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Technology and the Environment

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TECHNOLOGY AND THE ENVIRONMENT*

Vernon W. Ruttan

Introduction

A belief that the application of science to the solution of practical problems represented a sure foundation for human progress has represented a persistent theme in American intellectual and economic history [26, 64]. During the two decades following World War II this belief was seemingly confirmed by the dramatic association between the progress of science and technology and rapid economic growth. The technological revolution in American agriculture, the growth of industrial productivity, the contributions of science to military and space technology and the virtual elimination of the business cycle seemed to reinforce this perspective.

By the late 1960's, however, the formula which had permitted the U. S. to move into a position of scientific, economic, and political leadership in the world community was faced with both an intellectual and a "populist" challenge[1]. A view has emerged to the effect that the potential consequences of the power created by modern science and technology--as reflected in the cataclysm of war, the degradation of the environment, and the psychological cost of rapid social change--are obviously dangerous to the modern world and to the future of man. The result has been to seriously

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question the significance of scientific progress, technical change, and economic growth for human welfare.

Three Generalizations

In my judgment the response by economists to the challenges posed by these concerns has been overly defensive. Nevertheless, it seems useful to re-emphasize certain considerations that have frequently been ignored in the heat of the challenge to economic thought and economic policy. Let me summarize my own perspectives in the form of three generalizations.

First, man has, throughout history, been continuously challenged by the twin problems of (a) how to provide himself with adequate sustenance, and (b) how to manage the production and disposal of what, in the recent literature, has been referred to as "residuals"--and in less elegant language as garbage [43]. Failure to make balanced progress along both fronts has, at times, imposed serious constraints on society's growth and development[2/]. The current environmental crisis represents, in my view, one of those re-occurring times in history when technical and institutional change in the treatment of residuals has lagged relative to progress in the provision of sustenance, conceived in the broad sense of the material components of consumption.

Second, in relatively high income economies the income elasticity of demand for the commodities and services related to sustenance is low, and declines as income continues to rise; while the income elasticity of demand for more effective disposal of residuals and for environmental amenities is high and continues to rise[3]. This is in sharp contrast to the situation in poor countries where the income elasticity of demand for sustenance is high and the income elasticity of demand for environmental amenities is low. The sense of environmental crisis in the relatively affluent countries at this time stems primarily from the dramatic growth in demand for environmental amenities.

Third, the capacity of a society to solve either the problem of sustenance or the problems posed by the production of residuals is inversely related to population density and the rate of population growth; and it is positively related to its capacity for innovation in science and technology and in social institutions. I take it as axiomatic that population growth is competitive with improvements in the quality of life in poor countries and that achievement of a population growth rate well below 1.0 percent per year within the next generation would represent a highly desirable policy objective for all nations. At the same time it is clear that in the high income countries of the West, and in Japan, neither current nor projected population growth represent, in the foreseeable future, a serious constraint on the capacity to provide desirable increments in both sustenance and environmental amenities [48]. The advance of science and technology has enabled modern society to achieve a more productive and better balanced relationship to the natural world than in the ancient civilizations or in the earlier stages of Western industrial civilization. And continued technical advance is essential for further advances in both the material and esthetic dimensions of culture. The fundamental significance of technical change is that it permits the substitution of knowledge for resources; or of less expensive and more abundant resources for more expensive resources; or releases the constraints on growth imposed by inelastic resource supplies. In this perspective the rhetoric about "finite earth" is clearly misleading. The impact of science and technology has been to expand the size of "space ship earth" along those dimensions that are most significant for human existence.

Resource Requirements for Growth

Let me now return to the resource requirements for growth. We are now in the second major wave of concern with natural resource policy since World War II, and the fourth since Malthus [8]. The first post-war wave of concern was in the late 1940's and the early 1950's. This concern focused primarily on the quantitative relations between resource availability and growth--on the adequacy of land, water, energy, minerals, and other natural resources to sustain growth. The reports of the President's Materials Policy Commission [62] and the President's Water Resources Policy

Commission [63] were the landmarks among the post-war resource assessment studies generated by this wave of concern.

