waste. As a result, waste, just like natural resources, is not represented in any manner in the standard production function. The only mention of pollution was the occasional textbook example of the laundry enterprise which suffers a loss because of a neighboring smokestack. Economists must therefore have felt some surprise when pollution started to strike everybody in the face. Yet, there was nothing to be surprised about. Given the entropic nature of the economic process, waste is an *output* just as unavoidable as the input of natural resources [27, 514f, 519, 523f]. "Bigger and better" motorcycles, automobiles, jet planes, refrigerators, etc., necessarily cause not only "bigger and better" depletion of natural resources but also "bigger and better" pollution [31; 32, 19f, 305f]. But by now, economists can no longer ignore the existence of pollution. They even have suddenly discovered that they "actually have something important to say to the world," namely, that if prices are right there is no pollution [74, 49f; also 10, 12, 17; 49, 11f; 80, 120f][22]—which is another facet of the economists' myth about prices (Sections IV and XI).

Waste is a physical phenomenon which is, generally, harmful to one or another form of life, and, directly or indirectly, harmful to human life. It constantly deteriorates the environment in many ways: chemically, as in mercury or acid pollution; nuclearly, as by radioactive garbage; physically, as in strip mining or in the accumulation of carbon dioxide in the atmosphere. There are a few instances in which a substantial part of some waste element—carbon dioxide is the salient example—is recycled by some "natural" processes of the environment. Most of the obnoxious waste—garbage, cadavers, and excrement—is also gradually reduced by natural processes. These wastes only require some space in which to remain isolated until their reduction is completed. There are troublesome hygienic problems involved, but the important point is that such wastes do not cause permanent, irreducible harm to our environment.

Other wastes are *disposable* only in the sense that they may be converted into less noxious ones by certain actions on our part, as when part of carbon monoxide is transformed into carbon dioxide and heat through improved combustion. A great part of sulphur dioxide pollution, another example, may be avoided through some special installations. Still other wastes cannot be so reduced. A topical example is the fact that we cannot reduce the highly dangerous radioactivity of nuclear garbage [46, 233]. This activity diminishes by itself with time, but very slowly. In the case of plutonium-239, the reduction to fifty percent takes 25,000 years! However, the harm done by radioactivity concentration to life may very well be irreparable.

Here, just as for the accumulation of any waste, from rubbish of all kinds to heat, the difficulty is created by the finitude of accessible space. Mankind is like a household which consumes the limited supply from a pantry and throws the inevitable waste into a finite trash can—the space around us. Even ordinary rubbish is a menace; in ancient times, when it could be removed only with great difficulties, some glorious cities were buried under accumulated rubbish. We have better means to remove it, but the continuous production calls for another dumping area, and another, and another . . . In the United States the annual amount of waste is almost two tons per capita and increasing [14, 11n.]. We should also bear in mind that for every barrel of shale oil we are saddled with more than one ton of ashes and to obtain five ounces of uranium we must crush one cubic meter of rock. What to do even with these "neutral" residuals is a problem vividly illustrated by the consequences of strip-mining.

[22] In addition, Harry Johnson finally came to see that a complete representation of a production process must necessarily include the output of waste [49, 10].

To send the residuals into outer space would not pay on a large and continuous scale.[23]

The finitude of our space renders more dangerous wastes which persist for a long time and especially those which are completely irreducible. Typical of the last category is thermal pollution, the dangers of which are not fully appreciated. The *additional* heat into which all energy of terrestrial origin is ultimately transformed when used by man[24] is apt to upset the delicate thermodynamic balance of the globe in two ways. First, the islands of heat created by power plants not only disturb (as is well known) the local fauna and flora of rivers, lakes, and even coastal seas, but they may also alter climatic patterns. One nuclear plant alone may heat up the water in the Hudson River by as much as 7°F. Then again the sorry plight of where to build the next plant, and the next, is a formidable problem. Second, the additional global heat at the site of the plant and at the place where power is used may increase the temperature of the earth to the point at which the icecaps would melt —an event of cataclysmic consequences. Since the Entropy Law allows no way to cool a continuously heated planet, thermal pollution could prove to be a more crucial obstacle to growth than the finiteness of accessible resources [79, 160].[25]

