

The Economics of Natural Resource Scarcity and Implications for Development Policy and International Cooperation

Of course it is useless to think of substituting any other kinds of fuel for coal. . . . To extend the use of petroleum then is only a new way of pushing the consumption of coal. It is more likely to be an aggravation than a remedy.—Jevons (1906, pp. 183–84)

The entire issue of resource scarcity has been dramatically brought to world attention as a result of two events that occurred quite by coincidence at the same time: the formation of the effective OPEC cartel which forced a rapid fourfold increase in the price of oil and the doomsday forecasts emanating from the world modeling systems associated with the Club of Rome report. This is not the first time in history that there have been natural resource crises and predictions of impending doom, nor is it likely to be the last. So far, however, doom has not arrived. Why, then, have the predictions proved so wrong? They have certainly been made by men of learning and distinction—Malthus, Mill, and Jevons among them.

We do not intend to argue from history that current concerns about scarcity, population growth, and pollution are frivolous. It is certainly not unfounded pessimism to point out that severe problems loom on the horizon if present rates of population growth continue. The dangers of unchecked environmental pollution are also certainly very real. And we recognize that considering natural resource use as completely separate and distinct from environmental considerations misses an essential element of the problem.

While recognizing the validity of some of the issues raised by the doomsday models, however, we consider them quite inadequate as a tool

for appraising the likelihood and impact of the crises they predict (Kay and Mirrlees 1975).

It is our view that the application of neoclassical economic theory to the natural resource area provides a much more powerful and illuminating framework for considering these issues and allows consideration of factors that will be powerful determinants of future resource use but which have been consistently underestimated in the forecasts of doom throughout the years. The most significant of these factors are surely the extraordinary substitution possibilities (in both consumption and production) induced by changes in the relative prices of resources and the often unpredictable and dramatic technological innovations which provide alternative means of satisfying human needs (Rosenberg 1973).

Economic theory focuses attention on the role of prices in allocating resources both spatially and intertemporally. It provides a rigorous conceptual framework for an understanding of the behavior of resource markets and makes explicit those assumptions required to deduce necessary and sufficient conditions for predicting particular outcomes. When such outcomes are deemed socially desirable, the theory provides explicit guidelines for implementing policy designed to achieve those desirable ends. On the other hand, when the assumptions of the theory are violated in practice, the theory can serve as a tool both for predicting alternative sets of outcomes and for evaluating the relative merits of proposed changes in the institutional organization of the economy.

Economic theory demonstrates that under certain sets of conditions markets do what we want them to do. We are, therefore, better off analyzing the conditions that are violated in practice and formulating policies to correct these conditions than simply ignoring the theory because of real world departures from some of the simplifying assumptions.

This chapter, therefore, is written in the spirit of allowing economic theory to alert us to the respects in which natural resource markets do not achieve the desired goals and to serve as a guide to how policy intervention can help markets to function more effectively.

The first section makes the point that physical resource scarcity as such has no necessary economic meaning. It presents an economic definition of scarcity, suggests how it can best be measured, and analyzes what implications, if any, it has for economic growth. The second section then examines, within the context of a highly simplified economic framework, the conditions that must hold for efficient use of exhaustible natural resources. It points out that there are innumerable efficient paths for resource use, but to take the next step and decide which efficient path is optimal involves value judgments. Only when these value judgments are made explicit can appropriate policies be designed to achieve the desired ends.

A third section discusses how various complicating factors inherent in economic life—uncertainty, risk, externalities, disequilibrium, and institutional constraints—alter the ability of markets to achieve an efficient path. The fourth section contains our policy recommendations for achieving efficient and optimal resource use within a context of international cooperation. The final section concludes the paper with a statement of our own values—that, in our judgment, the ultimate aim of development should be to raise the living standard of the poor everywhere—and of our strongly held view that the issue of efficient resource use is conceptually different from the issue of the optimal distribution of income and power, a distribution which should be pursued through active use of domestic tax policy.

Natural Resource Scarcity

Exhaustible natural resources such as petroleum, coal, copper, or iron cannot help but become scarcer in a purely physical sense if they are being used by man to satisfy economic wants. Also, the ability of natural environments to recover from harm done to them by by-products of the economic system is surely not limitless.

What is at issue, however, is whether the seemingly straightforward conclusion that if such resources are not consciously conserved we will face inevitable economic decline is, in fact, warranted. Much attention has been recently given to this question. One answer—provided by the so-called doomsday models of Meadows, Forrester, and others—is that the exhaustion of natural resources together with population growth and increasing environmental contamination will indeed lead inexorably to declining standards of living unless drastic conservation measures are taken. Another answer—provided by neoclassical economists—is that physical resource scarcity as such has no obvious economic meaning or necessary economic consequences.

History alone tells us that the consequences of increasing physical scarcity are hard to predict and often turn out to be completely outside the widest range of theorizing by technological experts of any given era. Malthus, Jevons, Ricardo, Mill, and others predicted a steady decline in the quantity of natural resources as a result of economic growth and, in turn, a declining potential for income growth as more labor and capital would have to be used per unit of constant quality resource extracted. All have proved wrong so far. We take the position that such predictions are no more likely to prove right than they have been to date and that assessing the economic consequences of physical resource scarcity is, indeed, a complicated matter. This section, therefore, discusses the question of

what economic meaning can be attached to resource scarcity and how such scarcity can fruitfully be measured.

The Economic Meaning and Measurement of Resource Scarcity

There are two main ways in which scarcity of natural resources may have economic significance: (1) they are in some sense essential inputs into the production of goods which satisfy economic wants; and (2) they or perhaps the natural environment around them satisfy economic wants directly *in situ*, without being extracted and processed. In both cases, how economically significant the scarcity is depends on the extent to which the resources in question can be replaced by others. To quote Smith (1978), ". . . scarcity must be treated in relative terms. . . . Any scarcity index must take account of the process by which the resource is supplied, as well as the nature of all demands for it." As Solow (1974b) has observed, "If it is very easy to substitute other factors for natural resources, then there is in principle no 'problem.' The world can, in effect, get along without natural resources, so exhaustion is just an event, not a catastrophe."

A common way of measuring resource scarcity—by taking the estimated physical quantity of reserves of a given resource and dividing it by annual demand (current or projected at current growth rates) to produce a concept called "number of years worth of consumption still available" (Albers et al. 1976)—is both conceptually and empirically an inadequate measure of scarcity.

First, it is well known that reserve estimates are often very unreliable because it is simply not worth the expenditure to map out more than a few years' worth of reserves at a time, and price increases often render known but previously uneconomic reserves worth extracting and induce exploration for new deposits. Some physical resource measures may give a better indication of quantities than others (Brobst and Pratt 1973), but this does not change their lack of economic significance. In essence, measured reserves themselves are outcomes of economic decision making and so cannot be treated as if they will not respond to changing economic conditions (Pindyck 1978b).

Second, projecting levels or rates of growth of demand more than a few years into the future is an uncertain exercise at best and potentially quite misleading. Price changes, shifts in demand patterns, environmental regulations, technological changes, and other forces have often turned yesterday's growth into today's decline. Examples of natural resources for which this has occurred are easy to find: tin, lead, and mercury come immediately to mind.

The only significant redeeming feature of such an exercise would be its use in the case of natural resources for which no markets exist, that is,

those which are basically public goods.* In these cases, while the measure would still suffer from the drawbacks cited above, there would be no alternative because there is no market in which the social valuation of the resource can be measured. However, it does not seem to be used for these types of natural resources, perhaps because of the inherent difficulty in measuring quantities of clean air, clean water, etc.

Economists have devoted much effort in recent years to devising and evaluating alternative measures of economically relevant natural resource scarcity. The most widely considered measures are the real price of natural resource products, the unit cost of natural resource products, and the scarcity rental rate of natural resources *in situ* (Barnett and Morse 1963; Barnett 1976).

Real price is defined as the market price of a natural resource product relative to a benchmark price such as a GNP deflator. As can be shown formally (Fisher 1976, for example), market price is conceptually the sum of marginal extraction cost (equivalent to unit cost) plus the scarcity rental. The real price measure thus incorporates the other two scarcity measures. It is considered by most analysts as probably the most appropriate measure of the three because it has the essential property, at least in principle, of summarizing "the sacrifices, direct and indirect, made to obtain a unit of the resource"—that is, "the labor and capital (and other resource) inputs required to extract and convert it, and an indirect cost, the value of future consumption foregone" (Fisher 1976).

The unit cost measure suffers because (1) if the quality of the resource is declining, the unit costs of extraction will increase irrespective of the magnitude of future scarcity; (2) it deals only with the supply side of a resource market whereas demand considerations are also important in assessing economic scarcity; (3) it is difficult to quantify because even for a single resource, data must be aggregated across firms with different technologies, different factors, and different factor costs for the same factor; and (4) in the presence of certain types of technological change, it can move in a direction opposite to that of the real price (see Brown and Field 1976; Fisher 1976; Smith 1978; Heal 1976; Solow and Wan 1976).