A basic issue in these resource assessment studies was an operational definition of scarcity. Physical indicators were clearly inadequate and misleading. The scarcity implications of indicators such as (a) estimated reserves of energy and mineral resources and (b) of the productive potential of agricultural land failed to materialize. Indeed, surpluses of resource products have frequently been apparent even as scarcity predictions were announced.

In 1952 the President's Materials Policy Commission concluded that, "in the U. S. the supplies of the evident, the cheap, the accessible are running out" [62]. However, during the last decades we have enhanced our ability to upgrade old resources, to discover new ones, to utilize them more efficiently, and to adjust to changes in relative resource availabilities. There has been a decline in the resource component of national output and both an absolute and relative decline in employment in the resource sectors [4]. If the Materials Policy Commission were writing today it would have to conclude that there have been abundant examples "of the non-evident becoming evident; the expensive, cheap; and the inaccessible, accessible."

Clearly an operational definition of resource scarcity requires an indicator that reflects economic as well as technical considerations. After a decade of methodological discussion and technical debate it has generally been accepted by economists and by knowledgeable scientists and resource program administrators that the price system provided the most effective indicator available of both absolute and relative resource scarcity [4]. A secular increase in the price of the product of a resource industry--the price of crude oil or the price of wheat--relative to the general price level can be regarded as a reasonably accurate indicator of resource scarcity. Similarly, a secular decline in the real price of the products of a resource sector can be regarded as an indicator of a reduction in scarcity. In fact, the relative prices of most broad classes of resource products have been declining (forestry, minerals, agriculture). Some resource products, the non-fuel minerals for example, are intermittently plagued with specific shortages (copper, sulfur, tin, etc.). But a stretch of high prices has not yet failed to induce successful efforts to locate new deposits, exploit old ones, and promote substitution of more abundant for relatively scarce resources [47,61].

There has been some questioning, during the last several years, whether these propositions remain as firmly grounded in empirical fact as they appeared to be in the early 1960's [57]4/. There has, for example, been rising concern with respect to energy shortages and with the drain which economic growth in the developed countries places on world resources [83]. The current energy "crisis" appears to reflect institutional contraints on allocative mechanisms and the increasingly effective efforts of the raw material producing countries to broaden their shares of the economic rent from exploitation rather than technological or resource contraints [76, 84]. And the stress which economic growth in the U. S. and in the other rich countries is placing on world resources appears to reflect excessive investment in military and space technology and effort, which is not only excessive when evaluated in terms of net social return on a global basis, but is relatively intensive in its demands on energy and materials resources[5/].

The Demand for Environmental Services

In this second post-war wave of concern with natural resource policy the traditional concern with the adequacy of the natural resource base to sustain growth has been supplemented by an intense concern with the stress on the environment associated with economic growth. We are now experiencing the effects of a rapidly rising demand for environmental services pressing against a relatively inelastic supply. The rising demand for environmental services is derived from two sources. One source is the rising demand for the environmental assimilation of residuals. This source of growth in demand is derived from growth in commodity production and consumption plus the energy production and transportation services associated with commodity production and consumption [43, 71].

The second source of growth in demand for environmental services is associated with the rapid growth in consumer demand for environmental amenities--for the direct consumption of environmental services--arising out of rapid growth in per capita income and a high income elasticity of demand for such environmental services as freedom from pollution and congestion[6/]. The rising competition between the demand for environmental services for the disposal of residuals and for resource amenities is resulting in a dramatic rise in the economic value of common property resources formerly regarded as free goods [31, 43].

As economists have worked with other environmental scientists on issues related to the demand and supply of environmental services, the problem of operational definitions of demand, supply, and scarcity have again risen as a central concern in the field of resource economics. It is again apparent, as when the concern was primarily with the quantitative or materials (or resource input) dimensions of resource policy, that physical criteria (algae bloom, sulphur dioxide and carbon dioxide concentration in the air, biochemical oxygen demand (BOD) levels and concentrations of non-degradable pollutants in streams or lakes, destruction of rare natural environments) are, by themselves, no better guides to the solution of resource and environmental policy issues than in the past.

