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THE SCARCITY OF RESOURCE ECONOMICS

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"Even though it may be impossible to mine to a depth of one mile at every point in the Earth's crust, by the time A.D. 100,000,000 I am sure we will think of something."

Wilfred Beckerman (1972)

To question the long-run adequacy of natural resources is to ponder the future of the human race. Answers to all other economic questions hinge on this ultimate ponderable. Economists have contributed to the framing and pursuit of this overarching question. Ultimate answers, of course, are not in the offing, and so one might expect economists to condition their analyses and proffer specific resource use and development prescriptions with some modesty and attention to the larger, long-run question. But in the arena of resource and development policy, humility and conditional prescriptions have been evaded through incomplete, blindly optimistic, and -- too frequently -- flippant, arguments as to why resources over the long run are not of special concern. This essay addresses the incongruous role economists have played -- as theorists, empiricists, and participants in the policy debate -- with respect to the ultimate ponderable.

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The only major economic inquiry of resource scarcity was undertaken by Barnett and Morse (1963) more than two decades ago. They argued that if resources were becoming more scarce, more capital and labor would be necessary over time to extract resources. Their empirical analysis clearly indicated that this was not the case from the late 19th century through 1957 except in the case of forestry. Their work reframed the question and initiated empirical analysis. It was a good start that raised an abundance of issues. The scarcity of resource economics, to a large extent, stems from the inappropriate reception of this study. We should have accepted it as an exciting first analysis rife with beguiling questions for further research.

Instead, we accepted it as sufficient evidence that resources were not scarce over the long-run. Although good work has been undertaken since, there has not been another major conceptual and empirical analysis. Our predisposition to optimistic conclusions was demonstrated by our vociferous attack by economists on the 'Limits to Growth' model developed by Meadows et.al. (1972) and similar attack on the Global 2000 report (U.S. Council on Environmental Quality and U.S. Department of State, 1980) The optimists do not totally dismiss the fears of unbridled growth. But because their arguments have not been openly questioned within the discipline and have been quoted widely beyond, they have set the image of the profession as a whole.

This image does not convey a picture of modest scientists testing the null hypothesis from every angle before cautiously suggesting the nature of truth. More important, the possibility of long-run resource scarcity raises theoretical and methodological issues. Most of these issues were identified in one form or another by Barnett and Morse but were deftly skirted by them and have been almost ignored since. This paper elaborates on these conceptual difficulties and related measurement problems.

ON THE NATURE OF THE QUESTION.

As neoclassical economists, we frequently define our field as the science of optimally allocating scarce resources to alternative uses. Indeed, without constraints or 'scarcities', there is no allocation or economic problem. Our empirical research and conceptual debate have addressed whether resources will be more or less accessible in the future if we proceed along our present course. This is not a typical economic question. Our theoretical framework is designed to answer how scarce resources can best be allocated. Can the framework be turned on its tail to determine from how resources are allocated whether they are scarce? In the next section I argue that it cannot. Here I simply want to argue that the scarcity question, as framed to date, has diverted us from the real and fuller task before us.

When the neoclassical model is extended into the future in its most general form, future generations should hold rights to resources just as current generations do. Now the 'should' in the foregoing sentence is a little conspicuous in a supposedly objective essay. But if the allocation of resources between uses over time is to be comparable to the allocation between uses over groups and regions at a point in time, then future generations must be treated more or less equally. This is not simply a question of parallel treatment or of equity, both of which are important. Rather, it is a requirement for the competitive conditions which our generalized model assumes. Given the essential nature of air, water, soil, and materials from which things can be made and services derived competitive conditions can only prevail if future generations have rights to resources. If only the current generation holds rights, for example, it is Pareto optimal for the current generation to use up all of the resources. This outcome violates the assumptions upon which the whole model is built. Alternatively, since individuals several generations in the future could never trade their labor with current generations, resources are all that they could even hypothetically exchange.

Within this general model where future generations hold rights to resources, allocation over time entails exchange between generations. If future generations could, they might choose to trade their rights to some natural resources for other natural resources held by current generations, or for more industrial capital, works of art, improved technologies, or productive environmental transformations. In a world of perfect knowledge, there would be one intergenerational exchange that simultaneously determined all resource prices and rates of interest over time. In a world of surprise, exchanges would occur repeatedly as a fine tuning process.

