# Economic Growth, Resource Availability, and Environmental Quality

*By* V. KERRY SMITH AND JOHN V. KRUTILLA*

It has now been a decade since *The Limits to Growth* by Donella Meadows et al. helped rekindle economists' interest in the importance of natural resource for economic activities.[1] Today, confidence seems to have replaced concern. At least one prominent economist has explained this change by suggesting that erroneous analysis lay at the heart of any conclusion implying economically important natural resources were growing increasingly scarce.[2] Indeed, current books on the subject such as Julian Simon's *The Ultimate Resource* (1981) offer conclusions that are reminiscent of Harold Barnett and Chandler Morse's classic study *Scarcity and Growth* (1963).

Are these judgements warranted? Has research since 1973 provided answers to the questions derived from theoretical analyses of the relationship between natural resources and the maintenance of material well-being? We think not. While these conclusions ultimately may be judged to be appropriate, such a judgement cannot be made on the basis of the present evidence. In what follows we will develop our reasons for this skepticism, considering first the conventional explanations for how resource stringencies have been avoided and what the past decade's research has added; then, in Section II we discuss what has been missed and why it may be important.

## I. Have We Learned About Economic Responses to Finite Resources?

The available explanations of how increasing natural resource scarcity had been avoided can all be summarized using the reasons Barnett and Morse adduced to explain their finding that the relative prices and "real unit costs" of natural resource commodities had not increased over nearly a hundred years.[3] These were:

1) When higher grade sources of a resource are exhausted, lower grade sources are found in greater abundance. Moreover, the qualitative difference in various stocks diminish with the lowering of the grades of resources.

2) As a specific resource becomes more scarce, the rate of increase in its price tends to be offset by substitution of other resources. All but the most insistent demands for the resource are thereby reduced or eliminated.

3) Price increases also stimulate greater exploration to locate new deposits and provide incentives for a greater degree of recycling.

4) Technical change is directed toward reducing the costs of providing natural resource commodities, either through reduction in the extraction costs from existing deposits, or the introduction of techniques that make previously uneconomic deposits a part of the economic reserves.

In our judgement, the most appropriate general summary of research on the econom-

*Centennial Professor of Economics, Vanderbilt University, Nashville, TN 37235, and Senior Fellow, Quality of the Environment Division, Resources for the Future, respectively. This paper draws upon research supported by the National Science Foundation under NSF-CER-S7715083 and DAR-79-21805.

[1] Of course, the Arab-Israeli war and emergence of OPEC as an effective cartel a year or so after the book's publication provided tangible stimuli to this concern.

[2] In a speech given at the Annual North American Meeting of the International Association of Energy Economists, Hendrik Houthakker observed that "In a strict economic logic, the world will *never* run out of any mineral. Resource scares are merely errors of analysis" (1983, p. 3). Of course, under ideal conditions the price of a depleting mineral will restrict consumption before it is exhausted. This in itself does not assure that in the real world resource stringencies will be met with smooth adjustment.

[3] The Barnett-Morse real unit cost measure corresponds to the inverse of a total factor productivity statistic.

ics of natural resources during the past decade is that it has enhanced the analytical precision with which the preceding explanations can be described. We know, for example, that given a finite resource stock, per capita consumption (with constant population) can be maintained indefinitely provided there is sufficient ability to substitute a producible input, such as capital, for the finite resource. By contrast, in the absence of resource augmenting technical change, if the elasticity of substitution between capital and the natural resource is less than unity, then consumption must ultimately decline to zero. Of course, this pessimistic conclusion can be reversed provided there is a small, positive rate of resource augmenting technical change in the economy's production activities.

