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RESOURCE SCARCITY, INTERTEMPORAL ALLOCATION, AND COEVOLUTIONARY DEVELOPMENT

by

Richard B. Norgaard

California Agricultural Experiment Station
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The scarcity of natural resources and the optimal use of resources over time have been among the important, long-standing, and productively disturbing issues in economics. The subdiscipline of natural resource economics centers on these questions while other subdisciplines, especially development economics, hinge on their answers. Scarcity and allocation questions have been framed predominantly in a physical science-engineering format as issues of the adequacy and use of separable energy and material factors of production. Beyond economics, there is another view that posits man's future in terms of how well he interrelates with nature. This second view is based in natural philosophy and, more recently, in the science of ecology. In this paper, I juxtapose these two views and suggest a linkage--the concept of social and ecological coevolution--which yields some interesting insights into resource scarcity, intertemporal allocation, and economic development.

Within economics, to date, both questions of resource adequacy and intertemporal allocation have been framed and modeled in a stock-flow format. Resource use is a flow which depletes an existing stock of reserves while new discoveries and technological changes can augment the stock. The two landmark works--Hotelling's [1931] theoretical framing of intertemporal allocation and Barnett and Morse's [1963] empirical analysis of resource scarcity--and the subsequent literature take a "bathtub" perspective of the world.[1] In this more recent view, man's tenure on earth is a question of the relative rates at which the bathtub of separable physical resources is both draining and filling.

A different and historically antecedent view contends that man's tenure on earth depends on maintaining a harmonic relationship with the natural world.

This perspective emphasizes man's options and limits as part of a much larger living system. The perspective is grounded morally in nearly every religion in the world. In the United States, the view has been developed further by such philosopher-naturalists as George Perkins Marsh, John Muir, Aldo Leopold, Joseph Wood Krutch, and Loren Eisely. The development of ecological knowledge during the past century has provided an increasingly strong scientific foundation for this perspective. Far more than does the physical science-economic bathtub perspective, this view provides the philosophical and scientific bases for the environmental movements during the past century and for much of our resource and environmental policies.

The disparity of the two views is rooted in the differences between the physical and biological sciences and in their disciplinary separateness. Cross-fertilization between disciplines, however, occurs typically when real-world decisions must be made. In this regard, economists find themselves in a good position but poorly equipped to assist the interchange. Why this is so is clear. The bathtub view conveniently stresses separable resources which are combined in economic production and related to each other through markets. The harmony-with-nature view, on the other hand, emphasizes complex relationships within ecological systems--relationships that cannot be integrated neatly with existing economic models. For this reason, the harmony-with-nature view has received only brief attention in the economic literature.[2]

The coevolutionary perspective adopted in this paper provides a link between economic and ecological paradigms. The perspective emphasizes how man's activities modify the ecosystem and how the responses of the ecosystem provide cause for subsequent individual action and social organization. A linkage is quite different from a grand synthesis of previously incongruous paradigms. Through a linkage, each discipline enriches the other because of their differences. Neither discipline must abandon its past. Eventually, however, new emphases and approaches arise because of this enrichment. This paper identifies and explores some of the new directions indicated by the coevolutionary perspective for natural resource economics.[3]

Coevolutionary Development

The ecosystem evolved from simple, one-celled anaerobes to the highly diverse, oxygen-based system of today. The oxygen we breathe, the plant and animal life we eat, and the hydrocarbons we tap to fuel our industries are all due to biological processes that evolved and functioned over time. Man could not have existed before this evolutionary process occurred, and the relatively favorable position in which man now finds himself is still attributable more to evolutionary good luck than to man's ingenuity or other characteristics.

In ecology, coevolution refers to an evolutionary process based on reciprocal responses of two closely interacting species [Ehrlich and Raven 1964]. Coevolutionary explanations have been given for the shape of the beaks of hummingbirds and of the flowers they feed on, the behavior of bees and the distribution of flowering plants, the biochemical defenses of plants and the immunity of their insect prey, and the nature of numerous other tightly interactive components of the ecosystem. The concept can be broadened to encompass any on-going feedback process between two evolving systems. Social and ecological systems also interact. When this interaction is not mutually destructive, the two systems coevolve.

Until the exploitation of coal and the industrial revolution, economic and social development was largely coevolutionary. Man, perhaps more than any other species, deliberately and significantly disturbs his environment. Through natural selection and, increasingly, through trial, error, and learning, individual men and societies have changed the way in which they interact with ecosystems. In the early years, changes in these relationships largely entailed niche expansion by out-competing similar species in the food chain. Later, through increasingly effective agricultural practices, man moved down the food chain, displacing numerous species along the way and transforming soil-plant relationships farther down the chain. These changes occurred over centuries through a process of reciprocal reactions and responses between social and ecological systems. Such interactive changes did not always favor man but, when they did, there was coevolutionary development.