This imaginary world without surprise or resources has been formally modeled. Perhaps the contemplation of resources induces such realism in our mathematical economists that the brink comes into view, preventing the final step. And yet the numerous models of resource allocation over time based on the Hotelling model -- with the current generation of owners of resources maximizing their return such that their royalties rise at a rate of interest determined by the current generation's decisions in the capital market -- are also unrealistic. Note first that royalties and interest rates in the generalized model would be affected by how resource rights were distributed between generations and by differences in taste and technology over time. As individuals, people do dedicate property to their own future generations and occasionally to future generations in general. As a society we have instructed every state and federal agency with control over public resources to act as an agent for future generations. What then is the significance of our models to date? What do they tell us about efficiency and how do they provide policy guidance?

Our theory in its most general form presumes that future generations have rights to resources. While future generations will never be able to bargain with current generations, their interests can be represented to a considerable extent by general public policies and the specific decisions made by public agencies. While some resource allocation models have been constructed around the assumption of a central planner, too little economic thought has been dedicated to the design of institutions which reflect the questions raised by our economic models. Meanwhile, the economists who are most outspoken in the policy debate are arguing for less government involvement per se rather than government involvement consistent with the assumptions of theory or that offsets their weaknesses.

If resources are not scarce in the long-run, these theoretical issues and questions of appropriate institutions are less critical. But they do not disappear. The empirical findings do not indicate that resources will be costless in the future; they simply indicate that the cost will be less or at least no greater than today. Accepting these conclusions as evidence that the long-run does not need be considered is a far cry from our usual passion for optimality. Perhaps resources should be even cheaper for future generations, or perhaps we should use resources even faster now, increase our investment in research and the development of resource extraction technologies, and let future generations apply even better techniques to even lower grade deposits at costs that may be higher or lower. Alternatively, if resources will be less scarce in the long-run, we should be asking whether we are optimally making the long-run shorter.

ON THE USE OF ECONOMIC VERSUS PHYSICAL INDICATORS.

> "The notion that such limits exist gains plausibility from the use of physical terms to indicate relevant quantities -- acres of arable land, tons of chrome ore reserves -- implicitly invoking the physical finiteness of the earth as the ultimate bound. But this is fundamentally misleading. Resources are properly measured in economic, not physical, terms."
>
> Carl Kaysen (1972)

The economic literature on scarcity has consistently argued that whether resources are becoming scarce can only be judged by looking at economic indicators such as resource prices, extraction costs, or royalties. Scarcity entails the interplay of many factors including: 1) the abundance of resources of different qualities, 2) extraction technology, 3) the cost of capital, 4) the cost of labor, 5) knowledge of resources, 6) the behavior of extractive industries, and 7) the demand for resource products. Only economic indicators signal the interplay of these factors. The most compelling argument for using economic indicators addresses the interdependence between just the first two of these factors. Resource quality cannot be defined independently of technology.

Our arguments for economic indicators, however, assume that economic reasoning is reversible. Can an argument developed to determine optimal behavior for the allocation of scarce resources be used to analyze behavior to determine whether resources are scarce? The answer is yes, but only if behavior is optimal. Unfortunately optimal behavior is undefined unless resources are scarce and is extremely unlikely except in the case where resource owners, including decision-makers in public agencies, already know how scarce resources really are. If they already knew this, we should simply ask them. But of course if we knew they knew, we would not be concerned with the issue.

Let's pursue this in greater detail. In a Ricardian world where the industry knows which resources can be extracted most cheaply and behaves either under competitive conditions or as a monopolist maximizing the present value of its rents, an increase in resource extraction costs would indicate scarcity. If the industry has this knowledge and behaves accordingly, a decrease in costs might indicate that technology is improving faster over time than resource quality is decreasing. This is the primary explanation given by Barnett and Morse and others for observed declines in extraction costs.

But extraction costs could also decline because the industry does not know where the cheapest resources are and does not extract them first. Indeed, this is precisely the argument given by Barger and Schurr (1944) for not considering Ricardian increases in extraction costs in their study of productivity in the mineral industries.

