. In some instances, state and federal environmental statutes force private developers and public resource managers to consider the value of the amenity services which would be foregone as a result of development. Nonetheless, Krutilla and Fisher [17] argue that insufficient attention continues to be given to the values of environmental preservation.

PRICE EFFECTS OF TAXES, MONOPOLY, UNCERTAINTY AND EXTERNALITIES

In the Hotelling model, the optimal price for a resource is the sum of lease value and marginal social cost of extraction. Deviations from optimal prices arise when lease values are computed incorrectly (as is the case when private operators view their operations as subject to uncertainties that a social planner would not perceive), when privately computed costs diverge from social costs (as in the case of preferential taxation, information externalities, and the like), when monopoly rents are earned, and when regulation needlessly increases private marginal cost (as in the case of our federal mining laws). It becomes apparent that to answer the questions posed at the outset of this report, that is, whether or not non-renewable resources are indeed too cheap, one must analyze in detail the determination of optimal price and the impact of each of these separate influences on market price.

In the appendix, it is shown that the optimal price for a resource equals marginal social costs of extraction, plus lease value. It is also shown that when there is no stock effect (that is, when output does not depend upon the amount of minerals remaining in place), the lease value grows at compound interest. When there is a stock effect, lease values no longer need rise at the rate of interest; in fact, they may actually fall with the passing of time.

As a very general proposition, it appears that taxes may be characterized as affecting private marginal costs of extraction. Taxation creates a divergence between private and social costs of extraction. Now all corporate activities are subject to taxation, so the divergence between private and social costs cuts across all industries. The real issue from the standpoint of resource allocation, both natural and otherwise, is whether or not the mining sector experiences significantly different tax rates from other sectors of the economy. From the available evidence, one can conclude that, on balance, the mining sector does benefit from special provisions of the income tax laws. A recent report [2] contains estimates of the impacts of taxation and tax subsidies on the price of final outputs of the extractive sector. The more significant of these effects are listed in Table 1. It should be noted that the most likely impacts may be as little as half of the reported upper limits.

TABLE 1. PERCENTAGE IMPACT ON MARKET PRICE

Mineral	Depletion	Severance taxes*	Expensing of exploration and development
Pig Iron	-3%	+3%	Unknown
Copper	-6%	+1.5%	"
Lead	-3%	+1%	"
Aluminum	-2%	+0.2%	"

* The severance tax on iron extraction in Minnesota can be offset to a considerable extent by credits for labor employed. The true impact on price is less than 3%. Severance taxes for other minerals are averages of effective rates in the two or three states with the largest share of domestic output.

Expensing of exploration and development, another tax deduction which lowers the burden on mining firms, is unlikely to have an impact as large as depletion deductions. Our detailed examination of financial statements for over a dozen mining concerns revealed that expensing was listed infrequently as a factor which lowered effective tax rates by more than 1 percent, whereas depletion typically reduced effective income tax rates by from 5 percent to 15 percent or more.

Two factors suggest that the price impacts of monopolistic control over resources are negligible for most minerals. First, few mineral producers have an actual monopoly position (the De Beers diamond cartel and the OPEC oil cartel being two notable exceptions); world markets for most resources are highly competitive. Second, the rates of return on mining investments, after adjustment for risk, appear to be no higher than for comparable investments in manufacturing.*

One of the basic results of the Hotelling model is that in a competitive market there are two components to resource prices, marginal extraction cost and lease values. A condition for equilibrium in the market for mineral deposits is that the owners of the deposits must be offered a return equal to the going rate of return on alternative investments. Uncertainty, whether it be over future prices, technology, or ownership rights, is reflected as an increase in the rate of return which must be earned on ore deposits left in their undisturbed state [13, 37]. The greater the uncertainties, the more likely it is that mining firms would behave pretty much as if price equalled the marginal cost of extraction. However, one can easily demonstrate that lease values are small relative to extraction costs so long as exhaustion of a particular grade of ore does not appear imminent in the immediate future. Therefore, uncertainty, per se, is unlikely to exert a significant effect on most renewable resource prices.

