A Historical Approach to Future Economic Growth

The history of technological advance suggests an optimistic outlook for future economic growth.

Glenn Hueckel

The massive outpouring of literature in the past 3 years assessing the possibilities for future economic growth attests to the great success of Dennis Meadows and his team in their stated purpose to "open . . . debate" on the implications of their "world model" among "a wider community than that of scientists alone" (*1*, p. 23). The importance of such a debate is underscored by the profound policy implications of the work done by the Meadows team and by Jay Forrester (*2*), their methodological mentor. Forrester calls for "an end to population and economic growth" as the only way to avert an alarming future of excessive pollution, natural resource depletion, and starvation all leading to the collapse of modern society (*3*). The Meadows group concludes that the only way to avoid "a rather sudden and uncontrollable decline in both population and industrial capacity" in the next century is to establish a "state of global equilibrium" in which population and the capital stock and, apparently, industrial output are constant (*4*).

The danger with such proposals is that policies to implement them may be demanded before society has had the benefit of a full debate on the problem. Only a few months after the publication of Forrester's *World Dynamics*, the *Ecologist* used that report as a basis for a call for an end to economic growth in Britain and a reduction in British population to 30 million, roughly the level which obtained in 1880 (*5*). Similarly, Anthony Lewis claims (*6, 7*) that: "The conclusion of the scientists [is that] . . . there is only one way to avoid the pattern of boom crashing into earthly limits. That is to moderate all the interconnected factors: population, pollution, industrial production. *The essential is to stop economic growth*" (emphasis added). These views have also found their way into some textbooks where they are presented as established fact. Hardesty, Clement, and Jencks refer to Forrester's work to support their contention (*8*, p. 89) that ". . . all developed countries, capitalist or socialist, must give up their unquestioning allegiance to the credo that 'more is always better'" and that "It is unavoidable that continued increases in output will eventually overcome the effect of any technological improvement" (*8*, p. 90). They give no suggestion that such "continued increases in output" might spur continuous technological advance. Indeed they argue (*8*, pp. 90–91): "Blind faith in *continuous* future technological developments is foolish when action can be taken now to change man and his institutions."

It is my belief that a historical perspective to this problem indicates that an optimistic view of the possibility for "continuous future technological developments" is not as "foolish" as Hardesty and his collaborators would have us believe. Numerous critics have suggested that the conclusions obtained from the world models are extremely sensitive to the initial assumptions made by the model-builders. Indeed, Boyd has shown that the opposite conclusion of continuous economic advance (though accompanied by an eventual retardation in population growth) can be obtained by altering slightly the assumptions regarding technological change (*9–11*). The debate has led several authors to appeal to the historical record. One such author has written, concerning the question of natural resource depletion (*12*, p. 40): "The only hard data which can be brought to bear on this issue are, as usual, historical data; there is no possible way of proving the correctness of a possible future" (*13*). Another study which surveys the technological advance in certain industries since the late 19th century, concluded (*14*) that "the technological component of the world simulation model proposed by Meadows *et al.* and Forrester is best represented by an exponential growth function." Such a view is even more optimistic than that assumed by Boyd (*9*).

The author is assistant professor of economics at Purdue University, West Lafayette, Indiana.

Technology and Past Growth

A number of recent studies have indicated that technological change has had a profound effect on past economic growth, having accounted, for example, for half or more of the past increases in net output per capita in the United States and Great Britain (*15*). Although these studies are subject to rather wide margins of error, they generally lead most economists to agree with Musson (*16*, p. 24) that ". . . there is now no doubt whatever of the considerable importance of technical progress, including intangible factors such as educational improvement and growth of scientific and technical knowledge, in the process of economic development." In spite of the importance of technological advance in the phenomenon of economic growth, it has been called the terra incognita of modern economics (*17*); and it is in the exploration of this "unknown land" that a knowledge of past technological change is so helpful.

Technology and the Market

Generally, the historical data support the contention that the direction of technological change is influenced by market forces. As Rosenberg has put it (*18*, p. 37):

> Inventive activity, after all, involves the use of scarce and valuable resources which have a wide range of alternative uses, and therefore even on purely a priori grounds one would not expect to find such resources distributed in a random way among the different sectors of the economy. Like other economic activities, inventive activity is responsive to market forces and the prospects of financial gain.

This, of course, does not mean that all inventors or all scientists are necessarily motivated by prospects of financial gain, but it does suggest that in the main, the problems toward which people turn their innovative resources are those that promise the greatest financial rewards.

This proposition has implications for both an understanding of past technological change and an assessment of future advance. It undermines the hypothesis that technological advance is of necessity pollution-creating or resource-depleting and thus makes it impossible to argue that the level of pollution in modern society is solely the result of past technological advance. Yet, this is precisely the view implied by the Meadows team when they take "pollution generation" and "per capita resource usage" as functions only of the level of "per capita industrial output." In the case of pollution, the function is simply assumed to be linear; and in the case of resource usage, the functional form employed in the model assumes that as economic growth raises per capita incomes in the rest of the world to the 1970 level in the United States, world resource usage will approach the corresponding U.S. rate (*1*, pp. 102–103 and 107–109; *19*). Such an event is very unlikely, however, because other countries do not possess the same mix of resource endowments and thus will not develop with the same structure of relative input prices as that which characterized the U.S. experience.

