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Growth, Resources and Environment: Some Conceptual Issues

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Fundamental limitations on resource availability will become increasingly important, as present and future generations attempt to satisfy their demands for goods, services and amenities. The prognosis for the future of civilization is uncertain, but the more pessimistic predictions paint an ugly picture (Meadows, *et al.*; Heilbroner). In this paper, some relevant concepts are presented and some broad-brush policy approaches suggested.

The production and consumption of *material goods and services* (M.G.S.) and *environmental amenities* is subject to *resource* scarcity.[1] Choices must be made as to the mix of M.G.S. and environmental amenities to be produced in any time period, and the relative size of the total consumption bundle in each time period. What kinds of things will each generation consume, and how much will each generation consume relative to preceding and future generations?

Intertemporal Allocation

Let us examine first what economic theory suggests about the problem of intertemporal allocation and, second, what some fundamental laws of physics indicate. Are our economic growth models consistent with the physical laws governing the operation of our universe?

Growth Models

The problem of economic growth has often been analysed as one of determining the optimal rate of capital accumulation in a world where resources are inexhaustible. The results obtained by Dorfman are typical. If social welfare is maximized in the long run by maximizing the present

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value of consumption over time, the rate of consumption in each time period must be chosen so that the marginal productivity of capital is equal to the sum of (1) the social discount rate, (2) the rate of physical deterioration of capital and (3) an expression representing the additional psychic cost of saving a unit of capital at the beginning of each time period rather than the end. From Dorfman's model, it can be deduced that the optimal growth paths, under many conditions, approach the situation in which consumption and the capital stock grow exponentially at a rate determined by the rates of population growth and technological change. Once an optimal growth path is attained, any further growth in *per capita* consumption is wholly dependent on technological change. "Plateau" consumption depends on the social discount rate, higher discount rates resulting in lower steady state consumption per capita.

Turnpike models such as Dorfman's are highly unrealistic. Nevertheless, they enable identification of several key variables: the social discount rate, the rate of population growth, the rate of technological change, and the rate of physical deterioration of capital.

Solow, and Dasgupta and Heal have constructed more sophisticated models which permit the inclusion of exhaustible resources. They show that, even with the optimistic assumption that technological progress and the resource base are adequate to permit a high steady state level of consumption, the application of a positive social discount rate may result in per capita consumption tending asymptotically to zero. In other words, a society may choose eventual extinction.

Solow takes us one important step further, by considering the possibility of substitution of inexhaustible inputs for exhaustible resources. His conclusion is that if the elasticity of substitution between exhaustible resources and other inputs is one or greater, and if the elasticity of output with respect to reproducible capital exceeds the elasticity of output with respect to natural resources, then a constant population can maintain a constant level of per capita consumption into the very long term future. If either of these conditions fails to be satisfied, the highest level of consumption which can be maintained into the long, long term is zero. Neither Solow nor this author can offer much empirical guidance as to the likelihood of fulfillment of these necessary conditions. However, it must be noted that their fulfillment in the long term will require considerable and continued human ingenuity.

Two Laws of Thermodynamics

The laws of thermodynamics provide knowledge about the functioning of our universe which sound economics cannot ignore. Let us look at the Second Law (the *entropy law*) first. This law states that the entropy of a closed system continuously increases, or that the order of such a system turns steadily to disorder. It indicates that our universe will inexorably "run-down" or exhaust itself in the very long run, even in the absense of man's activities. The activities of man in increasing the rate of entropic degradation bring the inevitable end closer in time (Georgescu-Roegen). Thus, the long-term economic problem is best analyzed in terms of *adjusting the rate of conversion of low entropy to high entropy* or, perhaps more graphically, the rate of exhaustion of our universe.

The entropy law has great value in clarifying several of the issues pertinent to intertemporal allocation and growth theory.

a) It places the role of *technology* in perspective. For the most part, technology does not "expand the size of space ship earth along those dimensions that are most significant for human existence," as Ruttan (p. 708) and Schultz (p. 238) would have us believe. Rather, the technologies of the industrial and post-industrial revolutions have mostly enabled us to consume and otherwise exhaust our universe at an ever-increasing rate, making massive transfers of wealth from future to present generations. However, not all technologies are equally destructive to low entropy per unit of value produced. The search for and implementation of technologies which are less destructive of low entropy would seem to be a potentially rewarding activity.

b) It enables us to perceive the "dichotomy" of *reversible* versus *irreversible* change as really a continuum.[2] The nonexistence of reversible change emphasizes the need for "with" and "without" project analysis and the inclusion of preservation values in project evaluation. It also provides a useful warning that recycling has inherent limits. The kind of partial recycling which is possible is not sufficient to make any exhaustible resource inexhaustible. The determination of the efficient degree of recycling is itself an economic problem.