As an illustration, assume that at a price of $6 above the current market price of copper (all in real terms) substitutes which are more abundant (e.g., aluminum) will have completely replaced copper as an input to industry. Suppose further that this substitution will occur in 100 years and that in the intervening 100 years copper will be obtained at constant marginal cost. Then the pricing equation would read:

$$P(2077) = C'(1977) + \lambda e^{100r}$$

Substituting in $6 for the difference between price in 2077 and the marginal cost of extraction from deposits being mined, one has: $\lambda e^{100r} = \$6.00$, solving for the lease value, λ, one obtains $\lambda = \$6.00\ e^{-100r}$

The table below presents more details of the relationship between the rate of discount r, the time remaining until complete substitution occurs, and the imputed value of the deposit. Given reasonable real rates of discount and the assumptions con-

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* <u>Fortune</u> reports summary statistics of rates of return for various industrial groupings among the largest 500 industrial corporations. These summaries indicate that over the past decade mining firms have averaged a rate of return approximately 1 percent in excess of that in general manufacturing, a difference which may be attributable entirely to differences in risk.

cerning quantities available and eventual substitution possibilities, the lease value of copper deposits today is quite small.

TABLE 2. HYPOTHETICAL LEASE VALUES

Rate of discount	Years remaining before substitution	Lease value, $ per lb.
r = .05	10	3.64
	20	2.21
	30	1.34
	40	.80
	50	.49
	60	.30
	70	.18
	100	.04
	200	.0003
r = .10	10	2.21
	20	.80
	30	.30
	40	.11
	50	.04
	100	.0003
r = .20	10	.80
	20	.11
	50	.0003

The inclusion of deposits of varying quality gives the example a greater correspondence to reality. Suppose as before that exhaustion occurs in 100 years and that substitution will be at a price of $6 above the current market price of 60 cents per pound. Instead of a single quality of copper available at a constant cost of 60 cents per pound for the next 100 years, assume that 60-cent copper will satisfy demand for 40 years and that copper with a marginal extraction cost of $1 per pound will be used thereafter. Figure 2 depicts the approximate pattern of marginal extraction cost, market price, and lease value over the next 100 years. Lease values are computed by working backward from the year 2077, assuming a discount rate of 10 percent. Lease values for $1 copper in the year 2017 equal $.01388 per pound, and for 60-cent copper in 1977 lease values are $.00758 per pound. Compared to the previous example, where all copper for the next 100 years had a marginal extraction cost of 60 cents, lease values in 1977 have increased by some 25 fold. The 60-cent copper will be depleted 40 years hence, and not held off the market beyond that date, because beyond that date the lease