Apparently, the Meadows team thinks that the amount of output (which is largely determined by the level of technology in use) is the sole (or, at any rate, the most important) determinant of existing levels of pollution and resource consumption. However, the work of Rosenberg and other economic historians suggests that technological advance is not an "either-or" proposition; there seems to be a surprisingly wide range of alternative possible methods of getting a job done, each method being characterized by a different mix of capital, labor, and resource inputs; and the particular alternative chosen by society is determined by the prevailing structure of the relative prices of those inputs. Thus, if modern technology is lavish in its use of natural resources or excessively polluting, it is because that technology was developed under conditions of very low relative prices for those natural resources and for the privilege of using the environment as a waste receptor.

Resource Prices and 19th-Century Technology

The most striking historical examples of the impact of input prices on the choice of technology in the United States are related to those resources that were most abundant in this country—land and wood. As Rosenberg has noted (*18*, p. 25), ". . . a major thrust of [American] agricultural innovation in the second half of the 19th century was to increase the acreage which could be cultivated by a single farmer . . . ." In support of this statement he cited Parker's finding that some 60 percent of the increase in U.S. cereal output per worker between 1840 and 1911 can be attributed to the rise in the acreage-worker ratio made possible by mechanization.

On the other hand, English agriculture, being characterized by a much lower land-labor ratio, managed a considerable increase in output during the period of that country's industrialization by choosing techniques that raised output per acre at the expense of higher inputs of labor and capital. Far from driving labor off the land, the 18th- and 19th-century enclosures and advances in farming techniques tended to raise labor requirements in agriculture (*20*). However, when the costs of those labor inputs increased relative to capital, as they did during the Napoleonic Wars, many farmers responded quickly to reduce their labor requirements wherever possible. At first this resulted in the increasing use of machines designed to minimize the labor necessary in the winnowing, chaff-cutting, and threshing operations of the farm. Later, after solutions had been found to the more difficult mechanical problems involved, reapers, haymaking machines, and other more complex devices were added to the list (*21*). English farmers were thus able to increase total output and output per laborer throughout most of the 19th century, in spite of their relatively limited ability to increase land inputs, through the substitution of greater amounts of capital.

After 1870, England became increasingly dependent for her food upon the land-intensive agriculture of the United States, Argentina, Australia, and Russia; but this too was the result of further technological change which can be viewed as a response to the opportunities for trade indicated by, among other things, the existing differentials in grain and meat prices between those countries and England. Thus, the application of the compound engine to ocean-going steamships in the mid-1850's brought an immediate 50 percent reduction in coal requirements and contributed to the removal of barriers to long-distance trade in bulky commodities (*22, 23*). Similarly, efforts to develop methods of refrigeration to allow the transportation of fresh meat over long distances began in the 1850's in the major meat-producing countries—Australia, Argentina, and the United States—and finally culminated in 1880 in the successful shipment to London of fresh Australian beef and mutton, which sold at an average price of 5½ pence per pound, well above the prevailing Melbourne price of 1½ to 2 pence per pound (*24*).

During its period of industrialization, the United States had vast forest reserves. According to the 1860 census, the lumber industry was surpassed in size only by the cotton textile industry, in terms of value added by manufacture. Because of this great resource abundance, the American lumber industry developed sophisticated woodworking machinery which amazed European visitors. However, these machines were adopted in Europe to only a limited extent because they were quite wasteful of wood. The same products were manufactured in Europe with slower, more labor-intensive, less mechanized techniques that resulted in far less sawdust on the shop floor. Indeed, Rosenberg quotes one English visitor who, writing in 1872, commented that: "Lumber manufacture, from the log to the finished state, is, in America, characterized by a waste that can truly be called criminal . . ." (*18*, pp. 27–28). However, the American techniques appeared wasteful only to a visitor accustomed to manufacture under a different set of relative prices—a set in which wood was relatively scarce and thus valuable. To American eyes the mechanized techniques did not appear wasteful at all; indeed they were appreciated because they economized on another factor which was relatively scarce in American society—labor.

This ability of society to alter technology to suit the existing resource endowment is further illustrated by the contrast between the forms of steam technology employed in the United States and England. Although developed simultaneously on both sides of the Atlantic in the early 19th century, the high pressure steam engine was used far more extensively in the United States than in England, where it seldom displaced the low pressure engine as a stationary power plant. The high pressure engine was cheaper to build but apparently was more extravagant in its fuel requirements. Thus, the Americans adopted a technology which allowed them to "buy" a reduction in capital costs for relatively large inputs of natural resources (*18*, p. 65; *25*).