> One of the outstanding characteristics of the history of oil and gas exploitation in this country has been the continual migration to new flush production areas... The data indicate not only that these new fields have replaced fields of declining productivity, but that successive shifts in production have also been accompanied by higher levels of productivity per well than obtained in older fields.
>
> Barger and Schurr (p. 178-9)

If the industry does not know which deposits are least costly and its behavior is accordingly non-Ricardian, resource extraction costs do not indicate anything about how technology is offsetting declining quality. Henry Carey originally argued that history was proving Ricardo wrong. The extent to which Ricardo or Carey are correct can be assessed, at least in so far as quality and technology are separable, by looking directly at the physical quality of resources being exploited.

A similar problem concerning knowledge and behavior would arise if we could observe changes in royalties over time. If resource owners knew the total stocks of resources of different qualities and optimized a la Harold Hotelling (1931), royalties for any given quality would rise at the rate of interest. But if resource owners knew the total stocks of each quality resource, we could just ask them about scarcity. Indeed, we would only have to ask one of them!

Both the methodology stemming from the model of Ricardo and the methodology stemming from Hotelling assume widespread knowledge of the answer we seek. Since prices should equal costs plus royalties, looking to resource prices as an indicator of scarcity combines the knowledge and behavioral assumptions of both Ricardo and Hotelling. We must conclude that if our economic indicators give us correct signals, then resource owners are already fully informed about scarcity and optimizing. If resource owners are not fully informed and optimizing, the indicators have no meaning. In either case, no policy change can logically follow.

This circularity in our reasoning cannot be overstressed. Economists have been concerned about the scarcity of resources because of the public's concern over the adequacy of knowledge and the appropriateness of behavior of both private and public resource allocators. Indicators which assume that the knowledge of decision-makers is complete and behavior is appropriate generate neither additional knowledge nor policy guidance. The circle draws tighter as we realize that many of the remaining resources -- especially fossil fuels, trees, and wilderness -- are mainly located on public lands and that we are effectively analyzing and exploring the public's concern with the knowledge and behavior of public agencies.

Tight little tautologies are broken by expanding the model to include more information ... thereby creating a bigger tautology. We need not be naive about the nature of knowledge. And so I am not advocating that we throw out what we have done but am merely pointing out how ridiculous our little circle looks by itself. I am arguing both for doing what we have done better and for combining it with, rather than juxtaposing it with, the approaches of the natural sciences.

MEASUREMENT PROBLEMS

Doing what we have done better entails confronting some real measurement problems. Analyses of capital and labor per unit of output have been limited to the capital owned by the extractive firm and labor hired by the firm, ignoring the capital and labor embedded in purchased inputs. Ricardo argued that a farmer could offset the lower productivity of poorer quality land by simply employing more labor and capital per unit area. History, however, clearly shows that productivity has been increased through purchased inputs.

Expenditures on purchased inputs such as fuel, electricity, water, fertilizers, pesticides, application and harvesting services, and information provision -- the inputs associated with modern agriculture -- now rival expenditures on wages for hired labor and interest and depreciation on capital owned directly by the farmer. Increasingly, farm owners neither hire nor own. They contract for management, obtain the services of capital used on the farm indirectly through contracts for inputs and services, and employ contract labor as well.

Purchased inputs, especially energy, are increasingly important in the mineral industries. The mineral industries have also found it advantageous to purchase labor and capital through input and service contracts rather than hire labor or own capital themselves. Purchased inputs -- themselves consisting of labor, capital and natural resources -- link agriculture and mining with every significant sector of the economy and with the far corners of the earth. In part, there are new inputs Ricardo never dreamed of; in part, "round aboutness" has increased and made the firm's own capital and hired labor much less important.

As a second step to improving our analyses, we should give more attention to the determination of the cost of capital. Capital is not easily measured under the best of circumstances. It is especially difficult when capital largely consists of exploration knowledge and holes in the ground -- both of which are treated as expenses for tax purposes and confuse the data thereafter; when diverse but changing tax policies are available to resource industries; when the rate of interest varies -- from less than zero to more than ten percent during the last decade alone; and when the return to resource extraction capital fluctuates even more widely than have resource prices in international markets.

Much of the interest in looking at resource extraction prices directly rather than extraction costs stems from the difficulties of measuring capital. Unfortunately, this approach simply hides the capital measurement problem. Resource extraction prices still reflect variations in interest rates, tax policies, and short run fluctuations in demand for capital rather than the scarcity of resources.

Acknowledging the difficulties of economic measurement and the complexities of the interactions between economic, technological, and resource factors should lead us to look at changes in natural resources themselves, changes in technology that can be directly observed, and changes in labor, capital and purchased inputs together in order to get better insights into the whole interacting system. We should be integrating our findings with those of natural scientists and students of technological change rather than juxtaposing our results.