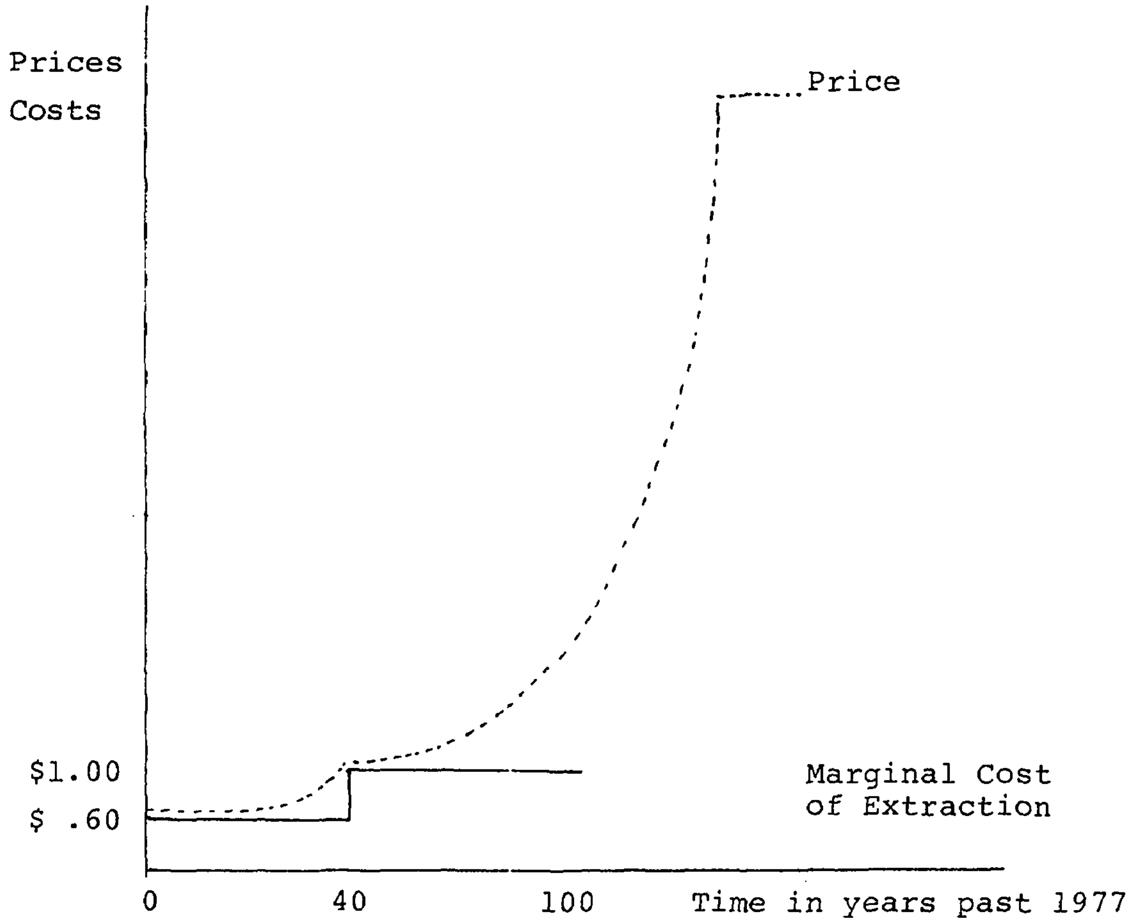

Figure 2. Time Profile of Prices and Extraction Costs.

value on 60-cent copper ceases to increase as fast as the interest rate. It is interesting to note that $1 copper has a lease value today ($.00025 per pound) even though it will not be mined for 40 years.

Although sufficient data on reserves, demand, and so forth are not available to enable one to compute precise mineral lease values, a reasonably accurate estimate can be obtained for copper. Bennett [5] has compiled data on all known and inferred copper deposits and coupled this with an analysis of the cost structure of mining. He concluded that known and inferred deposits available at $.50 per pound (1973) prices totaled about 82 million tons or approximately 50 years of output at present production rates. Even with a 6% compound rate of growth in demand, these reserves would be adequate for more than 25 years of production. At a price of $.75 per pound, another 30 years of reserves become available. Given the tendency of the industry to underestimate reserves and the absence of any correction for future technological change which could lower the cost of mining, it may be assumed that reserves at $.75 per pound would be significantly larger than the figure reported by Bennett.

If one assumes the lease value of $.75 ore will be nominal (say less than $.05 per pound) 50 years hence, the lease value of deposits being mined today would be $.025 per pound using a 5 percent discount rate and $.002 using a 10 percent discount rate. If one assumes that the $.50 ore deposits will be exhausted in only 25 years, the lease value at a 5 percent discount rate is $.086. Although this latter figure is fairly large relative to the price of copper, a more reasonable set of assumptions would produce significantly lower figures for lease values.

To date relatively little attention has been devoted to the measurement of the last of the four market forces, externalities in mineral exploration and production, yet these forces are potentially the most significant in terms of creating a divergence between market prices and the social costs of production. Sufficient information is not available with which to estimate quantitatively any of the externality impacts; we are left with the qualitative conclusions discussed earlier.

CONCLUSIONS

This paper has reviewed some of the evidence as to how severely prices are affected by the various market forces which are assumed away in the Hotelling model. For those forces for which price effects could be estimated, the distortion between actual and optimal prices appears to be rather small in most cases. Furthermore, forces which stimulated premature development and lower prices many years ago may act to increase prices today, particularly if the size of the remaining resource stock affects the amount of mineral which can be extracted for a given application of labor and capital. Therefore, we find that at any point in time many of the forces act in opposing directions and over time a force may change in terms of the direction of its impact on price.