Cultural ecologists have described how the structures of social systems from an anthropological perspective are related to ecosystem characteristics under hunting and gathering, grazing, and traditional agricultural technologies [Netting 1977]. The rise of paddy rice culture can be viewed as an increasingly effective environmental transformation which required some types of social development and allowed others [Geertz 1963]. Ecologists are also becoming increasingly sensitive to how man's activities have affected the evolution of ecosystems [Ellenberg 1979, Edens and Koenig 1980].

Coevolutionary development can be envisioned as a sequential process in which a surplus of energy and human capital beyond that necessary to maintain the social and ecological systems in their present states is directed to or fortuitously results in the establishment of a new interaction between the two systems. If this new interaction is more favorable to man and a surplus produces further beneficial changes, then coevolutionary development is underway. A surplus can result from transforming the ecosystem so that it captures a greater portion of the sun's energy or transforming it so that it uses less energy for its maintenance needs. Similarly, a surplus can occur by changing technologies, structures, or values so that the social system uses less energy for its maintenance needs. If the gains from development are real, not simply one generation living at the expense of the next or one region or group living at the expense of others, it is difficult to imagine how the gains could arise other than by a process of positive feedbacks between the social and ecological systems whereby the two systems coevolve in a manner favorable to man.

Resource-Exploitive Development[4]

In the stock-flow perspective, the world consists of effectively unlimited stocks of various materials of different qualities or different levels of entropy. Given a particular array of technologies, only the stocks of a particular quality or better are resources, i.e., stocks that can be exploited with a net gain in labor and capital. Clearly, if technology remains constant, any increase in economic well-being in one time period must be at the expense of economic well-being in other time periods. If technology improves, the stock of resources expands, but resource limits still imply that more today means less tomorrow. The only way to break out of the stock constraint and have development is to make continuous technological improvements--forever--which augment resource stocks more rapidly than their use depletes them. Indeed, even maintaining the economy at one level of development requires continuous technological advance to offset resource depletion.

Georgescu-Roegen [1971] has effectively counterargued that technological change simply allows us to exploit low-entropy resources faster and, thereby, to transform the favorable order of the natural world into a homogeneous garbage dump sooner. This devastating critique is valid within the physical science boundaries of the stock-flow view of the world. But the critique, like the view itself, assumes that continuous technological advance is possible. Ever more sophisticated technology to exploit increasingly intractable resources requires continuous improvements in man's abilities. In 1870, about 0.25 percent of the population between 18 and 65 years of age was enrolled in higher education acquiring the knowledge to develop and utilize new technologies. In 1920, almost 1 percent of the working-age population was investing in higher education rather than working. This proportion rose to 6.2 percent by 1970 and an estimated 9.7 percent in 1980.[5] This dramatic increase is representative of other phenomenal changes in our society, most importantly the rise of a substantial research and development component and of public and private bureaucracies to capture the gains and minimize the side effects of new technologies. These social transformations necessary for technology's advance have limits. It is not surprising that the cost and productivity of the research and development establishment and the size and effectiveness of bureaucracies are identified as major factors limiting economic development in the United States today.

Development based on resource exploitation becomes even more difficult to imagine when we acknowledge the existence of environmental systems and attempt to include them in the resource stock-flow picture. Increasingly, we are becoming as concerned with the vulnerability of environmental systems to stock exploitation as we are concerned with the adequacy of the stocks themselves. The changes wrought by energy development on air, soil, and water and on the life systems they support are the major issues of U. S. energy policy today [Budnitz and Holdren 1976, Lave and Silverman 1976, Gollehon, et. al. 1981]. Environmental impacts and their resolution are not easily added to the stock-flow model. Indeed, these effects are labeled externalities because they are external to all of our models and are given significant consideration only in the nearly separate subdiscipline of environmental economics.

Concern with the adequacy of stock resources and the increasingly intractable social and environmental consequences of stock-resource exploitation has led to more interest in renewable resources [Harte and Jassby 1978; King and Cleveland 1980]. The relative cost of tapping the sun's energy--directly, indirectly through wind and hydropower and, even more indirectly, through agriculture and forestry--has, no doubt, declined significantly since the embargo by the Organization of Petroleum Exporting Countries (OPEC). Our approach, however, still is to treat renewable resources as separable and analogous to flows from stocks and to treat the environmental consequences of tapping these flows as external costs [Holdren, Morris, and Mintzer 1980]. The approach taken to renewable resources, thus far, is closer to the stock-flow model than to the coevolutionary perspective with its emphasis on compatible social and ecological adjustments.