ON THE BOUNDARIES OF THE ANALYSIS

> In the fuel area, for example, consumers have choices among bituminous coal, anthracite coal, manufactured gas, natural gas, fuel oil, and electricity. Any onset of relative scarcity in one fuel would swing consumers to the less scarce substitutes. (p.130)
>
> ... international trade ... vastly enlarges the possible scope of substitutions ... it dilutes the impact of scarcity by distributing it over a wider area than the national economy under observation. (p.134)
>
> Barnett and Morse (1963)

Several difficulties with our analyses can be categorized as 'boundary problems'. Drawing lines, separating the important from the unimportant, simplifies analysis. Dividing the problem up can be especially helpful in getting started. On the other hand, at some point we must ask whether the divisions have been made appropriately. Given the nature and importance of long-run resource scarcity, it is clear that our analyses should both be extended beyond the existing boundaries and should also be reformulated within the boundaries characteristic of other models. However, the scarcity of resource economics is also clearly reflected in how we have addressed our boundaries.

The idea that substitution, for example, mitigates resource scarcity is a "shifty" boundary game. The problem of scarcity is initially posed with respect to one resource or region and then the boundaries are removed so that other resources can substitute or other regions come into the analysis. Clearly, however, if aluminum and copper are both good conductors of electricity, then an analysis of the scarcity of conductors of electricity must be carried out for both copper and aluminum together. The fact that aluminum is a substitute for copper says nothing about the scarcity of the combination of the two though it says a lot about the appropriate boundaries of the analysis. Similarly, substituting to imported materials may temporarily relieve domestic scarcities but simultaneously raises the broader issue of global scarcity. We damn ourselves as logicians when we argue that not having defined our boundaries appropriately supports our conclusions that resources are less likely to become scarce.

But as in the preceding section, I am persuaded that we need more economic analysis, more studies of elasticities of substitution between resources, not less. However, we should use these studies to derive insights into how the boundaries of our analyses should be constructed rather than as evidence of scarcity.

Our analyses need to extend into the realm of how, as well as whether, technology is outpacing the niggardliness of nature. The costs of developing and adjusting to new technologies need to be addressed. Barnett and Morse at least acknowledged this question in their Chapter 11 entitled 'Self-Generating Technological Change'; but no empirical data are provided or cited. An analysis of the historical costs of generating technological progress would have given considerable insight. The only mention of the these costs occur in a footnote:

> It is true that sociotechnical progress is not costless, but it is also doubtful that its cost can confidently be assigned a rising trend in either the near or distant future. It is also relevant that research is both labor intensive and enjoyable. There is therefore, some question whether an increasing aggregate outlay on it should fully be regarded as a social cost. People need some form of activity... (p. 244)

Barnett and Morse were writing at a time of considerable technological optimism. The literature on growth accounting and the economics of technology was just emerging. It is more difficult to explain the absence of empirical work on the technological costs of offsetting resource scarcity since Barnett and Morse. If our framework of thinking about declining resource availability primarily leads us to technological change as the hope for the future, then we must cross this boundary and undertake empirical work on the process of technological change. There are real economic costs of generating, adapting to, and coping with the social and environmental side effects of new technologies in terms of schooling, research and development, and institutional change. Though these costs are increasingly discussed in the scientific community, we have yet to attempt an empirical analysis that relates these costs to offsetting resource scarcity.

This boundary will not be easily crossed. Some technologies have been developed specifically for resource extraction industries. In these instances, the research and development costs can be weighed against the benefits of reduced resource scarcity. Much of the technological change, however, is embodied in the quality of the capital, labor, and inputs used within the industry. The costs of developing embodied technological change are much more difficult to assign to the extractive industry. The difficulties of such an exercise for each of the extractive industries suggests that a macro model is needed.

New technologies and the exploitation of lower quality resources have increased the occurence of non-market interdependencies. Much has been written on the unintended consequences of technologies developed within increasingly narrowly defined disciplines. Similarly, there is a vast literature on the environmental consequences of mining marginal ores and farming marginal lands. Separability or divisibility and resource quality go hand and hand. High quality ores have lower entropy. They are less connected to other minerals and can be mined with less waste, less impact on the environment, and with less energy and other inputs introduced from other systems. High quality agricultural land doesn't erode easily and doesn't need water collected and delivered from afar. This increased non-market interconnectedness as we use 'better' technologies and poorer resources necessitates non-market feedbacks: political activity by affected individuals and communities; decisions by congressional bodies; monitoring, compensation, regulation, and enforcement by social and environmental agencies; and research and training in universities.