However, even if it were found that the various market forces effectively cancel one another leaving no net effect on price, one could not say that resources were being allocated properly. Just because prices are approximately correct does not mean that goods are produced at the least total cost to society. When governmental controls are poorly designed, costs of an activity such as mineral development may be needlessly increased. Thus we may find that outlays attributable to legal uncertainties, court costs, and searches for rightful owners are higher under existing systems of mineral exploration and development than they would be under some alternative systems. At the same time, the U.S. government and no doubt other governments, too, subsidize the mineral industry through the tax code, leading to a divergence in social rates of return in different industrial sectors. The consequence is too much investment in mining relative to other, more heavily taxed sectors. Consequently, mineral prices do not reflect the full cost of the labor and capital used in mineral production.

A second cautionary note is also in order. Even if mineral markets act in some approximate fashion to allocate resources over time in a manner deemed optimal today by existing members of society, there is no guarantee that these same individuals will not wish for an alternative allocation when the decisions are viewed from other perspectives in time. When the decisions on natural resource development have the potential for effecting massive transfers of wealth and income among generations, the development decisions which are deemed optimal by living individuals may be highly undesirable from the viewpoint of unborn generations. Because these future generations can never be fully represented today, there will always be an inherent bias in development toward those projects which favor the present generation. Just as the discipline of economics offers little guidance as to how assets should be distributed among individuals today, so too does economics offer little as to the weights which should be attached to the satisfaction derived by members of unborn generations. Nonetheless, by making planners aware of the intertemporal income effects of various decisions, economists help to make planners aware of the impacts of their decisions.

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APPENDIX: VALUING THE BENEFITS OF RESOURCE CONSERVATION: THE DOMESTIC COPPER INDUSTRY AS A CASE STUDY*

INTRODUCTION

The fundamental question which we address may be stated as follows: Under the resource development policies of the United States are non-renewable resources, particularly non-fuel minerals, extracted at rates which maximize overall societal well-being? This is an important question in that rapid development and exhaustion of our minerals would endanger our own well-being as well as that of future generations. Conversely, if we withhold too much from the market today, we risk lowering the current standard of living as well as the future stock of accumulated wealth.

The Environmental Protection Agency (EPA), the sponsor of this research, is particularly concerned with the rate of development of U.S. non-fuel minerals. The EPA is mandated by Congress to perform research, promulgate regulations, establish standards, and make legislative recommendations concerning the recovery and reuse of recyclable materials. Now, the context of resource recovery is typically one of competition between primary, virgin-based materials and secondary materials recovered from the industrial and post-consumer waste streams. The extent to which existing governmental policies and other market forces operate either to stimulate or retard virgin material development will affect the prices of virgin materials. Shifts in virgin material prices affect recycling and, moreover, impact overall societal well-being.

HISTORICAL PERSPECTIVE ON CONSERVATION

The historical literature on resource conservation reveals that present concerns with the rate of resource depletion, the level of non-renewable resource prices, and the maximization of societal welfare were also felt in the past. The nineteenth century economists, Malthus, Mill, and Ricardo noted the effects of increasing resource scarcity. They observed that economic growth may be curtailed or restrained as resources become more expensive to locate and extract. Mill further noted that private mining concerns do not typically consider aesthetic benefits to society. We will return to this point later.

The Conservation Movement, as its name implies, advocated the preservation and conservation of the nation's finite resources and argued that these resources were being needlessly

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wasted and would soon be exhausted. One of the more notable successes of the Movement was the creation of several National Forests under President Theodore Roosevelt. The views of the Conservation Movement have been echoed by many other writers. In 1935, the well-known geologist C.K. Leith warned that "depletion is further advanced than even mining men generally realize." He estimated that reserves of crude oil, lead, and zinc were only 15 to 20 times that of the annual consumption rate.

