Scarcity and Growth Reconsidered

Edited by V. Kerry Smith

Published for Resources for the Future
by The Johns Hopkins University Press
Baltimore and London

Manufactured in the United States of America

Library of Congress Catalog Card Number 78-27236
ISBN 0–8018–2232–7
ISBN 0–8018–2233–5 (pbk.)
Library of Congress Cataloging in Publication data will be found on the last printed page of this book.

Contributors

HAROLD J. BARNETT
Professor, Department of Economics, Washington University, St. Louis, Missouri

DONALD A. BROBST
Chief, Eastern Mineral Resources Branch, U.S. Geological Survey, Reston, Virginia

GARDNER M. BROWN, JR.
Professor, Department of Economics, University of Washington, Seattle, Washington

HERMAN E. DALY
Professor, Department of Economics, Louisiana State University, Baton Rouge, Louisiana

BARRY C. FIELD
Associate Professor, Department of Economics, University of Miami, Coral Gables, Florida

ANTHONY C. FISHER
Professor, Energy and Resource Program and Department of Economics, University of California, Berkeley, California

NICHOLAS GEORGESCU-ROEGEN
Distinguished Professor of Economics Emeritus, Vanderbilt University, Nashville, Tennessee

H. E. GOELLER
Senior Engineer, Oak Ridge National Laboratory, Oak Ridge, Tennessee

BRUCE M. HANNON
Director, Energy Research Group, Office of Vice Chancellor for Research, University of Illinois, Urbana, Illinois

JOHN V. KRUTILLA
Senior Fellow, Resources for the Future, Washington, D.C.

V. KERRY SMITH
Fellow, Resources for the Future, Washington, D.C.

JOSEPH E. STIGLITZ
Professor, All Souls College, Oxford University, Oxford, England

Resources for the Future, Inc.
1755 Massachusetts Avenue, N.W., Washington, D.C. 20036

Resources for the Future is a nonprofit organization for research and education in the development, conservation, and use of natural resources and the improvement of the quality of the environment. It was established in 1952 with the cooperation of the Ford Foundation. Grants for research are accepted from government and private sources only if they meet the conditions of a policy established by the Board of Directors of Resources for the Future. The policy states that RFF shall be solely responsible for the conduct of the research and free to make the research results available to the public. Part of the work of Resources for the Future is carried out by its resident staff; part is supported by grants to universities and other nonprofit organizations. Unless otherwise stated, interpretations and conclusions in RFF publications are those of the authors; the organization takes responsibility for the selection of significant subjects for study, the competence of the researchers, and their freedom of inquiry. RFF support was provided by the Ford Foundation.

This work was begun in RFF's natural environments program and completed within the quality of the environment division, Walter O. Spofford, Jr., director. It was funded by Resources for the Future, the Ford Foundation, and the John Simon Guggenheim Memorial Foundation. V. Kerry Smith is a Senior Fellow at Resources for the Future. The book was edited by Ruth B. Haas. Charts were drawn by Federal Graphics.

RFF editors: Joan R. Tron, Ruth B. Haas, Jo Hinkel, Sally A. Skillings

Contents

Foreword

In recent years, a renewed interest has emerged in the availability of natural resources for continued material well-being and economic growth. Sharply rising energy costs, increased prices of natural resources generally, widening popular support for a clean environment and improved health, the current uncertain state of the economy, and a genuine concern for the future have all contributed to the public's recent questioning of whether or not it will be possible to provide and maintain a reasonably high material standard of living for all while ensuring that the overall quality of life remains unchanged.

Despite a history of research in this area and the current resurgence of this activity, a number of fundamental issues concerning natural resource scarcity remain both controversial and unresolved to this day. While the main concern involves the continued erosion of a finite natural resource base and whether or not technological improvements can keep pace with rapidly increasing demands for goods and services, it does not represent the whole story. A spectrum of other related problems confronts our society as well. An increasingly important set involves the detrimental side effects of production technology. These byproducts range from despoiled landscapes and pollution to toxic materials in the environment. Although some effects are limited to local degradation, others are more global in character and may even threaten natural systems which are essential for the support of life. The latter, more severe, impacts appear to be associated with some of the new technologies. Material well-being and the quality of the natural environment are integrally related, and policies established to address one will ultimately have an impact on the other. Clearly, the provision of goods and services and the uses and quality of the natural environment must be considered as a whole, and tradeoffs will be necessary.

The conference upon which this volume is based addressed some of these issues by bringing together in a single forum a wide range of professional opinion covering three principal areas of current research on resource availability.

In the first area, dealing with economic modeling of the role of natural resources, Joseph Stiglitz presents an overview of the neoclassical perspective on the contribution of natural resources and stresses that for the most part natural resources are not sufficiently different from other inputs to production activities to require amendments in this type of analysis. Herman Daly and Nicholas Georgescu-Roegen disagree completely with Stiglitz. They maintain that physical laws imply that natural resources are essential for the maintenance of human well-being and therefore conventional economic models must be substantially amended to reflect this.

In the section on geological appraisals of the limits of resource availability, the second area of research, H. E. Goeller evaluates resource availability from the perspective of several hundred years, ignoring any of the impediments—economic, legal, and political—that might prevent the realization of these ultimate prospects. By contrast, Donald Brobst points out that it is essential to both recognize and take account of these impediments in any assessment of the physical quantities of resources available for future use by mankind.

In the third section, on economic measures of resource scarcity, Gardner Brown and Barry Field question past measures of resource scarcity and offer some guidance as to how one might approach the problem under idealized conditions. While the data necessary for carrying out their suggestions currently do not exist, the authors do suggest ways in which construction of these more desirable measures might be undertaken. On the other hand, Harold Barnett maintains that the same tools and measures that were used in his and Chandler Morse's now classical study of resource scarcity published by Resources for the Future almost two decades ago (*Scarcity and Growth: The Economics of Natural Resource Availability,* 1963), are still capable of being used today. Moreover, Barnett uses a wide array of more recent international data with these measures to develop the original thesis of *Scarcity and Growth* that natural resources, with the possible exception of timber, do not appear to be becoming increasingly scarce. Fisher's paper reviews both of these arguments and provides a link between cost, price, and rent-based measures of resource scarcity.