This "trade-off" of capital for natural resources is especially striking in the application of steam to inland water transportation. The steamboats that plied the Western rivers in the United States were built with high pressure engines that made lavish use of the abundant cordwood along those rivers. In the East, however, where fuel was not as plentiful, there was a greater preference for the fuel economy of the low pressure engine (*18*, p. 71). Similarly, one of the selling points of Franklin's "Pennsylvanian Fire Place" was its relatively low fuel consumption —a point of considerable importance for the populous New England and Middle Atlantic colonies and one which Franklin stressed in his published "account" of the new invention (*26*): "Wood, our common Fewel [sic] which within these 100 Years might be had at every Man's Door, must now be fetch'd near 100 Miles to some Towns, and makes a very considerable Article in the Expence of Families . . . since Fuel is become so expensive, and (as the Country is more clear'd and settled) will of course grow scarcer and dearer; any new Proposal for Saving the Wood, and for lessening the charge and augmenting the Benefit of Fire . . . may at least be thought worth consideration."

Resource Scarcity and Technological Change

The point I am stressing, that societies tend to adopt technologies that are compatible with the existing resource endowment, has a corollary that is also supported by historical experience: when that resource endowment changes, as existing supplies of nonrenewable resources are depleted, the techniques in use are adapted to that change through the utilization of new methods of extraction and exploration, through the introduction of substitutes for the resource whose supply is diminished, or (as in the case of the Franklin stove) through the application of techniques to improve the efficiency in use of that resource. Thus Barnett and Morse (*27*) concluded, ". . . the increasing scarcity of particular resources fosters discovery or development of alternative resources, not only equal in economic quality but often superior to those replaced." This past tendency to develop new resources leads economists to argue that while the geological reserves available in the earth's crust are "(almost) infinitely greater" than the 250-year supply which is assumed in the Meadows model (*1*, p. 126), "whether what is geologically available becomes economically exploitable reserves depends on market conditions and the state of resource technology" (*12*, p. 41). Consequently, it is to the omission from the Forrester and Meadows models of any kind of functioning price system that many economists object.

Historically, it has been the increases in price of a given resource as existing supplies are depleted that have stimulated new efforts at exploration, extraction, and substitution. The most dramatic examples of substitution for scarce resources are seen during periods of war when a country is cut off from its traditional supplies. The introduction of the Leblanc process for the production of synthetic alkalis in France during the Napoleonic Wars, the Haber nitrogen fixation process in Germany during World War I, and synthetic rubber in the United States during World War II were all responses to the loss of sources of natural supplies (*18*, p. 21).

War is not the only inducement to this type of technological advance, however. Page (*12*) has reviewed some of the recent improvements in mining and processing technology that have allowed the exploitation of mineral sources that had earlier been ignored. Among these are two advances in the extraction of gold from the ore: the use of mercury first, and later the cyanide process, allowed the exploitation of material which, with the earlier technology, had been considered waste. Likewise, the lowest grade of copper ore that can be utilized has declined from a level of 3 percent in 1880 to about 0.4 percent today. Similar reductions in the lowest feasible grade of ore have taken place in the production of iron, aluminum, and numerous other minerals.

Difficulty of Prediction

This past ability of rising prices to stimulate "resource-saving" technological change implies that reasonably accurate predictions about future resource supplies and usage rates are impossible to make with our present imperfect knowledge of the process of technological change. Such predictions must take into account the likelihood that rising prices will induce a more efficient use of the resource, the introduction of substitutes, and will possibly result in the availability of even greater future supplies through the utilization of new methods of extraction and exploration. These trends have given the lie to numerous past predictions about the rate of resource usage, and there is no reason to believe that predictions made today will not suffer the same fate. Thus, if a 1944 forecast had proved correct, the United States would by now have exhausted its reserves of tin, nickel, lead, zinc, and some 17 other minerals. Instead, the following decade witnessed the discovery of new deposits of these materials containing a greater estimated quantity than that discovered in the previous 25 years (*12*, pp. 38–39).

Predictions of future petroleum supplies which have recently been so prevalent and so ominous share a trait common to past predictions because they are based on the very restrictive concept of "proved reserves." As Landsberg and Schurr have noted, that concept represents the producers' "best estimate of the volume of petroleum in *known* fields that can be profitably recovered with *present* technology" (emphasis added). Thus, rather than being a reasonably accurate measure of future supplies, "The proved reserves may best be thought of as the current working stock or inventory of unrecovered petroleum that producers carry for the efficient accomplishment of their operations" (*28*, p. 27; *29*). The inability to accept this limitation on the concept of "proved reserves" has led to many strikingly inaccurate predictions of future resource depletion. The chief geologist of the U.S. Geological Survey reported in 1920 that only 7 billion barrels of petroleum remained to be recovered with existing techniques. He predicted that, at the contemporary annual rate of consumption of a half-billion barrels, American oil resources would be exhausted in 14 years—by 1934. However, when that fateful year arrived, 12 not 7 billion barrels had been produced and there was an additional 12 billion barrels of "proved reserves" (*28*, p. 98).