The main drawbacks to the scarcity rental rate are that (1) it may fall as depletion proceeds if lower quality deposits become more economical to market, whether or not other indicators give evidence of economic scarcity;** (2) in situations of high elasticity of substitution (indicating that

*A "pure" public good has the property that one individual's consumption does not subtract from the amount available for consumption by other individuals. Classic examples are bridges and natural beauty. It is well known that markets cannot allocate public goods efficiently.

**Fisher (1976). The same idea was expressed by Ricardo and Mill.

increasing physical scarcity will not pose a serious economic problem) the rental rate could still rise at the rate of interest (Brown and Field 1976); and (3) it is difficult to observe empirically both because it involves data on ore quantity and quality that companies exploiting the deposits may not want to release and because tax laws may constitute an incentive to underestimate (or at least understate) it.

Market measures of scarcity do have their own drawbacks, however. First, the common property or public good aspect of some natural resources means that in those cases such a measure may not exist because the resources are not traded on markets or are free for the taking. The problem of measuring and evaluating the seriousness of scarcity of exhaustible common property resources is recognized as one of the major cases in which a market system will fail to give society the proper signals. Second, the absence of sufficiently comprehensive futures and forward markets for resources means that the methods by which people form expectations about the future course of prices can influence the actual price path thus limiting the usefulness of prices as scarcity indicators. Heal's work (1978) on this subject shows explicitly that prices need not accurately indicate relative scarcity under these circumstances. Third, changes in the institutional environment such as tax laws or property rights and in market structure may significantly affect the course of prices while real economic scarcity is unchanged. However, even though these effects can be significant, it is also possible to estimate them in practice.*

Although these drawbacks limit the confidence that can be placed in conclusions drawn from market measures of scarcity, their usefulness is not entirely impaired. Much of the current theoretical work on the economics of exhaustible resources concerns the nature of the modifications to standard results caused by deviation from "ideal" conditions. That is, attempts are made to characterize the price path that would result under the conditions of uncertainty, oligopoly, etc., so that empirically these types of effects could be recognized. This work bears directly on scarcity measurement because it enables modification of the usual measures to account for common real world conditions.

*In an ideal world of perfect competitive markets, real price would be close to an ideal measure of relative scarcity. In any realistic setting it may have its own drawbacks, of course, in that market prices can reflect changes in market structure and institutional arrangements and may have volatile speculative components, none of which are necessarily related to increasing scarcity. The real price will also, in general, be sensitive to the choice of a benchmark price. However, this may not necessarily be a drawback: "A consumer probably should be interested in the price of resource products relative to other products he purchases and would therefore use a retail price index or the equivalent. A firm using a resource product as an input should be interested in the price of other inputs such as labor or capital, or an index of other factor prices" (Brown and Field 1976).

Scarcity measurement is a useful exercise which, if done carefully, can yield valuable information about changes in relative scarcity that otherwise can only be guessed at. The essential point is that prices do convey information on scarcity values which otherwise could be obtained, at perhaps substantial cost, only by sifting through enormous amounts of geologic, demographic, legal, and technical data. Prices monitor the informed judgments of market participants and industry experts as to the likely future course of demand, supply, and the institutional environment and thus can give advance warning of impending scarcity.

Scarcity and Growth

If we have defined scarcity in an economically meaningful sense and devised ways of measuring it, let us now see whether anything can be said about its potential impact on economic growth. The obvious first question to ask here (Stiglitz 1976) is why should the scarcity of natural resources impose a greater burden than scarcity of other factors of production or commodities? When other factors or commodities are scarce their prices tend to be bid up and producers or consumers turn to substitutes. The economic impact of scarcity of a natural resource could thus be alleviated by substituting labor, capital, or another factor for the resource in the production process of a given good or by substituting other goods that use less of the resource. Alternative ways out of an otherwise binding resource constraint could be provided by technical progress which economizes on the use of natural resources or by increasing returns to scale (Rosenberg 1973).

Dasgupta and Heal (1974), Solow (1974b), and Stiglitz (1974) have analyzed the conditions under which it is possible for an economy to sustain a constant per capita level of consumption with an exhaustible resource as an input to production. Although the results vary depending upon the particular assumptions made, a common thread in these studies is the crucial nature of the elasticity of substitution between natural resources and capital in the limit as the stock of the natural resource declines.* If that elasticity is greater than one, then natural resources will not prove to be a

*The elasticity of substitution between two factors of production is defined as the percentage change in the ratio of the amounts used of the two factors induced by a given percentage change in their price ratio. If K and N represent quantities of capital and natural resources, respectively, and P_K and P_N their prices, then the elasticity of substitution between K and N ,

$$\sigma = \frac{\frac{d(K/N)}{K/N}}{\frac{d(P_N/P_K)}{P_N/P_K}}$$

constraint on the consumption standard. If it is equal to one but the share of capital in national income is greater than the share of natural resources, or if there is resource-augmenting technical change, again no resource constraint will appear. In short, as depletion of the resource drives up its price relative to the price of capital, it is possible to substitute capital for the resource at a rate "faster" than the rate of the resource's price increase. As the resource's price increases, the demands made on it decline along with its supply, and the reduced supply, therefore, does not constrain output. This can be true even if resources are necessary for production in the sense that output would fall to zero without at least some resource input. In the words of Peterson and Fisher (1977), "The simple fact that resources are finite, and are necessary for production, does not imply that the resource-using economy must eventually stagnate and decline."

So the question of the potential effect of resource scarcity on growth is essentially empirical—how large is the elasticity of substitution between natural resources and capital? Humphrey and Moroney (1975) estimated that in only two out of six U.S. manufacturing sectors studied was the elasticity of substitution between reproducible capital and an index of natural resource products greater than one, and in two other sectors the elasticity was negative, indicating complementarity rather than substitutability. These estimates are not, however, especially reliable (and elasticities could, in any case, change significantly as the resource gets nearer to depletion). Berndt and Wood (1975) discuss elasticity of substitution in some detail.

Efficiency and Optimality in Economies with Exhaustible Natural Resources

In the previous section we discussed ways of detecting economically significant scarcity of exhaustible resources and concluded that real price was probably the most appropriate measure with an increasing trend of real price indicating increasing economic scarcity. This section discusses the policy implications of finding increasing economic scarcity in this sense.

We submit that increasing scarcity of an exhaustible resource has no obvious economic implications until more is known about the underlying forces giving rise to the indication of scarcity. If the resource is being used efficiently, in a sense to be made precise below, then government policy can only improve welfare by causing a shift to another efficient path of resource use preferred to the initial path. If resources are not being used efficiently, then welfare can be increased by a shift to an efficient path. But that we may be wasting our resources on an inefficient path does not automatically imply that they are growing economically scarcer.

The truly important questions from a policy perspective thus become: are we using our exhaustible resources efficiently and are we using them optimally? The first part of this section characterizes efficiency in the use of natural resources and discusses the ability of markets to achieve efficiency. The second part characterizes the optimal use of exhaustible resources under various conditions and discusses appropriate policy measures to ensure an optimal use of resources.

Efficient Use of Exhaustible Resources

Economists have an explicit definition of economic efficiency: A resource is being allocated efficiently if a unit of the resource has the same value in all of its uses.* (Note that "value" as yet has nothing necessarily to do with observed prices—it could just as easily reflect shadow prices from an economic plan.) The rationale behind this concept is straightforward. If a resource had higher value in one use than in another, the total value of the resource to society could be increased by shifting some of the resource from the lower value use to the higher value use. Other things equal, transferring the resource to its higher value use will improve the economic welfare of society.**

The concept of economic efficiency is often used in static situations. At a given moment in time, if the marginal social product of a resource differs in two uses (both current), then this is said to be evidence of inefficiency. Such evidence is usually searched for by examining market structure and government regulations, or by looking for externalities and public good aspects of resource use. The efficiency concept generalizes easily to a dynamic context: Alternative uses of a resource include uses at different rates, so efficiency is achieved if the value of the resource is the same whenever it is consumed as well as in the varying ways in which it may be used (Stiglitz 1976). As Dasgupta and Heal (1978, chapter 7) have emphasized, dynamic or intertemporal efficiency refers to an entire path of resource use through time, so judging whether or not a current pattern of resource use is efficient requires not only looking at current rates of use but "peering into the distant future" as well.

The main issues of interest here are the conditions characterizing an in-

*Hertzmark (1978) and Berry et al. (undated) explore the relationship between thermodynamic and economic efficiency concepts. It turns out that under certain circumstances thermodynamic efficiency requires price paths similar to those required for economic efficiency.

**In this discussion we abstract from real world problems such as transactions costs which can limit the degree to which reallocating resources toward an efficient configuration will actually increase welfare. Welfare here refers strictly to economic welfare. In general, we will be dealing with the utility of consumption of goods and services rather than more general quality-of-life indicators.

tertemporally efficient resource use path and whether a market system can guarantee efficiency.