We apparently believe that we just have to do things differently in order to dispose of pollution. The truth is that, like recycling, disposal of pollution is not costless in terms of energy. Moreover, as the percentage of pollution reduction increases, the cost increases even more steeply than for recycling [62, 134f]. We must therefore watch our step—as some have already warned us [6, 9]—so as not to substitute a greater but distant pollution for a local one. In principle at least, a dead lake may certainly be revitalized by pumping oxygen into it, as Harry Johnson suggests [49, 8f]. But it is as certain that the additional operations implied by this pumping not only require enormous amounts of additional low entropy but also create additional pollution. In practice, the reclamation efforts undertaken for lands and streams degraded by strip-mining have been less than successful [14, 12]. Linear thinking—to borrow a label used by Bormann [7, 706]—may be "in" nowadays, but precisely as economists we ought to abide by the truth that what is true for one dead lake is not true for all dead lakes if their number increases beyond a certain limit. To suggest further that man can construct at a cost a new environment tailored to his desires is to ignore completely that cost consists in essence of low entropy, not of money, and is subject to the limitations imposed by natural laws.[26]

Often, our arguments spring from the belief in an industrial activity free of pollution. It is a myth just as lulling as the belief in everlasting durability. The sober truth is that,

[23] The cover photograph of *Science*, 12 April 1968, and the photographs in *National Geographic*, December 1970, are highly instructive on this point. It may be true that—as Weinberg and Hammond [83, 415] argued—if we had to supply energy even for 20 billion people at an annual average of 600 million BTU per capita, we would have to crush rock only at twice the speed at which coal is now being mined. We would still face the problem of what to do with the crushed rock.

[24] Solar energy (in all its ramifications) constitutes the only (and a noteworthy) exception (Section IX).

[25] The continuous accumulation of carbon dioxide in the atmosphere has a greenhouse effect which should aggravate the heating of the globe. There are, however, other divergent effects from the increase of scattered particles in the atmosphere: agriculturally oriented changes of vegetation, interference with the normal distribution of surface and underground water, etc. [24; 57]. Even though experts cannot determine the resultant trend of this complex system in which a small disturbance may have an enormous effect, the problem is not "an old scare," as Beckerman says in dismissing it [4, 340].

[26] Solo [73, 517] also asserts that because of growth and technology, the present society could eliminate all pollution "(with the one possible exception of radiation refuse)" at a bearable cost. It is only because of some perversity of our values that we are not doing it. That we could devote more effort to pollution disposal is beyond doubt. But to believe that with nonperverse values we could defeat the natural laws reflects an indeed perverse view of reality.

our efforts notwithstanding, the accumulation of pollution might under certain circumstances beget the first serious ecological crisis [62, 126f]. What we experience today is only a clear premonition of a trend which may become even more conspicuous in the distant future.

VI. MYTHS ABOUT MANKIND'S ENTROPIC PROBLEM

Hardly anyone would nowadays openly profess a belief in the immortality of mankind. Yet many of us prefer not to exclude this possibility; to this end, we endeavor to impugn any factor that could limit mankind's life. The most natural rallying idea is that mankind's entropic dowry is virtually inexhaustible, primarily because of man's inherent power to defeat the Entropy Law in some way or another.

To begin with, there is the simple argument that, just as has happened with many natural laws, the laws on which the finiteness of accessible resources rests will be refuted in turn. The difficulty of this historical argument is that history proves with even greater force, first, that in a finite space there can be only a finite amount of low entropy and, second, that low entropy continuously and irrevocably dwindles away. The impossibility of perpetual motion (of both kinds) is as firmly anchored in history as the law of gravitation.

More sophisticated weapons have been forged by the statistical interpretation of thermodynamic phenomena—an endeavor to reestablish the supremacy of mechanics propped up this time by a *sui generis* notion of probability. According to this interpretation, the reversibility of high into low entropy is only a highly improbable, not a totally impossible event. And since the event is *possible,* we should be able by an ingenious device to cause the event to happen as often as we please, just as an adroit sharper may throw a "six" almost at will. The argument only brings to the surface the irreducible contradictions and fallacies packed into the foundations of the statistical interpretation by the worshipers of mechanics [32, ch. vi]. The hopes raised by this interpretation were so sanguine at one time that P. W. Bridgman, an authority on thermodynamics, felt it necessary to write an article just to expose the fallacy of the idea that one may fill one's pockets with money by "bootlegging entropy" [11].