By definition, technological advance implies the discovery of solutions to problems to which no answer is currently available. Thus, we cannot visualize the form and implications of a given solution until the solution has been found. However, even when a particular innovation is perfected, the innovator often does not foresee all its uses. Edison, for example, saw his new phonograph primarily as a business machine, much like the modern dictaphone. Its most important uses, in music and entertainment, were seen by others (*30*). In the same way, railroads were originally conceived as feeders to existing canals, and the early radio devices were thought of only as supplementary to wire communication, to be used where wire could not be employed, as on seagoing ships. We may be tempted to scoff at these and other failures to foresee what seem to us to be commonplace uses of commonplace devices but, as Rosenberg reminds us (*31*), ". . . in history, we always have the immense advantage of knowing how the story ended." It may be more appropriate to base upon these past failures a skeptical approach to modern predictions of the future.

The Past as a Guide for the Future

While society has obviously been very successful in its past technological advance, objections have been raised to the use of that experience as a guide in our contemplation of future resource availability on the grounds that past economic development took place under the especially favorable conditions of resource abundance. Thus Mishan has suggested (*32*): "The advance of technology in the West over the past 200 years might well be attributable to especially favorable circumstances. Certainly there was no problem up to the present of limits to the assimilative capacity of the biosphere. Nor was there a problem of the availability of cheap fossil fuels." However, this view is itself the result of a lack of sufficient perspective.

Rosenberg reminds us that what constitutes a natural resource depends upon the level of technological knowledge achieved by society (*18*, p. 19). Thus, in the early 19th century, crude oil encountered at the earth's surface or in salt wells was viewed as an obnoxious nuisance or, at best, was bottled and sold as patent medicines (*33*). Similarly, the vast coal deposits of England were of little value until the late Middle Ages when it became known that the substance could be used as fuel. Even then, however, coal was of no use in what was to become its most important industrial application until the problem of the mineral impurities imparted by the new fuel to coke-smelted pig iron could be solved. The first step in this long process was not made until the first decade of the 18th century when Abraham Darby developed a new casting process which allowed him to use profitably the lower quality coke-smelted pig iron. However, because the cost of the new mineral fuel remained higher than that of the more commonly used charcoal, the English iron industry did not generally employ coal in the blast furnace until after 1750 (*34*).

In the United States, the rich coal reserves in eastern Pennsylvania went ignored even longer than did English coal. The Pennsylvania deposits consisted largely of anthracite which, because it contains no gas, is very difficult to ignite. Therefore, these deposits could not be utilized in the type of blast furnace developed in England. Not until the development of the hot blast in 1828 (a procedure which, by preheating the blast before it enters the furnace, allows the introduction of anthracite as a fuel) could those eastern coal deposits be put to use (*18*, p. 80).

Thus, from his 20th-century vantage point, Mishan can look back over the relatively short period of a century or two and argue that past economic growth is "attributable to [the] especially favorable circumstances" of mineral resource abundance (*32*). However, it is well to remember that had he lived at the beginning of the 18th century, many of those resources which appear abundant to 20th-century eyes would have been unknown to 18th-century commentators along with the modern uses of two of the most important raw materials of industrialized economies. Indeed, Landes (*23*, p. 41) has suggested that the British Industrial Revolution, that 18th-century outpouring of innovation which so profoundly affected Western society, can be characterized in part as a "substitution of mineral for vegetable or animal substances." Thus, the introduction of coal came at a time when the British economy was facing another "energy crisis": the supply of charcoal could not keep up with the growing 17th- and 18-century demand for fuel (*35*).

Perhaps a more appropriate lesson to draw from the experience of the past two centuries is not to focus on the availability of natural resources but rather to focus on the process by which society was able to advance its technological knowledge to the point where those resources could be employed for the satisfaction of human wants. Can we be so sure that there are not other substances available in equal or greater abundance whose uses as substitutes for present resources we will soon learn? The history of society's past ability to make use of previously unknown resources suggests grounds for some optimism on this question; and Brown clearly admits the possibility of future resource abundance when he writes (*36; 37*, p. 127): "The basic raw materials for the industries of the future will be seawater, air, ordinary rock, sedimentary deposits of limestone and phosphate rock, and sunlight. All the ingredients essential to a highly industrialized society are present in the combination of those substances."

The Desirability of Future Growth

In spite of his assurance of abundant future resource supplies, Brown is rather pessimistic about the desirability of future growth. He worries first that, "We are quickly approaching the point where, if machine civilization should, because of some catastrophe, stop functioning, it will probably never again come into existence" because the abundant natural resources with which that machine civilization was built have been depleted and because the new resources which can be substituted for the old require such highly sophisticated technology. Second, if such a catastrophe is avoided, Brown suggests that the complex technologies of the future will require that man "live in a world where his thoughts and actions are ever more strongly limited, where social organization has become all-pervasive, complex, and inflexible, and where the state completely dominates the actions of the individual" (*36; 37*, pp. 128–129). Thus, it would appear that even if future economic growth is physically possible, it will create either an extremely vulnerable society or one which is characterized by totalitarian controls.