It does seem clear that any analytical system that will improve our capacity to arrive at an operational definition of scarcity must be capable of integrating physical and biological information with economic, social, and behavioral knowledge on both the demand and the supply side[7]. This is an essential step in the establishment of priorities for investment and management. In addition to the conceptual difficulties there is a basic lack of data about the eco-system. My own reading of the literature leads me to the conclusion that no one knows, with any useful degree of precision, the extent to which the basic metabolic processes of the biosphere are being disturbed by activities leading to environmental modification. And there is even less information as to whether the effects of the environmental modifications that are occurring are, on balance, favorable or unfavorable to the future of the human environment--to the future of man[8]. There can be no question, however, that the problems of environmental congestion and pollution have achieved serious dimensions in specific localities and regions and that the casual use and diffusion of certain materials, such as chlorinated hydrocarbons, represents a serious threat to environmental stability, public health, and economic activity.

With the exception of work on the economics of recreation services and cultural amenities, economists have not seriously tackled the problem of providing quantitative measures of the demand for resource amenities[9/]. Nor do we have a generally accepted theory of aesthetics that can serve as an effective guide to non-market choices in the ordering of priorities for investments designed to provide the resource amenities for which the market fails to make adequate provision [46]. We have, as yet, no clearly acceptable guides to priorities in public policy with respect to environmental quality.

Induced Technical Change

Recent debate with respect to environmental policy has tended to polarize around two alternatives. One is the anti-growth movement. Boulding [10, 11] and others have suggested a model, based on analogy with the bio-ecological model of a stable equilibrating system, which suggests the necessity of redirecting economic activity to limit the environmental stress resulting from human intrusions on the natural environment. My own inclination is to emphasize a second alternative, the redirection of technical effort to permit continued acceleration of the performance of the eco-system.

Technical effort can be redirected toward reducing environmental stress. This alternative has been disregarded in much of the literature of the "environmental crisis". In past this stems from the positive, almost metaphysical, value placed on "equilibrium" in the bio-ecological model. In my judgment it stems to an even greater degree from a view that progress in science and technology is essentially autonomous-unresponsive to social and economic forces[10/].

By and large, this view has remained unchallenged by the historians and philosophers of science and by most social scientists. In economics, for example, technological change has typically been treated as exogenous to the development process[11/].

Recent theoretical and empirical investigations, however, are resulting in a new perspective which views technical change as a dynamic response to resource endowments and to the social and economic environment. Hicks suggested, as early as 1932, that the direction of technical change could be influenced by changes or differences in the relative prices of factors of production [40]. This view was challenged by Salter [73]. The dominant view in economics has been that firms are motivated to save total cost for a given output; at competitive equilibrium each factor is being paid its marginal value product; therefore, all factors are equally expensive to firms; hence there is no incentive for competitive firms to search for techniques to save a particular factor[12/].

The major weakness of this argument was the failure to recognize that the process of technical change is, itself, a resource using activity. It is now clear that much of scientific research, and also a large part of education and training can, for purposes of economic analysis, be regarded as resource using activities producing new forms of physical and human capital that are more efficient than older forms [75].

As prices change firms are not limited to simply reallocating resources among known technical alternatives--along the neo-classical production function. They can instead allocate resources to open up new technical opportunities, which expand the scope for factor substitution, along a perceived innovation possibility frontier or meta-production function. Introduction of this perspective has lead to an extension of the neo-classical theory of the firm to demonstrate that it is rational for firms to allocate research and development resources to facilitate the substitution of increasingly less expensive factors for more expensive factors[13/].

The basic limitation of the theory of induced innovation, as it now stands, is that the discussion has been conducted entirely within the framework of the theory of the firm. There is no theory of induced innovation in the public sector. But development processes are not limited to those which are well understood or have been adequately modeled. The specific mechanisms which act to induce technical change in the private sector are a sub-set of the more complete set of processes which induce learning behavior in the direction established by social priorities within a wide variety of institutional settings.