Assume for simplicity that we are concerned only with aggregate output, produced without externalities, so that we needn't worry for the moment about allocations of the resource among different uses at any given moment of time—static efficiency is not of concern. Suppose that social welfare is measured by some increasing function of aggregate consumption of output in a given period.* Consider any two adjacent periods of time. If there is a positive rate of return to capital, evidenced by a market interest rate or a social discount rate used by planners, then this should be incorporated in the measurement of value for the following reason: If a unit of the resource is extracted and used in the first period, it has a certain value measured by its marginal productivity in the production of aggregate output. It is worth expending an amount of output equal to the marginal product (MP) of the resource (valued in terms of aggregate output) in the first period in order to have the use of the resource in that first period. If this amount of output were instead invested in capital formation, however, its value in the next period would have increased by a factor of $1 + r$, where r is the marginal productivity of capital. Suppose that the marginal product of the resource grew by *less* than this factor from the first period to the next. Then the value to a private owner or to the state of a unit of the resource in the ground would be lower in the second period than in the first, in comparison with the alternative use of the output needed to obtain the use of the resource. This would induce the holder to use up his stocks of the resource in the first period. If, in contrast, the marginal product of the resource grew by *more* than the discount factor, then the resource would be more valuable in the second period, and this would cause its use to be delayed until then.

Using the yardstick of the rate of return on capital—because investment in new capital formation is the alternative productive use of the output needed to obtain a unit of the resource—we have established that the marginal product of the resource must grow from one period to the next at the rate r in order for the resource to be used efficiently. If not, welfare could be increased by shifting the use of some of the resource from one period to another, until its value was the same in both periods.** Because this applies to any two adjacent periods, a necessary condition for efficient use of an exhaustible resource is that the percentage rate of change

*This in effect ignores distribution problems within generations. This issue is irrelevant to the discussion here, but see our comments in the introduction and conclusion.

**By shifting resource use appropriately among periods, the value will be equated in different periods because of diminishing return to the resource, holding quantities of other factors of production fixed.

of its marginal product must always equal the rate of return on capital. In a competitive economy in which firms maximize the present discounted value of profits, the marginal product of a resource equals its real price, and the rate of return on capital equals the interest rate. This casts the efficiency criterion in the familiar form of the Hotelling rule (1931): real price must rise at a rate equal to the rate of interest.

So far it has been assumed that the marginal extraction cost is constant and that the real price of the resource depends only on its use. If technology is not constant, then the Hotelling rule for efficiency must be modified to account for the fact that at different points of time it costs different amounts of aggregate output to extract a unit of the resource. For efficiency to hold, therefore, the real price should rise at a rate which is a weighted average of the interest rate and the rate of change of the marginal extraction costs, where the weights are the share of scarcity rental and cost in price.

But even this modified version of the Hotelling rule does not guarantee efficiency: although it is a necessary condition, it is not sufficient. It is entirely possible for it to be met and for the stock of the resource still never to be entirely depleted, because an exponentially rising real price may eventually choke off all demand before the point of total depletion is reached. It is clearly inefficient to leave some of the resource in the ground forever when its value (marginal product) has not fallen to zero (in fact, as the resource nears depletion, its value is likely to be quite high if substitutes do not become available).^{*} Adding to the Hotelling rule the stipulation that in the limit the entire stock of the resource should be depleted gives us both necessary and sufficient conditions for an intertemporally efficient pattern of natural resource use. The depletion condition guarantees "global efficiency" and also points up the importance of someone taking the long view where natural resources are concerned. This is one of the main insights of dynamic natural resource economics. The intuitive condition for efficiency, derived by generalizing the familiar static condition, is not sufficient in this case. The price may rise with the interest rate, but if it starts from the "wrong" level then the resource could be depleted too quickly or too slowly for efficiency.

The question now becomes, can a market system guarantee an efficient use of exhaustible resources? That is, will the modified Hotelling rule be met? This question is important because, other things equal, markets are more efficient than alternative resource allocation systems. Working

^{*}This applies to natural resources which have no use other than as factors of production. For resources which also have value as "natural amenities," efficiency may well require leaving some of the resource permanently unextracted. We focus on issues related to this subject in the next section.

within a market framework is, again other things being equal, preferable to nonmarket policies.

If we again simplify matters by assuming the absence of externalities, uncertainty, or disequilibrium, then it is a well-established result that perfectly competitive markets will indeed allocate exhaustible resources efficiently. Under these conditions the economy will necessarily be in intertemporal competitive equilibrium, which is characterized by the existence of a complete set of forward markets extending into the indefinite future. Given that these forward markets exist, the Hotelling rule is also the condition for the existence of an intertemporal competitive equilibrium, and because it also guarantees efficiency under these conditions (having ruled out disequilibrium), the market will support an intertemporally efficient allocation of exhaustible resources (Dasgupta and Heal 1978, chapter 8).

It is important to note that this result is contingent on a set of conditions which are quite severe. Dasgupta and Heal (1978, p. 22), who originated many of the findings discussed here, state that ". . . the claim that a decentralized competitive environment will ensure an efficient utilization of natural resources is a very tenuous one." It is, nevertheless, a useful claim, for we now have a benchmark against which to compare actual market performance. This we do in the following section where we review recent research results on how well a market allocates exhaustible resources when the stringent assumptions used above are relaxed. Before leaving this issue, one potential source of inefficiency will be briefly examined here: imperfect competition. It is relatively easy to analyze; it is widely prevalent in exhaustible resource markets; and in some cases it has quite straightforward policy implications.

Beginning with the case of a single firm controlling all deposits of a given resource, we can easily show that whether or not the efficiency conditions are violated depends upon how the elasticity of demand for the resource changes over time. This is familiar from static monopoly theory: the monopolist takes account of the downward sloping demand curve facing him while competitive producers are so small relative to total demand that they perceive an infinitely elastic demand at the market price. A private or public monopolist who wants to maximize the present discounted value of profits can be shown to extract at a rate which causes his marginal revenue—rather than price—to rise at the rate of interest; he produces so as to set the discounted value of marginal revenue equal in all periods. If the elasticity of demand does not change over time, then marginal revenue is proportional to price, and having marginal revenue rise at the rate of interest means price will do so as well.* In this case monopoly

*Marginal revenue $MR = P(1 + \frac{1}{\epsilon})$, where P is price and ϵ is the elasticity of demand. If ϵ remains constant then it is easy to see by logarithmic differentiation that marginal revenue and price rise at the same rate.

causes no inefficiency because it results in a price path identical to the competitive price path. The type of resource for which this might hold would be one which is an inexpensive but essential input into a product for which no substitutes exist within its price range. Chromite as an input into stainless steel is a good example.

If, instead, the demand elasticity for the resource increases over time (that is, demand becomes more elastic) due, say, to the development of substitutes for the resource in response to its increasing price, then the monopolist would like to cause price to rise at a rate lower than the rate of interest. It can be demonstrated that this will lead to a price path which is above the competitive path initially and then below it after a certain point, provided that the entire stock of the resource is eventually extracted in both cases. This leads to excessive conservation by the monopolist in the initial period with that excess made up for by too rapid depletion later in a clearly inefficient allocation (Heal 1978).

If the market is characterized not by a pure monopolist but by one large supplier (or a cartel) and a group of smaller competing producers, then matters become more complex. Depending upon the particular assumptions made about extraction costs for the cartel and for the "competitive fringe," complex price paths can result. In general, they follow the pattern of the monopolist facing an increasing demand elasticity and produce a market that does not support an efficient allocation. The direction of the bias is toward excessive conservation. Because oligopoly and restrictive cartel practices are obviously prevalent in such markets as oil, for example, scarcity is less likely to be a problem than it would be in a more competitive situation.

Dasgupta and Heal (1978) and Pindyck (1978a) have simulated the petroleum market in an attempt to check the predictions of this theory against an actual market that seems to conform to the oligopoly with competitive fringe pattern. Both sets of results confirm that the current price is now above the competitive price but is likely not to rise much at all in real terms over the next two decades whereas the price in a competitive market would be lower now but rising faster in the future. Pindyck also reports that the formation of the OPEC cartel raised the present value of the discounted stream of future profits to OPEC countries by 55 percent—a substantial inducement for the cartel to stay together.

Another form of oligopolistic behavior which has received attention in the literature is the case in which there exists a "backstop technology" which, at a relatively high price, makes available an essentially unlimited supply of a substitute for the resource in question. Nordhaus (1973), who coined the phrase, gave the example of the breeder reactor providing an unlimited energy source as a substitute for fossil fuels, although at a substantially higher price per BTU.

The equilibrium outcome in this situation would be for the cartel to price the resource in such a way that there is no incentive to develop the backstop technology. This involves a period during which price rises at a rate that allows the cartel's marginal revenue to rise at the rate of interest, followed by a period during which the price is slightly below the price at which the backstop technology becomes economical. As Heal (1978) points out, the private return to lowering the price of the backstop technology via technical improvement is zero, because the cartel will find it rational to lower its price until it is again just below the backstop price. However, because the social return in terms of increased consumer surplus may be substantial (because the resource price will fall), government intervention may be called for.