If the continuing debate over natural resource adequacy is to be finally resolved, the underpinnings of each position's arguments must be understood. The literature has been dominated for too long by the rhetoric from each school without substantial progress toward an appreciation of the reasoning responsible for their conclusions. The objective of this volume is to identify the sources of the differences in each group's arguments and, in so doing to direct attention to avenues for future research.

Indeed, the conference has already led to a program of research at RFF supported by the National Science Foundation and the Electric Power Research Institute. It is our sincere hope that this first product of this program at RFF will stimulate research that will both enhance our understanding of the issues surrounding judgments on natural resource adequacy and contribute to the public policy initiatives in the area.

March 1979

Walter O. Spofford, Jr.
Director, Quality of the
Environment Division

Stiglitz, page 37 in isolation

tions and to suggest what kind of evidence might resolve them. There are, of course, important policy issues in which one's position inevitably depends on the answers to these unresolved questions. What is one to do until these are obtained? Some preliminary thoughts on this question constitute the third objective of this paper.[1] However, there are a few distinctions which will help clarify the scope of my subject.

First, it is obvious that continued exponential growth is impossible, if only because eventually, at a strictly positive growth rate, the mass of people would exceed the mass of the earth. I am not concerned here with such very long-run problems. (Similarly, I am not concerned with long-run problems arising from the laws of thermodynamics.) I am concerned here with the more immediate future.

Second, it is important to distinguish between natural resources which can be treated as *private goods,* such as coal, oil, and iron, and those which are basically *public goods,*[2] such as air and water. Whether public intervention is required in the allocation of the former is at least a moot question about which we shall have much to say later; but in the case of the public goods, appropriate allocation inevitably will require some type of government action. There is a third category of natural resources—those which are normally publicly managed but which are really private goods, as for example, forests. A clear distinction has to be made between these resources and true public goods.

Although it is often clear whether the good is a public good, a private good, or a publicly provided private good, there are some ambiguous cases. The fish in a lake are often thought of as a public good although fish caught by one individual may reduce the amount available to others, and property rights for fishing in a lake could be given to an individual. The appropriate method of organizing the allocation of such goods is one of the more important issues in the economics of natural resources.

Third, I have not yet defined what I mean by natural resources. Presumably a natural resource is any commodity or factor which is provided by nature and not produced, or producible, by man. Although such a definition is not very precise, it will suffice for our purposes. (Most of what we think of as natural resources, such as oil, require human activity

[1] I was asked by RFF to present a survey of the neoclassical view of the problem of the scarcity of natural resources. I have chosen to provide an "interpretive review" rather than an exhaustive review of the literature; for the latter, see Peterson and Fisher [1].

[2] The distinction I have in mind is based on the traditional definition of public goods: those involving difficulties in appropriability and those in which the marginal cost of an extra person enjoying the benefits of the good is zero. Thus coal can be marketed just like any other produced good and if one person burns a unit of coal, it is not available for use by any other individual. It would be hard to charge for the use of air.

solution may be inequitable. We shall have a few words to say on this in section VI.

III
The Viability Issue: Is Sustained Growth Possible in the Presence of Exhaustible Natural Resources?

Any analysis of the economics of natural resources should, I think, begin with the question of why the scarcity of natural resources is different from the scarcity of any other factor of production (or any commodity, for that matter). The layman's response to this question would probably be that if we run out of corn we can produce more corn. With natural resources there is simply nothing we can do. This, of course, is not a completely satisfactory answer.

For there to be a meaningful natural resource problem, several conditions need to be satisfied:

1. A resource must be in limited supply relative to current usage rates; thus, if there are several hundred years' worth of reserves[3] of some natural resource, there is, at most, a very long-run problem.

2. It must be nonrenewable and nonrecyclable. Natural resources (such as metals) do not disappear after they are used; rather, they become available for reuse. Only that part which is not renewable—or more precisely, that part, for which the cost of renewing to a marketable state will exceed the market prices—is exhausted in economic terms. The net utilization rate of natural resources may thus be considerably less than the gross.

3. It must be essential, that is, it must be required for production (or consumption).

4. There cannot exist substitutes for it; for example, capital cannot be substituted for it in production.

5. It must be impossible to improve the efficiency with which the resource is utilized beyond some point; for there to be an immediate problem, we must be near that point. Technical change which increases the productivity of a resource is referred to as "resource-augmenting technical progress," since its effect is equivalent to an increase in the stock of the resource.

[3] I have used the term "reserves" in the casual way that it is usually used; it is important to observe, however, that the natural economic definition of reserves is not that conventionally employed, for example, by geologists. Since the amount of a natural resource which can be extracted depends on the expenditure on extraction, reserves is an economic, not a geological concept. The appropriate definition entails an analysis of how much can be extracted, not at current market prices, but at market prices that will prevail as the supply becomes smaller; there is some presumption that this may be significantly larger than that implied by the conventional definitions.

6. It must be impossible to develop a substitute for the given resource.

Several of the recent articles on the economics of natural resources have attempted to make more precise the conditions under which it is possible to sustain a constant per capita consumption [2–4]. Most of these conditions are fairly intuitive.

The assumption that the natural resource is essential implies that the isoquants (between the natural resource and the other produced factors of production) never hit the axis of the produced factor. (See figures 2-1 to 2-7 where the other factor of production is taken to be capital. In figure 2-1 natural resources are essential; in figure 2-2 natural resources are not essential.) Note that what is crucial for the question of whether the natural resource is essential is not any property of the production (isoquant) function when there is a large input of natural resources. If the isoquant has relatively little curvature (i.e., is flat, as in figure 2-3) we might be tempted to extrapolate the curve and to infer that the natural resource is nonessential, but the curvature could easily be changed as the resource input becomes small, so that although at present it is easy to substitute, say capital, for resources, eventually it becomes quite difficult. Conversely, it may be quite difficult to substitute now (the isoquant can still be quite curved) but when the resources become sufficiently scarce, we may be able to switch to a completely different technology, for which the substitution is relatively easy, and the isoquant does hit the axis (figure 2-4).