Occasionally and *sotto voce* some express the hope, once fostered by a scientific authority such as John von Neumann, that man will eventually discover how to make energy a free good, "just like the unmetered air" [3, 32]. Some envision a "catalyst" by which to decompose, for example, the sea water into oxygen and hydrogen, the combustion of which will yield as much available energy as we would want. But the analogy with the small ember which sets a whole log on fire is unavailing. The entropy of the log and the oxygen used in the combustion is lower than that of the resulting ashes and smoke, whereas the entropy of water is higher than that of the oxygen and hydrogen after decomposition. Therefore, the miraculous catalyst also implies entropy bootlegging.[27]

With the notion, now propagated from one syndicated column to another, that the breeder reactor produces more energy than it consumes, the fallacy of entropy bootlegging seems to have reached its greatest currency even among the large circles of literati, including economists. Unfortunately, the illusion feeds on misconceived sales talk by some nuclear experts who extol the reactors which transform fertile but nonfissionable material into fissionable fuel as the breeders that "produce more fuel than they consume" [81, 82]. The stark truth is that the breeder is in no way different from a plant which produces hammers with the aid of some hammers. According to the deficit principle of the Entropy Law (Section III), even in breeding chickens a greater amount of low entropy is consumed than is contained in the product.[28]

[27] A specific suggestion implying entropy bootlegging is Harry Johnson's: it envisages the possi-

Apparently in defense of the standard vision of the economic process, economists have set forth themes of their own. We may mention first the argument that "the notion of an absolute limit to natural resource availability is untenable when the definition of resources changes drastically and unpredictably over time. . . . A limit may exist, but it can be neither defined nor specified in economic terms" [3, 7, 11]. We also read that there is no upper limit even for arable land because "arable is infinitely indefinable" [55, 22]. The sophistry of these arguments is flagrant. No one would deny that we cannot say *exactly* how much coal, for example, is accessible. Estimates of natural resources have constantly been shown to be too low. Also, the point that metals contained in the top mile of the earth's crust may be a million times as much as the present known reserves [4, 338; 58, 331] does not prove the inexhaustibility of resources, but, characteristically, it ignores both the issues of accessibility and disposability.[29] Whatever resources or arable land we may need at one time or another, they will consist of accessible low entropy and accessible land. *And since all kinds together are in finite amount, no taxonomic switch can do away with that finiteness.*

The favorite thesis of standard and Marxist economists alike, however, is that the power of technology is without limits [3; 4; 10; 49; 51; 74; 69]. We will always be able not only to find a substitute for a resource which has become scarce, but also to increase the *productivity* of any kind of energy and material. Should we run out of some resources, we will always think up something, just as we have continuously done since the time of Pericles [4, 332–334]. Nothing, therefore, could ever stand in the way of an increasingly happier existence of the human species. One can hardly think of a more blunt form of linear thinking. By the same logic, no healthy young human should ever become afflicted with rheumatism or any other old-age ailments; nor should he ever die. Dinosaurs, just before they disappeared from this very same planet, had behind them not less than one hundred and fifty million years of truly prosperous existence. (And they did not pollute environment with industrial waste!) But the logic to be truly savored is Solo's [73, 516]. If entropic degradation is to bring mankind to its knees sometime in the future, it should have done so sometime after A.D. 1000. The old truth of Seigneur de La Palice has never been turned around—and in such a delightful form.[30]

In support of the same thesis, there also are arguments directly pertaining to its substance. First, there is the assertion that only a few kinds of resources are "so resistant to technological advance as to be incapable of eventually yielding extractive products at constant or declining cost" [3, 10].[31] More recently, some have come out with a specific law which, in a way, is the contrary of Malthus' law concerning resources. The idea is

bility of reconstituting the stores of coal and oil "with enough ingenuity" [49, 8]. And if he means with enough energy as well, why should one wish to lose a great part of that energy through the transformation?