Before moving to a discussion of optimal resource use, we should note that many critics question the appropriateness of the concepts and techniques of neoclassical economics in the context of natural resources. The question has been posed "whether there are unique features of the processes by which the extractive services of natural resources are used, that make the conventional neoclassical production analysis ill equipped to deal with the problem for which it is being employed" (Smith and Krutilla 1976). One frequent criticism is that the conventional analysis, as described above, ignores the "common property" aspects of natural resource uses and that comparisons between two alternative uses (*in situ* common property final consumption services versus extractive intermediate goods) are inappropriate "in deriving the demand for the services of natural resource" (Smith and Krutilla 1976). Other critics point to the extreme lack of realism involved in assuming perfect foresight or the existence of a complete set of forward and risk markets; to the lack of a theory describing behavior out of equilibrium when expectations are not fulfilled; and to the absence of descriptions of behavior in the presence of uncertain property rights, stock size, and future technological conditions.

Those familiar with contemporary theoretical economics will recognize these points as the focus of much ongoing work—often in a more general context than natural resource economics per se because the criticisms apply to many different areas of economic theory. We shall explore some of this work in the next section, in which we flesh out the simplified theory presented here by incorporating more realistic but also more complicating factors into our analysis.

Optimal Use of Exhaustible Resources

The issue of efficiency in the use of exhaustible resources is concerned with waste. If we are not using our resources efficiently, then we are wasting them, and it is possible in principle to make all generations from the

present onward better off by switching to an efficient path of resource use. Such a switch would allow more output to be produced from the fixed available stock of exhaustible resources which could then be distributed among generations in such a way as to make any or all future generations better off.

Optimality, in contrast, is concerned with a different question: Given that efficient use is being made of available resources, which efficient path should we be on? That is, how should the maximum producible output be distributed through time? There is an unlimited number of efficient paths; an optimal path picks one of these and declares it the "best." It is obvious that we are now out of the realm of descriptive or "positive" economics and into the realm of ethical or "normative" economics. Choosing an optimal path means choosing who is to be made better off at the expense of whom because, given the efficiency, there is no way to make one individual or generation better off without making another worse off. This is clearly an ethical choice and necessarily involves value judgments.

Although the market can be used as a tool for achieving an optimal path already decided upon, it cannot without intervention guarantee that the optimal path will indeed be followed. This results from the fact that previous market allocations have determined, at least in part, the current and future distribution of wealth and income which in turn heavily influences the particular efficient outcome the market comes up with (assuming that the market does indeed allocate efficiently). We thus recognize that the market can achieve the efficient resource allocation decided upon as optimal only if income and wealth are distributed in an appropriate way. Page (1977, p. 163) describes this well-known fact: "For each distribution of market power in the present and implied intertemporal allocation of resource usage, there exists a social welfare function and discount rate such that maximization of the present value of this social welfare function under this discount rate leads to the same allocation of resource usage as given under the efficiency criterion."* The first section of this chapter notes the normative views we bring to the subject of the optimal depletion of exhaustible resources and the accompanying optimal distribution of wealth and income through time and within the present generation. Here we discuss the characteristics of optimal depletion paths generated by different broad classes of ethical norms.

The first point to be made is that when considering optimal depletion of exhaustible resources, we generally are trying to maximize economic welfare through time. This has two interrelated implications.

*Page uses the phrase *efficiency criterion* to denote the outcome of a set of perfect markets.

One is that the welfare of a given generation is not derived directly from the availability to that generation of a given stock of natural resources (again leaving natural amenities aside for the moment) but from the consumption possibilities per capita as a whole. A larger stock of natural resources will, other things equal, imply higher potential welfare but so also will a larger capital stock, improved technology, and lower population. In the words of Stiglitz (1976), "One should not look at equity in a narrow sense of simply looking at the division of natural resources between the present and future generations; the present generation may give future generations fewer natural resources (this is inevitable in the case of exhaustible natural resources), but it will give future generations a higher level of technology and more capital."

The second implication is that we must put weights on the welfare of different generations. This is where ethical norms come in. Should the standard practice of discounting of future utilities be employed? If so, at what rate? Should the objective be to equalize the welfare of different generations as much as possible? Why should the present generation save and invest a portion of its output in order to improve the welfare of succeeding generations? How does one deal with the fact that population growth increases the size of future generations?

The standard application of optimal economic growth theory to an economy with exhaustible resources goes as follows. The objective is to maximize, for either a finite or infinite horizon, the present discounted value of the utility of consumption. In order to focus on intergenerational equity it is usually assumed that the intragenerational distribution of welfare will follow the same pattern for each generation; for example, each individual has identical tastes and receives an equal share of current output. This assumption simply allows us to focus on the essential aspects of the problem without needless complications. We can concentrate on the utility of a typical individual and simply multiply by the number of individuals to obtain a generation's "total welfare" which is then weighted by the discount factor applied to this generation. This discount factor is selected by society to reflect both ethical criteria and economic conditions. For example, it has been argued that there is no ethical justification for weighting the utility of future generations less than that of the current generation. A positive discount factor would, however, still be appropriate if there is a positive rate of return on capital because in this case the current generation sacrifices some of its output in order to accumulate capital which increases the output available to future generations. Thus it is frequently asserted that the social rate of return to capital is the appropriate discount rate, and it is known that under certain circumstances the market rate of interest will equal the social rate of return to capital.

The maximization is subject to three sorts of constraints. First, the size of the resource stock (assumed to be known) naturally constrains output and, therefore, welfare if the resource is essential in the sense made precise in the previous section. Second, not all the currently produced output can be used for consumption: some must be invested in order to maintain or increase the size of the capital stock (the optimal rate of growth of the capital stock is an outcome of the maximization). And third, consumption levels cannot fall below survival minimums, and resource use and capital stock cannot be negative.

The results of exercises along these lines can be classified according to three criteria: whether population growth is included, whether an infinite horizon is used, and whether a positive discount rate is used. With respect to the first criterion, it is argued by Dasgupta and Heal (1974) that because this problem is concerned with the implications of finite resource stocks for intertemporal planning, it is inappropriate simply to assume a constant exogenous rate of population growth; in the long run such a constant rate of growth will be impossible. Ideally, therefore, an optimum population policy should be part of the model, but because this is such a complex problem, they instead consider only a constant population through time and rationalize that decision by suggesting that "the objective of zero population growth has been accepted and achieved" (Dasgupta and Heal 1974). Other analyses have used the standard assumption of exogenous exponential population growth. With respect to the second criterion, although infinite horizon planning models are rarely used in practice, both types of models have been explored in the literature. An infinite horizon is often justified theoretically by noting that a finite horizon arbitrarily leaves out of account all future generations beyond a certain point in time. The third criterion has already been commented on. Models have been developed with and without a positive discount rate, and the special case of Rawls' "max-min" criterion has received attention as well.

Dasgupta and Heal (1974), assuming constant population, show that with a positive discount rate and an infinite horizon, per capita consumption will generally rise over time at first and then fall continuously. Furthermore, they find that if the resource is essential, it is optimal to deplete an approximately constant percentage of the resource stock each period and so imply that it is not optimal to exhaust the resource stock.* The

*These and other authors in the field generally use rather special functional forms, such as Cobb-Douglas or Constant Elasticity of Substitution production functions and iso-elastic utility functions. The latter have the property of constant elasticity of marginal utility at all levels of consumption.

higher the discount rate (that is, the less weight we put on the welfare of more distant future generations), the larger is this percentage. If, instead, the discount rate is zero, they find that the influence of the productivity of capital causes per capita consumption to rise continuously. (It should be noted that this particular result was derived under the assumption that the elasticity of substitution is equal to one and that the elasticity of output with respect to capital is greater than the elasticity of output with respect to the resource.)

Stiglitz (1974) analyzes another case in which per capita consumption grows through time along an optimal path. He uses a model in which population grows exponentially, utility is discounted, and the production function is of the Cobb-Douglas type. Optimizing over an infinite horizon, Stiglitz demonstrates how the choice of the discount rate affects the optimal path. For example, if the discount rate is high relative to the rate of technical progress, then the more elastic is marginal utility and the lower is the optimal rate of depletion. This runs counter to the intuitive result from simpler models that a higher discount rate necessarily implies more rapid depletion (Stiglitz 1974).

In an interesting model analyzed by Solow (1974a), the ethical criterion used is Rawls' max-min standard applied intertemporally. This amounts to maximizing the welfare of the poorest generation. The Rawlsian criterion, in a model with an infinite horizon, no population growth, no technological change, and a Cobb-Douglas production function, implies that the per capita consumption of each generation is the same and that the largest constant consumption level possible depends directly on the size of the initial capital stock. Each generation invests enough of its output in creating new capital to replace the resources it has used up. This suffices to maintain output constant through time because, under the Cobb-Douglas assumption, the elasticity of substitution between capital and natural resources is one. This result contrasts sharply with the results of the almost identical model analyzed by Dasgupta and Heal (1974) in which a discount rate of zero allows consumption to grow without bound. Depletion of natural resources proceeds more slowly in their model because capital accumulation is not constrained by the requirement that earlier generations not be made worse off by investing a lot so that later generations can enjoy a higher standard of living. Solow summarizes the implications of the max-min criterion by noting its main difficulty: "It requires an initial capital stock big enough to support a decent standard of living, else it perpetrates poverty, but it cannot tell us why the initial capital stock should ever have been accumulated" (Solow 1974a).