The concept that economists usually use for measuring the ease of substitution is the "elasticity of substitution," which gives the percentage change in the input ratio (say, of natural resources to capital) which would be engendered by a percentage change in the relative price of capital to natural resources.[4] If a 1 percent change in relative prices does not give rise to a change in factor inputs (figure 2-5), the elasticity of substitution is zero; if we discontinue using the factor whose price has risen, we say that the elasticity is infinite. The central case where a 1 percent change in factor prices gives rise to a 1 percent change in factor inputs is called the Cobb–Douglas production function.[5] If the elasticity of substitution between natural resources and capital and/or labor is

[4] The production function $Q = \phi([aK^\rho + (1 - a)R^\rho]^{1/\rho}, L)$ where Q is output; K is the stock of capital; R is the flow of natural resources used in production; L is the labor supply has a constant elasticity of substitution between K and R: $\partial Q/\partial K = \phi[aK^\rho + (1 - a)R^\rho]^{1/\rho - 1}aK^{\rho-1}$; $\partial Q/\partial R = \phi[aK^\rho + (1 - a)R^\rho]^{1/\rho - 1}(1 - a)R^{\rho-1}$

$$-1/\sigma \equiv \text{elasticity of substitution} = \frac{d \ln [(\partial Q/\partial K)/(\partial Q/\partial R)]}{d \ln K/R} = \frac{1}{(\rho - 1)}.$$

[5] The Cobb–Douglas production function can be written: $Q = K^{\alpha_1}R^{\alpha_2}L^{\alpha_3}$, $\alpha_1 + \alpha_2 + \alpha_3 = 1$. With a constant population, a sustained per capita consumption is possible if $\alpha_1 > \alpha_2$.

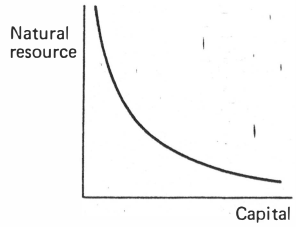

Figure 2-1. Natural resource essential.

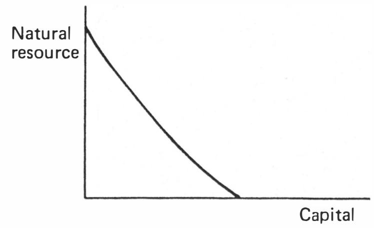

Figure 2-2. Natural resource not essential.

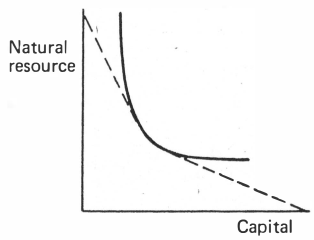

Figure 2-3. Local high elasticity: resource essential.

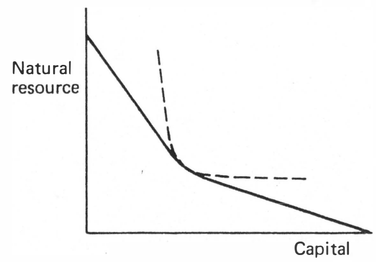

Figure 2-4. Local low elasticity: resource inessential.

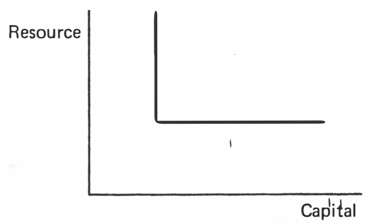

Figure 2-5. Zero elasticity of substitution.

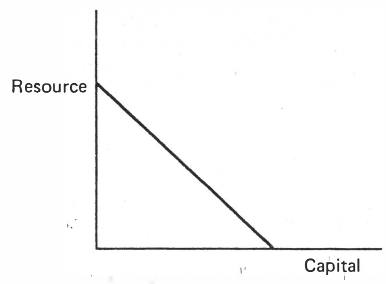

Figure 2-6. Infinite elasticity of substitution.

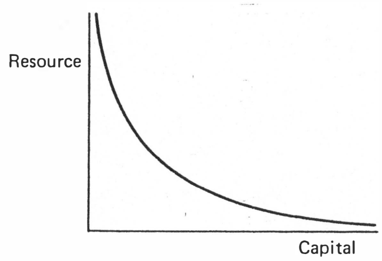

Figure 2-7. Unity elasticity of substitution.

constant, then a sustained constant per capita consumption is feasible if (1) the elasticity is greater than unity, or (2) if the elasticity is unity and if the share of capital exceeds that of natural resources.

If the elasticity of substitution is not constant, what is crucial is what happens to the elasticity asymptotically as resource input goes to zero. In these cases the produced input is sufficiently substitutable for the natural resource that the decrease in supply of the natural resource can be compensated for by an increased supply of capital. Of the two cases, the Cobb–Douglas case is clearly the most interesting for there natural resources are essential in the sense that some input of the natural resource is required for production (the isoquants never do hit the axes). But a small input of natural resource can be compensated for by a sufficiently large input of capital, and whether that is feasible for the economy depends simply on the relative shares of the two.

The conditions under which technical change makes sustained per capita consumption viable are also easily interpretable. The development of a produced substitute can be interpreted as changing the isoquant so that in fact it does hit the natural resource axis. The other condition is that there be a strictly positive rate of resource-augmenting technical progress.[6] If the input of the natural resource were to decline at the rate of the resource-augmenting technical progress—clearly a feasible policy—the effective input would be constant, and with a constant population a constant per capita level of consumption would thus be viable.

IV
The Forecasting Issue

The way we have posed the problem makes it easy to see what is required if we are to forecast the future: we need to know to what extent it will be possible to substitute produced goods for natural resources and we need to know the likelihood of technical changes which will lead either to the development of substitutes or to an increase in the efficiency with which we use what resources we have.