[28] How incredibly resilient is the myth of energy breeding is evidenced by the very recent statement of Roger Revelle [70, 169] that "farming can be thought of as a kind of breeder reactor in which much more energy is produced than consumed." Ignorance of the main laws governing energy is widespread indeed.

[29] Marxist economists also are part of this chorus. A Romanian review of [32], for example, objected that we have barely scratched the surface of the earth.

[30] To recall the famous old French quatrain: "Seigneur de La Palice / fell in the battle for Pavia. / A quarter of an hour before his death / he was still alive." (My translation.) See *Grand Dictionnaire Universel du XIX-e Siècle*, Vol. X, p. 179.

[31] Even some natural scientists, e.g., [1], have taken this position. Curiously, the historical fact that some civilizations were unable "to think up something" is brushed aside with the remark that they were "relatively isolated" [3, 6]. But is not mankind, too, a community completely isolated from any external cultural diffusion and one, also, which is unable to migrate?

that technology improves exponentially [4, 236; 51, 664; 74, 45]. The superficial justification is that one technological advance induces another. This is true, only it does not work cumulatively as in population growth. And it is terribly wrong to argue, as Maddox does [59, 21], that to insist on the existence of a limit to technology means to deny man's power to influence progress. Even if technology continues to progress, it will not necessarily exceed any limit; an increasing sequence may have an upper limit. In the case of technology this limit is set by the theoretical coefficient of efficiency (Section IV). If progress were indeed exponential, then the input i per unit of output would follow in time the law $i = i_0 (1 + r)^{-t}$ and would constantly approach zero. Production would ultimately become incorporeal and the earth a new Garden of Eden.

Finally, there is the thesis which may be called the fallacy of endless substitution: "Few components of the earth's crust, including farm land, are so specific as to defy economic replacement; . . . nature imposes particular scarcities, not an inescapable general scarcity" [3, 10f].[32] Bray's protest notwithstanding [10, 8], this *is* "an economist's conjuring trick." True, there are only a few "vitamin" elements which play a totally specific role such as phosphorus plays in living organisms. Aluminum, on the other hand, has replaced iron and copper in many, although not in all uses.[33] However, *substitution within a finite stock of accessible low entropy* whose irrevocable degradation is speeded up through use cannot possibly go on forever.

In Solow's hands, substitution becomes the key factor that supports technological progress even as resources become increasingly scarce. There will be, first, a substitution within the spectrum of consumer goods. With prices reacting to increasing scarcity, consumers will buy "fewer resource-intensive goods and more of other things" [74, 47].[34] More recently, he extended the same idea to production, too. We may, he argues, substitute "other factors for natural resources" [75, 11]. One must have a very erroneous view of the economic process as a whole not to see that there are no material factors other than natural resources. To maintain further that "the world can, in effect, get along without natural resources" is to ignore the difference between the actual world and the Garden of Eden.

More impressive are the statistical data invoked in support of some of the foregoing theses. The data adduced by Solow [74, 44f] show that in the United States between 1950 and 1970 the consumption of a series of mineral elements per unit of GNP decreased substantially. The exceptions were attributed to substitution but were expected to get in line sooner or later. In strict logic, the data do not prove that during the same period technology necessarily progressed to a greater economy of resources. The GNP may increase more than any input of minerals even if technology remains the same, or even if it deteriorates. But we also know that during practically the same period, 1947–1967, the consumption per capita of basic materials increased in the United States. And in the world, during only one decade, 1957–1967, the consumption of steel per capita grew by 44 percent [12, 198–200]. What matters in

[32] Similar arguments can be found in [4, 338f; 59, 102; 74, 45]. Interestingly, Kaysen [51, 661] and Solow [74, 43], while recognizing the finitude of mankind's entropic dowry, pooh-pooh the fact because it does not "lead to any very interesting conclusions." Economists, of all students, should know that the finite, not the infinite, poses extremely interesting questions. The present paper hopes to offer proof of this.

[33] Even in this most cited case, substitution has not been as successful in every direction as we have generally believed. Recently, it has been discovered that aluminum electrical cables constitute fire hazards.