Empirical investigation of the induced innovation process has not been constrained by the lack of a fully articulated theory of induced innovation. Schmookler's definitive studies suggest that while autonomous discoveries in pure science--those unmotivated by technical or economic objectives--sometimes provide the stimulus for technical change in the science based industries, most technical change derives from the recognition of a technical problem or opportunity evaluated in economic terms [41, 69, 74][14].

The work that Yujiro Hayami and I have recently completed goes beyond the earlier literature to demonstrate historically the effective operation of an "induced innovation" mechanism in public sector research and development similar to the Hicksian theory of induced innovation in the private sector [33, 34]. In both Japan and the United States a common basis for rapid growth in agricultural output and productivity was the adaptation of agricultural technology to the sharply contrasting factor endowments in the two countries. In both countries public and private sector agricultural research developed a remarkable capacity to generate a continuous sequence of innovations in agricultural technology biased toward removing the most serious constraints on growth of agricultural output. In Japan these innovations were primarily biological and chemical. In the United States they were primarily mechanical and engineering. Only in the last several decades has there been what appears to be a movement toward convergence in patterns of technical change in the two countries.

Our empirical tests of the induced innovation hypothesis clearly support the conclusion that the enormous changes in factor proportions, and in factor productivity, represented a process of dynamic factor substitution associated with non-neutral changes in the production surface induced by secular shifts in relative factor prices. In both the United States and Japan the progress of public sector agricultural research has been powerfully directed by the conditions of resource supply and product demand to the extent that these forces were reflected through factor and product markets. There is also evidence to suggest that in recent years, when the implications of market forces in both factor and product markets have been partially obscured by non-market constraints on resource use, there has been substantial misallocation of public sector agricultural research resources.

Let me emphasize that the model of induced innovation which we have developed remains incomplete. It does not possess formal elegance. It does not adequately explain the feedback process by which public sector resource allocation responds to relative factor endowment and factor accumulation--or to environmental stress. It has been argued that the failure of public sector allocative processes stems from the absence of an adequate feedback mechanism linking the "political objective function" to performance [14, 60]. In the case of the United States, however, there is a clear presumption that the existence of a decentralized agricultural research system, the state agricultural experiment station, effectively simulated the innovative behavior postulated by the theory of induced innovation.

Induced Institutional Innovation

The rapid rise in the economic value of environmental services is placing increasing stress on traditional social institutions developed in a environment in which access to "common property" environmental services was regarded as a free good. Under present institutional arrangements certain elements of the physical and social environment continue to be undervalued for purposes of market transactions, even though they have become common property resources of great and increasing value[15/]. The effect has been to bias the direction of technical effort toward excessive production of a wide range of residuals and spillover effects.

In this view the environmental stress resulting from pollution and congestion is not simply a by-product of the autonomous forces of technical change. The system of legal and economic institutions which govern the use of common property resources has failed to evolve in a manner that is consistent with (a) the rising demand for capacity to receive and assimilate the residuals resulting from commodity production and consumption and (b) the shift to the right in the demand for resource amenities associated with high and rising per capita incomes. The effect of continued undervaluation of environmental services has been to induce a pattern of technical change which is biased in the direction of excess residual production and away from increased efficiency in the supply of resource amenities [43, 77].

Let me emphasize this point. Traditional production theory implies that if the price of a factor input is zero (or close to zero) that factor input will be used until the value of its marginal product approaches zero. This will occur even though the marginal social product may be negative. In an environment characterized by rapid economic growth technical change, induced by relative factor prices, will result in a bias in the direction of technical change. As a result, the demand for the resource that is priced below its social cost will grow more rapidly than in a situation where substitution possibilities can occur only along a "given" production surface. As a result, the "common" resource, the capacity of the environment to absorb residuals for example, will undergo stress more rapidly than in a world characterized by a constant level of technology, or even by "neutral" technical change. The effect is to accelerate the widening of the gap between the private and social costs of environmental services.

