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ENERGY AND ECONOMIC MYTHS*

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> So you can now all go home and sleep peacefully in your beds tonight secure in the knowledge that in the sober and considered opinion of the latest occupant of the second oldest Chair in Political Economy in this country, although life on this Earth is very far from perfect there is no reason to think that continued economic growth will make it any worse.
>
> Wilfred Beckerman

I. INTRODUCTION

There is an appreciable grain of truth in one of Percy Bridgman's remarks that the economic profession is the most opportunistic of all. Indeed, economists' attention has continually shifted from one problem to another, the problems often being not even closely related. Search all economic periodicals of the English-speaking world before 1950, for example, and you will hardly find any mention of "economic development." It is curious, therefore, that economists have over the last hundred years remained stubbornly attached to one particular idea, the mechanistic epistemology which dominated the orientation of the founders of the Neoclassical School. By their own proud admission, the greatest ambition of these pioneers was to build an economic science after the model of mechanics—in the words of W. Stanley Jevons—as "*the mechanics of utility and self-interest*" [48, 23]. Like almost every scholar and philosopher of the first half of the nineteenth century, they were fascinated by the spectacular successes of the science of mechanics in astronomy and accepted Laplace's famous apotheosis of mechanics [53, 4] as the evangel of ultimate scientific knowledge. They thus had some attenuating circumstances, which cannot, however, be invoked by those who came long after the mechanistic dogma had been banished even from physics [23, 69–122; 5].

The latter-day economists, without a single second thought, have apparently been happy

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to develop their discipline on the mechanistic tracks laid out by their forefathers, fiercely fighting any suggestion that economics may be conceived otherwise than as a sister science of mechanics. The appeal of the position is obvious. At the back of the mind of almost every standard economist there is the spectacular feat of Urbain Leverrier and John Couch Adams, who discovered the planet Neptune, not by searching the real firmament, but "at the tip of a pencil on a piece of paper." What a splendid dream to be able to predict by some paper-and-pencil operations alone where a particular stock will be on the firmament of the Stock Exchange Market tomorrow or, even better, one year from now!

The consequence of this indiscriminate attachment to the mechanistic dogma, whether in an explicit or a tacit manner, is the viewing of the economic process as a mechanical analogue consisting—as all mechanical analogues do—of a principle of conservation (transformation) and a maximization rule. The economic science itself is thus reduced to a *timeless* kinematics. This approach has led to a mushrooming of paper-and-pencil exercises and increasingly complicated econometric models which often serve only to conceal from view the most fundamental economic issues. Everything now turns out to be just a pendulum movement. One business "cycle" follows another. The pillar of equilibrium theory is that, if events alter the demand and supply propensities, the economic world always returns to its previous conditions as soon as these events fade out. An inflation, a catastrophic drought, or a stock-exchange crash leaves absolutely no mark on the economy. Complete reversibility is the general rule, just as in mechanics.[1]

Nothing illustrates better the basic epistemology of standard economics than the usual graph by which almost every introductory manual portrays the economic process as a self-sustaining, circular flow between "production" and "consumption."[2] But even money does not circulate back and forth within the economic process; for both bullion and paper money ultimately become worn out and their stocks must be replenished from external sources [31]. The crucial point is that the economic process is not an isolated, self-sustaining process. This process cannot go on without a continuous exchange which alters the environment in a cumulative way and without being, in its turn, influenced by these alterations. Classical economists, Malthus in particular, insisted on the economic relevance of this fact. Yet, both standard and Marxist economists chose to ignore the problem of natural resources completely, so completely that a distinguished and versatile economist recently confessed that he had just decided that he "ought to find out what economic theory has to say" about that problem [75, 1f].

One fundamental idea dominated the orientation of both schools. A. C. Pigou stated it most explicitly: "In a stationary state factors of production are stocks, unchanging in amount, out of which emerges a continuous flow, also unchanging in amount, of real income" [68, 19]. The same idea—that a constant flow can arise from an unchanging structure—is at the basis of Marx's diagram of simple reproduction [61, II, ch. xx]. In the diagram of expanded reproduction [61, II, ch. xxi], Marx actually anticipated the modern models—such as that with which W. W. Leontief swept the profession off its feet—which ignore the problem of the primary source of the flow even in the case of a

[1] Some economists have insisted that, on the contrary, irreversibility characterizes the economic world [e.g., 60, 461, 808; 25], but the point, though never denied, was simply shelved away. It is in vain that some now try to claim that standard equilibrium analysis has always considered negative feedbacks [4, 334]. The only feedbacks in standard theory are those responsible for maintaining equilibrium, not for evolutionary changes.

[2] For a highly significant sample, see G. L. Bach, *Economics*, 2d ed. Englewood Cliffs, N.J.: Prentice-Hall, 1957, p. 60; Paul A. Samuelson, *Economics*, 8th ed. New York: McGraw-Hill, 1970, p. 72; Robert L. Heilbroner, *The Economic Problem*, 3rd ed. Englewood Cliffs, N.J.: Prentice-Hall, 1972, p. 177.

growing economy. The only difference is that Marx preached overtly that nature offers us everything gratis, while standard economists merely went along with this tenet tacitly. Both schools of thought shared, therefore, the Pigouvian notion of a stationary state in which a material flow emerges from an invariable source. In this idea there lies the germ of an economic myth which, as we shall see (Section VIII), is now preached by many concerned ecologists and some awakened economists. The myth is that a stationary world, a zero-growth population, will put an end to the ecological conflict of mankind. Mankind will no longer have to worry about the scarcity of resources or about pollution—another miracle-program to bring the New Jerusalem into the earthly life of man.