This problem can be approached in several different ways. The "engineering approach" examines the set of presently available techniques and attempts to assess the difficulties associated with developing new technologies. There seems to be an "informed consensus" that within the next 100 years technologies for the production of essentially a boundless supply of energy at "reasonable cost" (for example, solar energy)

[6] A production function with factor-augmenting technical progress may be written: $Q = F(K, R, L, t) \equiv F[\mu(t)K, \gamma(t)R, \lambda(t)L]$.
One unit of resource at t is a perfect substitute for $1/\gamma(t)$ units at time zero.

will become available. On other issues, for example, whether the atmosphere will be affected by certain technological developments, there seems to be less of a consensus. The economist, I suspect, has relatively little to say on these technological issues. The economist's approach is, in some sense, much cruder. He attempts to look at the past and to extrapolate from that into the future. It is not, however, obvious what the appropriate method of extrapolation is. The crucial question is what is to be taken as a constant. For instance, is the average *rate* of growth of the input of oil and the *stock* of presently discovered oil to be taken as given? If so, we are probably indeed in trouble. Or is the rate of increase of discovered resources to be taken as given, in which case prospects are not quite so bleak. And if the rate of growth is to be calculated, over what period should we make the calculation? How is one to choose among these alternative hypotheses and calculations?

Economists approach this problem by formulating a model which is sufficiently general to encompass the entire range of competing hypotheses as special cases and then subjecting the model to empirical testing. In principle then, we should be able to ascertain, at least by extrapolating from past experience, which hypothesis is more reasonable.

If this were as easily done as said, there would be far fewer disputes. Three problems are repeatedly encountered. (1) The data may not be able to distinguish among hypotheses; that is, two alternative hypotheses could be equally consistent with past observations, yet have very different implications for the future. (2) Most tests involve some kind of parameterization; thus, the actual test performed is not of the hypotheses in their most general form. (3) The structure of the economy may have changed, making "testing" of alternative hypotheses on the basis of past data inappropriate.

Let me illustrate these points with the issue at hand. We identified in our earlier discussion two parameters determining the future viability of the economy: the elasticity of substitution and the rate of technical progress augmenting natural resources. I focus my attention here on attempts to measure the former. The question, as we noted earlier, is whether the elasticity of substitution between natural resources and, say, capital, is greater or less than unity (again, recall that what is crucial is the limiting elasticity as the input of natural resources goes to zero). Note that no simulation exercise will ever resolve the question of the correct value of a parameter such as the elasticity of substitution. Moreover, if we know the value of the elasticity, analytical methods can completely answer the question of whether the economy is viable in the long run; we do not need to resort to simulation. What simulation can do—if we have a reasonable model with reasonable estimates of the parameters—is to give us some feel for how long the long run is (for example, if there is a "long-run natural resource problem," is it likely to make itself evident in 50 or 500 years?). Simulation may also enable us to identify the crucial parameters but, here as elsewhere, direct analytical methods are likely to be less ambiguous.

The easiest way of obtaining an estimate of the elasticity of substitution entails introducing one further assumption: that of competitivity, that the prices of (returns to) factors of production equal the value of the marginal productivity of the factor. With this additional assumption, if the elasticity of substitution were much less than unity, then we should expect the share of various natural resources in national income to have changed dramatically; those which have become relatively scarce should have a rapidly increasing relative share, those for whom unexpectedly large supplies have been found (and hence, whose scarcity had previously been overestimated) should have a falling share. In fact, at least in the aggregate, such dramatic shifts do not for the most part seem to have occurred if we take as our period of calculation the past 100 years; obviously if we look only at the past few years we could obtain quite different results. In the one case—land—where there has been a marked change in the share over the past several hundred years, it has been in the wrong direction. The share of land, for instance, in the past was as high as 50 percent; today it is much less in spite of a much larger ratio of population to land.

Resource optimists might argue that the share, say of land, has declined either because the elasticity of substitution is not low and/or because the effective supply of natural resources (land), taking account of technical change, has increased.

Resource pessimists might argue against these results in a number of different ways. (1) The competitive assumption on which the analysis was based might not be true, but for them to argue that the elasticity is low, they must argue further that the degree of monopoly in natural resources has changed in a significant way. (2) The future may not be like the past: it is at this point then that recourse has to be made to the "engineering approach" discussed earlier. (3) The particular parameterization implicit in the above calculation that the elasticity of substitution is constant is not correct: for example, they might argue that as resources become scarcer, the elasticity declines.

I am not aware of any convincing test of this hypothesis; my own guess is that the data are consistent with the hypothesis of a constant elasticity of substitution, but that if some parameterizations involving nonconstant elasticities were employed, nonzero point estimates of the rate of change of the elasticity would be observed. I am not sure whether the point estimates would side with the pessimists or optimists, but the value might well vary according to the parameterization adopted. My own suspicion is that the standard errors would be large enough to allow pessimists and optimists to continue arguing their case.

No matter how the test turned out, either side could argue against the result on the grounds that the analysis had been carried on at too high a level of aggregation. A real test, it might be argued, entails an analysis at a much more disaggregated level, taking into account different productivities of different firms within the industry, elasticities of substitution within each sector, and intersector elasticities of demand. Thus, for instance, changes in the distribution of firms within a sector (say, the difference between best practice and average practice) would result in the aggregate elasticity of substitution appearing not to be constant, although the "best practice" production function does have a constant elasticity.[7] Similarly, even if the production of neither commodity A nor commodity B allows the substitution of capital for natural resources, if commodity A uses less of the resource relative to capital than does commodity B, by substituting commodity A for commodity B, we can reduce our utilization of natural resources. Thus, estimating the full potential for substituting other factors for natural resources requires an understanding of all the possible patterns of substitution available in consumption and production.

Once we recognize possible methods of substituting produced for nonproduced goods, a further kind of technological adaptation becomes possible: tastes may change to reflect the changing environment. Although there is a widespread feeling that tastes are "endogenous," that they respond to changing circumstances, the extent to which changed patterns of consumption reflect a rational response to changing prices (the changed patterns of consumption reflect the changes in the best method of obtaining the "basic wants" but the underlying utility function

[7] For a more extended discussion of the relationship between micro and macro production function see K. Sato [5, 6].