Models of resource exploitation and measures of resource adequacy, to date, nearly ignore both the public resources used to generate and sustain new technologies and the social and environmental consequences of resource exploitation. Indeed, by looking only at labor and capital used per unit of output produced, the most accepted measure of scarcity ignores even purchased inputs. In U. S. agriculture, expenditures on fuel, electricity, water, fertilizers, and pesticides--the very inputs that characterize modern agricultural technology--now rival expenditures on labor. The production and distribution of these inputs link agriculture with every significant sector of the U. S.

economy and with resources from the far corners of the earth. The exploitation of lower quality hydrocarbons requires greater expenditures on energy and water. The stock-flow approach and the indicators that economists have developed around this type of model slight the interconnections within and between social and ecological systems. The bathtub approach is weak in the very areas of resource policy concern today.

The Coevolutionary Emphasis

Many economic views of western history emphasize the dramatic increase in the productivity of the few individuals still working in the primary sector, an increase that is generally seen as stemming from those individuals being freed of environmental constraints. The coevolutionary perspective emphasizes the increase in individual task specialization and the increase in the organizational complexity of maintaining feedback mechanisms between specialized actors within the social system and with the ecosystem. These perspectives are not incompatible. The coevolutionary perspective, however, stresses social and environmental feedbacks and the evolution of both social and ecological systems.

Agriculture in Western Europe and North America was once a small-scale, labor-intensive, polycultural, near-subsistence interaction of the social system with the ecosystem. From this, it coevolved to a large-scale, mechanized and energy-intensive, monocultural commercial farming interaction buoyed by farm implements and agrochemical industries; a highly developed marketing system; and public institutions to generate and disseminate knowledge, develop new inputs, regulate markets, absorb risk, limit distributional impacts of adjustments, and control environmental and health-related externalities. The various elements of the social system evolved, in part, in reaction to the nature of the responses of the ecosystem to man's activities. While monocultural production brought increasing returns to scale with mechanization, their ecological instability encouraged the development and use of agrochemicals and of risk-spreading institutions. Similarly, responses of the ecosystem to agrochemicals have led to new pesticide and water pollution regulatory institutions as well as to new research programs in agricultural experiment stations. Equally important, the institutional responses frequently encouraged further changes in similar directions. Crop insurance and regulated markets, for example, reduce the risks of monocultural production and make it even more attractive. Today's agricultural ecosystems have soil features, weed dynamics, and insect-crop interactions that reflect coevolution of the ecosystem with the social system much the same as today's agricultural institutions reflect the vulnerability of disturbed soil to wind and water erosion, the rapid adaptations of insect populations to chemical treatment, and the susceptibility of monocultural systems to variations in the weather.

The concept of coevolution provides a link between economic and ecological thinking and enhances our perception of interrelationships. The coevolutionary perspective, however, is only a perspective; it is not a formal model. As such, it provides an interesting viewpoint from which to evaluate the stock-flow model. Perspectives are also important in knowledge gathering, information acquisition, and "informal" decision making.[6] While a formal coevolutionary model may never be possible, the next section indicates how the stock-flow model could be modified to incorporate coevolutionary phenomena.

Stock Resources in a Coevolutionary World

The concept of coevolutionary development has been presented, thus far, simply in the context of social and ecological interactions. Implicit in the presentation was the assumption that these interactions could continue at their current levels as long as the sun shines. Social and ecological systems can, of course, coevolve along a path where the interactions at any point along the way cannot be sustained. This would, by definition, occur when the interaction does not meet the maintenance needs of the two systems. Coevolutionary development was defined as a change which either met the maintenance needs or produced a surplus and favored man.

Stock resources cannot be relied upon for maintenance needs in the coevolutionary development framework since they cannot be used in perpetuity. Stock resources, however, can be used to affect coevolutionary change. Instead of having to rely on a surplus from the existing interaction for the investments necessary to change to a new interaction, stocks can be exploited to make the change. Given a social and ecological interaction that is not generating a surplus but has a coevolutionary opportunity, the option to exploit stock resources eliminates the problem of whether or not the chicken can come before the egg.

The fact that stock exploitation for consumption does not fit the definition of coevolutionary development does not mean that a society should not attempt resource-exploitive development. However, given the existence or the potential of coevolutionary development options, stock-resource use for consumption or investment in resource-exploitive development has several coevolutionary opportunity or user costs.