This process has been clearly apparent in agriculture. One effect of the agricultural commodity programs has been to make land more expensive [38]. At the same time, the capacity of the environment to absorb the residuals from crop and livestock production has been treated as a free good. As a result, scientific and technical innovation, in both the public and the private sector, has been overly biased toward the development of land substitutes--plant nutrients and plant protection chemicals and crop varieties and management systems which reflected the overvaluation of land and the undervaluation of the social costs of the disposal of residuals from agricultural production processes[16/]. In retrospect it seems apparent that the same biases in factor prices have lead to underinvestment in technological effort directed toward pest and soil management systems consistent with the social value of environmental services.

Such examples are not, of course, restricted to agriculture. Nor do I want to underestimate the positive contribution of the programs initiated in the 1930's and 1940's toward stabilizing an inherently unstable sector of the economy and to the reduction of soil erosion, a dominant environmental issue a generation ago. The significance of the example is simply that the environmental stress that is now being experienced would have occurred more slowly in an environment in which the direction of technological effort was not itself responsive to distortions in the pricing of both conventional factor inputs and environmental services.

A redirection of technical effort in response to the rising economic value of environmental services will involve a complex interaction between technical and institutional change. Extension of the theory of "induced innovation" to include the process of institutional innovation adds significantly to our understanding of this process. <u>It seems consistent with historical experience to view institutional change as resulting from the efforts of</u>

<u>economic units (households, firms, bureaus) to internalize the gains and externalize the costs of economic activity; and of efforts by society to force economic units to internalize the costs and externalize the gains</u>.

Where internalization of the gains of innovative activity are difficult to achieve, institutional innovations involving public sector activity became essential. The socialization of much of agricultural research, particularly the research leading to advances in biological technology, represented an example of public sector institutional innovation designed to realize for society the potential gains from advances in agricultural technology. The political and legislative history of farm price programs, from the mid-1920's to the present, can be viewed as a struggle between agricultural producers and society, generally, regarding the partitioning of the new income streams resulting from technical progress between agricultural producers and consumers.

The environmental movement, in spite of its extra baggage--including its extensive "demonology" and its resurrection of discarded concepts from the underworld of science--is contributing to the creation of a social and political environment in which it may become feasible to more adequately institutionalize the redirection of technological effort and carry through the reforms necessary to redefine the ownership rights in an increasingly valuable set of common property resources.

Guidelines for Environmental Policy

It seems clear, at this time, that any significant progress in resolving the conflict arising out of the growing demands for environmental services must involve a redefinition of property rights in such a way that innovative activity in both the private and the public sector can be appropriately guided by explicit and pervasive economic and social incentives.

This is, of course, not a new process in western economic development. The modernization of land tenure relationships, including the elimination of the commons and the shift from share tenure to lease tenure and owner-operator cultivation in much of western agriculture was, in large part, the result of an effort to achieve a system of property rights that would permit individual farmers to internalize part of the gains from innovative activity.

I would like to suggest several guidelines for the institutional reforms that are now needed if we are to achieve effective development and management of our environmental resources.

First, the principal limitation of the ecological perspective stems from its preoccupation with the adaptive behavior of an interdependent biological community under a stable set of ecological interrelationships [25]. But the concept of equilibrium, however valid it may be as an analytical tool, is clearly misleading as a guide to environmental policy and planning. Robbins [67, p. 143] taught us years ago that in economics "equilibrium is just equilibrium." There have been similar challenges in ecology to the "climax" theories of ecological succession [65].

Much of recent discussion of resource and environmental policy has in my view been too narrowly based (a) on analogies with stable, or even "dynamically" stable, micro-systems borrowed from bio-ecology and (b) on the ultimate global implications of basic geo-physical principles [30]. These models provide too little scope for learning behavior, leading to the higher levels of system performance that are characteristic of viable social systems. The discount rate which I apply to my own activity forces me into a somewhat shorter time perspective than the eventual "running down" of the universe implied by the second law of thermodynamics. Comments to the effect that the level of production and consumption, rather than the form of production and consumption technology, determines the environmental impact because they do not "reduce the mass of residuals but only change their form" are not particularly enlightening. The form, location, and durability of residuals is a central issue! The implications for the quality of life of the discharge of raw sewage in the Potomac River and of the discharge of organic wastes from sugar beet processing in the Red River Valley is not a simple function of the size of the biochemical oxygen demand (BOD) imposed on regional watercourses[17/].