Many of the attempts to estimate the elasticity of substitution are based on cross-sectional data, rather than the heuristic time series approach that we have employed above. There are a number of problems involved in using these cross-sectional estimates as a basis of predicting the long-run elasticity of substitution; this is not the place for an extended discussion of these econometric problems except to note one that has not received sufficient attention in the literature. Consider the traditional method of estimating constant elasticity functions, originally introduced by Arrow and coauthors [7], entailing regressing marginal product (wage) on average product. Assume that labor is not homogeneous and one cannot observe how many "efficiency units" are associated with any particular individual. Then, if some firms hired mostly efficient workers and paid them a high wage, and if some firms hired mostly inefficient workers and paid them a low wage, it would appear as if there were a positive elasticity of substitution, even though the elasticity might have been zero.

remains unchanged) rather than a change in basic attitudes and preferences remains a moot question.

Where does this leave us? The kinds of tools economists have used in the past are not likely to resolve this issue for those who are firmly committed to one side or the other in this debate. Yet it seems that what economic theory does remind us of is "that there is more than one way to skin a cat." If the resource pessimists are correct that we are going to be facing a serious resource problem in the immediate future, they must convincingly show that (1) within each sector the elasticity of substitution is low and the demand elasticities are also low, so that as resources become scarcer we do not, or cannot, substitute less resource-intensive commodities for more resource-intensive commodities; (2) the prospects of adapting tastes to the new set of economic circumstances are poor; and (3) the prospects are bleak for technical changes that would enable us better to use what resources we have.

The more mundane forecasting problem of estimating the likely impact of increasing scarcity of natural resources on our standard of living not only requires a knowledge of some of the same critical parameters, but also entails information concerning a few other parameters.

Elasticity of Demand. If the elasticity of demand for natural resources is high (either because there are readily available substitutes in production or because there are readily available substitutes in consumption which are less resource intensive), then increasing scarcity will not be a serious problem. Note that while for the question of viability we needed to know what happened to the elasticity as the resource input became arbitrarily small, here we only need to know the elasticity associated with levels of input not too different from those at present—a far easier question.

Costs of Extraction. There is, however, an argument that to assess the impact of increasing scarcity in the short run we need not know the demand elasticity; in competitive markets prices will be rising in such a way as to make net royalties (price minus cost of extraction) rise at the rate of interest.[8] The level of prices and the patterns of consumption are affected by the nature of the demand curve, but not changes in the price level.[9] Thus, to forecast real price movements all we need to do is fore-

[8] Consider a competitive firm. It must decide whether to extract a unit of oil today, receiving net $p_t - c_t$ where p is the price and c_t is the extraction cost; or to extract it tomorrow, receiving net $p_{t+1} - c_{t+1}$ whose present value is $(p_{t+1} - c_{t+1})/(1 + r_t)$ where r is the rate of interest. In equilibrium, it must be indifferent, that is, $(p_{t+1} - c_{t+1})/(1 + r_t) = p_t - c_t$ or in continuous time $(\dot{p} - \dot{c})/[p(t) - c(t)] = r(t)$.

[9] Of course, changes in the consumer surplus, that is, welfare, associated with given changes in the price will depend on the elasticity of demand, so that the impact of a given increase in prices will be greater the lower the demand elasticity.

Stiglitz, pages 61--62

will be kept below their market-clearing level, they will not have the incentive to take the efficient precautionary policies; firms will extract too much oil today (since they obtain a return on holding a precautionary stock that is less than its social value) and individuals will adopt technologies of consumption involving less flexibility than is socially optimal.[20]

VI
The Intertemporal Equity Issue

One of the major issues underlying the debate concerning natural resources is whether, with present policies, our descendants will be left in an impoverished state, without natural resources. What is of concern here is an equity issue—the welfare of our descendants versus the welfare of the present generation. There are two important observations to be made in this respect.

First, one should not view equity in a narrow sense of simply looking at the division of natural resources between 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. One has to look at the relative welfare of the different generations and there is a strong presumption that future generations may be better off than the present generation. On grounds of equity it might be argued that we should consume even more now (including more natural resources).

Second, the appropriate instrument to use for obtaining more equitable distribution of welfare (if one believes that the present distribution is not equitable) are general instruments, for example, monetary policy directed at changing the market rate of interest. These do not lead to an inefficient allocation of resources. (Obviously, prior to using such general instruments, policies directed at correcting inefficiencies in the allocation of resources, as discussed in the previous section, have to be adopted.)

There has been an extensive recent literature concerned with the optimal pattern of consumption of natural resources. Although the models employed in this literature are obviously overly simple, they do give us a method of obtaining a rough check on whether the present allocation,

[20] Indeed, recent regulatory policies have punished those who have adopted flexible technologies: electricity generating plants which were convertible to coal were required to do so, forcing those who had adopted the flexible technology to pay more for their fuel than those who had not.

with all its market distortions, is different in a significant way from an optimal allocation. We solve for the optimal rate of extraction, using the utilitarian criterion, that is,

$$\max \int U(c)e^{-\delta t}e^{nt}\, dt$$

where $U(c)$ is the utility associated with a per capita consumption flow of c, n is the rate of growth of population, and δ the rate of discount, subject to the national income constraint,

$$C + \dot{K} = F(K, R, L, t) = K^{\alpha_1}R^{\alpha_2}L^{\alpha_3}\, e^{\lambda t}$$

(where F is a constant return to scale production function, which we have specialized as the Cobb–Douglas production function, with λ being the rate of technical progress; K is aggregate capital; L is labor; R is resource flow; and C is aggregate consumption), and to the resource constraint

$$\int R(t)\, dt = S$$

where S is the stock of the resource today.