The first of these user costs is that the stock resources will not be available for investment in coevolutionary change. Since the optimum future coevolutionary development path is not known at any point in time, the coevolutionary investment user cost of exploiting stock resources is, at best, a probability-weighted, discounted sum of the higher investment costs using other resources of reaching alternative social system-ecosystem interactions and the discounted value of any interactions foregone.

The second user cost, and probably the more important, is that the social system and the ecological system are likely to evolve during stock exploitation to states that are poor starting points for subsequent interaction, let alone coevolution, when the resource becomes depleted. Ecologists warn us repeatedly of the potential detrimental consequences of species extinction and irreversible ecosystem transformations [Ehrlich and Ehrlich, 1981; Myers, 1979]. Social systems suffer from similar transformations. Nearly a decade after the OPEC embargo, institutions in both the developed and developing world are still changing and at great cost in order to complement the new relative prices for energy-related goods and services. In the United States, the tendency to favor switching to other stock resources, such as coal and oil shale rather than to solar or wind power, is probably better explained by the compatibility of prior institutions than by relative costs in a narrower technological sense.

Development paths take social and ecological systems to states from which other development paths may be difficult or impossible to reach. Some paths, presumably, retain more options and flexibility; they eliminate fewer options and allow changing paths at lower cost. The second type of opportunity costs of exploiting a resource is the future transition costs or value of the options totally excluded by the social and ecological system transformations associated with the exploitation. Since the optimum coevolutionary development path is not known at any point in time, the transition-related user costs in a coevolutionary world will, at best, be a probability-weighted sum of the discounted expected costs of transitions to alternative social system-ecosystem interactions.

The pursuit of a coevolutionary development path can have analogous opportunity effects but there is the potential for benefits as well as for costs. I stressed earlier that evolution has, by chance, favored man. Initially, the world did not have the biological components or even the physical order which man now labels as resources. From a perspective limited to man and earth, evolution has been a negentropic process.[7] The coevolutionary view clearly challenges the connections between thermodynamics and economic development drawn by Georgescu-Roegen [1971]. Although one cannot deny the universal applicability of the Second Law of Thermodynamics, the possibilities for local entropy decreases must be admitted. Georgescu-Roegen [1971] acknowledges the incredible energy and long life of our sun and its importance to economic well-being over the long run. His references to biological processes and evolution, however, tend to be limited to the directionality or irreversibility of biological processes, phenomena he associates with the directionality of the Second Law of Thermodynamics.[8] What Georgescu-Roegen does not fully acknowledge is that man could not have existed on the earth four and one-half billion years ago, before life began to evolve an order--through the use of solar energy--that had low entropy for man. The oxygen we breathe, the plant and animal life we eat, and the hydorcarbons we tap to fuel our industry are all due to biological processes. Even the ordering of minerals has improved for man over eons by various physical processes stemming from solar energy and the gradual cooling of the earth.

This seemingly optimistic view, however, must be tempered by three severe caveats. First, evolution and our favored position therein have largely been a process of chance. Unless man learns how to influence the process, we are as likely to go the way of the dinosaur as not. Second, although no available data are adequate, many scientists are of the persuasion that we are currently exploiting the accumulated low entropy of our environment, through both extraction and pollution, to the detriment of future generations far faster than we are coevolving with nature to the benefit of future generations. In this sense, Georgescu-Roegen may be quite correct; most of the technologies we associate with development may simply allow us to utilize low-entropy stocks faster. And, third, too little of our knowledge accumulated to date or of our current accumulation effort is directly applicable to the immense task of influencing coevolution to our benefit. A coevolutionary path of progress will not easily be found or followed.

The negentropic potential of coevolution raises an interesting theoretical issue. Components of the ecosystem which are viewed as having low value (high entropy), given an existing social and ecological interaction, may be highly valued resources under a different interaction. This is a third new type of opportunity cost. There is also the possibility that low-entropy resources will have a higher entropy after a coevolutionary change. In this case, the user cost under the current social and ecological interaction will be perceived as being higher than it really is, and too little of the resource will be used prior to the coevolutionary change. Since the optimum coevolutionary path is not known at any point in time, this third type of user cost will, at best, be a probability-weighted sum of the expected user costs under alternative future social system-ecosystem interactions.

Conclusions

Economic thought typically stems from and reinforces real-world institutions. There is good reason to believe that stock resource exploitation in fact reflects a bathtub view of the world that is poorly integrated with the evolution and potential for evolution of social and ecological systems. To the extent this is the case, stock resources are being misallocated for lack of consideration of coevolutionary opportunity costs. These costs fall into three categories: (1) the losses associated with not being able to use stock resources for investment in coevolution, (2) the losses associated with returning to and accepting a less advantageous coevolutionary path when the stock is depleted, and (3) the losses associated with not taking into account the shifts in the relative qualities of resources at different stages of coevolution. Ignoring coevolutionary opportunity costs results in an overuse of stock resources, or at least an overuse of the types of stock resources we now use and for the purposes we use them.

