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THE LIMITS TO SUBSTITUTION: META-RESOURCE DEPLETION AND A NEW ECONOMIC–ECOLOGICAL PARADIGM

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Some of my best friends are economists. Indeed, some of my closest relatives are economists. I believe that, perhaps even more than ecologists, economists hold the key to the human future. It therefore is critical that members of the two disciplines learn to understand one another and to do so quickly. A certain frankness and willingness both to give and to receive criticism (and to reject erroneous criticism) is required if ecologists and economists—basically members of sister disciplines—are to forge an understanding that will permit them to work together to solve the human predicament. Today, I have been asked to give; tomorrow I will no doubt receive. I pledge to pay careful attention to those who will attempt to point out errors in the essay that follows.

It has long been clear to ecologists that the extreme growth orientation of neoclassical economics is a major component in the failure of politicians, businessmen, and others advised by economists, as well as the public at large, to recognize the increasingly serious predicament of *Homo sapiens*. There are, of course, some farsighted economists who have attempted to swim against the tide of dogma in this area—Herman Daly being an outstanding example. But Daly's cogent analyses (building on the work of Mill, Boulding, and Georgescu-Roegen) have been largely ignored by the establishment within the economic community, although they are attracting the attention of some of the brighter young economists. Indeed, there is a young subdiscipline of environmental economics in which some promising work is being done: for example, Perrings' new book (1987). But environmental economics is itself a mere subdiscipline, fairly low in the professional pecking order. It has only minimal influence on the mainstream of economic thinking. Rather than being central in economic education it is Ch. 45 in the standard texts—an appendage, an afterthought.

From the viewpoint of an ecologist, the failure of the dismal science to contribute to solving the human predicament is understandable from a cursory examination of what economists are taught. All one need do is to look at the circular flow diagram that "explains" the generation of gross

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national product in any standard economics test. There are no inputs into the circular flow; it is simply a diagram of a perpetual motion machine, an impossibility except in the minds of economists. The text does not, of course, give any coverage at all to what is now the central question of economics—what the scale of the economic system can be before it irretrievably damages the ecological systems that support it.

The majority of economists have never been taught that ecosystems provide humanity with an absolutely indispensable array of services, including maintenance of the gaseous quality of the atmosphere, amelioration of climate, operation of the hydrologic cycle (including the control of floods and the provision of fresh water to agriculture, industry, and homes) disposal of wastes, recycling of the nutrients essential to agriculture and forestry, generation of soils, pollination of crops, provision of food from the sea, and maintenance of a vast genetic library from which humanity has already withdrawn the very basis of its civilization. While these services are "free", they would, of course, be infinitely costly to replace.

There already are abundant signs that the scale of the human economy is already larger than can be supported over the long term. At the moment, we are only maintaining somewhat more than five billion people (many of them in utter poverty and degradation) by doing something that no traditional economist would ever recommend for an individual family—squandering a one-time inheritance. Today's level of overpopulation can only be maintained by rapid depletion of Earth's irreplaceable capital—not just mineral resources, but rich agricultural soils, groundwater, and the diversity of other organisms that are working parts of ecosystems. Worse yet, in the process of using up our capital, we are severely damaging the apparatus that supplies us with our only major source of income—natural and agricultural systems which are able to capture the energy of the sun and make it available to humanity.

Since they are unaware of the stress that natural systems are now under, most economists believe that the scale of economic activity can be increased indefinitely (or at least so far into the future that limits to growth need be of no concern today). Many share with Beckerman (1972) the notion that economic growth has gone on since the time of Pericles and can continue for another 2500 years into the future. While a few simple calculations (e.g., Parsons, 1977) show that idea to be ludicrous, its casual acceptance is partly rooted in two related (although not always explicitly recognized) axioms of mainstream neoclassical economics: that there in an infinite number of resources, and that a satisfactory substitute can always be found for the role of any one of them.

Biologists unfamiliar with economic ideas are often shocked when they discover that an industry appears to be deliberately destroying its resource base. The problem first came to my attention when it became clear that the whaling industry was deliberately harvesting whales at a rate that would lead to their extinction. Until then, it had not dawned on me that industries dealing with biological resources were not necessarily concerned with achieving long-term maximum sustainable yields from them (which could be "uneconomic"), but were only concerned with maximizing the return on their capital. If exterminating the resource (wiping out the whales, clearcutting tropical rainforests, exhausting the soils on industrial farms) brought a maximum return, then the resource would be destroyed.

Economists understand very well that, under certain circumstances, present value maximization will result in extinction of the resource being exploited. The rationale of the whalers' behavior came as a surprise to me, but, of course, would not have surprised an economist. I realize that not all economists favor such blind adherence to maximization of present value, but the only one I have seen who has taken the problem seriously enough to suggest an alternative is Page (1977), and his approach has not been accepted by the mainstream.