The exact nature of the optimal consumption path (which, unlike the case without resources, may not be monotonic) depends on the elasticity of marginal utility, the rate of time preference, the rate of population growth, and the rate of technical change.[21] If the utility function is logarithmic $U = \ln c$, then it can be shown that the optimal rate of extraction is just equal to the pure rate of time discount minus the rate of population growth $(R/S) = \delta - n$. If $\delta - n$ is a number around 3 percent, this means that we should use up 3 percent of our remaining stocks each year, that is, at *current* rates of consumption, we have approximately thirty-three years' supply left, a number which is certainly smaller than our stock of energy-producing materials.

VII
Two Policy Issues

In the preceding two sections we discussed several policy issues in the context of whether a sustained level of per capita consumption growth is feasible and whether there are systematic misallocations of natural resources arising from market failure. In this section I wish to look at two further policy questions which have received widespread discussion.

[21] The general formula is that, asymptotically: $R/S = ([\delta(1 - \alpha_1) - \nu\lambda])/(1 - \alpha_1 - \alpha_2\nu) - n$ where ν is the elasticity of utility [4].

4

Comments on the Papers by Daly and Stiglitz

Nicholas Georgescu-Roegen

The two papers presented at this session are so opposed in outlook that a commentator could not possibly find himself in sympathy, even partially, with both of them. Given my own stand on the crucial role played by natural resources in the economic process, it may be superfluous to say with which of the two papers I am in substantial agreement. Yet I deem it necessary to state from the outset that I am entirely out of sympathy with the manner in which J. E. Stiglitz dealt with his topic.

True, his task could hardly be more thankless. But he has chosen to set up a line of multifarious but ineffective fires in defense of a position to which many standard economists still cling with the tenacity of original sin. This position is that the analytical models designed by standard economics are completely fit to deal with the issue of optimal allocation of natural resources among successive generations, an issue that affects the survival of the human species. It is my contention, expounded in several of my writings, that this position is dangerously false.[1] Neoclassical economics—or standard economics, as I prefer to call the discipline as practiced for the past fifty years—has paid practically no attention to natural resources. To be sure, legions of production functions in the neoclassical literature contain the factor land, by which is meant, however, only Ricardian land. But Ricardian land raises no issue for the intergenerational allocation of resources. This is *the* problem of natural resources.[2]

Stiglitz avoids the admission, embarrassing nowadays, that the main body of standard economists has paid no attention to this vital problem. For the defense that economists have long since recognized the seriousness of the limitations of resources, Stiglitz has little choice other than

The author held an Earhart Fellowship during the preparation of this paper.

[1] See especially Georgescu-Roegen [1].

[2] And since we cannot possibly control the flow of solar energy reaching the earth, the problem of natural resources is reduced to that of *mineral* resources.

mentioning, not a neoclassical economist, but Malthus. Curiously, even that defense witness has no glory, because Malthus's forebodings "have not been borne out—at least not yet." This bare assertion is to be expected. Standard economists, having paid no attention to the problems raised by the size of population, cannot recognize now any valid point in Malthus's position. In this connection, one may cite Blaug's glaring verdict: "The Malthusian theory of population is a perfect example of metaphysics masquerading as science" [2].

Before disposing of Malthus in such expedient fashions, one should take account of the fact that millions of humans are half-alive in abject misery, dying slowly of squalor and starvation. Above all, one should (if one can) imagine a United States populated as thickly as Bangladesh: it would contain not less than 5 billion people, more by one quarter than today's population of the whole earth. Actually, Malthus—we can say it now—was not Malthusian enough; he allowed for population to increase indefinitely provided it would not grow too fast.

By now it is fashionable among standard economists to say high and loud that one does not need to invoke thermodynamic laws in order to realize that exponential growth must eventually run into physical barriers.[3] Stiglitz does not want to be an exception. Like all the others, he also ignores the question that now cries for an answer: Why have we then labored for years to fabricate and sell a theory of economic development based on exponential growth?

The claim that standard economics is not concerned "with very long-run projections, but rather with the more immediate future," is another means of avoiding the main issue that would incriminate the standard position. The problem of resources is not confined to the "foreseeable future," as many other writers also insist, but concerns the entire future. Obviously, if one takes the foreseeable future to be just 24 hours, then, as Wilfred Beckerman assured us, we all could go to bed tonight without worrying in the least about what growth may do to those of us who will be alive the day after tomorrow. If the standard position concerns only what will happen to natural resources "in the immediate future" of this moment of the twentieth century, then all the din about how the market mechanism (especially that moulded on standard assumptions) can save us from ecological catastrophes is utterly idle. But if the claim is that exponential growth can prevail not only in our immediate future but also in any "immediate future" in the future, then the claim acquires a factual, nonparochial significance. The opposite position

[3] See, for example, Landsberg [3]. But, sadly, these writers ignore the fact that thermodynamics tells us some fundamental things about the economics of resources that are not as obvious.

is that exponential growth has been only one historical interlude caused by a unique mineralogical bonanza of the past hundred years.

I am the first to agree with Stiglitz that a specific policy geared for the future should ideally be based upon some solid projections. Since any *quantitative* projection whatsoever is ultimately based on some time-invariant matrix, Stiglitz is right in searching for some constant element. I further agree with him on the indescribable predicament of the econometrician trying to discover a *historical* law on the basis of past observations. Concerning parameterization, years ago I pointed out that the situation of the econometrician is analogous to that of a deft sculptor who can prove to you that there is a beautifully carved Madonna inside almost any log.[4] How can one then tell what is really inside a log?

Let me also make another of Stiglitz's points stronger. If we are able to predict that after a certain age people are likely to develop arteriosclerosis, it is only because we have been able to observe millions of humans growing old. Unfortunately, we have not observed and will never observe another people struggling to survive on a planet such as ours. This is why we cannot say for sure what is in the cards for us as a species. By observing a single human until he reaches the age of, say, thirty, we may very well conclude that he will never develop arteriosclerosis. It is legitimate to expect, therefore, that data pertaining to the period of minerological bonanza mentioned above—such as those so ably used by Harold Barnett and Chandler Morse in support of their famous thesis—should support any hypothesis of continuous growth.