[34] The pearl on this issue, however, is supplied by Maddox [59, 104]: "Just as prosperity in countries now advanced has been accompanied by an actual decrease in the consumption of bread, so it is to be expected that affluence will make societies less dependent on metals such as steel."

the end is not only the impact of technological progress on the consumption of resources per unit of GNP, but especially the increase in the rate of resource depletion, which is a side effect of that progress.

Still more impressive—as they have actually proved to be—are the data used by Barnett and Morse to show that, from 1870 to 1957, the ratios of labor and capital costs to net output decreased appreciably in agriculture and mining, both critical sectors as concerns depletion of resources [3, 8f, 167–178]. In spite of some arithmetical incongruities,[35] the picture emerging from these data cannot be repudiated. Only its interpretation must be corrected.

For the environmental problem, it is essential to understand the typical forms in which technological progress may occur. A first group includes the *economy-innovations,* which achieve a *net* economy of low entropy —be it by a more complete combustion, by decreasing friction, by deriving a more intensive light from gas or electricity, by substituting materials costing less in energy for others costing more, and so on. Under this heading we should also include the discovery of how to use new kinds of accessible low entropy. A second group consists of *substitution-innovations,* which simply substitute physico-chemical energy for human energy. A good illustration is the innovation of gunpowder, which did away with the catapult. Such innovations generally enable us not only to do things better but also (and especially) to do things which could not be done before —to fly in airplanes, for example. Finally, there are the *spectrum-innovations,* which bring into existence new consumer goods, such as the hat, nylon stockings, etc. Most of the innovations of this group are at the same time substitution-innovations. In fact, most innovations belong to more than one category. But the classification serves analytical purposes.

Now, economic history confirms a rather elementary fact—the fact that the great strides in technological progress have generally been touched off by a discovery of how to use a new kind of accessible energy. On the other hand, a great stride in technological progress cannot materialize unless the corresponding innovation is followed by a great mineralogical expansion. Even a substantial increase in the efficiency of the use of gasoline as fuel would pale in comparison with a manifold increase of the known, rich oil fields.

This sort of expansion is what has happened during the last one hundred years. We have struck oil and discovered new coal and gas deposits in a far greater proportion than we could use during the same period (note 38, below). Still more important, all mineralogical discoveries have included a substantial proportion of *easily* accessible resources. This exceptional bonanza by itself has sufficed to lower the real cost of bringing mineral resources *in situ* to the surface. Energy of mineral source thus becoming cheaper, substitution-innovations have caused the ratio of labor to net output to decline. Capital also must have evolved toward forms which cost less but use more energy to achieve the same result. What has happened during this period is a modification of the cost structure, the flow factors being increased and the fund factors decreased.[36] By examining, therefore, only the relative variations of the fund factors during a period of exceptional mineral bonanza, we cannot prove either that the unitary total cost will always follow a declining trend or that the continuous progress of technology renders accessible resources almost inexhaustible—as Barnett and Morse claim [3, 239].

Little doubt is thus left about the fact that the theses examined in this section are

[35] The point refers to the addition of capital (measured in *money terms*) and labor (measured in *workers employed*) as well as the computation of net output (by subtraction) from *physical* gross output [3, 167f].

[36] For these distinctions, see [27, 512–519; 30, 4; 32, 223–225].

anchored in a deep-lying belief in mankind's immortality. Some of their defenders have even urged us to have faith in the human species: such faith will triumph over all limitations.[37] But neither faith nor assurance from some famous academic chair [4] could alter the fact that, according to the basic law of thermodynamics, mankind's dowry is finite. Even if one were inclined to believe in the possible refutation of these principles in the future, one still must not act on that faith now. We must take into account that evolution does not consist of a linear repetition, even though over short intervals it may fool us into the contrary belief.

A great deal of confusion about the environmental problem prevails not only among economists generally (as evidenced by the numerous cases already cited), but also among the highest intellectual circles simply because the sheer entropic nature of all happenings is ignored or misunderstood. Sir Macfarlane Burnet, a Nobelite, in a special lecture considered it imperative "to prevent the progressive destruction of the earth's irreplaceable resources" [quoted, 15, 1]. And a prestigious institution such as the United Nations, in its Declaration on the Human Environment (Stockholm, 1972), repeatedly urged everyone "to improve the environment." Both urgings reflect the fallacy that man can reverse the march of entropy. The truth, however unpleasant, is that the most we can do is to prevent any unnecessary depletion of resources and any unnecessary deterioration of the environment, but without claiming that we know the precise meaning of "unnecessary" in this context.