Complete and ideal markets will lead to an efficient intertemporal allocation of an exhaustible natural resource (see Partha Dasgupta and Geoffrey Heal, 1979, chs. 6–8). Moreover, under specialized assumptions, noncompetitive market structures, including monopoly and some types of oligopolistic markets, can lead to efficient extraction profiles. However, the assumptions required for this outcome within noncompetitive markets are stringent and, therefore, unlikely to be fulfilled. Nonetheless, departures from either competitive markets or noncompetitive market structures that would lead to efficient intertemporal resource-use profiles are likely to favor excess conservation rather than too-rapid depletion. Within the set of models of noncompetitive behavior, those formats that introduce limited forms of competition do not always imply extraction profiles that fall between the extremes of perfect competition and monopoly. The formulation of these limited competition models affects the role played by strategic behavior in their respective solutions. This role determines the relationship between the extraction profiles selected and those from competitive and monopoly markets. Incomplete markets affecting the risks experienced by individual firms also lead to a tendency for conservation in intertemporal extraction choices. In general, then, private markets (with complete information) are not likely to lead to excessively rapid depletion of natural resources.

This conclusion seems to imply that past theoretical research provides little basis for public sector concern or involvement in judging (or influencing) the availability of natural resources. However, such a judgement can be misleading. In concluding their comprehensive treatment of the economic theory of exhaustible resources, Dasgupta and Heal observed that even if one assumes there exist extensive low grade resource deposits, economists should nonetheless pay particular attention to the processes involved in allocating exhaustible resources for at least two reasons: (a) efficient use of these resources requires consideration of the rate and timing of depletion of each quality level of the resource and concern for the transitions between them; and (b) recognition of the potential for substitution for exhaustible resources is not the same as certain knowledge of the availability of such substitutes. In the presence of uncertainty, prudence requires explicit consideration of the consequences of exhaustion as one of a set of possibilities facing the economy.

Of course, as Barnett-Morse recognized two decades ago, theory is not the only source of insight into the importance of exhaustible resources to the economy. It should be possible to gauge, based on private market transactions, whether the stringency of natural resources has been increasingly a negative factor in the performance of the economy.

Along with the theoretical models addressing the role of natural resources in aggregate economic activity and the performance of private firms in extracting them, this insight has fostered inquiry into the definition and performance of indexes of resource scarcity. This work has generally rejected Barnett and Morse's preferred index and favored some measure of the Hotelling rent as an ideal scarcity index. Unfortunately, as we elaborate more fully in what follows, the practical measurement of these rents has to date eluded resource economists.

## II. What Have We Missed?

We now comment on limitations in the research developed in four areas: the treatment of natural and environmental resources in aggregate models of economic growth; the specification of the role of natural resources in production activities; the available empirical evidence on the viability of Hotelling-type models for describing firm behavior and market outcomes involving natural resources; and attempts to gauge, using both physical and economic criteria, the availability of natural resources.

Nearly all of the formal economic models addressing the importance of exhaustible resources for the maintenance of economic well-being describe decisions in a stylized framework. They characterize how an ideal centralized planning economy, seeking to maximize discounted social utility, would allocate a single exhaustible natural resource optimally. While such models greatly simplify the description of how economic activities use natural resources, in some cases this has been regarded an advantage. That is, to the extent these models permit the fundamental dimensions of a problem to be isolated and these dimensions are found to be important regardless of the nature of the technical details that are present in the real world, then clearly the models have served their purpose.

Unfortunately, recent evidence (see Heal, 1982, and Morton Kamien-Nancy Schwartz, 1982) is calling this premise into question. These models are quite sensitive to the specification of society's objective function and especially to the prospect of one (or more) state variable(s) influencing society's well-being. For example, if the process of extracting or using the exhaustible resource leads to a stock pollutant (i.e., pollution that accumulates in a fashion similar to a capital stock over time) affecting society's well-being, then: the asymptotic behavior of the model's choice variables will be sensitive to initial conditions; there is the prospect for multiple steady-state solutions; and choice variables may exhibit cyclic behavior. These findings imply that the technical details often assumed "away" as part of the development of a simple description of the aggregate use of natural resources *will* matter to the model's results and that these results may not easily generalize. Thus, if these modifications are judged important and relevant, then simplified aggregate models are unlikely to provide a useful basis for policy with exhaustible resources. Unfortunately, little progress has been made (beyond the identification of the problem) to re-address the issue of judging the importance of exhaustible natural resources to the economy as a whole within a framework that incorporates these technical details.