It is therefore curious that after insisting on such difficulties, Stiglitz claims that the burden of proof is on "the resource pessimists," such as me, to convince the resource optimists that some elasticities are low. This sort of argument would be in order only if the optimists had already offered some acceptable proofs that those elasticities are high. Worse still, the issue does not even concern elasticities at all. It concerns the physical finitude and the irrevocable exhaustibility of natural resources.

Stiglitz, however, even raises the question of "how essential" natural resources are. Apparently, like Robert M. Solow (whom he cites in this respect), Stiglitz believes that physical production can be maintained at the same level if capital (or some other factor) is continually substituted for natural resources.

This conjuring trick devised by Solow is easily shown up. Exclusive preoccupation with paper-and-pencil (PAP) exercises habit has led to accepting these exercises without any concern for their relation to facts. On paper, one can write a production function any way one likes, without

[4] See Georgescu-Roegen [1, chapters 10 and 12].

regard to dimensions or to other physical constraints.[5] A good example is the famous Cobb–Douglas function, but the Solow–Stiglitz variant adds the sin of mixing flow elements with fund elements, namely,

$$Q = K^{\alpha_1} R^{\alpha_2} L^{\alpha_3} \tag{1}$$

where Q is output, K is the stock of capital, R is the flow of natural resources used in production, L is the labor supply, and $\alpha_1 + \alpha_2 + \alpha_3 = 1$ and, of course, $\alpha_i > 0$.[6]

From this formula it follows that with a constant labor power, L_0, one could obtain any given Q_0, if the flow of natural resources satisfies the condition

$$R^{\alpha_2} = \frac{Q_0}{K^{\alpha_1} L_0^{\alpha_3}} \tag{2}$$

This shows that R may be as small as we wish, provided K is sufficiently large. *Ergo,* we can obtain a constant annual product indefinitely even from a very small stock of resources $R > 0$, if we decompose R into an infinite series $R = \Sigma R_i$, with $R_i \to 0$, use R_i in the year *i,* and increase the stock of capital each year as required by (2). But this *ergo* is not valid in actuality. In actuality, the increase of capital implies an additional depletion of resources. And if $K_i \to \infty$, the R will rapidly be exhausted by the production of capital. Solow and Stiglitz could not have come out with their conjuring trick had they borne in mind, first, that any material process consists in the transformation of some materials into others (the flow elements) by some agents (the fund elements),[7] and second, that natural resources are the very sap of the economic process. They are *not* just like any other production factor. A change in capital and labor can only diminish the amount of waste in the production of a commodity; no agent can create the material on which it works. Nor can capital create the stuff out of which it is made. In some cases, it may also be that the same service can be provided by a design that requires less matter or energy. But even in this direction there exists a limit, unless we believe that the ultimate fate of the economic process is an earthly Garden of Eden.

The question that confronts us today is whether we are going to discover *new* sources of energy that can be safely used. No elasticities of some Cobb–Douglas function can help us to answer it. As to the scarcity

[5] More on this point in Georgescu-Roegen [4, chapter 9] and [1, chapters 2, 4, 5].

[6] The slipshod manner in which the factors are defined is another consequence of the infatuation with PAP exercises.

[7] See Georgescu-Roegen [4, chapter 9] and [1, chapters 2, 4, 5].

of matter in a closed system, such as the earth, the issue may, in my opinion, prove in the end more critical than that of energy [1, chapters 1; 5].

No one could possibly argue with some of the statements of section II of Stiglitz's paper; if they are taken with a grain of salt they may give some useful indication of the direction in which a market may move because of government intervention or changes in the industrial structure. But this does not settle the great issue at stake, namely, whether the market mechanism can be an instrument for the intergenerational distribution of natural resources. In view of Stiglitz's insistence that the market is fit for this role, I can hardly overemphasize my reasons for its denial.

To be sure, those who share Stiglitz's position also argue that although markets admittedly have serious failures, if prices were right everything else—depletion and pollution—would also be right.[8] But no one has yet defined "right" prices. (I assume that by "right prices" they do not mean the "just prices" of the Scholastics.) The rub is that market prices depend on many factors: income distribution, taxation systems, industrial structures, taste spectrums, etc.[9] To wit, the price of gasoline would certainly be different if the geographical distribution of oil deposits were different from what it actually is. I cannot see how we could say which conditions would bring about the right prices. Were the prices right or wrong when large tracts of land were deforested? Were the prices of crude oil until the establishment of the OPEC right or wrong? What kind of perfect market would have prevented the squandering of crude oil over the past forty years?

From another approach, we may note that in order to arrive at the "true" cost of any material commodity, we must know the true values of natural resources *in situ,* which constitute the first cost item. Some economists trained in the neoclassical tradition have occasionally spoken of the "true scarcity value" of natural resources *in situ.*[10] Yet, to my knowledge, the determination of these values is a problem totally ignored by all tints of economic theory. For perhaps the only reasonable solution we may turn to a general, albeit rarely used, economic principle, which is that the value of an irreproducible good—whether Leonardo's Mona Lisa or some crude oil in its earthly pouch—is its auction price. However, the ordinary formulation of this principle omits to add the *sine qua non* condition that all those having a possible interest in the

[8] See references in [1, p. 13].

[9] I naturally exclude the thought that the economic process works over time, even in some acceptable approximation according to the simplified assumptions of the Leontief system.

[10] For example, Amouzegar [6].

commodity must be allowed to bid. Otherwise, if only my neighbor and I were to bid on the Mona Lisa, for example, I may obtain it for a few dollars, since my neighbor hates Renaissance paintings.

The moral is obvious. To arrive at the true scarcity value of any mineral resource, all users of the resource must bid, that is, all users in this generation as well as future ones.[11] Unfortunately, the future generations cannot be present to bid now. The current generation must therefore take into account their needs. Devising a way by which this can be done is admittedly a difficult but not impossible problem. Suffice it to say here that the solution lies in the domain of ethics rather than that of economics.