c) It focuses our attention on the use of flow resources as a means of increasing the value of output per unit of entropic degradation, at the same time warning us that flow resources do not quite offer a panacea in the ultimate sense.[3]

The First Law of Thermodynamics (the principle of conservation of matter-energy) is also pertinent. Since neither production nor consumption is a waste-free process (Ayres and Kneese), and since waste disposal is costless in neither money nor entropy terms, increasing consumption and/or investment increases the rate of entropic degradation by increasing the demand for low entropy for waste disposal (as well as in the ways discussed above).

Long-Term Prospects and Policies

The impact of careful consideration of these two laws of thermodynamics is to magnify somewhat the pessimism of the more pessimistic findings presented by the growth theorists. Our current policies emphasize the development and implementation of technologies which make us more effective in the exhaustion of exhaustible resources, and appear to be based upon a social discount rate somewhere near the opportunity cost of capital in the private sector (which is positive and relatively high). Continuation of these policies into the long term seems certain to result in Solow's case where consumption eventually declines to zero. It is left to others to estimate or guess how far in the future this will occur. However, it does not seem unrealistic to suggest that the intervening time may be measured in hundreds rather than millions of years.

It is useful, however, to consider the kinds of policy changes which may prolong the span of human civilization. In research and development, emphasis could be placed on finding modes of production and consumption which increase *entropy efficiency*. A more entropy efficient process is simply one which produces a greater value of output per unit of entropic degradation. The use of flow resources and the development of more entropy efficient technologies (e.g. those which reduce friction, genetic improvements in plant and animal species, etc.) are potential methods of increasing entropy efficiency. And, it seems that the maximization of the long-run welfare of the human species requires a high level of entropy efficiency.

The *social rate of time preference*, made effective through the *social discount rate*, determines the rate at which we, on the one hand, invest for future generations and, on the other, "sell out" future generations by exhausting their universe without their consent. Further, where exhaustible resources are privately held, in the absence of policies to the contrary, the decision to hold or to extract these resources will depend on the market rate of interest, that is, the price of capital. For a private holder to continue holding, he must expect the net price of the resource (i.e. net of extraction and marketing costs) to continue growing exponentially at a rate at least equal to the rate of interest in the private sector (Hotelling, Solow).

For those who would prefer to see society provide more generously for future generations, two kinds of discount rate problems arise. (1) There is no good reason to assume the market rate of interest, which is established in relatively short-term capital markets, to be equal to the social rate of time preference applied to the exhaustion of resources over the very long term. Since future generations (and even today's children) are not able to represent themselves in today's markets, their welfare is a collective good. Olson provides ample reason to expect under-provision of such a good in the market. (2) There is no good reason to assume that a politically determined social discount rate will assure intergenerational equity. Future generations are unable to represent themselves in the political arena. A politically determined social discount rate will at best reflect what today's adults (weighted by their political power[4]) are willing to provide for future generations.

One may express the pious, but perhaps futile, hope that some combination of altruism and survival instinct of humanity will result in some reduction of the social rate of time preference, expressed in reduced social discount rates. Those who find the outcome of capital markets acceptable for the short-term allocation of capital but not for the intergenerational allocation of exhaustible resources will perhaps opt for policy solutions such as a system of graduated severance taxes, falling through time, on exhaustible resources (Solow).

Long-term solutions will require not only some adjustments in *total consumption* (and it should be noted that the prospects for *per capita consumption* can be improved by *stabilising population*), but also adjustments in the *consumption mix*. As entropic degradation continues, it can be expected that relative scarcities will change. These changes will be reflected, sooner or later, in changing relative prices and/or shadow prices. Adjustments in the consumption habits of consumers will be necessitated.

Resource Allocation for the Near Future

So far, this discussion has proceeded in terms of aggregate consumption over the long-term. Now, let us consider resource allocation and the mix of goods and amenities to be produced in the short-term. This is the kind of problem which economics seems best equipped to handle.

The static theory of resource allocation is most instructive, not only in the conclusions it generates but also in the assumptions required to achieve those conclusions. These assumptions can be interpreted as warnings as to how real world outcomes might vary from the theoretical optimum.

If actual distributions of income, wealth, legal rights, etc., coincide with the distributional preferences of society, *if* all rights are nonattenuated[5], and *if* all of the requirements of pure competition are satisfied, unfettered markets will result in socially optimal production and consumption patterns, given resource scarcity and the existing tastes and preferences of the participants in those markets.