It is important to point out that actually implementing this sort of optimality analysis faces many obstacles, not the least of which is the inability

of the present generation to dictate policies to future generations, even assuming they have identical preferences. Discussions of second best alternatives note that forced conservation of natural resources, although inefficient, could at least guarantee that future generations will have some production possibilities. Forced saving plans could achieve the same purpose. Peterson and Fisher (1977) provide a useful summary of this literature.

The discussion of this section has revealed certain points worth reemphasizing. First, it is crucial to be very explicit about the ethical norms one uses when planning intertemporal consumption. Second, we have explicit conditions under which the resource constraint does not inevitably cause the economy to stagnate and decline; thus empirical work can provide extremely useful guidance as to whether we are in fact likely to face a binding resource constraint. And, third, the analysis of imperfect competition reveals some areas in which government policy could clearly eliminate inefficiency. We return to these points in later sections when we discuss policy implications and recommendations.

Uncertainty, Externalities, and Other Complicating Factors

The discussion so far has been of natural resources in a rather pristine economic world. Perfectly operating markets have been our context, except in the discussion of imperfect competition; externalities associated with depletion of natural resources have been absent; perfect certainty with respect to the future course of prices, demand, technology, and stock size have all been assumed; markets have always been in equilibrium; and institutions other than markets have not been incorporated.

This section incorporates certain factors that, although they complicate the analysis, are important considerations in the real world in which policy decisions must be made—uncertainty and risk, externalities, disequilibrium, and institutional constraints. In some cases, the complications result in intuitively plausible modifications to conditions derived in the simpler framework. In others, however, the results are complex modifications difficult to interpret—the price one must pay for moving closer to reality.

Uncertainty and Risk

Uncertainty and risk permeate most aspects of natural resource industries to a greater degree than in many other areas. The total stock of a resource is invariably unknown, and although increasing the effort devoted to exploration may result in increasing known reserves, the timing and size of discoveries are to a large degree unknown in advance. Also, future

demand for a resource is in general unknown. Substitutes may be developed which render a resource uneconomic to use, but when such a substitute will be found cannot be known with certainty even though, again, increasing the research and development effort increases the probability of discovering such a substitute sooner. The more likely the discovery of a substitute which reduces the value of the resource stock, the riskier it is to hold stocks of the resource.

We are not completely in the dark about the course of future discoveries and technological developments, however, and we can proceed by describing as much as we know about the relationships between exploration and research and development effort and the likelihood of discovery and development of substitutes. We can then examine the implications of the remaining uncertainty for efficiency and optimality.

Suppose that an exhaustible resource is an essential input into the production of aggregate output in an economy. Research is underway on a product which is a perfect substitute for the resource in production and which would, when fully developed, be available in essentially unlimited supply at a constant cost. This scenario is not too farfetched a representation of the energy industry with, for example, solar energy as the substitute for fossil fuels. It is assumed that the characteristics of the substitute technology are known with certainty and that the only unknown is the date at which it becomes feasible to use it. For now we assume that the timing of the innovation cannot be influenced by increased research and development expenditures (an assumption we later relax).

In this framework it has been shown that if there is a positive probability of the substitute being developed at any time, and if risk-neutrality* prevails, then an intertemporal competitive equilibrium will be characterized by the following inequality at each moment of time: $r_t \leq \dot{p}_t/p_t \leq r_t + \theta_t$ where r_t and p_t are interest rate and price of the resource at time t ; \dot{p}_t/p_t the instantaneous rate of change of price at time t ; and θ_t is the probability that the substitute will be available at time t , given that it has not become available previously.** Because $\theta_t > 0$ for all t , the Hotelling rule is modified in a simple manner: price rises at a rate at least as fast as the interest rate and at most as fast as the interest rate plus a factor representing the conditional probability of discovery of the substitute. The interpretation of this result is straightforward: once the substitute is in use, the remaining resource stocks will lose some or all of their economic value. Therefore, in equilibrium, in order for there to be sufficient inducement

*An individual is said to be risk-neutral when he is indifferent between any two outcomes with the same expected value and different variances.

**Note that θ_t is time-variant; for example, given that a substantial research effort is directed toward development of the substitute, θ_t probably increases over time.

to hold stocks of the resource and run the risk of a capital loss, the price must rise at a higher rate than otherwise to compensate the holders for bearing this risk. This could imply either a lower or a higher extraction rate than would prevail without uncertainty because two counteracting forces are at work.

On the one hand, the resource will be worth less at the date of availability of the substitute; there is an inducement to deplete the resource more rapidly than otherwise. On the other hand, the consequences of running out of the resource before the substitute is available are drastic under the assumption that the resource is essential for production until that time. If the initial stock is relatively large, the latter factor will dominate and the extraction rate will be lower than with perfect certainty. If the stock is small enough, then the former motive will dominate and the extraction path will be more rapid (Dasgupta and Stiglitz 1976).

In another analysis with a model of this type, Dasgupta and Heal (1974) found that when a monopolist owns either the resource stock or the right to produce the substitute or both, then the resulting extraction rate is definitely biased downward. In each case the resource is extracted too slowly for intertemporal efficiency. In a special case in which a planner is attempting to find the optimal depletion path in a model of this type with the added stipulation that once the substitute becomes available the existing resource stock *and* the existing capital stock become valueless (their prices fall to zero), the Hotelling rule becomes exact again: $\dot{p}_t/p_t = r_t + \theta_t$. This demonstrates the restrictive assumptions required in order to account for uncertainty by increasing the discount rate by a determinate amount (Dasgupta and Heal 1974).

The simple modification to the Hotelling rule brought about by incorporating this particular form of uncertainty is due mainly to the exogenous and costless nature of the technological change. In models which explicitly allow for incremental research and development effort—which reduces output available for consumption or capital formation and increases the probability of successful development of the substitute—the optimal depletion rate can no longer be characterized by a simple variant of the Hotelling rule. Several conditions characterize the optimal depletion rate, including one which states that if part of aggregate output is used for research and development, then the marginal expected value of using output for research and development must equal its marginal value in its alternative productive use, namely capital formation. But the research and development effort need not begin immediately along the optimal path and also does not necessarily increase until the substitute is developed. Again, the size of the initial resource stock plays a key role in determining when research begins and when the effort peaks and starts

declining (assuming the effort has not reached fruition already). Eventually, as the resource stock declines, it will be found worthwhile to begin the research and development effort which will entail declining per capita consumption until the effort pays off. The important point is that it is optimal to delay work on the substitute until the growing size of the capital stock and the declining size of the resource stock make the marginal expected value of the research and development effort comparable to the marginal value of other uses of aggregate output (Kamien and Schwartz 1978).*

Another type of uncertainty, peculiar to natural resources, concerns the size of the stock, the extraction costs of different deposits, and the value of exploration (Petersen 1975). The results of models designed to examine these issues hinge on whether it is possible (at a cost) to generate information about various resource deposits in the process of exploring without actually drilling the deposits. If it is assumed that this is not possible, that the only way to gain information about a particular deposit is by drilling it, then it has been shown that the optimal exploration and extraction policy will be characterized by a "reservation cost" strategy (Gilbert 1976a). This strategy means that if a deposit is drilled and it is found that the extraction cost is above a certain cutoff level, then the resource should not be extracted immediately but saved for later. If the extraction cost is below this level, the deposit should be worked right away. The optimal cutoff level of extraction costs is endogenous to the model and naturally varies through time as lower cost deposits are depleted. A key result in this area is that competitive, profit maximizing firms will follow the socially efficient exploration and extraction path (Gilbert 1976b).

When it is possible to generate information concerning deposits without actually drilling them, the latter result is reversed. It is common in models of imperfect information to find that when information has value in determining the appropriate rate of extraction but can be produced only at some cost, competitive firms will, in general, not efficiently allocate investment in this type of information. This is a consequence of the inevitable externalities associated with the production of information. The reasons why externalities cause market allocations to be inefficient are discussed below. In general, the efficient extraction rate under this type of uncertainty is slower than the efficient rate for the mean value of the resource stock (Gilbert 1976b).

A third type of uncertainty concerns future demand for the services of the resource. The results for this type of model indicate that if all produc-

*These models, of course, neglect technological developments the characteristics of which cannot be anticipated in advance and also the general benefits to society of basic research and learning by doing.

ers of the resource agree on the nature of the uncertainty facing them, and if they are risk-neutral, then the market allocation will be efficient, given that the expected value of utility is maximized. If, however, producers are risk-averse while society is risk-neutral, then depletion would be too rapid—because in order to minimize the variance of their expected profits, producers find it worthwhile to extract the resource quickly and forego some potential future profits rather than leave it in the ground and face the possibility, however remote, of a sharp decline in future demand (Weinstein and Zeckhauser 1975).

Externalities

An externality (positive or negative) is said to exist whenever the actions of one producer or consumer affect the welfare or production possibilities of another agent in a way not accounted for by flows of commodities on markets. In general, an externality occurs when a decentralized economy has, for whatever reason, insufficient incentive to create a market for commodities that are actually changing hands. Three main types of externalities are recognized in the literature (the terminology follows Bator 1958):

1. Ownership externalities which reflect an inability actually to appropriate the full value from a factor of production which has a positive marginal product. An example is the case in which information generated by one producer about a resource deposit cannot be kept from other producers so that the producer who made the effort to collect the information does not receive the full benefit from it.
2. Technical externalities in which, for example, a production process generates an unwanted by-product or reduces the value of adjoining locations.
3. Public goods externalities, cases in which one individual's consumption of a good does not subtract from the amount available to other consumers. Clean air is an example of a public good, as are bridges, national defense, and national historical monuments. The recent cancellation of the \$450 million Pyramid Oasis project in Cairo points up the increasing sensitivity to such externality issues in all parts of the world.