We have made substantial conceptual progress and undertaken numerous empirical analyses of environmental costs. We have begun to ponder the political economy of new technologies, environmental transformation, and institutional response. But to too great of an extent we have chased after popular issues: wilderness recreation, pesticide use, soil erosion, and biological diversity. We have not synthesized our research into coherent images of development and the environment and tied these into the issues of long-run resource scarcity.

The costs of developing and adapting to technical change are diffuse and interconnected. Many of these costs cannot be assigned to specific resources. Furthermore, developing and adapting to technology have restructured what is a benefit and what a cost. Consider the trend in higher education. A century ago a college education was a sublime experience for the fortunate few for whom the spoils of progress were sufficient that they did not have to work. Today, a college education is expected for about 40% of new positions and only a few graduate of our students at our best universities can be described as elated. Extrapolating from the sublime to the ridiculous, a log linear regression on data over the past century (with an R square of 0.98) indicates that one hundred percent of the working-age (18-65 years) population will be attending school by the year 2062. The role of education has clearly changed; more and more time is needed for formal training to continually develop, use, monitor, and control the unintended consequences of new technologies used to exploit marginal resources; and the trend cannot continue.

Boundaries, given the intricacies and importance of long run resource use questions, will always be difficult to defend. But we are so far from defensible boundaries now that our efforts will be best spent extending the limits of our current models and developing alternative models with different boundaries.

CONCLUSIONS.

I have argued that to question the long-run scarcity of resources is a peculiar question within economics which, as framed to date, has detracted us from the real questions of intergenerational allocation. I have argued that our logic has fallen short. The scarcity of resources cannot be determined from behavior unless resource allocators are already fully informed of scarcity and are behaving optimally. And I have argued that we have prematurely terminated our determinations. We have argued that technological change offsets resource scarcity without investigating how or at what cost. We have investigated numerous categories of unintended effects of exploiting marginal resources with new technologies without linking these studies to the question of resource scarcity and long-run development. Our false search for a simple indicator of scarcity has dissuaded us from a thorough investigation.

I strongly believe that the ultimate imponderable will not succumb to the deterministic methods of neoclassical economics. But it seems to me that those who believe more strongly in these methods and have been drawing rather precise conclusions independently of the ultimate ponderable are obligated to build logical models and pursue the costs of technology and the linkages with environmental quality. I openly bait the hook, look forward to acquiring insights from whatever logical quantitative analyses might uncover, and trust that, having pursued the the difficulties of determining the future with logical arguments that extend in all directions, the quantifiers will acknowledge the limits of their methodology.

For ultimately we will never know the future from the past. Our environment, technology, social order, and knowledge are coevolving. Both new components and new relationships keep arising over time. For this reason, we should also ponder resource strategies that assume incomplete knowledge. Ciriacy von Wantrup's (1952) arguments for the use of 'Safe Minimum Standards' for renewable resources addresses our inability to predict both the behavior of environmental systems and the unfolding of the future. Richard Day's (1978) plea for adaptive approaches to resource use over time should be considered further. Analyses of our predicament from entropic (Georgescu-Roegen, 1971) and evolutionary perspectives (Boulding, 1978; Norgaard, 1984) also provide insights. Institutional economists have also shown renewed interest in resources and social development (Swaney, 1985). Given the incompleteness of our knowledge, elements of Daly's (1973) 'Steady-State' strategy are as defensible as blindly proceeding. We should be more adept with and open to the information generated by alternative models, in short, more pluralistic.

Resource economics would hardly exist if it were not for its contributions to the pursuit of the ultimate ponderable. And in fact for the past two decades, with the exception of some excellent work on energy after the crisis, it has hardly existed. Fallacious arguments have been allowed to stand, measurement problems that tantalize other subdisciplines have been ignored, linkages to technology and environmental spillovers have yet to be made, and the institutional implications of our arguments and findings have not been pursued. And last, but by no means least irksome, the only economists who are vocal in the policy arena are the retainers of our unfettered market heritage.

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