It would be an arduous task to compile an unabridged compendium of the ways in which the essential conditions are violated in the real world. However, some violations which are especially pertinent to the resources issue will be enumerated below.

a) There is no evidence that the *distributional variables* are coincident with social preferences, and considerable suspicion in some quarters that they are not.

b) Resource markets, particularly in energy and mineral resources, appear to be especially susceptible to *noncompetitive influences*. International cartels of resource exporting nations have arisen, perhaps partly in response to a long history of international corporate oligopoly in the extraction and marketing sectors. Corporate oligopoly is no longer confined to individual resources. Energy conglomerates, for example, threaten to modify substitution patterns by changing long-established price cross elasticities on the supply side.

c) *Attenuation of property rights* is not unknown in the markets for M.G.S. and seems almost the rule rather than the exception in markets for environmental amenities.

Economists, led by Ayres and Kneese, have rediscovered the *First Law of Thermodynamics*. The myths of waste-free production and total consumption have been exploded. Waste disposal is an integral part of production and consumption processes. In effect, the production and consumption of M.G.S. tends to use environmental resources and reduce the flow of environmental amenities.

Where the expense of waste disposal is external to the private economic calculations of producers and consumers, *externality* is pervasive rather than unusual and empirically insignificant. Without corrective social action, in the form of regulation, price modification, or redefinition of property rights[6], the market will underprovide environmental amenities. The problem is broader than indicated by the more restrictive definitions of externality, in that environmental resources are often of the *common property* variety and environmental amenities are often *public goods*.

Attenuation of property rights often results from *government action*, particularly in the regulatory field. Thus, government is a major contributor to the list of market imperfections.

One suspects that, even in the absence of the kinds of market imperfections discussed above, some serious adjustment problems would face our society in the near term. The changes in relative scarcity and prices which we are now experiencing are not entirely due to market imperfections. The immense production of M.G.S. in aggregate and the particular kinds of M.G.S. we are producing (i.e. kinds which are often highly destructive of low entropy) suggest that depletion of at least some resources is well under way. Thus, some relative and absolute changes can be expected in resource prices, necessitating adjustments in consumption habits.

Sharp changes in the patterns of relative and absolute scarcity are likely to have major distributional consequences. Thus, it is important to assure that the costs of dislocation and adjustment are not borne disproportionately by the poor. Since price changes are essential to provide the incentive for changing consumption habits, it is best that perverse redistributional consequences be alleviated by lump sum transfers.

The short-term needs, in the most general terms, are for policies aimed at (1) promoting distributional justice, (2) promoting competitive structures (or structures which perform in the manner of competitive structures) in resource markets, (3) eliminating, to the extent possible, market imperfections attributable to attenuated structures of property rights[7], and (4) assisting, or at least not impeding, the process of market adjustment to changing relative scarcity.

Reconciling the Immediate and Long-Term Solutions

The long-run outcome will be largely the result of a long sequence of short-term policy decisions to solve short-term problems, or "crises", as we typically call them. However, I have serious reservations about some of the policy directions in which our crisis mentality seems to be leading us.

If it can be agreed that the long-term problem can best be attacked by the reduction of prevailing rates of time preference, the development and use of entropy efficient technologies and flow resources, and the adjustment of consumption habits to the emerging realities of scarcity, then the policy question, in simplistic but nevertheless useful terms, is to find ways to make the necessary adjustments without causing excessive dislocations and demanding excessive sacrifices from present generations. Policies for the near future must start us moving in directions compatible with and contributory to the long-term solution.

Economists are long accustomed to using *prices* as the best indicators of the interactions of scarcity and consumer demands. However, in analyses designed to identify long-run solutions, the uncritical use of existing prices is dangerous, for the reasons discussed below (in addition to those suggested by market imperfections). Crucial prices can be expected to change drastically as our uncertain future unfolds. Technological developments will change cost ratios in production while future demands of M.G.S. and environmental amenities are most uncertain. Human values are fundamental to utility functions, which are fundamental to the price ratios of goods, services and amenities. Yet value systems can be expected to change, as a result of propaganda, in accommodation to new views of reality (we are already seeing some of this reflected, for example, in the market for automobiles), and in other ways not well understood. And if, as some believe, the present value system of our culture is incompatible with the long-term survival of our civilization, the process of changing value systems might fruitfully be encouraged. All of this provides a warning that the implementation of solutions (particularly those involving massive and perhaps publicly subsidized capital investment) based on current prices may perpetuate our problems by delaying essential adjustments in technology and human demands.