Stiglitz asserts that the foregoing argument about the independence of the present market from the demand of future generations is fallacious. His point is that since each owner sells to a future owner, who sells to another, and so on, the algorithm will take care of the interests of all future owners *now*. I submit that, on the contrary, it is his argument that is fallacious, the usual fascination with formalism being again responsible for the misinterpretation of the PAP algorithm. It is beyond doubt that each individual's actions are geared to the future. But his decisions are based only on whatever evidence the individual has at *that* moment and, moreover, they concern only the probable events within his time horizon. That is, his evidence does not encompass the whole future, nor is his time horizon unlimited (optimistically, it may be taken to cover about thirty years only). Hence, nothing beyond that time horizon bears upon the usual decisions of any individual. It would be preposterous to maintain that, even in a businesslike society such as the United States, the earlier owners of oil fields acted on the thought that one day this country might experience a dangerous shortage of fuels. Had they done so, the shortage would have probably not come so early.[12]

With one important exception (to be considered presently), Stiglitz never instructs us about the criterion of optimality served by the market mechanism and instead speaks only of "efficiency" and "efficient market" without explaining the meaning of these terms. This fact might be taken as an unintentional admission that, whatever the markets may do, they cannot be relied on for a reasonable intergenerational allocation of natural resources. But there is that exception, a mathematical model in which there is a criterion of optimality to be satisfied under the constraint of a given (finite) amount of resources.

[11] I must hasten to add that even this *Gedankenexperiment* is not completely satisfactory. The auction price still depends on the income distribution. But this seems to be the best we can do even in the abstract.

[12] The above argument can be easily supported by a graphical analysis, for which see Georgescu-Roegen [1, pp. 30–32].

The model goes back to the famous 1931 article of Harold Hotelling [7]. Beautiful mathematical piece though that article is, it set a fallacious pattern of approach to the economics of exhaustible resources. As Stiglitz and every other writer who has been stirred by the recent events argue,[13] resources must be distributed so that *the sum of discounted future utilities*

$$\int_0^{\infty} U(c_t)e^{-\rho t}dt \qquad (3)$$

must be a maximum, where $U(c_t)$ is the *utility intensity* of c_t, and ρ is the constant discount rate of the future.[14]

As we all know, the idea that future pleasures and pains do not appear to an individual as vivid as present ones constituted a main point of Jeremy Bentham's hedonistic calculus. W. Stanley Jevons introduced it in economics with some very careful considerations [9]. He separated the discount factor into a probability coefficient that the event will actually occur and a coefficient to represent the underestimation of the future experience. But Jevons, while recognizing that the individual's decisions are influenced by both factors, argued that the underestimation of the future is an irrational trait. When tomorrow comes we will be as hungry and as thirsty as we are today. Hence, we should not fail to put aside equal amounts for future satisfactions.[15] However, the reduction resulting from the uncertainty of the future must be retained because of its statistical validity. For a most elementary illustration, let us consider a population of three individuals, one of whom will die each day. If they possess among them six daily rations, they should distribute them in time by discounting the future only according to the probability of survival. This yields the distribution 3, 2, 1, not 2, 2, 2. As we see, the saying "let's eat, drink, and be merry today because tomorrow we may die" makes sense, *but only because humans are mortals.*

For quasi-immortal entities—such as a nation and especially mankind—discounting the future is wrong from any viewpoint. There is no specific reason why such an entity will not experience the same needs at all times. Nor is it subject to a mortality table. The upshot is that equation (3) may apply to a single individual in managing his narrow affairs myopically, but when we come to ask how to distribute resources among generations, we must not in any way discount the future.

To be sure, if all future utilities are treated alike, the beautiful solution reached by Hotelling is of no use anymore. The focus of the problem

[13] For example, Koopmans [8].

[14] For my argument I need not preserve the factor corresponding to the population growth in Stiglitz's formula.

[15] The point has been taken up in greater detail by Strotz [10].

is entirely shifted. The *analytical* solution is to spread resources evenly in time, which in the case of an infinite time horizon yields the paradoxical result that each year a null amount of resources should be consumed. The analytical impasse is eliminated by noting that what we may, for example, seek now is the maximum "amount of life," measured in man × years, which is tantamount to obtaining the longest life span for the human species [4, p. 304; 1, p. 23]. This solution presupposes that we know the standard level at which mankind must live as well as the future movement of population. Stiglitz's observation that resource planning requires a tremendous amount of information, most of which cannot possibly be available, is very welcome at this point. This is why whenever we may try to prescribe a quantitative policy for the economy of resources we can only play the tune by ear. Besides, instead of basing our recommendations on the ultrafamiliar principle of maximizing "utility," we should try *to minimize future regrets.* This seems to be the only reasonable (I do not think that we could call it rational) recipe for dealing with the most uncertain of all uncertainties—historical uncertainty. We should thus slow down the depletion of fossil fuels so as not to put ourselves in the impossible position of not having enough support for the search for other sources of energy, regardless of whether such a possibility is at present real or not. Had we tried to minimize regrets, we would not be so pressed today by the alarming dwindling away of crude oil resources.

Admittedly, all these considerations take us far away from the teachings of standard economics. But this is precisely the point that needed to be brought home at last.

Turning now to Herman Daly's paper, I do not think I am wrong in judging that by now he has associated his name with a steady-state economy, just as other economists have associated their names with the position "come what may, we will find a way, provided prices are right." For this reason I think that Daly's name should appear in the group "Humanist Economists" in his table of growth critics.[16]

This paper represents an improvement on Daly's earlier pleas. One new point deserves special attention. It is the map in which the hierarchy of ends and means is correlated with the categories of disciplines that keep the human mind continuously on the run. To have a single element by which everything is in the last analysis guided or judged has been a need felt by all truly philosophical schools. All great philosophers have imagined, if not a religious God, at least a philosophical one as the ulti-

[16] I have a few other ideas about that table but they are not important enough to mention here, save one: Agrarians in general, not only American Agrarians, deserve great credit for having opposed excessive economic growth.

(end of excerpt)