It should come as no surprise to us to learn that known reserves of most of these minerals have increased even faster than consumption with the consequence that the nominal date of exhaustion has been pushed still farther into the future. An examination of some of the factors which have acted to alleviate, at least temporarily, the predicted resource scarcity will help us to focus on the determinants of the optimal rate of resource depletion.

One of the effects we should expect is that resources should exhibit a secular pattern of increasing price. However, as examination of trends in resource prices reveals that, contrary to predictions, resources have generally become cheaper in terms of the labor and capital required to extract them. The only noteworthy exceptions appear to be forest products and fisheries. One need not be reminded of the low prices of some materials today. The price of copper, for example, is actually lower in real terms than it was 10, 20, or even 30 years ago.

Another observed effect of resource scarcity, especially when scarcity affects relative prices, is the substitution of more abundant resources for those which become relatively scarce. For example, the depletion of the rich iron ore deposits near Lake Superior drove up the price of high-grade ores relative to the low grade taconite ores. Over time the change in relative prices stimulated the development of technologies to concentrate the taconite ore as a feedstock to the steel industry.

Substitution, however, may occur even when a resource is relatively abundant. For instance, although copper is not considered paricularly scarce today - with stocks of refined copper on hand worldwide equal to more than one year's rate of consumption - substitution of cheaper materials and better technologies threaten the markets once dominated by copper. For example, it is generally acknowledged that glass fibers will make inroads into markets now held by copper wire, particularly those for the transmission of information, and there is little that the copper industry can do if glass can perform the same functions at a lower cost.

Does the fact that resources, at least the non-fuel minerals, appear to be no more expensive or even less expensive than they were decades ago indicate that private markets are developing minerals too rapidly and that we are conserving too few resources for the future? In order to answer this question we have to examine more closely what is meant by the optimal rate of development and consider how governmental policies and market forces affect this rate.

OPTIMALITY IN RESOURCE EXTRACTION

Some forty years ago, Hotelling sought to define the optimal rate of natural resource depletion. Hotelling's definition in essence is that society should produce resources so as to maximize the present value of what consumers would be willing to pay for the resource over and above what it costs producers to deliver the resource. Using this definition of optimality, Hotelling was able to show that a privately owned, profit-maximizing resource sector would produce with a time profile which just matched that for social optimality. It is important to note, however, that a number of conditions must be satisfied in order for private decisions to lead to maximum societal well-being. The following are the most important of these conditions:

1. Competition must prevail.
2. There must be no uncertainty regarding future demand, resource availability, and the tenure of ownership.
3. The relationships between private costs and societal costs must not be distorted by externalities and diverse forms of taxation.

Although the first of these conditions may be satisfied approximately for many of the non-fuel minerals, especially when foreign competition is considered, it is clear that the second and third conditions are not satisfied. Using copper as a sample case, we may explore some forces which distort the production of the industry away from the rate which would be considered optimal.

1. Uncertainty

Several classes of uncertainty have affected production decisions of the domestic copper industry, probably to a far greater extent than is the case for the average U.S. industry. In the 1960's a major source of uncertainty to the copper industry was the prospect that foreign properties, most notably in Chile, would be expropriated. A second source of uncertainty, that of future demand conditions, is a matter of much concern to the industry today (e.g., potential loss of telecommunications markets to glass fibers). A third source is associated with regulation and taxation. Will the industry be forced to comply with EPA's latest environmental regulations or will the standards be relaxed somewhat for non-ferrous smelters? Will new royalties on mineral production be imposed by state or Federal governments (as proposed, for example, in H.R. 9292)? Assuming resource owners are averse to risk, each source of uncertainty will tend (other things equal) to stimulate production from existing mines and diminish the incentives for new exploration. During the short run life of existing mines, which in the case of copper may be several decades, output may be larger than optimal. In the long run industry output will be adversely affected by diminished incentives for exploration and output may fall short of what is socially optimal.