Second, the historical decline in the relative importance of the natural resource component in economic activity, resulting from technical change and changes in consumer behavior, means that we have already sharply reduced the cost of preservation of a broad class of resource amenities. In a relatively affluent society we give up very little real economic growth by the preservation of rare natural amenities [46]. Failure to harvest the timber or mineral resources of the Boundary Waters Canoe Area or the High Sierras, or to develop the potential power resources of unique natural features such as the Grand Canyon or Hell's Canyon, will have no measurable impact on national economic growth.

Third, redirection of scientific and technological effort along a path induced by environmental stress is an essential component of any effort to achieve consistency between viable development of the social environment and the natural environment.

The capacity of the social system to achieve substantial increases in performance will depend on its ability to achieve productivity growth--to identify new and more efficient sources of growth in the supply of social and environmental amenities [7]. Agriculture, for example, can never again release as many workers to other sectors of the U. S. economy as it released during the last four decades. It can never again serve as a "leading" growth sector [72]. I see little likelihood, for example, that alternative transportation systems will replace automobile transportation in the near future unless such systems can yield growth dividends, in the form of real cost reductions, including user inputs of time [55].

The redirections of effort, in both the natural and social sciences, toward those areas of social conflict arising out of environmental stress represents an exceedingly difficult challenge to institutional innovation. Much of the investment to support this effort, particularly in the areas of biological technology and in the social sciences, must come from the public sector. The spill-over effects are so great that there is little inducement for private sector investment to produce the knowledge about the basic physical, biological, and social relationships necessary to resolve the conflicts associated with environmental stress and institutional change.

The public sector has traditionally experienced great difficulty in generating support for research designed to produce social change. There has been an implicit acceptance of the Marxian view that the "mode" or the technology of production should dominate social organization [9, 50]. Let me attempt to clarify. When society invests in plant or in medical science research it anticipates that it will obtain a pay-off in terms of technical change--higher national average crop yields and lower mortality rates. When society invests in social science research, it anticipates that the results will contribute to the "conservation" of existing social institutions. Yet radical changes in family life, religion, and in social and economic organizations have clearly been induced by the sharp decline in the cost of population growth resulting from advances in agricultural and health technology. These changes serve to identify the public health and agricultural scientist, not the economist, the psychologist, the sociologist, or the political scientist, as the major source of radical social change in our time. Yet, the easiest way for a social science research project to get its budget cut off is to consciously design a research program to produce social change. This "head in the sand" approach to institutional innovation, with its pretense of ethical neutrality, is exceedingly costly to society and may be dangerous to the future of man [25, p. 217].

Fourth, as a general system of environmental management the regulatory approach is a dead end. The history of direct federal or state regulation of large industries is characterized by consistent failure when evaluated either in terms of equity or efficiency. Under the best of circumstances the decision process of the regulatory agencies have become hopelessly mired in technical, legal, and administrative overburden. And, over the longer run, the regulators have tended to become instruments of the regulated[18/].

This is not to argue that the regulatory approach is not of value in specific instances. A major source of current concern with the impact of technology on the environment is due to the accelerated rate of advance in science and technology relative to the rate of institutional change. It has also been argued that biological and social systems are characterized by threshold or overload phenomena--"The road that suddenly jams up when one more car appears on it, the river that refuses to clean itself up under a single addition of sewage. . ." [12]. These characteristics clearly call for investment in a much more extensive system of monitoring and assessment of environmental, technological, and social change [58, 80, 81]. The potential pay-off to more sensitive monitoring of these systems is extremely high. Direct regulation and prohibition is clearly called for to prohibit those types of environmental pollution from which health hazards and aesthetic offense is obvious, dangerous, and immediate. I also agree with Mishan [52, 53] that direct legal prohibition should be reexamined in terms of its effectiveness in redirecting technical effort.