The problem of externalities has come up frequently in our discussion because of the widely held belief that externalities often occur in connection with the extraction of exhaustible resources. Exploration activities, pools of oil under adjoining parcels of land, environmental degradation caused by mining, and even overcrowding of national parks exemplify externalities involving natural resources (see Dasgupta and Heal 1978, chap-

ter 15, for discussion of these examples). In general, one cannot expect markets to allocate resources efficiently when externalities are present. The reason is simply that the complete set of markets required for an efficient allocation does not exist. For example, there is no market for pollution in which individuals can purchase the right to emit pollutants or the right to avoid pollution. In some cases where markets for information do exist, they are generally not as extensive as would be required for efficiency.

The presence of externalities clearly warrants consideration of policy intervention to lead to an efficient resource allocation. A natural question to ask is whether an appropriate policy would establish markets for those commodities for which the private incentive to do so is apparently insufficient. This type of policy has been studied extensively, particularly with respect to establishing the "optimum" level of pollution. However, there are a number of reasons why this may not be the most feasible approach to the externality problem (Dasgupta and Heal 1978, chapter 3). First, for a market to exist, it must be possible to exclude those who do not purchase a good from enjoying the benefits of it. This is clearly next to impossible for goods such as clean air, national defense, and even a pool of oil under adjoining parcels of land. Second, the existence of a market does not automatically guarantee that its outcome will be a competitive equilibrium. For externalities specific to a certain locale, the number of people who might be involved in a market would be quite small and the market structure might be more of a bilateral oligopoly than a competitive one. Third, in the case of technical externalities, a market may not guarantee even the existence of a competitive equilibrium. For example, when pollution is a joint product of a production process, it may be impossible for technical reasons to establish equilibrium simultaneously in the market for the produced good and for the pollution (there is the possibility of a nonconvex production possibility set).

If the establishment of a complete set of competitive markets is infeasible, what other ways exist for dealing with external effects? Borrowing from the large body of literature on the subject, especially the useful survey by Mishan (1971), one can identify several. One solution, and probably the best one from a theoretical viewpoint, is to impose optimal excise or "Pigouvian" taxes and subsidies in such a way as to induce the market toward an efficient allocation. Although this can be a relatively simple theoretical exercise, it is extremely difficult in practice to obtain the information needed for the calculation of such taxes and subsidies. One does not frequently observe Pigouvian taxes being imposed in practice.

Another commonly proposed solution, particularly in cases in which there are common property aspects involved, is regulation of access or property rights. This regulation may involve political restrictions and

standards which implicitly determine the extent of externalities present.* Most of the remedies suggested involve modifying legal rights, market structure, or prices and incomes facing the participants and then allowing the market to follow its course. In many cases this will be the best way of eliminating an externality without undue disruption of other activities.

Disequilibrium

One of the assumptions underlying most of the previous analysis is that markets are always in equilibrium or, at least, that they tend to move quickly to their new equilibrium positions after a shock. This assumption is very likely to be valid when futures markets and risk markets exist because these institutions enable people to form accurate expectations about the future. Such markets mean that an unexpected shock such as a large new discovery, or a change in the degree of market power exercised by a cartel, even though unpredictable, will not lead to an unstable trend or spiral away from its new equilibrium position. In the absence of futures and risk markets, individuals must find another way of forming their expectations about future prices. One possible method is simply to extrapolate past price trends into the future with a model relating the rate of change of price to excess demand. Another way is to use a forecast based on all available relevant information including likely trends in demand, discoveries, government regulations, business cycles, and so forth. The former method may be characterized as "adaptive expectations" and the latter as "rational expectations."

It turns out that the method of expectation formation assumed is a crucial determinant of whether or not a market for an exhaustible resource will exhibit short-run stability. Stiglitz (1975) argues the matter in the following way. First, suppose that expectations are formed by the adaptive method and that the market is initially in intertemporal equilibrium. Suppose that an exogenous shock leads producers to expect that the rate of price increase will exceed the interest rate for the next few periods. This leads them to view holding their stocks in anticipation of capital gains as a more profitable activity than extracting and selling the resource, so production ceases (or slows down if there are fixed costs). The reduced rate of output relative to demand causes the current price to be bid up and reinforces the expectation of a rate of price increase in excess of the interest rate. This reinforces owners of the resource stock in their belief that holding the resource off the market will be profitable and causes the price actually to rise at a rate greater than the interest rate, whereas the new

*It can be argued that the profit motive itself determines the nature of the environment in which it operates. This view is undoubtedly true to a degree but ignores the evolution of legal restrictions on economic behavior.

long-run equilibrium would be characterized only by a shift in the level of the price with no change in the rate of price increase.

Heal (1978) and Stiglitz (1974) consider the same situation but suppose that expectations are formed rationally. Now an exogenous shock which leads to the expectation of higher prices in the future will lead to an immediate increase in the price level with no change in the rate of price increase. The market attains its new long-run equilibrium quickly and directly because individuals expect the resource stocks to be a better asset than others in the economy, so they immediately purchase it, bidding up its price to the point at which the expectation of a future price increase no longer is warranted.

The role of expectations formation is thus very important for the short-run stability of natural resource markets when futures and risk markets do not exist. Evidence about which expectations hypothesis seems to conform to empirical behavior is an important research aim in economic theory, and it is now possible to construct tests which distinguish alternative expectations hypotheses on the basis of empirical data. One can readily see that natural resource markets are often characterized by short-run instability leading to violent price fluctuations which may indicate the presence of adaptive expectations formation. But the implications for government policy are not clear because often the shocks to the market are caused by governments themselves. Two recommendations that do emerge from a study of this problem are the desirability of establishing long-term risk and futures markets and of promoting stable government regulations. We elaborate on this in our policy discussion in the next section. First, however, we discuss how government actions may adversely affect natural resource markets.

Institutional Considerations

Markets do not function in a vacuum. Rather, as we are painfully aware, a complex array of private and, primarily, government institutions form the environment in which natural resources are allocated. Government policies in the form of general taxes, subsidies, regulations, and similar interventions directed specifically toward natural resources have a strong influence on the efficiency with which markets allocate natural resources. This large and complex area has been surveyed in detail by Brannon (1975) and Stiglitz (1975); here we restrict discussion to some of the government interventions which have fairly obvious impacts on natural resource markets.

Taxes of various kinds affect natural resource industries. Income taxes generally are not distortional, but special provisions that apply to natural resource industries are a different matter. These include the depletion al-

lowance which makes the petroleum industry, for instance, a more attractive investment prospect than it might otherwise be. The allowance's effects lead to a faster depletion rate, particularly under monopoly, and could induce more exploration than is optimal. It is also argued that special treatment of some natural resource industries penalizes others which are generally the more risky and capital-intensive ones (Stiglitz 1974).

Government leasing policy can have a significant impact on whether lowest cost deposits are extracted before higher cost deposits as required for efficiency. The so-called "diligence clause" requiring some development of a tract within five years of leasing it, for instance, could cause firms to extract deposits which they would otherwise hold off the market while waiting for the price to rise (Stiglitz 1975).

Price regulations also have strong observable effects on natural resource markets. Holding the price fixed results in obvious inefficiencies because efficiency requires an increasing price unless technical change offsets the rising scarcity rental. Fixed prices can induce excessive depletion as firms observe that there is no return to holding stocks off the market.

General economy-wide taxes create a wedge between rates of return available to private investors and the social discount rate which reflects the actual productivity of capital. That wedge can result in significant departures from efficiency if the social discount rate is considered the appropriate figure by which to discount future utility and profits.

Finally, the recent tendency to substitute political motivations for economic considerations in determining production rates for key energy resources obviously reduces the ability of any economic theory to predict adequately the future course of extraction patterns, prices of energy, or impacts in either developing or developed nations.

Implications for Development Policy and International Cooperation

We have devoted considerable space to a review of the economic theory of exhaustible resources. We turn now to the all-important policy implications of the theory. What are appropriate policies with respect to natural resources for national, regional, and international bodies interested in promoting economic development and international cooperation?

The importance of natural resources to the great majority of developing countries is incontestable. A perusal of data for 83 developing nations which belong to the International Monetary Fund reveals that 27 of them get over half of their export earnings from exhaustible resources; when agricultural, fishery, and forestry products are included, most developing countries get nearly 100 percent of their export earnings from natural resources. The significance of these numbers lies in the fact that most devel-

oping countries do not have large indigenous capital goods sectors and so are forced to rely on imports of capital goods in order to achieve desired levels of investment.* Earnings from natural resource exports thus provide crucial foreign exchange and relieve bottlenecks that would arise if developing countries were forced to build up their capital stocks from scratch. A number of familiar issues related to this reliance on natural resource exports are relevant here.