The tacit acceptance by mainstream economists of behavior leading to the extermination of resources is based on the first axiom. Since an infinite array of resources is believed to exist, after one has been utterly destroyed, there will always be another that can also be exterminated for profit. It is presumed that we can live in a world of high discount rates forever—no need to worry about how today's actions will influence people a decade hence, since those people will be dealing with an entirely new set of resources.

These attitudes have, for example, retarded the conservation of petroleum worldwide and permitted rapid depletion of accessible portions of the Ogallala aquifer under the high plains of the United States. The water in that giant aquifer accumulated over several ice ages; in some places where recharge rates are about one half inch a year, four to six feet of irrigation water has been withdrawn annually. The decision to mine the aquifer to economic exhaustion in less than half a century—the greatest overdraft of groundwater in human history (roughly equivalent to the flow of the Colorado River)—was made deliberately on the assumption that there is an infinite number of tappable water resources. As the state engineer of New Mexico put it, "We can always decide to build some more water projects" (quoted in Reisner, 1986, p. 11; this reference contains an excellent overview of the Ogallala situation). The result of exhaustion of the aquifer in the next few decades will be the bankruptcy of farmers of the high plains and a reduction in harvest of grain in the United States, much of which is now exported.

Theoretically (in an unreal world), there *could* be an infinity of resources, each having dramatically different properties. Even though the opportunities to profit from exhaustion of that stock might be infinite, some resources might be irreplaceable in terms of the functions they can serve in the human economy. Since such a proposition would cast doubt on the "grow-forever" central dogma, many economists have resorted to the classic technique of assuming the problem away, justifying their handwaving by a total misinterpretation of the fundamental physical, chemical, and biological rules that govern the real world.

Barnett and Morse (1963) most clearly expressed the idea that one resource is just like another:

"Advances in fundamental science have made it possible to take advantage of the uniformity of energy/matter—a uniformity that makes it feasible without preassignable limit, to escape the quantitative constraints imposed by the character of the earth's crust... Nature imposes particular scarcities, not an inescapable general scarcity. Man is therefore able, and free, to choose among an indefinitely large number of alternatives. There is no reason to believe that these alternatives will eventually reduce to one that entails increasing cost—that it must sometime prove impossible to escape diminishing quantitative returns. Science, by making the resource base more homogeneous, erases the restrictions once thought to reside in the lack of homogeneity. In a neo-Ricardian world, it seems, the particular resources with which one starts increasingly become a matter of indifference". (p. 11).

Of course, Barnett and Morse had the laws of physics exactly backwards —since it is the *lack* of homogeneity that makes "resources" possible. Energy and matter are not "uniform" because in some circumstances matter is converted into energy (and in theory the reverse can take place), any more than a fine goblet and a pile of broken glass are "uniform". But even if economists were not profoundly ignorant of physics, the practical difficulties commonly encountered in making inorganic substitutions (e.g., nuclear power for fossil fuels, aluminium wire for copper wire) should have led economists to question this obvious fallacy. Economists are even less aware that there are severe problems in making organic substitutions, such as dams to replace the flood-control service of forest ecosystems when the latter are destroyed, or insecticides to substitute for pest control services of natural predators when the predators are killed off (Ehrlich and Mooney, 1983). In fairness, it should be noted that the Barnett-Morse thesis has received in-house criticism from economists and an extreme version of the "substitution" fallacy, limited to the relatively simple case of mineral resources, has been presented by two physical scientists, Goeller and Weinberg (1976). Economists certainly have no monopoly on error.

Of course, some substitutions, such as plastics for other structural materials, petroleum for coal, and small computers for gigantic machines and entire libraries, appear to be very successful. Indeed, the success of the computer industry in sharply reducing the materials and energy required in processing information might be viewed as the ultimate proof that humanity can do anything it sets its collective mind to and improve its environment in the process.

The largely unquantified ultimate social and environmental costs of such "successful" substitutions eventually may provide an entirely different perspective on them, as considerations of loss of privacy, enhancement of destructive power of weapons, and air and soil pollution at source of manufacture might eventually produce in the case of computers. But at the moment, there is no way of making the necessary calculations. The key point is that there is plenty of evidence that the real opportunities for adequate substitution are limited and that even quite successful inorganic substitutions have their drawbacks. For example, plastic cannot now substitute for metals or other materials in many applications, disposal of plastics is an extremely serious environmental problem, and in the long run the plastics industry will suffer from depletion of (and competition for) the petroleum and other fossil fuels from which it is made.

Several conclusions can be drawn from the problem of meta-resource depletion—that is, the reduction of the total number of Earth's exploitable resources through the extermination of populations and species of other organisms, the destruction of forests, the poisoning of aquifers, the erosion of soils, the using up of high-grade ores, and so on. As the process of using up its capital continues, industrial civilization will gradually grind to a halt —providing that war, social breakdown, epidemics, catastrophic climate change, or some other discontinuity does not destroy it first. The timing of such an outcome depends on too many variables to predict accurately, but certainly it is possible before the middle of the next century, and action to avert it should be started *now*.