For the present, however, I would confine subsidization, direct prohibition, and regulation to a much smaller role than in current environmental policy. The decision making and allocative capacities of both the legislative and judicial systems are clearly overloaded [22]. Institutional systems must be sought which are capable of internalizing incentives for environmental management. Hopefully it will be possible to avoid some of the mistakes which have resulted in the confusion of public and private property rights in water and have contributed to the failure to take fuller advantage of market mechanisms in the allocation of water resources. Clearly the implications--technical, legal, economic, social--of alternative forms of pollution rights and the organization of "markets" in pollution rights should be well up on the research agenda. There is some indication that this perspective is now receiving more serious consideration in environmental legislation [59].

Fifth, the system of information linkages and incentives designed to guide consumption and production activities and technological effort must be pervasive. The necessary behavior modifications are not confined to the decisions of a few corporate executives or national level decision makers. Nor can they be achieved through a public relations effort to inspire a new "ethics of conservation"[19/]. The spatial characteristics of the supply and utilization of environmental services represents a serious constraint on the centralization of environmental decision processes. By and large the situations characterized by serious environmental stress are relatively location specific. It is primarily at the level of the region or locality that the serious environmental stress occurs and that intensive monitoring and management efforts must be undertaken [43, 44].

The formal analysis on which we can draw for environmental and resource planning and policy is seriously deficient. Analytical capacity seems limited to models which employ, either implicitly or explicitly, inelastic supplies of commodity inputs and environmental services, fixed technical coefficients, highly aggregated production and consumption activities, and "given" consumer tastes [3, 21, 43, 44, 54, 78]. The information requirements of the more sophisticated models that are available seem to preclude their implementation. And even the most advanced models seem unable to incorporate the dynamic properties of the world with which most of us are familiar--including induced changes in technology and the response of consumer tastes and behavior to new opportunities.

This leads me to search for an alternative to "environmental management," in the narrow sense of the term, and to concentrate on the institutional modifications consistent with decentralized decision processes. I see no feasible alternative but to search for institutional innovations capable of establishing property rights with respect to environmental subsystems; the establishment of firms or authorities with appropriate incentives to manage such subsystems; and the use of market or market-like mechanisms to direct the use and production of commodity and service inputs and outputs of such systems [24].

The available analytical models provide weak guides to managerial decision processes by a hypothetical world or national Environmental Control Authority. Yet they do provide some insights into the behavior of households, firms, and bureaucracies--information that is essential in the design of environmental policies to guide the behavior of the firms or authorities established to manage specific environmental sybsystems. It seems likely, for example, that the extent to which relative factor and product prices for resource commodities and services reflect relative resource endowments and consumer preferences they will also serve to induce an "efficient" path of technological effort by private and public sector firms, bureaus, and authorities.

<u>Finally</u>, I would like to exphasize that the environmental crisis is not primarily a problem of crisis in man's relationship to nature. Rather it is only one element of a more pervasive crisis in the sociopolitical environment. In most respects, however, the technical difficulties associated with reversing environmental deterioration may be relatively easy. In the case of sociopolitical deterioration the process may be cumulative [42]. In my judgment it is much more important to concern ourselves with deterioration in the sociopolitical environment than of the physical environment.

Footnotes

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1/ The populist literature is typified by Reich [66] and Ehrlich [28]. For a more serious treatment of the same issues see Commoner [23], Ehrlich [29], Mumford [56], and Caldwell [17]. Among economists Boulding [10, 11] and Mishan [51, 52, 53] have been particularly outspoken.