There is, of course, no doubt that the double-edged sword of technological advance gives man the power either to make life more pleasant or to destroy it; but that is not a very convincing reason to stop growth. It does mean, however, that societies must pay increasing attention to their relations with one another so as to ensure that man's awesome knowledge is never used for the destruction of civilization. But Brown's point relates to the possibility that civilization could be rebuilt after some unforeseen catastrophic event, and here his concern seems rather extreme. He seems to make the error of equating growth with machines. However, Ames and Rosenberg have suggested (*38*) that "one may argue that industrialization is, in large measure, a learning process. The capital stock of any economy includes the acquired skills—technical, managerial, professional—in short, the 'intangible capital' embodied in its living population." Moreover, they have noted that "such skills, once acquired, constitute a major portion of an economy's capital stock" and that to ignore such "intangible capital" can lead to serious prediction errors. Thus, they argue that "astonishment at the rapid rates of postwar recovery in Germany and Japan is due, in part, to persistent failure to give appropriate recognition to the importance of intangible 'human capital' " (*38*). This suggests that while it is possible for some catastrophe to eradicate permanently "machine civilization," as Brown fears, it is rather unlikely since such a catastrophe would have to destroy not only all of society's machines, but all of the accumulated knowledge and skills of its labor as well.

Identifying Value Judgments

This is not the only error that one encounters in the numerous discussions of the desirability of future economic growth. By its very nature, that debate requires that the contribution of each individual be based on his own personal preferences; and thus leads to the incorrect and dangerous assumption that those preferences are held by the rest of society. Beckerman has criticized Mishan, for example, for including in his discussion of the social costs of air travel not only noise and air pollution but also overcrowding at holiday resorts (*39*):

> . . . all this may well be true but to propose, as Mishan does, an international ban on all air travel cannot be justified on these grounds alone. It may be perfectly feasible for a small 'elite' to make their way slowly to Delphi by road and mule, but for the average American secretary or Lancashire textile worker, with only two weeks' paid holiday, it is quite out of the question. To presume that the benefits obtained by thousands or millions of such people from their packaged tours . . . would be less than the loss incurred by a much smaller number of people on account of the disruption of their solitude is either a reflection of a value judgement or an unsubstantiated guess.

Of course, the danger is that those writers who make this "unsubstantiated guess" often base upon it proposals for immediate policy actions which imply as much totalitarian control over individual behavior as Brown fears will be necessary at some point in the future if growth continues. Thus Goodman argues (*40*) that as air travel increases airport congestion, ". . . the less immediate utility it provides, the greater the costs, and the more damaging the remote effects"; because he presumes to judge the level of utility gained by air travelers other than himself, he proposes as a solution that ". . . it is time for technologists to confer with sociologists and economists and ask deeper questions. *Is so much travel necessary?* [italics mine] Are there ways to diminish it?" (*40*).

Most economists would respond that these are the wrong questions to ask. The proper approach is to ask whether those individuals whose actions result in damaging "remote effects" (what an economist would call "external diseconomies") are paying the full social costs of those effects. If the answer is in the negative, then it is the responsibility of the policy-makers to see that such payment is made through the use of effluent charges, minimum air quality standards, higher airport landing fees, or some other control policy. Such policies will, of course, raise the cost of air travel and transfer the costs of the "remote effects" arising from it (or from any other pollution-creating activity) from the rest of society to the individual engaged in that activity. Once this is done, however, the question of the necessity of the travel must be left up to the individual making the trip. In a society that values individual freedom, he is, after all, the only person who has the right to answer that question.

Some economists, recognizing the difficulties involved in making judgments about the satisfaction obtained by others from increased consumption, have tried to prove scientifically the undesirability of further economic growth; but their efforts have simply resulted in a disguised restatement of the value judgments embedded in the work of Mishan and Goodman noted earlier. Thus Daly presents the proposition that ". . . for the poor, growth in GNP [gross national product] is still a good thing, but for the rich it is probably a bad thing"; and he argues that this follows from ". . . the two most basic laws of economics: (a) the law of diminishing marginal utility, which really says nothing more than that people satisfy their most pressing wants *first*—thus each additional dollar of income or unit of resource is used to satisfy a less pressing want than the previous dollar or unit; (b) the law of increasing marginal cost . . ." (*41*). However, this apparently "scientific" justification of a statement, which is in fact nothing more than a reflection of the particular set of preferences held by Daly, is based on an incorrect definition of the "law of diminishing marginal utility." That concept, to the extent that it is a generally accepted "law" of economics, states that the incremental satisfaction obtained from consumption of a *particular commodity* declines as consumption of that commodity increases *while consumption of all other commodities remains constant.* In other words, the "law" of diminishing marginal utility is a statement of the mathematical concept of a partial derivative of a hypothetical utility function taken with respect to a single commodity or service while quantities of all other consumables are held constant. Consequently, since increases in income represent the ability to increase consumption of all goods and services, the "law" of diminishing marginal utility, by definition, cannot be applied to changes in income levels.

The concept that increases in income yield diminishing increments in satisfaction has been around since the 18th century, when it was first proposed by Daniel Bernoulli; and it is still referred to by economists today as the "Bernoulli hypothesis." However, as the phrase implies, it is nothing more than a hypothesis; it is certainly not one of the "two most basic laws of economics." Indeed, other hypotheses have been formulated to describe the shape of the "income-utility function" which suggest that, over a certain range, increases in income yield rising increments in total utility; and, in many cases, these conform more closely to observed behavior than does the Bernoulli hypothesis (*42*). Thus, the "undesirability" of future growth has not been objectively proved; nor can it be on the basis of the Bernoulli hypothesis for, even if that hypothesis were empirically verified, to use it as Daly does in support of the argument that growth for the poor is "a good thing" while for the rich it is "probably a bad thing" raises the problem of identifying the point at which an individual or society moves from the classification of "poor" to "rich"; and as soon as we attempt to answer that question for individuals other than ourselves we commit the very error that Beckerman has warned against.