These considerations suggest that research to identify and evaluate policy solutions must incorporate *materials flow analysis* and *energy budgeting* (better yet, entropy budgeting, if techniques can be made applicable) into economic analyses.[8] Energy budgeting, for example, is potentially helpful in providing early warning of coming changes in scarcity and price relationships.

One suspects that some of our current policies are quite myopic, viewed from the perspective suggested above. Policies aimed at simply substituting somewhat less scarce fossil fuels for the very scarce ones may fall in that category. It is easy to see why coal gasification and liquefaction are receiving encouragement: the final products are compatible with existing systems for distribution, marketing and end use. In that sense, the process of short-term adjustment to scarcity of oil and natural gas is eased. Yet, supplies of coal will not last forever and in the interim preceding exhaustion (a period of perhaps no more than a few hundred years, at current rates of use), expanded rates of extraction will come at increasing costs in terms of both money and environmental amenities.[9] Nuclear energy production based on breeder reactor technology would enable us to utilize an exhaustible resource which is expected to last hundreds and possibly thousands of years. However, future generations would be left with the burden of the perpetual care of plutonium, which is both extremely toxic and a prime weapon material (Krutilla and Page). Shale oil appears to be available in large quantities, but its extraction appears to be both environmentally devastating and of relatively low energy efficiency (i.e. the amount of energy used in extraction approaches the amount produced).

One wonders why flow sources of energy, the sun, the winds and even the tides, have received research and development expenditures which are only a small fraction of those devoted to these exhaustible resources. One answer may lie in the area of property rights. Private sector entrepreneurs could expect to capture the patents to technologies they develop, but not the ownership rights to the resources whose value is suddenly increased. Regardless of any institutional reasons for our current low level of effort in developing flow energy sources, one suggestion emanating from the logic developed herein is that more effort should be made.

These arguments are not intended to deny the need for continued exploitation of exhaustible resources. That is essential, if for no other reason, to ease the burdens of adjustment placed on present generations. However, a shift in emphasis toward utilization of flow resources seems called for, starting immediately.[10]

One may also be critical of policies which seem aimed at slowing the adjustments of consumers to the emerging realities. Continued and substantial public expenditure on highway development is one example. It seems that adjustments in the use of petroleum products (not only as energy sources, but also in the production of a wide range of goods including pesticides, fertilizers and plastics) must be made eventually, if not immediately.[11]

There are indications that it is current policy to allow the under-provision of environmental amenities in general (occurring in the first instance as a result of pricing problems in externality and public goods situations) relative to M.G.S. to continue.[12] Even if this is consistent with current voter preferences (and I do not concede that it is), it seems inconsistent with any acceptable long-run solution.

The above comments are directed primarily at American society, yet an international perspective is also essential. *Population pressures,* if unchecked, combined with the traditional use of less developed countries as suppliers of raw materials (often exhaustible resources) to more prosperous countries, seem to guarantee that per capita consumption in many of the L.D.C.'s will not rise to the levels enjoyed in western Europe and North America.[13,14] This suggests the need for stringent population control in many L.D.C.'s. It may even be desirable to encourage this process by offering some international redistribution of income and wealth as a *quid pro quo.*

In the more prosperous nations, population growth seems to be slowing down. Considering, particularly, the impact of population in reducing the level of environmental amenities, it seems there is nothing to gain from a reversal of this trend.

Concluding Comments

The doomsday predictions, perhaps typified by the Club of Rome report (Meadows, *et al.*), seem to have been largely discounted. However, there is no serious disagreement that, if the world economy were to maintain its present course, disaster would strike in a relatively few years. On the contrary, the prevailing argument is that the doomsday theorists have grossly underestimated the human ability to make adjustments in technology, resource substitution, and consumption habits.

Even the so-called "optimistic" studies such as the Ridker report[15] amplify the need for such adjustments. Public policy must be directed at encouraging the essential adjustments without placing excessive burdens on present generations. Some directions for public policy can be suggested.

a) The rate of resource exhaustion and, more generally, entropic degradation, which has been increasing apace, must be decreased. Appropriate policies include (1) the reduction of the social rate of time preference, (2) a system of graduated severance taxes, falling through time, on exhaustible resources, (3) a conscious policy of risk aversion where disasterous outcomes reversible at great expense, if at all are possible, and (4) conscious efforts to control population growth.

b) The development and implementation of technologies to use flow resources should be encouraged through (1) ingenious modifications to the system of property rights and (2) direct public investment, to the extent that efforts through (1) fall short of achieving the goal.

c) Efforts to end the systematic underprovision of environmental amenities (resulting from market imperfections), begun in earnest in the first few years of the current decade, should be continued without interruption.[16]

d) Increasing scarcity (perhaps with the exception of that attributable to monopoly influences) should be allowed to be reflected in market prices. Sudden, shocking and perverse distributional consequences should be alleviated through lump sum transfers.