First and foremost, everything possible must be done to reduce the human population to a size compatible with living on income—with harvesting a maximum sustainable yield of renewable resources. This is a *sine qua non* for the long-term persistence of civilization, because nonrenewable resources are just that. Related to this is the need to halt the conversion of potentially renewable resources, particularly soils and groundwater, into nonrenewable ones. Note that the mathematics of population growth mandate that, even if humane action is taken immediately, it will be many decades before there is any chance of reducing the human population size by lowering birth rates (of course, rising death rates can overtake us any time).

Soils, which are normally produced on a time-scale of inches per thousand years are being lost through erosion on a scale of inches per decade. Again, this is in part due to the high-discount-rate world of the economist in which soil is viewed as just one more rapeable resource rather than as an absolutely indispensible underpinning of civilization.

Similarly, society increasingly depends on groundwater for a critical portion of its food supply. The Ogallala aquifer is just one of thousands being pumped out much faster than they can be recharged. Overdraft of aquifers can convert a renewable resource into a nonrenewable one when the aquifer collapses or is invaded by salt water. Paving over recharge areas can have the same effect, carrying rainwater to drains and then to the sea, rather than permitting it to percolate through the soil to recharge aquifers. And the pollution of groundwater by toxic substances is becoming a worldwide problem. Such pollution can be virtually irreversible, as the normal processes by which sunlight and microbial action break down many pollutants in surface waters do not occur in aquifers. Continuing destruction of groundwater resources, coupled with climate change and burgeoning numbers of people, will greatly aggravate already severe problems of human hunger.

In my opinion, whether humanity will be able to move toward a population size and economic system sustainable largely on income will depend in no small degree on the profession of economics. That, in turn, will require substantial revisions in the professional training of economists. It is already recognized by many economists that graduate education in the discipline focuses too little on important questions of policy and too much on learning to manipulate esoteric mathematical theory based on preposterous assumptions. Colander and Klamer (1987), whose survey showed that many graduate students in economics realize that advancement in the field requires emphasis on such questionable exercises, conclude "that graduate economics education is succeeding in narrowing student's interests". But Colander and Klamer, in their survey of the student's opinions of the importance of reading in other fields to their development as economists, did not list ecology or any other biological science among the fields to be scored by the students. In addition, the lowest score given was to physics. Only 2% of the students considered it very important, 6% important, 27% moderately important, and 64% unimportant. Small wonder that the equivalent of perpetual motion machines remain imbedded in economic thought.

Somehow a new ecological–economic paradigm must be constructed that unites (as the common origin of the words ecology and economics imply) nature's housekeeping and society's housekeeping, and make clear that the first priority must be given to keeping nature's house in order. Unless considerable instruction on the basics of how the physical–biological world works is included in the training of professional economists, most of them will continue to whisper the wrong messages in the ears of politicians and businessmen. The latter, in turn, will continue to see growth of the global economy as the cure rather than the disease.

Of course, resistance to those messages could be much enhanced if every high-school and college student in the nation could be required to take at least one course that gave a basic overview of the "state of the planet". At Stanford University, there recently has been a considerable uproar over the content of required "Western Civilization" courses. But most students (and most faculties) remain ignorant of the size and growth patterns of the human population, what is involved in producing food, how ecosystems provide essential services to society, the comparative deployment of U.S. and Soviet nuclear forces, how their perceptual systems give them a biased and inadequate view of the modern world, the basic theory of evolution, the laws of thermodynamics, or (to move to economics) the notion of present value or whether our children will actually have to "repay" the national debt. All these are much more important to the average citizen than what Plato or Wright wrote or who was gathered at the Council of Vienna (not that well-educated people shouldn't know those things also!). The complacency with which our education system at all levels accepts the production of citizens unequipped to deal with the modern world is a national disgrace.

Can economists reform their discipline and help pull humanity through the crisis decades ahead? Can they begin to interact more with ecologists so that this blissful ignorance of important economic concepts that so pervades my discipline can be alleviated. I hope so. I also hope that my own colleagues will become more receptive to what their sister science can help them to understand. After all, the roots of the names of our disciplines are the same, and their fundamental concerns are deeply intertwined.

You will know there is a chance when the President's Council of Economic Advisors recommends that it be subsumed in a new "Council of Ecological and Economic Advisors", when a central problem of economics is seen to be devising an economic system with the proper scale and attributes to permit it to function permanently within environmental constraints, when growth is always discussed in a context of counterbalancing shrinkage and redistribution, and when all ecologists are required to have a course in environmental economics as part of their training. When that has occurred, mainstream economics as a profession will have become a force for survival rather than for destruction, as it all too often is now—and mainstream ecologists will look to economists for desperately needed help in creating a sustainable society.

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