VII. GROWTH: MYTHS, POLEMICS, AND FALLACIES

A great deal of confusion stains the heated arguments about "growth" simply because the term is used in multiple senses. One confusion, against which Joseph Schumpeter insistently admonished economists, is that between *growth* and *development*. There is growth when only the production per capita of current types of commodities increases, which naturally implies a growing depletion of equally accessible resources. Development means the introduction of any of the innovations described in the foregoing section. In the past, development has ordinarily induced growth and growth has occurred only in association with development. The result has been a peculiar dialectical combination also known as "growth," but for which we may reserve another current label, namely, "economic growth." Economists measure its level by the GNP per capita at constant prices.

Economic growth, it must be emphasized, is a dynamic state, analogous to that of an automobile traveling on a curve. For such an automobile it is not possible to be inside a curve at one moment and outside it at the very next moment. The teachings of standard economics that economic growth depends only on the decision at a point in time to consume a larger or a smaller proportion of production [4, 342f; 74, 41] are largely off base. In spite of the superb mathematical models with which Arrow-Debreu-Hahn have delighted the profession and of the pragmatically oriented Leontief models, not all production factors (including goods in process) can serve *directly* as consumer goods. Only in a primitive agricultural society, employing no capital equipment, would it be true that the decision to save more corn from the current harvest will increase the next year's average crop. Other economies are growing now because they grew yesterday and will grow tomorrow because they are growing today.

The roots of economic growth lie deep in human nature. It is because of man's Veblenian instincts of workmanship and idle curiosity that one innovation fosters another —which constitutes development. Given,

[37] See the dialogue between Preston Cloud and Roger Revelle quoted in [66, 416]. The same refrain runs through Maddox's complaint against those who point out mankind's limitations [59, vi, 138, 280]. In relation to Maddox's chapter, "Man-made Men," see [32, 348–359].

also, man's craving for comfort and gadgets, every innovation leads to growth. To be sure, development is not an inevitable aspect of history; it depends on many factors as well as on accidents, which explains why mankind's past consists mainly of long stretches of quasi stationary states and why the present effervescent era is just a very small exception.[88]

On purely logical grounds, however, there is no necessary association between development and growth; conceivably, there could be development without growth. Because of the failure to observe the preceding distinctions systematically, it was possible for environmentalists to be accused of being against development.[89] Actually, the true environmentalist position must focus on *the total rate* of resource depletion (and the rate of the ensuing pollution). It is only because in the past economic growth has resulted not only in a higher rate of depletion but even in an increase of per capita consumption of resources that the argument drifted so as to turn around the economist's guidepost—the GNP per capita. As a result, the real issue came to be buried under the sort of sophistries mentioned in the preceding section. For even though on purely logical grounds economic growth might occur even with a decrease in the rate of resource depletion, pure growth cannot exceed a certain, albeit unknowable, limit without an increase in that rate—unless there is a substantial decrease in population.

It was natural for economists—who unflinchingly have hung on to their mechanistic framework—to remain completely indifferent when, at various times, the Conservation Movement or some isolated literati, such as Fairfield Osborn and Rachel Carson, called attention to the ecological harm of growth and the necessity of slowing down. But a few years ago the environmentalist movement gained momentum around the problem of population—*The Population Bomb,* as Paul Ehrlich epitomized it. Also, a few unorthodox economists shifted to a physiocratic position, albeit in greatly modified forms, or made a try at blending ecology into economics [e.g., 8; 9; 19; 29; 32]. Some became concerned with good, instead of affluent life [8; 65]. Moreover, a long series of incidents proved to everybody's satisfaction that pollution is not a plaything of ecologists. Although depletion of resources has also been going on with increased intensity at all times, it ordinarily is a volume phenomenon below the earth's surface, where no one can see it truly. Pollution, on the other hand, is a surface phenomenon, the existence of which cannot possibly be ignored, much less denied. Those economists who have reacted to these events have generally tried to harden further the position that economic rationality and the right kind of price mechanism can take care of all ecological problems.