No policy can repeal the entropy law. However, the kinds of policies suggested above will allow us to live with that law as best we can. And, that seems eminently desirable.

Footnotes

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This paper (   ) is published with the approval of the Director of the Kentucky Agricultural Experiment Station. The comments of Dick Norgaard, Angelos Pagoulatos, and others helped me clarify several important points. The views expressed herein, however, are mine alone. The superficial treatment of many issues and the omission of others is not to my taste, but is occasioned by space limitations.

[1]The key words in this sentence are not quite the same as those in the title. This redefinition of the topic at hand is deliberate.

M.G.S. is difficult to define with precision. However, we can include, as a first approximation, all of those items which are market goods and services (i.e. those which contribute to the Gross National Product). *Growth* is then a secular and continuous increase in the output of M.G.S. By focusing on the output of M.G.S., we place growth in its proper prospective. It is simply one of the possibilities for the future: stagnation, decline, and unstable patterns involving phases of growth, stagnation and/or decline are the other possibilities.

Environment is a complex matrix of *environmental amenities*, which are of value to consumers although often entering G.N.P. indirectly if at all, and *resources*.

[2]Since all change involves some entropic degradation, no change is completely reversible. However, many changes are partly reversible, i.e. they may be reversed at some finite cost or, in other words, if some

finite amount of low entropy is introduced into the system. The polar cases of the continuum will seldom (irreversible) and never (reversible) be observed.

[3]The characteristics of flow resources place some limitations on their potential uses. (a) No resource will continue to flow at an undiminished rate forever. The flow of solar energy, however, is expected to continue for a very long time. (b) The rate of flow of a flow resource is for the most part unresponsive to man's attempts to control it. (c) A flow resource must be used when it is provided. If not used today (or at least captured and stored) today's flow cannot be used tomorrow. (d) Flow resources tend to flow into stocks. Thus, all of a flow cannot be used without lowering a stock. Capture of a substantial proportion of the flow of solar energy may lower the temperature of the earth. (e) All but the most primitive production processes using flow resources seem to require the stimultaneous use of some exhaustible resources.

[4]See Bartlett for some insights into the relationships between political and economic power.

[5]That is, fully specified, rigidly enforced, exclusive, transferable, and in no way inconsistent with the marginal equalities necessary for efficiency.

[6]The author prefers this latter approach, to the extent that it is feasible. He is aware of some of the limits to its feasibility.

[7]This implies elimination or modification of many existing public policy and regulatory instruments.

[8]Energy budgeting alone, however, is also misleading. Some forms of energy and low entropy can be used more cost-effectively than others. Outputs are not all of equal value.

[9]There is another, short-term, reason to be wary of immense investments in coal conversion. The current price of oil contains a large element of monopoly profit which could be reduced at will. Oil substitutes produced from coal could overnight become the higher cost alternative.

[10]A major problem facing the policy analyst is the scheduling of the depletion of each exhaustible resource and the implementation of technologies to bring flow resources on line. The risk averse will apply the principle "better too soon than too late" to the latter.

[11]The monopoly element in current petroleum prices makes all policy pronouncements subject to revision on short notice.

[12]On the other hand, particular goals proposed by public agencies (e.g. "zero discharge" into the nation's water ways) go beyond the efficient level of internalization and, if doggedly persued, would result in overprovision of some kinds of environmental amenities.

[13]"If the whole world developed to American standards overnight, we would run out of everything in less than 10 years", (Boulding, p. 166).

[14]The exceptions occur where it is possible to extract huge monopoly rents on raw materials for a long and continuing period (as the OPEC nations have done for few years, as of now).

[15]Ridker *et al.* estimate that resource scarcity will cause few severe shortages in America during the next 30 to 50 years. However, their

definitions and assumptions suggest some cause for concern. Severe shortage is defined as a situation leading to a relative price increase of 50% or greater for any raw material. Thus, Ridker's conclusion could be consistent with sharp relative price increases for many resources. That study assumes continued technological progress and resource substitution, and continued unimpeded imports of raw materials. The possible impacts of (a) increased monopoly influences and (b) rising resource demands in the rest of the world are ignored. Thus, it is possible to read Ridker's "optimistic" study as suggesting less than unrestrained optimism.

[16] And, perhaps, redirected toward making fuller use of the inherent efficiencies of the market system. Total reliance on the market, however, would be naive.

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