Looking at resource allocation more broadly, not considering coevolutionary opportunity costs distorts the relative costs of factors and prices of products. Skills associated with stock-resource exploitation are overvalued relative to skills associated with environmental management. Stock resource-intensive products are underpriced relative to labor and flow resource-intensive products. Research effort is overallocated to exploitation technologies and underallocated to environmental management technologies. If we had more of a harmony-with-nature view of the world that incorporated coevolutionary opportunity costs, our economy would probably be significantly different.

From an even broader perspective, however, it is difficult to imagine possible institutional changes that would insure that coevolutionary opportunity costs would be reflected in economic decisions. In part, this is because the evolutionary way of thinking is not well developed. More importantly, however, it is unlikely that coevolutionary opportunity costs can be neatly accounted for in property rights, liability rules, or procedural rules because the course of evolution is unknown. The real uncertainty of the future doesn't increase as we shift from a bathtub to coevolutionary perspective. Indeed, to the extent the coevolutionary perspective is more realistic, uncertainty should decrease. Evolutionary perspectives, however, explicitly acknowledge change and uncertainty. Both variables and parameters change with evolution.[9] It seems that more explicit acknowledgement of a coevolutionary perspective would entail great contradictions or a clear move away from formal analysis and formal institutions--especially large, inertia-bound, centralized institutions--toward more informal and flexible institutions. The gains from taking a coevolutionary world view may be more easily captured through the development of conservation philosophies, land ethics, and social pressure than through new legislation.

Footnotes

The author is Associate Professor, Department of Agricultural and Resource Economics, University of California, Berkeley.

[1]When David W. Seckler, now with the Ford Foundation, was a Professor at Berkeley, he jokingly referred to this as the "Mother Hubbard's Cupboard" view of resource scarcity.

[2]See, for example, Barnett and Morse [1963], pp. 22-33. Kenneth Boulding has most persistently kept the harmony-with-nature view from completely disappearing from the economic literature.

[3]In earlier articles, I applied the perspective to the specific problems of development in the Amazon [Norgaard, Richard B. "Sociosystem and Ecosystem Coevolution in the Amazon," Journal of Environmental Economics and Management 8 (Sept.): 238-54] and reviewed its roots and its general significance to agricultural development economics [Norgaard, Richard B. "Coevolutionary Agricultural Development" (forthcoming in Economic Development and Cultural Change].

[4]This section assumes that the reader is familiar with Hotelling [1931], Barnett and Morse [1963], Georgescu-Roegen [1971], Dasgupta and Heal [1979], Burness, Cummings, Morris, and Paik [1980], and Smith [1980].

[5]A log-linear estimate of the relationship between time and the proportion of the working-age population enrolled in higher education at the beginning of each decade between 1870 and 1980 has a surprisingly good fit. Simple regression analysis yields the equation, $\ln Y = -3.6303 + 0.0312t$ with an $R^2 = 0.98$ (with all due respect for Harvard, R^2 was highest with $t = 0$ set around the year 1800). If this relationship continues, 100 percent of the

population will be enrolled in institutions of higher education by the year 2063 with no one left for administration, teaching, and maintenance. One can certainly argue that higher education serves more purposes than to develop the personnel to discover and work with new technologies. But even if 50 percent of the enrollment has been unrelated to developing and living with new technologies, the date when 100 percent of the working population "must" be in school is only pushed back to 2086. The point is not to suggest that this will indeed happen but to illustrate the absurdity of presuming that the future can be a continuation of the past.

[6] I use the term "informal" in reference to decisions made or adjusted without reliance on formal models and quantification. Informal should not connotate looseness, subjectivity, or any other negative quality. In spite of the increasing faith in formal decision making, Stuart Dreyfus [1980] makes a strong case for the use of more informal processes in economic and social decision making.

[7] Evolution does not defy the Second Law of Thermodynamics. Evolution can only be viewed as negentropic by ignoring the universe beyond man and earth (see Harold F. Blum [1968] and Kenneth E. Boulding [1981] pp. 149-151).

[8] See, in particular, Chapter 8, "Evolution versus Locomotion," in Georgescu-Roegen [1971].

[9] See Boulding [1981] Chapter 1, and pages 87 and 88 for an interesting discussion of this and related issues.

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