But, curiously, the recent publication of *The Limits to Growth* [62], a report for the Club of Rome, caused an unusual commotion within the economics profession. In fact, criticism of the report has come mainly from economists. A manifesto of similar tenor, "A Blueprint for Survival" [6], has been rather spared this glory, apparently not because it was endorsed by a numerous group of highly respected scholars. The reason for the difference is that the *The Limits to Growth* employed analytical models of the kind used in econometrics and simulation works. From all one can judge, it was this fact that irked economists to the point of resorting to direct or veiled insults in their attack against the Trojan Horse. Even *The Economist* [55] disregarded proverbial British good form and in

[88] Some who do not understand how exceptional, perhaps even abnormal, the present interlude is (*Journal of Economic Literature,* June 1972, pp. 459f), ignore the facts that coal mining began eight hundred years ago and that, incredible though it may seem, half of the total quantity ever mined has been extracted in the last thirty years. Also, half of the total production of crude oil has been obtained in the last ten years alone! [46, 166, 238; 56, 119f; also 32, 228]

[89] Solow also claims that to be against pollution is to be against economic growth [74, 49]. However, harmful pollution can be kept very low if appropriate measures are taken and *pure* growth is slowed down.

the editorial "Limits to Misconception" branded the report as "the highwater mark of old-fashioned nonsense." Beckerman even ignored the solemnity of an inaugural lecture and assailed the study as "a brazen, impudent piece of nonsense [by] a team of whizz-kids from MIT" [4, 327].[40]

Let us begin by recalling, first, that economists, especially during the last thirty years, have preached right and left that only mathematical models can serve the highest aims of their science. With the advent of the computer, the use of econometric models and simulation became a widespread routine. The fallacy of relying on arithmomorphic models to predict the march of history has been denounced occasionally with technical arguments.[41] But all was in vain. Now, however, economists fault *The Limits to Growth* for that very sin and for seeking "an aura of scientific authority" through the use of the computer; some have gone so far as to impugn the use of mathematics [4, 331–334; 10, 22f; 51, 660; 52; 69, 15–17]. Let us observe, secondly, that aggregation has always been regarded as a mutilating yet inevitable procedure in macroeconomics, which thus greatly ignores structure. Nevertheless, economists now denounce the report for using an aggregative model [4, 338f; 52; 69, 61f, 74]. Thirdly, one common article of economic faith, known as the acceleration principle, is that output is proportional to capital stock. Yet some economists again have indicted the authors of *The Limits* for assuming (implicitly) that the same proportionality prevails for pollution—which is an output, too! [4, 399f; 52; 69, 47f][42] Fourthly, the price complex has not prevented economists from developing and using models whose blueprints contain no prices explicitly—the static and dynamic Leontief models, the Harrod-Domar model, the Solow model, to cite some of the most famous ones. In spite of this, some critics (including Solow himself) have decried the value of *The Limits* on the sole ground that its model does not involve prices [4, 337; 51, 665; 74, 46f; 69, 14].

The final and most important point concerns the indisputable fact that, except for some isolated voices in the last few years, economists have always suffered from growthmania [65, Ch. 1]. Economic systems as well as economic plans have always been evaluated only in relation to their ability to sustain a great rate of economic growth. Economic plans, without a single exception, have been aimed at the highest possible rate of economic growth. The very theory of economic development is anchored solidly in exponential growth models. But when the authors of *The Limits* also used the assumption of exponential growth, the chorus of economists cried "foul!" [4, 332f; 10, 13; 51, 661; 52; 74, 42f; 69, 58f] This is all the more curious since some of the same critics concomitantly maintained that technology grows exponentially (Section VI). Some, while admitting at long last that economic growth cannot continue forever at the present rate, suggested, however, that it could go on at some lower rates [74, 666].

Going through this peculiar criticism, one gets the impression that the critics from the economics profession proceeded according to the Latin adage—*quod licet Jovi non licet bovi*—what is permitted to Zeus is not permitted to a bovine. Be this as it may, standard economics will recover only with difficulty

[40] And later he asked, "How silly do you have to be to be allowed to join [the Club of Rome]?" [4, 339]. Kaysen [51] also is caustic in places. Solow [75, 1] just says that, like everyone else, he was "suckered into reading the *Limits to Growth*," while Johnson [49, 1] disqualifies intellectually all concerned ecologists right from the outset. Outside the economists' circle, John Maddox stands out by himself for seeking to impress the reader by similar "arguments."