One way of providing such a response involves detailed analyses of the role of natural resources in individual production activities. Prior to 1973, the empirical evidence on the role of natural resources in production activities was almost nonexistent. Since then, there has been an enormous increase in the number of studies (see Ernst Berndt and Barry Field, 1981, for a review of some of this evidence). The available data greatly constrain what can be done. Natural resources are, for example, routinely treated as an aggregate.[4] The pace of introduction of new technologies is not measured. Rather it is assumed to be capable of being approximated by a time trend. In addition, what we can observe is not necessarily relevant to the levels of input usage where resource exhaustion would imply that substitution must take place (i.e., at high capital resource ratios). In these circumstances heat and materials balances are more likely to be an important determinant of the sensitivity of production activities to these constraints.

Both theoretical (Lawrence Lau, 1982) and experimental evidence (Kopp and Smith, 1980, 1983) question the relevance of the available empirical results. Lau's analysis suggests that the conditions for meaningful economywide (or even sectoral) aggregate measures of resources are so stringent that there is little prospect of their being satisfied in actual production activities. Moreover, the experimental results, though much more limited in scope, indicate that aggregation can lead to substantial distortion in the measured substitutions between inputs. These

[4]Recently, Michael Hazilla and Raymond Kopp (1983) have provided the first detailed treatment of resource substitution identifying the constituents of a natural resource aggregate in their neoclassical cost model for the primary metals sector.

experimental findings are equally pessimistic concerning the performance of general indexes of the pace of technological change. Explicit indicators of the introduction of new technologies seem to be required for an accurate description of the effects of these technologies on input usage. Moreover, the available evidence with real world data (see for example, Michael Denny et al., 1981, and Randy Nelson, forthcoming) indicates that there are substantial differences in the description of the factor biases associated with general (i.e., time trend) versus more explicit indicators of new technologies' adoption patterns.

Despite the longstanding interest in the Hotelling model as a description of the behavior of the extractive firm, empirical tests of this model have been quite limited. Heal and Michael Barrow (1979, 1981) found some evidence of arbitrage behavior with both short-term price movements and long-run data. However, the relationships were not consistent with those implied by theory. Smith's (1981) analysis was even less encouraging for the viability of simple forms of the Hotelling framework. Nonetheless, these initial studies can be questioned because of their incomplete data and the corresponding need to use proxy measures for important variables. Recently, Scott Farrow (1983) has substantially improved on the data available for these earlier efforts by using proprietary information from a single resource extraction firm. After conducting the most thorough examination of the Hotelling model's implications to date, his conclusions are similar to those of earlier authors. Thus, at present, we do not have a good explanation for the Hotelling model's poor performance. Of course, Farrow's one firm over a single time period could well be an outlying case. Nonetheless, the empirical relevance of the framework is worthy of serious reconsideration. Our conclusions concerning the role of public policy in responding to the issues posed by Dasgupta and Heal, rely on firms behaving in accordance with some variant of a Hotelling framework.

Interpreting the economic significance of empirical findings is a process that necessarily involves judgement. Theory may suggest the presence of certain regularities (for example, the movements in resource prices net of extraction costs over time should be associated with the rates of return to assets comparable in risk and liquidity to the resource deposits). While the theory can be used to establish the general nature of this association, it relies on assumptions. Interpretation of empirical findings requires judgements on the correspondence of real world processes with these assumptions and the anticipated "strength" of the empirically measured relationships. Some economists might judge any association (however weak) in this case as support for the theory. Others will not. Most economists would probably adhere to the view that the market discipline is strong, and over time with repeated experience, we can expect to observe the predicted economic responses to resource stringencies. Economic agents will react as theory would suggest, though this may only be observable in qualitative terms and may not be evident from short-term observations of behavior. This view is completely consistent with the strategy adopted by Barnett and Morse. Ideally, a Hotelling rent provides the most appropriate signal of the scarcity of a natural resource. These rents are not readily measured directly, and indirect measures rely on the technical assumptions that are often suspect for some of the reasons we have identified. Consequently most current analyses have relied on the relative prices of natural resources to gauge their scarcity. In the most recent of these efforts, Margaret Slade (1982) finds clear evidence of increasing relative prices for eleven of the twelve minerals she considers over the period 1870 to 1978. However, the pattern is one of initially declining relative prices with an upturn that occurs primarily in the first and second quarters of the twentieth century, depending on the mineral.