Policies for the Future

While the past successes of technological advance suggest grounds for an optimistic view of the future, those successes and the weaknesses in the arguments against growth examined here do not imply that the proper attitude concerning this issue is one of complacency. Indeed, one could argue that the problems which society must face in the future are more difficult than those solved in the past not because they are not amenable to advances in technological knowledge but because changes in certain social institutions are necessary to bring that knowledge to bear on those problems. I have emphasized the proposition that the direction of past technological advance has been a function of market forces: a community allocates its inventive resources to those problems the solutions to which, in view of the prevailing structure of relative prices, appear to offer the greatest financial rewards. While this allocation does not in principle guarantee solutions to a community's problems, it certainly increases the probability that those solutions will be found.

Unfortunately, the common characteristic of most of the problems facing society today is that they relate to commodities or resources for which the unregulated marketplace generates no price information. This failure of the market to generate such information is the result of the lack of well-defined property rights in certain resources; and, to use Hardin's now famous phrase, that failure leads to the "tragedy of the commons" (*43*). Thus, because no one owns the air over a city, no one charges the local manufacturing plant a price for the privilege of using that air as a waste receptor, nor are the residents of the city charged for the pollutants emitted from their automobiles. To make matters worse, those resources are consumed collectively; consequently, even if a price could be set there would be no inducement for consumers to pay unless there was some element of compulsion—a characteristic not found in goods normally traded in the marketplace. Thus, while one need not pay the price of a ticket to a football game, admission to the stadium and enjoyment of the game is impossible without such payment.

On the other hand, even if the residents of a community were charged a price for the privilege of using the air as a receptor for the wastes from their automobiles, there would be little inducement for an individual to pay since he could not be excluded from such use. Such payment could normally be obtained only under some form of compulsion, such as a government requirement for the use of certain control devices or for periodic inspection and the payment of emissions charges. Even in the case of natural resources, where clear property rights are normally established, Solow, Clark, and others have shown that an unregulated market will not result in the socially optimal rate of exploitation if the rate at which society discounts future consumption differs significantly from the prevailing market rate of interest; this suggests, at a minimum, a possible need for government surveillance of the existing rate of exploitation (*44*).

It is clear that nearly all the problems on which Forrester, Meadows, and other antigrowth advocates focus require imaginative and well-considered social policies in which the government intervenes in the marketplace in such a way as to cause it to generate appropriate price signals to both producers and consumers in order to direct the allocation of inventive resources to the solution of those problems. Of course, the precise form of that intervention will be the subject of wide debate; but once the policies are implemented, the record of past technological change strongly suggests that future technology will respond to that new structure of relative prices.

In short, the antigrowth writers are quite correct when they note that the physical resources of the earth are finite. However, they err when they fail to recognize that there is nothing in our past or present experience which suggests the existence of a limit to man's ability to advance his knowledge about that world and about himself and to apply that knowledge to the removal of the physical constraints on continued growth in output and welfare as long as scarcity of the necessities and amenities of life remains a reality for some members of society. Because we are still far from that day when abundance for all is the rule, it is fortunate that the reading of the historical record presented here indicates that the solution to the "predicament of mankind" is not to dissipate our energies in panic and to bring world economic growth to a standstill, but to direct those energies to the development of social policies which will provide the incentives to direct future technology to seek solutions to those problems which some find so ominous.

References and Notes

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2. J. W. Forrester, *World Dynamics* (Wright-Allen, Cambridge, Mass., 1971).
3. ———, *Technol. Rev.* **73**, 66 (January 1971).
4. See (*1*), pp. 23–24. The discussion of the "state of global equilibrium" as conceived by the Meadows team (*1*, pp. 156–177) contains certain anomalies that create some confusion. We are told that "population and capital are the only quantities that need be constant in the equilibrium state" (*1*, p. 175). However, apparently that constancy is not crucial since the authors also argue for a "*dynamic* equilibrium" in which "a society could adjust to changing internal or external factors by rising or lowering the population or capital stocks, or both, slowly and in a controlled fashion, with a predetermined goal in mind" (*1*, p. 174). Moreover, we are told that "technological advance would be both necessary and welcome in the equilibrium state"; and certain types of such advance which would "enhance the working of a steady state society" are suggested. They include improvements in pollution control and resource usage and methods of harnessing new energy sources (*1*, p. 177)—precisely those changes that would weaken the "feedback loops" which constrain economic growth in the model. Consequently, it is surprising to read in the description of the simulations of the "equilibrium state" that "the economic system endeavors to maintain average industrial output per capita at about the 1975 level" (*1*, p. 166) and elsewhere that "since the amount of material production would be essentially fixed, every improvement in production methods could result in increased leisure for the population . . ." (*1*, pp. 175–176). Here it would seem that in spite of possible advances in technology which improve productivity and pollution control in the "equilibrium state," industrial output is assumed constant; and, for reasons