2. Distortions Between Private and Social Cost

(a) Taxation

Like all non-fuel mineral industries, the copper industry faces a large number of taxes and tax subsidies which affect the private cost of production and may in fact distort that cost relative to the true cost borne by society. Mineral prices will be distorted relative to other commodities to the extent that the taxes specific to mining affect the private costs of mineral production. The most significant of the mineral taxes are severance taxes and royalties. Tax deductions specific to the minerals industry include percent depletion deductions and expensing of exploration and development. Examination of some of these taxes and tax sudsidies in the copper industry revealed that in 1973 the deductions were approximately four times larger than the extra taxes and the net effect in that year was to lower the cost of producing copper by some 3 to 6 percent. In more recent years depletion deductions in the industry have been constrained well below the theoretical maximum by the 50 percent of net income limitation; thus the net impact on prices has no doubt been diminished and in fact may have been eliminated. Of course, whether the present situation of excess supply will persist is problematic. The future impact of taxes and tax subsidies on the industry is therefore difficult to assess.

(b) Externalities

Externalities are outputs of productive processes which impose costs or confer benefits which are not received by those engaged in the productive process. Since external diseconomies are not recognized as costs by individual mining firms, the decisions of these firms do not reflect these costs. Output is therefore stimulated and prices tend to be lower relative to a situation in which all of these costs are borne by the firm.

One of the more obvious externalities of the copper industry is air pollution from copper smelters. This particular externality has been recognized and is being internalized in the industry cost function by current EPA air pollution regulations. Perhaps less recognizable as externalities are the workplace injuries and illnesses in the mining industry, a portion of whose cost is now paid from general social insurance systems of welfare and social security. A third category of externalities arises from the discovery system for metallic minerals on public lands. Because this particular class of externality is both more subtle and of greater potential interest to this audience than are the others just noted, we will examine it in somewhat greated detail.

The General Mining Law of 1872 and Department of Interior regulations and rulings govern the development of hardrock minerals on public lands. Individuals are permitted free and open access to prospect for and claim any unclaimed valuable showings of hardrock and certain other minerals. A claim then gives the individual the right to extract the mineral. Under a system of open access the individual prospectors have little if any incentive to share their knowledge with potential rivals. The consequence is that some effort is duplicated and the search process is not conducted efficiently. Secondly, one individual's discovery of valuable minerals in an area typically stimulates others to file preemptive claims in the adjoining area. Until very recently only fragmented and incomplete records on the location of each claim were maintained by the regional offices of the Department of Interior. The result was considerable uncertainty as to who, if anyone, had prior claim to a particular tract of land. Although no comprehensive study has been conducted on the impact of the provisions of the General Mining Law on the cost of locating and producing minerals, we conjecture that the net effect has been to increase costs relative to those of other methods under which access is controlled (e.g., leasing).

Yet another form of externality arises when mining precludes alternative uses of the land. The Department of Interior has traditionally accorded mining priority over alternative (perhaps less socially valuable) uses of public lands, and mining firms have not had to include in their cost functions any of the opportunity costs associated with other activities which are foregone once mining has commenced. This situation is in marked contrast to arrangements under which private developers must bid against one another for the rights to use private lands, the winning bidder making a payment at least equal to the profits which could have been earned in the next most profitable activity.

EVALUATION

1. From The Perspective of Present Generations

The Hotelling approach asks that nonrenewable resources be extracted at a rate which maximizes the present value of social gains from production. Using the present value welfare test, we have identified several factors which distort production decisions away from that which would be socially optimal. We believe that two factors deserve to be singled out for their effect on production decisions of the mining industry. The first is the Federal tax code which confers a significant tax subsidy to the mining industry. This subsidy permits mining firms to acquire capital at lower rates than those enjoyed by the general class of manufacturing firms. Consequently, investment in mining is stimulated (at least historically), relative to what would produce optimal societal welfare. The second factor is the subsidy accorded mining by virtue of the fact that mining firms need not pay the opportunity costs of the public lands they aquire for mining purposes. This factor also serves to subsidize mining firms, making prices lower and output higher than would otherwise be the case.

2. <u>From The Perspective of Future Generations</u>

Decisions by current generations to produce and consume nonrenewable resources affect future generations in two ways; the future availability of these resources is diminished and, to the extent current production leads to increased wealth and saving the stock of capital which is inherited by future generations is augmented. Whether the future generations are made better off or worse off by our decisions today depends largely on the substitutability of capital for resources in the future. Decisions to produce and consume resources to maximize the present value of economic welfare may be quite compatible with the desires of future generations. There is no reason to believe that capital and other more abundant minerals (glass and aluminum) cannot fully substitute for copper as it becomes more scarce.