Thus, even the empirical record we have available which largely reflects the private costs of obtaining natural resources, does not support dismissing resource scarcity. If we add to this the social costs of pollution (including both "static" externalities and stock pollutants) then confident judgements on the long-term maintenance of economic well-being with a constant or growing population, in the presence of finite natural and environmental resources, seem unwarranted based on what we know today.

## REFERENCES


**Barnett, Harold T. and Morse, Chandler,** *Scarcity and Growth: The Economics of Natural Resource Availability,* Baltimore: Johns Hopkins University, 1963.

**Berndt, Ernst R. and Field, Barry C.,** *Modeling and Measuring Natural Resource Substitution,* Cambridge: MIT Press, 1981.

**Dasgupta, Partha S. and Heal, Geoffrey M.,** *Economic Theory and Exhaustible Resources,* Cambridge: Cambridge University Press, 1979.

**Denny, Michael et al.,** "Estimating the Effects of Diffusion of Technological Innovations in Telecommunications: The Production Structure of Bell Canada," *Canadian Journal of Economics,* February 1981, *14,* 24–43.

**Farrow, Scott,** "An Empirical Method and Case Study to Test the Economic Efficiency of Extraction from a Stock Resource," Working Paper 83-18, School of Urban and Public Affairs, Carnegie-Mellon University, May 1983.

**Hazilla, Michael and Kopp, Raymond J.,** "A Factor Demand Model for Strategic Nonfuel Minerals in the Primary Metals Sector," Quality of the Environment Division, Resources for the Future, November 1983.

**Heal, Geoffrey M.,** "The Use of Common Property Resources," in V. K. Smith and J. V. Krutilla, eds., *Explorations in Natural Resource Economics,* Baltimore: Johns Hopkins University, 1982, ch. 3.

______ **and Barrow, Michael M.,** "The Relationship Between Interest Rates and Metal Price Movements," *Review of Economic Studies,* January 1979, *47,* 161–82.

______ **and** ______, "Empirical Investigation of the Long-Term Movement of Resource Prices: A Preliminary Report," *Economics Letters,* No. 1, 1981, *7,* 95–103.

**Houthakker, Hendrik, S.,** "Whatever Happened to the Energy Crisis?," *Energy Journal,* April 1983, *4,* 1–8.

**Kamien, Morton I. and Schwartz, Nancy, L.,** "The Role of Common Property Resources in Optimal Planning Models With Exhaustible Resources," in V. K. Smith and J. V. Krutilla, eds., *Explorations in Natural Resource Economics,* Baltimore: Johns Hopkins University, 1982, ch. 2.

**Kopp, Raymond J. and Smith, V. Kerry,** "Measuring Factor Substitution with Neoclassical Models: An Experimental Evaluation," *Bell Journal of Economics,* Autumn 1980, *11,* 631–55.

______ **and** ______, "Neoclassical Modeling of Nonneutral Technological Change: An Experimental Appraisal," *Scandinavian Journal of Economics,* No. 2, 1983, *85,* 127–46.

**Lau, Lawrence J.,** "The Measurement of Raw Materials Inputs," in V. K. Smith and J. V. Krutilla, eds., *Explorations in Natural Resource Economics,* Baltimore: Johns Hopkins University, 1982, ch. 6.

**Meadows, Donella H. et al.,** *The Limits to Growth,* New York: Universe Books, 1972.

**Nelson, Randy,** "Regulation, Capital Vintage and Technical Change in the Electric Utility Industry," *Review of Economics and Statistics,* forthcoming.

**Simon, Julian,** *The Ultimate Resource,* Princeton: Princeton University Press, 1981.

**Slade, Margaret E.,** "Trends in Natural Resource Commodity Prices: An Analysis of the Time Domain," *Journal of Environmental Economics and Management,* June 1982, *9,* 122–37.

**Smith, V. Kerry,** "The Empirical Relevance of Hotelling's Model for Natural Resources," *Resources and Energy,* No. 2, 1981, *3,* 105–17.