which remain obscure, increases in productivity result only in increased leisure time. It is not clear how these apparently conflicting statements can be reconciled.
5. "Blueprint for Survival," *Ecologist* **2**, 1 (1972), quoted by C. Freeman, in *Thinking about the Future; A Critique of the Limits to Growth*, H. S. D. Cole, C. Freeman, M. Jahoda, K. L. R. Pavitt, Eds. (Chatto and Windus, London, 1973), p. 9.
6. A. Lewis, *New York Times*, 30 January 1972, quoted by Passell and Ross (*7*, pp. 25–26).
7. P. Passell and L. Ross, *The Retreat From Riches; Affluence and Its Enemies* (Viking, New York, 1973).
8. J. Hardesty, N. C. Clement, C. E. Jencks, in *Economic Growth vs. the Environment*, W. A. Johnson and J. Hardesty, Eds. (Belmont, Wadsworth, Calif., 1971).
9. See, for example, R. Boyd, in *Science* **177**, 516 (1972); Cole and Curnow (*10*); and Solow (*11*).
10. H. S. D. Cole and R. C. Curnow, in *Thinking about the Future; A Critique of the Limits to Growth*, H. S. D. Cole, C. Freeman, M. Jahoda, K. L. R. Pavitt, Eds. (Chatto and Windus, London, 1973), pp. 108–134.
11. R. M. Solow, in *The Economic Growth Controversy*, A. Weintraub, E. Schwartz, J. R. Aronson, Eds. (International Arts and Sciences Press, White Plains, N.Y., 1973), pp. 39–61.
12. W. Page, "The non-renewable resources subsystem," in *Thinking about the Future; A Critique of the Limits to Growth*, H. S. D. Cole, C. Freeman, M. Jahoda, K. L. R. Pavitt, Eds. (Chatto and Windus, London, 1973), pp. 30–44.
13. See also Passell and Ross (*7*, p. 11) and Meadows *et al.* (*1*, pp. 176–178).
14. C. Starr and R. Rudman, *Science* **182**, 358 (1973).
15. See, for example, M. Abramovitz, *Am. Econ. Rev.* **46**, 5 (1956); R. M. Solow, *Rev. Econ. Stat.* **39**, 312 (1957); S. Fabricant, in *National Bureau of Economic Research, 34th Annual Report* (National Bureau of Economic Research, New York, 1954), pp. 3–18; E. D. Domar, *Econ. J.* **71**, 709 (1961); E. F. Denison, *The Sources of Growth in the United States and the Alternatives Before Us* (Committee for Economic Development, New York, 1962), especially pp. 155–162; *Why Growth Rates Differ; Postwar Experience in Nine Western Countries* (Brookings Institution, Washington, D.C., 1967), especially pp. 279–295. For an excellent review article on this issue see Musson (*16*, pp. 8–29).
16. A. E. Musson, Ed., *Science, Technology, and Economic Growth in the Eighteenth Century* (Methuen, London, 1972).
17. J. Schmookler, *Invention and Economic Growth* (Harvard Univ. Press, Cambridge, Mass., 1966), quoted by Musson (*16*, p. 24).
18. N. Rosenberg, *Technology and American Economic Growth* (Harper & Row, New York, 1972).
19. See also Page (*12*, pp. 33–34); P. K. Marstrand and T. C. Sinclair, "The pollution subsystem," in *Thinking about the Future; A Critique of the Limits to Growth*, H. S. D. Cole, C. Freeman, M. Jahoda, K. L. R. Pavitt, Eds. (Chatto and Windus, London, 1973), pp. 80–81.
20. J. D. Chambers, *Econ. Hist. Rev. Ser. 2* **5**, 319 (1953). See also E. L. Jones, Ed., *Agriculture and Economic Growth in England, 1650–1815* (Methuen, London, 1967), pp. 21–25.
21. E. L. Jones, *Econ. Hist. Rev. Ser. 2* **17**, 322 (1964–1965); A. H. John, in *Land, Labour, and Population in the Industrial Revolution*, E. L. Jones and G. E. Mingay, Eds. (Arnold, London, 1967), p. 35.
22. See D. North, *J. Econ. Hist.* **18**, 543 (1958); M. E. Fletcher, *ibid.*, pp. 556–557; Landes (*23*).
23. D. S. Landes, *The Unbound Prometheus; Technological Change and Industrial Development in Western Europe from 1750 to the Present* (Cambridge Univ. Press, Cambridge, 1969), pp. 277–278.
24. Trade in canned meat had existed since the 1860's, but the low quality of this food and the opportunity to trade in fresh meat is indicated by the expression commonly used to describe the canned product: "Sweet Fanny Adams." The expression immortalized the name of a Hampshire woman who, in 1867, was the victim in a particularly gruesome murder in which her body was found cut into small pieces. The morbid humor of the sailors at Portsmouth soon caused them to suggest a connection between that crime and the canned meat they received in their rations. See J. C. Drummond and A. Wilbraham, *The Englishman's Food; A History of Five Centuries of English Diet* (Cape, London, rev. ed., 1957), pp. 322–325.
25. See P. Temin, *J. Econ. Hist.* **26**, 188 (1966); V. S. Clark, *History of Manufactures in the United States* (Carnegie Institution of Washington, Washington, D.C., 1929), vol. 1, p. 409.
26. B. Franklin, *An Account of the New-Invented Pennsylvanian Fireplaces* (1744), reprinted in *The Writings of Benjamin Franklin*, A. H. Smyth, Ed. (Macmillan, New York, 1905), vol. 2, p. 247.
27. H. J. Barnett and C. Morse, *Scarcity and Growth; The Economics of Natural Resource Availability* (Johns Hopkins Press, Baltimore, Md., 1963), p. 10. See also Passell and Ross (*7*, p. 32), Solow (*11*, pp. 44–48), and Rosenberg (*18*, pp. 18–23).
28. H. H. Landsberg and S. H. Schurr, *Energy in the United States; Sources, Uses and Policy Issues* (Random House, New York, 1968). Also quoted in Rosenberg (*18*, p. 19).
29. The same point has been made more recently by D. P. Brooks and P. W. Andrews, *Science* **185**, 14 (1974).
30. J. R. T. Hughes, *The Vital Few; American Economic Progress and its Protagonists* (Houghton Mifflin, Boston, 1966), pp. 175 and 201–202.
31. N. Rosenberg, *Explor. Econ. Hist.* **10**, 13 (1972).
32. E. J. Mishan, in *The Economic Growth Controversy*, A. Weintraub, E. Schwartz, J. R. Aronson, Eds. (International Arts and Sciences Press, White Plains, N.Y., 1973), p. 12.
33. H. F. Williamson and A. R. Daum, *The American Petroleum Industry*, vol. 1, *The Age of Illumination, 1859–1899* (Northwestern Univ. Press, Evanston, Ill., 1959), pp. 12–24.
34. C. K. Hyde, *Explor. Econ. Hist.* **10**, 397 (1973).
35. E. A. Wrigley, *Econ. Hist. Rev. Ser. 2* **15**, 1 (1962).
36. H. Brown, *The Challenge of Man's Future* (Viking, New York, 1954); reprinted in Johnson and Hardesty (*37*).
37. W. A. Johnson and J. Hardesty, Eds., *Economic Growth vs. the Environment* (Belmont, Wadsworth, Calif., 1971).
38. E. Ames and N. Rosenberg, *Econ. J.* **73**, 18 (1963).
39. W. Beckerman, "The desirability of economic growth," in *Conflicts in Policy Objectives*, N. Kaldor, Ed. (Blackwell, Oxford, 1971) [quoted by K. L. R. Pavitt, in *Thinking about the Future; A Critique of the Limits to Growth*, H. S. D. Cole, C. Freeman, M. Jahoda, K. L. R. Pavitt, Eds. (Chatto and Windus, London, 1973), pp. 154–155].
40. P. Goodman, in *Western Man and Environmental Ethics; Attitudes Toward Nature and Technology*, I. G. Barbour, Ed. (Addison-Wesley, Reading, Mass., 1973), p. 230.
41. H. E. Daly, in *Patient Earth*, J. Harte and R. H. Socolow, Eds. (Holt, Rinehart and Winston, New York, 1971), pp. 227–228.
42. For a brief summary of the theory on this point, see M. Blaug, *Economic Theory in Retrospect* (Irwin, Homewood, Ill., rev. ed., 1968), pp. 331–337.
43. G. Hardin, *Science* **162**, 1243 (1968).
44. See R. M. Solow, *Am. Econ. Rev.* **64**, 1 (1974); C. W. Clark, *Science* **181**, 630 (1973).