It is possible, however, to envision situations where the decision to maximize the present value of economic welfare will not be consistent with the desires of future generations. Were we to focus on the production of uranium ore, for example, we might conclude that future generations are being made worse off by our use of uranium and creation of long-lived, high-level radioactive waste.

CONCLUSION

The current Federal policy of permitting private firms to determine the rate of extraction of nonrenewable resources is, in most cases, fully compatible with the maximization of welfare of current and probably future generations. However, several important exceptions to this principal have been noted. Tax subsidies to mining distort capital and labor resource allocation in the economy and cause excessive activity to occur in the mining sector. Mining firms do not always pay the full social costs of their activities on the public lands. Finally, some forms of nonrenewable resource development have the potential for creating significant transfers of wealth away from future generations.

APPENDIX

This appendix presents the basic theory of the mine as developed in Peterson and Fisher [31]. With this basic theory the results of Section 4 were derived.

Using the notation of Peterson and Fisher, the production function for mineral output can be represented as:

$$Y = f(E,X,t)$$

where Y is extractive output, E is an index of labor and capital devoted to extraction, X is the resource stock, and t is time. Output and the resource stock are linked by the relationship that output is the time derivative of the resource stock. The mining firm's problem is to maximize the present value of profits from sales of extractive outputs, or:

$$\max \int_0^\infty [Pf(E,X,t) - WE]e^{-rt}dt$$

where P is the price of the resource, W is the cost of a unit of the composite capital and and labor input, and r is the rate of discount. From this expression one forms the Hamiltonian:

$$H = [Pf(E,X,t) - WE - q^Y]e^{-rt}$$

where q is the shadow price (lease value) attached to a unit of the stock of the resource at time t. By the maximum principle, the partial derivative of the Hamiltonian with respect to the control variable is set equal to zero.

$$H_E = PY_E - W - q^Y{}_E = 0$$

Rearranging terms in this last expression one obtains:

$$P = W/Y_E + q$$

The first term, W/Y_E, is just the marginal cost of extraction. This can be seen by noting that marginal cost is the partial derivative of cost with respect to output, or C_Y. Using the chain rule for derivatives, this may be expressed as $C_E E_Y$, or equivalently, C_E/Y_E. But, C_E, the rate at which costs change with respect to the use of the composite capital and labor input, is just equal to the cost of a unit of the composite input, or W. Thus W/Y_E is equal to the marginal cost of extraction, C_Y. As noted, the second term is the shadow price or lease value attached to a unit of resource in place. Therefore, at any point in time, price equals the marginal cost of extraction plus the lease value of the mineral in place.

Another condition which is necessary for a maximum of the profit expression is that lease values (others have termed this rent, net price, marginal user cost, and royalty) have a time profile described by:

$$\dot{q} = rq - H_X$$

where $\dot{q}$ is the time derivative of q. Substituting for H_X and rearranging terms one obtains:

$$\dot{q}/q = r + (1 - P/q)Y_X$$

That is, the lease values increase at the rate of interest plus an adjustment which is zero whenever there is no stock effect ($Y_X = 0$) or there is a zero marginal cost of extraction ($P = q$).

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16. ABSTRACT

The forces that determine prices of non-renewable natural resources are an important consideration in an evaluation of the social desirability of conservation through recycling. If prevailing market prices accord conservation benefits a value less than their true value to society, the prices are suboptimal and the solution may require governmental support of resource recovery and recyling.

A comprehensive review of the literature on natural resource economics reveals that numerous external forces can cause divergencies between the socially optimal prices and the prices that are actually determined in the market place. The forces act in varying directions and with varying intensities over time. It is, however, difficult to establish with any degree of precision the magnitude or even the direction of bias given to the prices acting on supply and demand. Moreover, the socially optimal level of resource conservation is likely to be viewed differently by individuals of different generations.

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