First, the sharp short-run price fluctuations characteristic of many markets for natural resource products have subjected development efforts to sudden severe shocks which can undermine the best planning efforts and leave an economy reeling. These price fluctuations result from the generally price-inelastic nature of the derived demand for many natural resource products on the one hand, and from the considerable lags involved in increasing extractive and processing capacity on the other. It is not uncommon to find new capacity appearing in response to previous high levels of demand just at a time when demand in industrial countries is falling because of a downturn in the business cycle and bringing a sharp drop in the resource price. Numerous proposals for stabilizing resource prices have been made and some, such as commodity agreements, have been tried in practice.

Second, the long-run trend in the terms of international trade of developing countries has been a subject of controversy for many years. It has been claimed that these terms of trade have undergone a secular deterioration throughout the present century. The counterclaim that the developing countries have, in fact, experienced an upward trend in their terms of trade has been made with equal forcefulness. One of the main reasons for cartel formation by developing nations has been the perception that without some kind of action, their terms of trade would continue to deteriorate.

Third, in an effort to overcome dependence on export earnings from natural resource products, many developing countries favor import substitution in an attempt to develop a diversified industrial structure. International trade policy thus becomes a policy instrument with profound effects on resource allocation and development efforts both within and between industrial countries and developing countries.

Another issue closely allied to trade policy is factor mobility and policies relating to it. This point arises in connection with issues such as the recycling of "petro-dollars" and foreign investment in the resource sectors of developing countries.

Before we discuss each of these issues in more detail, a caveat is in or-

*Imports of necessities such as food are also important but do not contribute directly to development.

der. Many of the policies we recommend are based on the assumption that governments are capable of imposing an optimal tax and tariff structure. For example, a common result from the theory of optimal taxation is that it is generally more efficient, in the sense of reducing total welfare by less, to raise a given amount of revenue by lump-sum or income taxes than by excise or trade taxes. This view ignores the obvious fact that most governments are severely constrained by various political factors and are unable or unwilling to carry out certain types of policies. The problem is discussed cogently by Sen (1972) and by Dasgupta and Stiglitz (1974), who evaluate the optimality of various tax structures under different types of constraints. We note that many of the policies suggested here may have to be modified in the light of particular constraints which exist in different countries. In the spirit of optimism, however, we consider it important to spell out optimal policies—that is, those which have the biggest potential impact on welfare—in the hope that understanding what should be done will help overcome narrow political vision in the effort to hasten the development process.

Price Fluctuations

The economic theory of natural resources is mainly concerned with long-run trends and as such has little to say about short-run phenomena such as price fluctuations caused by the business cycle and the lags involved in expanding capacity. Nevertheless, some insights can be gained from natural resource theory and some aspects of general price theory in analyzing this important problem.

Multilateral arrangements such as international commodity agreements are commonly proposed as a means of stabilizing the export prices faced by developing countries. Bilateral long-term contracts are also suggested frequently, but can arrangements of either breadth be effective? The Hotelling rule tells us that in the long run exhaustible resource prices will follow an exponentially increasing trend, once cost reducing technological improvements are no longer significantly affecting the market. Attempts to fix a resource price within fairly narrow bounds will sooner or later face the pressure of an increasing long-run trend in the price.

A more reasonable solution may be to attempt to limit price fluctuations around an increasing trend. In principle, a commodity agreement could be designed to do this. However, the benefits of successful price stabilization must be balanced against the costs of achieving it. The common tools employed in commodity agreements are buffer stocks and export controls. Buffer stocks can tie up an immense amount of resources if they are to be successful. Desai's study (1966) of the international agreement on tin, the only exhaustible resource for which one exists, showed

that the buffer stock required in order to meet the stabilization goal of the agreement would need to be inordinately large. The actual size of the buffer stock has been considerably smaller, and as a result the agreement has not been notably successful in dampening price fluctuations.

Although export controls are a powerful tool for preventing a price from falling, they too have a cost—in terms of lost sales. Inelastic demand may dictate a high price and low sales as a profit-maximizing strategy for a commodity agreement acting as a monopolist, of course, in which case the cost (to consumers) is the consumer surplus lost as a result of monopolistic actions.

Are alternative means for stabilizing export prices of developing countries available? The answer is probably no, but there are methods by which the harmful effects of sharp price fluctuations on developing nations' economies may be ameliorated. These methods stem from the well-known principle of welfare economics mentioned earlier: Under general conditions, an income tax is a less costly way (in terms of welfare) of raising a given amount of revenue than a commodity tax or some other form of price distortion, of which buffer stocks and export controls are examples.

An efficient method of alleviating temporary revenue shortfalls in developing countries because of price shifts would be loans from a fund set up for this purpose and managed by an international development agency such as the World Bank. The cost of maintaining such a fund would be less than the cost of stabilizing the price via the usual tools of commodity agreements, especially because repayments to the fund would be made during periods of high prices. This proposal recognizes the need for industrial countries to aid in offsetting temporary blows to economies which cannot easily absorb such shocks but provides that aid in a way which minimizes the cost and avoids distorting market price signals. It would be necessary in practice to determine when a price change is a signal of temporary disequilibrium and when it betokens a "real" change in underlying demand or supply conditions. Although this could be a difficult task, it should not be insurmountable and could aid market participants by providing additional information about future trends.

Terms of Trade

Prebisch (1950) and Singer (1950) popularized the notion that the terms of trade between primary products and manufactures, a relation not necessarily equivalent to the terms of trade between developing and developed countries but with some major exceptions approximately the same, had been declining for some time and would likely continue to do so. Singer argued that this decline did not reflect a trend in real costs; he held that, in fact, technological progress was reducing costs in manufacturing

at a faster rate than in primary industries so that one would have expected an improvement in terms of trade of primary products. The actual decline occurred, it was asserted, because of monopoly power in the developed countries used against the developing nations. Strong labor unions in the industrial countries were supposed to have appropriated the benefits of lower manufacturing costs and improved members' incomes so that prices of manufactured goods did not fall while the benefits of technological progress in primary industries in developing countries were appropriated by the industrial nations as a result of monopsonistic buying power.

Kindleberger (1956; 1964) has shown that the general pattern of trends in the terms of trade supported the Prebisch-Singer hypothesis through the early 1960s with some exceptions. The reasons emphasized by Kindleberger and others for the appearance of this trend differ somewhat from those of Singer and Prebisch. Differences in the capacities of developing versus industrial nations to shift resources and expand or contract supply of primary products in response to incipient price changes, along with differences in the relative ease of entry and exit and income inelastic demand for primary products, combined to give the result. The damaging effects of the observed decline in the terms of trade for developing countries are called into question, however, when it is remembered that lower relative prices can stimulate demand and thus increase the volume of trade and that the quality of manufactured goods has increased significantly over the relevant period, offsetting to some degree their higher relative prices. Other factors also working to mitigate the effects of declining terms of trade for developing countries include the declining relative price of internationally traded services, provided mainly by advanced nations, and the improved share of profits from foreign investments received by developing nations' governments.

What can we expect the trend in the terms of trade to look like in the future for developing country exporters of primary products? Natural resource theory provides some guidance. This century has witnessed sharp advances in the technology of extracting primary products, particularly nonrenewable resources, and the resulting declines in extraction cost have prevented scarcity rental increases from consistently forcing market prices up, although the cost declines experienced in manufacturing have been even greater. If, as some claim, the pace of technological progress has been slowing in recent years, and if this trend continues, the force of an exponentially increasing scarcity rental will begin to make itself felt in the form of rising market prices for nonrenewable resources relative to manufactured goods' prices. At the same time, demand for these resources may decline as cheaper substitutes are developed, a trend which has already affected tin and lead. Furthermore, raw material price in-

creases may well be passed along in the prices of manufactured goods imported by developing countries, and some of the benefits to exporters of higher natural resource prices may be offset. The petroleum price increases of the mid-1970s provide a case in point.

The above results may be difficult to disentangle, but no obvious case emerges for an effort to keep primary product prices artificially high over the coming years. Unexpected events such as major new discoveries, technological advances, and development of substitutes may offset the force of a rising scarcity rental, but the negative effects of such events on development prospects are best countered by nondistorting policy actions rather than by manipulated prices. The maintenance of artificially high prices (whether through government controls or cartel pricing arrangements) for primary products is likely to hasten the development of substitutes and increase the reluctance of industrial nations to cooperate in other ways with developing countries.

The formation of cartels has been chosen by a number of exporters as a means of ensuring a high relative price for their natural resource exports. The petroleum cartel, OPEC, has succeeded in maintaining the price structure imposed in late 1973 and early 1974, although the terms of trade of the OPEC countries appear to have declined since then, from their initial sharply improved level, as a result of induced inflation in the industrial countries. The worldwide recession of 1974-75, which many economists believe was caused in part by the oil shock, reinforced a decline, already induced by the price increases, in the demand for oil. This has naturally contributed to a slower relative rate of extraction. Although this means that scarcity is less likely to be a problem than otherwise, there is no presumption that the current extraction rate is efficient.