NEWS AND COMMENT

Genetics: Conference Sets Strict Controls to Replace Moratorium

Pacific Grove, California. In a meeting that will possibly rate at least a footnote in the history of science, an international group of biologists has voted in principle to lift the voluntary moratorium imposed last July on a new technique of genetic manipulation that involves constructing hybrid molecules of DNA. But the moratorium is to be replaced with safety conditions so stringent that for many experiments it will effectively remain in force for a period at least of months. The conference also recorded its wish that the most hazardous category of experiments made possible by the technique should not be performed under any circumstances whatsoever.

Like the moratorium that preceded it, the conference's statement has the power of moral censure only, but the guidelines it proposes will probably be followed closely by the national bodies in each country responsible for framing the relevant regulations.

Just as the moratorium seems to be unprecedented in the history of science, the action of the conference is a rare, if not unique, example of safety precautions being imposed on a technical development before, instead of after, the first occurrence of the hazard being guarded against.

The conference's decisions were reached in the explicit awareness that science no longer enjoys the automatic favor of governments and society, and that if the scientists present failed to regulate themselves in an evidently disinterested manner, others would do so for them. As it happens, the control measures proposed by the conference are considerably stricter than many of those active in the field believed necessary and furthermore include a quite novel safety feature stipulating that the organisms involved in the experiments shall be biologically incapable of surviving outside the laboratory.