[41] See in particular, [26] and [28]; also [32, 339–341]. More recently, and from a different viewpoint, W. Leontief also took up the issue in his Presidential Address to the AEA [54]. Symptomatically, the frank verdict of Ragnar Frisch in his address to the First World Congress of the Econometric Society (1965) still awaits publication.

[42] Some of the foregoing objections were also voiced from outside the economics profession [1; 59, 284f].

from the exposure of its own weaknesses by these efforts at self-defense.

Outside these circles, the report has been received with sufficient appreciation, certainly not with vituperation.[43] The most apt verdict is that despite its imperfections, "it is not frivolous." [44] True, the presentation is rather half-baked, betraying the rush for early publicity [34]. But even some economists have recognized its merit in drawing attention to the ramified consequences of pollution [69, 58f]. The study has also brought to the fore the importance of duration in the actual course of events [62, 183] —a point often emphasized by natural scientists [43, 144; 56, 131] but generally overlooked by economists [32, 273f]. We need a time lead not only to reach a higher level of economic growth but also to descend to a lower one.

But the much publicized conclusion—that at most one hundred years separate mankind from an ecological catastrophe [62, 23 and *passim*]—lacks a scientifically solid basis.

There is hardly any room for quarreling about the general pattern of relations assumed in the various simulations covered by the report. However, the *quantitative* forms of these relations have not been submitted to any factual verification. Besides, by their very rigid nature, the arithmomorphic models used are incapable of predicting the evolutionary changes these relations may suffer over time. The prediction, which sounds like the famous scare that the world would come to an end in A. D. 1000, is at odds with everything we know about biological evolution. The human species, of all species, is not likely to go suddenly into a short coma. Its end is not even in distant sight; and when it comes it will be after a very long series of surreptitious, protracted crises. Yet, as Silk pointed out [72], it would be madness to ignore the study's general warnings about population growth, pollution, and resource depletion. Indeed, any of these factors may cause the world's economy to experience some shortness of breath.

Some critics have further belittled *The Limits* for merely using an analytical armamentarium in order to emphasize an uninteresting tautology, namely, that continuous exponential growth is impossible in a finite environment [4, 333f; 51, 661; 74, 42f; 69, 55]. The indictment is right, but only on the surface; for this was one of those occasions when the obvious had to be emphasized because it had been long ignored. However, the greatest sin of the authors of *The Limits* is that they have concealed the most important part of the obvious by focusing their attention exclusively on exponential growth, as Malthus and almost every other environmentalist has done.

VIII. THE STEADY STATE: A TOPICAL MIRAGE

Malthus, as we know, was criticized primarily because he assumed that population and resources grow according to some simple mathematical laws. But this criticism did not touch the real error of Malthus (which has apparently remained unnoticed). This error is the implicit assumption that population may grow beyond any limit both in number and time *provided that it does not grow too rapidly*.[45] An essentially similar error has been committed by the authors of *The Limits*, by the authors of the nonmathematical yet more articulate "Blueprint for Survival," as well as by several earlier writers. Because, like Malthus, they were set exclu-

[43] A notable exception is Maddox [59]. His berating review of "A Blueprint for Survival" ("The Case Against Hysteria," *Nature*, 14 January 1972, pp. 63–65) drew numerous protests: *Nature*, 21 January 1972, p. 179, 18 February 1972, pp. 405f. But given the position of economists in the controversy, it is understandable that Beckerman [4, 341f] cannot conceive why natural scientists have not assailed the report and why they seem even to accept its thesis.

[44] *Financial Times*, 3 March 1972, quoted in [4, 337n]. Denis Gabor, a Nobelite, judged that "whatever the details, the main conclusions are incontrovertible" (quoted in [4, 342]).

[45] Joseph J. Spengler, a recognized authority in this broad domain, tells me that indeed he knows of no one who may have made the observation. For some very penetrating discussions of Malthus and of the present population pressure, see [76; 77].