2/ "The ancient urban centers also confronted a problem that continues today: the disposal of garbage and rubbish. . . life must have been unsanitary, unsightly and odoriferous, at least to the great masses of the poor. The evidence suggests the prevalence of high mortality rates. Many ancient cities appear to have been literally buried in their own rubbish" [16, p. 117]. See also Rosen [68] and Caldwell [17]. Anyone who has traveled extensively in poor countries will recognize that Brown's description remains valid for even small communities living near the subsistence level. In poor communities, use of energy to dispose of residuals is directly competitive with use of energy to provide for sustenance.

3/ Quantitative evidence with respect to the demand for environmental services is inadequate at this time.

4/ Professor Robert Manthy of the Department of Forestry of Michigan State University is engaged in a major study designed to update the Potter-Christy and Barnett-Morse time series data on resource consumption and prices.

5/ The assertion rests on inadequate documentation.

6/ I find Rothenberg's classification very helpful: "(1) pure congestion is the case where all users generate identical rates of quality interference per unit of activity and share equally in the resulting quality impairment; (2) pure pollution is the case where some users generate very high rates of unit interference while others generate zero rates and only the latter experience quality impairment; (3) the general case is where all users both generate impairment and share it. . . . The variety of both abuse and victimization prevents an easy or complete categorization of users into guilty and innocent" [71, p. 115].

7/ "There has developed in the contemporary natural sciences a recognition that there is a subset of problems, such as population, atomic war, and environmental corruption, for which there are no technical solutions. There is also an increasing recognition among contemporary social scientists that there is a subset of problems, such as population, atomic war, environmental corruption and the recovery of a livable urban environment, for which there are no current political solutions. . . . The common area shared by these two subsets contains most of the critical problems that threaten the very existence of contemporary man" [23]. The article by Crowe was written in response to an earlier article by Hardin [31].

8/ For a definitive statement of the current state of knowledge with respect to environmental problems of world wide significance see SCEP [80, 81]. For a useful review of the current state of knowledge with respect to agricultural and agriculturally related sources of pollution see the papers presented at the Symposium on Agriculture and the Quality of Our Environment [13], the Symposium on Pollutant Impact on Horticulture and Man [2], and the Symposium on Economic Research on Pesticides for Policy Decision Making [81]. For a more popular, and sometimes "populist" treatment see Harte and Socolow [32].

9/ The burgeoning literature in the field of recreation economics derives largely from Clawson's formulation [18, 19]. The work of Baumol [6, 7] has occupied a similar role in the economics of cultural amenities.

10/ "Not withstanding occasional declarations about its unlimited potentialities for social betterment science is not guided by any social purpose. As with technology, the effect on humanity are simply the by-products of its own self seeking. As a collective enterprise science has no more social conscience than the problem-solving computers it employs. Indeed, like some ponderous multi-purpose robot that is powered by its own insatiable curiousity, science lurches onward . . . . [52, p. 129].

11/ See, for example, the literature assembled by Rosenberg [70].

12/ For a review of the literature on induced innovation see Ahmad [1]; Hayami and Ruttan [34]; Smith [77].

13/ Ibid.

14/ Easterlin [27] has utilized an inducement perspective in his analysis of the long term decline in human fertility in the U. S.

15/ The reader is referred to Bator [5] for a review of economic thought with respect to the sources of market failure. See also Kneese [44].

16/ Headley [36] estimates that if the present land held out of production by government programs were returned to production, present levels of output could be maintained with pesticide use at about 20 percent of present levels. See also Headley [35, 37], Brewer [15], and Heady [38].

17/ Löf and Kneese [49] estimated that in 1950 the sugar beet industry alone accounted for 15 percent of organic wastes coming from all industries. The water residuals load generated by sugar beets has been substantially reduced since that time by process alternations.

18/ Regulatory agencies seem to have a common life cycle in which the last stage involves staffing of the agency administration from the ranks of the regulated. See Kohlmeier [45], Stigler [79], and the literature cited by Crowe [23].

19/ "The internalizing of new roles of conduct is essential to the effectiveness of ethics in society, but it cannot be obtained solely throuoh efforts focusedupon the values and behavior of individuals. . . . Ecologically valid ethics can not be effective until they are internalized in individuals and externalized in social institutions" [7, p. 298].

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