From the point of view of world welfare, the magnitude and rapidity of the OPEC price increases have seriously contributed to economic and political instability throughout the world. The industrial countries have suffered from the dual maladies of higher inflation and higher unemployment and have, tragically, resorted to higher levels of arms sales to highly unstable regimes in order to offset the balance of payments implications of the higher cost of oil. Oil-importing developing countries have had to curtail development programs in order to offset the increased constraint on foreign exchange reserves. It is ironic that the huge windfall profits to oil-exporting nations have themselves been a mixed blessing. In order to sustain artificially higher oil prices, production rates have been reduced well below actual production capacity, and higher real costs of unit output have resulted. Moreover, the scramble to modernize and to acquire western technologies has led to considerable economic waste as well as to political instability as the recent events in Iran serve to illustrate.

Defenders of the cartel's actions point out that the OPEC countries have provided aid to some other developing nations and that the Eurocurrency market has fostered the "recycling" of excess OPEC liquid capital to other countries with profitable investment opportunities. This amounts to an involuntary transfer payment from industrial oil importers to developing countries. Although we favor resource transfer in this direction, we note that this particular way of achieving it imposes a burden of efficiency on both the donors and the recipients—the latter because of the generally higher interest rate charged by private banks compared to official international agencies. Given the limited ability of OPEC countries to absorb and productively use more capital, this may be an opportune time for negotiation of a halt to further price increases in exchange for increased nonmilitary aid and technical assistance channelled through international agencies to their most productive uses.

Trade Policy

Import substitution and export promotion for manufactures are two policies favored by many developing countries as a way to overcome their dependence on export earnings from natural resource products. The former policy involves the imposition of high tariffs on, or outright prohibition of imports of, goods that the country would like to produce domestically. The latter policy aims at shifting resources into those manufacturing sectors the products of which can successfully compete with their higher-labor-cost counterparts in industrial countries. Textiles, electronic components, and steel are examples of the industries in which some developing countries find themselves with a comparative advantage. However, they face barriers to the markets of industrial countries in the form of tariffs which, even though not prohibitive, can still limit the revenue received by developing country exporters.

A well-known result from the theory of international trade is that under fairly general conditions potential world welfare is maximized under a free trade regime (Samuelson 1939). Every country could be made better off by an appropriate redistribution of the increased income available as a result of switching to a free trade regime. The inefficiencies associated with import substitution efforts since World War II are well known, as are those currently associated with the tariffs and other barriers to the exports of manufactures from developing to industrial countries. The benefits to developing nations of adopting a free trade policy, along with the adoption of such a policy by the industrial countries, could be quite significant—especially if one of the explicit aims of the policy is the promotion of development so that any substantial increase in revenue accruing to advanced countries would be contributed to a development fund.

South Korea and Taiwan provide encouraging examples of how the export of manufactures can spur development that benefits the majority of people in the country, while a recent episode in the Philippines demonstrates the impact on growth of removing various types of distortions (Williamson 1971; Williamson 1976). Although many developing countries may not be in a position to develop successfully manufacturing industries for export purposes, the more efficient resource allocation that would result from liberalized trade policies would be likely to offset any potential harm from relying on export earnings from primary products, provided the recommendations made above as an alternative to price stabilization efforts are implemented.

Foreign Investment

As part of the overall trade policy of many developing countries, it is common to find restrictions of various kinds placed on foreign direct investment. These restrictions are often specifically applied to natural resource industries which provide the country with a large part of its foreign exchange earnings. Foreign investment in the natural resource sector of a developing country is typically made by firms attempting to integrate vertically in order to assure themselves sources of supply of raw materials and perhaps even to erect barriers to entry by potential competitors needing the same raw material in their home country. These firms often have specialized technical knowledge to which they have exclusive rights, having developed and implemented extraction processes in other locations.

One of the main reasons forwarded for restrictions on foreign investment in the natural resource sector is that the foreign firms in this sector extract the resource at a rate more rapid than desired by a nation and repatriate too high a portion of their profits. This view induces developing country governments to nationalize existing foreign investments and prohibit further investment by foreign firms. However, this policy has a cost as well, because it may take a long time before the government can run extraction enterprises with the same degree of efficiency as the foreign firms.

Consider the reasons why a foreign firm would extract the resource at a rate considered too rapid by the developing country. If the firm and the country use the same discount rate in their calculations and have the same information, their desired extraction rates may still differ if their objectives differ. (That is, the firm is maximizing the present value of its stream of profits while the country presumably has a variety of social objectives involving growth, employment, inflation, income distribution, etc.) But this does not necessarily explain the divergence in desired extraction rates. It is entirely possible that in a period of declining demand for its product, the firm would like to extract at a slower rate than that desired by the

country. In this case differing discount rates are likely to be the cause. Private and social discount rates may differ for a number of reasons; the relevant one here is uncertainty over future property rights. If the firm attaches a high probability to expropriation or other restrictions, then it will tend to increase its discount factor and in turn move to more rapid extraction because a unit of the resource extracted becomes worth relatively more the sooner it is available. Firms are not likely to pursue a socially optimal exploration program if they believe they will get no benefit by doing so.

This is a case in which the effects of uncertainty have an obvious cure—creation of a relatively stable political environment with respect to foreign investment. This does not mean relinquishing all control of the natural resource sector to foreign firms; rather it means developing policies that allow foreign firms to operate in such a way as to maximize the gains to the developing country from their activities. Such a policy could involve, for example, a high tax on profits along with guarantees of security of investments. This type of policy may also have the beneficial effect of inducing a more nearly optimal exploration program. The best discovery prospects are currently located in the developing countries, and an increased exploration could be of considerable benefit to them.

Conclusions

Natural resource theory provides a conceptual framework which can aid in understanding the complex choices facing decision makers with responsibility for natural resource policy. The preceding sections have spelled out the contributions of the theory in some detail and pointed to the implications of the theory for policies relating to economic development and international cooperation. Although such theory is an invaluable aid to decision making, it cannot, as we have noted, provide the moral guidance which ultimately determines the program of action chosen. A crucial part of the decision making process is the values of the decision maker because these play an important role in the choice of goals. Too commonly these values remain implicit, and examination of the policy recommendations themselves is required in order to infer the nature of the goals behind them.

The single most important institutional factor likely to affect the future of the economies of both developing and developed nations is the trend toward cartelization of natural resource industries. It is in this area that economic theory is least likely to produce useful predictions because the rapidly emerging network of international resource cartels displays a disturbing tendency to use political rather than economic motivations as the

basis for resource production and distribution decisions. The major OPEC producers of the Middle East have come to view their natural resource endowment not simply as an economic resource to be optimally allocated over time, but rather as a political "weapon" to be wielded through the use of production quotas which in turn lead to an escalation of the prices of energy resources. The Arab oil embargo of 1973 and the subsequent quadrupling of oil prices was the first dramatic event symbolizing the "politicalization" of decision making in energy resources. As the disparity between outcomes of the market mechanism and outcomes of political decisions grows, we can predict only a growth in uncertainty and instability affecting both developing and developed nations.

The policies we advocate in this chapter tend to emphasize the value of the market mechanism in allocating resources efficiently. We note, however, that an optimal resource allocation will result from market forces only if the distribution of wealth and purchasing power conforms with the goals of the society's social welfare function. We do not propose that a market solution to natural resource allocation problems be carried out in a vacuum. Rather, explicit development goals and policies to implement them must precede any use of the market mechanism to achieve an optimal resource allocation.

An example of the importance of this is the overwhelming emphasis in development policy placed on growth of GNP to the exclusion of other aims until fairly recently. Only in this decade has it been widely realized that maximizing the growth of GNP does not automatically result in gradual improvement of the standard of living of the poor who, in our judgment, should be the ultimate target of development policy.

A redistribution of wealth from the advanced nations to the developing countries is crucial but cannot succeed in improving the lot of the poor unless significant and sometimes drastic changes occur in the social structure and government policies of many developing nations. We do not favor the imposition of Western values on non-Western nations, but the distribution of income and power in many developing countries is highly skewed. It is, therefore, largely up to the developing nation to assure a more equitable distribution of income. International policies, such as the ones described in the previous section, can make a substantial contribution to the achievement of development goals but cannot offset the effects of the ongoing and increasing concentration of wealth in the hands of elites. Rhetoric cannot hide the reality of poverty faced by the majority of developing countries' citizens.

The blame for this must fall in part on the advanced industrial nations of the West and East. Many corrupt, autocratic governments with little will to pursue broad development goals are propped up by either the

Western bloc or the Communist bloc. The arms race fostered by the advanced nations diverts an astounding amount of resources away from productive uses. Each side puts heavy emphasis on maintaining political and ideological bonds with its client countries while the economic and social development of the developing countries becomes an afterthought. Instead of allocating aid on the basis of strategic importance or political alliance, it behooves the advanced nations to channel assistance so as to maximize its impact on the development of the poor in all countries and to make aid contingent on its use for constructive purposes. The most significant mechanism for both improved efficiency and a more equitable redistribution of resources remains the free market. Increasing the possibilities of labor and capital mobility between nations can go a long way toward the establishment of an equitable world order, and it is our conjecture that long after the rhetoric of "North-South" dialogs is forgotten, market mechanisms will survive as the most compelling force in the production of both equity and efficiency.

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