Myths have always occupied a prominent role in the life of man. To be sure, to act in accord with a myth is the distinctive characteristic of man among all living beings. Many myths betray man's greatest folly, his inner compulsion to believe that he is above everything else in the actual universe and that his powers know no limits. In Genesis man proclaimed that he was made in the image of God Himself. At one time, he held that the entire universe revolves around his petty abode—at another, that only the sun does so. Once, man believed that he could move things without consuming any energy, which is the myth of perpetual motion of the first kind—certainly, an essentially economic myth. The myth of perpetual motion of the second kind, which is that we may use the same energy over and over again, still lingers on in various veiled forms.

Another economic myth—that man will forever succeed in finding new sources of energy and new ways of harnessing them to his benefit—is now propounded by some scientists, but especially by economists of both standard and Marxist persuasions (Section VI). Come what may, "we will [always] think up something" [4, 338]. The idea is that, if the individual man is mortal, at least the human species is immortal. Apparently, it is below man's dignity to accept the verdict of a biological authority such as J. B. S. Haldane that the most certain fate of mankind is the same as that of any other species, namely, extinction. Only, we do not know when and why it will come. It may be sooner than the optimists believe or much later than the pessimists fear. Consequences of the accumulation of environmental deterioration may bring it about; but some persistent virus or a freak infertility gene may also cause it.

The fact is that we know little about why any species bowed out in the past, not even why some seem to become extinct before our own eyes. If we can predict approximately how long a given dog will live and also what will most probably end its life, it is only because we have had repeated occasions to observe a dog's life from birth to death. The predicament of the evolutionary biologist is that he has never observed another human species being born, aging, and dying [29, 91; 32, 208–210]. However, a species reaches the end of its existence by a process analogous to the aging of any individual organism. And even though aging is still surrounded by many mysteries [32, 205], we know that the causes which bring about the end of a species work slowly, but *persistently and cumulatively,* from the first moment of its birth. The point is that everyone of us ages with each minute, nay, with each blink, even though we are unable to realize the difference.

It is utterly inept to argue—as some economists implicitly do—that since mankind has not met with any ecological difficulty since the age of Pericles, it will never meet with one (Section VI). If we keep our eyes open, however, we will detect, as time goes by, some sufficiently apparent symptoms which may help us arrive at some general idea of the probable causes of aging and, possibly, of death. True, man's needs and the kinds of resources required for their satisfaction are far more complex than those of any other species. In exchange, our knowledge of these factors and their interrelations is, naturally, more extensive. The upshot is that even a simple analysis of the energy aspects of man's existence may help us reach at least a general picture of the ecological problems and arrive at a few, but relevant, conclusions. This, *and nothing else,* is what I have endeavored to do in this paper.

II. MECHANICS VERSUS THERMODYNAMICS

No analysis of a material process, whether in the natural sciences or in economics, can be sound without a clear and comprehensive analytical picture of such a process. The picture must first of all include the boundary—an abstract and void element which separates the process from its "environment"—as well as the duration of the process. What the process needs and what it does are then described analytically by the complete time schedule of all inputs and outputs, i.e., the precise moments at which each element involved crosses the boundary from outside or from inside. But where we draw the abstract boundary, what duration we consider, and what qualitative spectrum we use for classifying the elements of the process depend on the particular purpose of the student, and by and large on the science in point.[3]

Mechanics distinguishes only mass, speed, and position, on which it bases the concept of kinetic and potential energy. The result is that mechanics reduces any process to locomotion and a change in the distribution of energy. The constancy of total mechanical energy (kinetic plus potential) and the constancy of mass are the earliest principles of conservation to be recognized by science. A few careful economists, such as Marshall [60, 63], did observe that man can create neither matter nor energy. But in doing so, they apparently had in mind only the *mechanical* principles of conservation, for they immediately added that man can nevertheless produce utilities by moving and rearranging matter. This viewpoint ignores a most important issue: How can man do the moving? For anyone who remains at the level of mechanical phenomena, every bit of matter and every bit of mechanical energy which enter a process must come out in exactly the same *quantity* and *quality*. Locomotion cannot alter either.

To equate the economic process with a mechanical analogue implies, therefore, the myth that the economic process is a circular merry-go-round which cannot possibly affect the environment of matter and energy in any way. The obvious conclusion is that there is no need for bringing the environment into the analytical picture of that process.[4] The old tenet of Sir William Petty, that keen student of human affairs who insisted that labor is the father and nature the mother of wealth, has long since been relegated to the status of a museum piece [29, 96; 31, 280]. Even the accumulation of glaring proofs of the preponderant role played by natural resources in mankind's history failed to impress standard economists. One may think of the Great Migration of the first millenium which was the ultimate response to the exhaustion of the soil of Central Asia following a long period of persistent grazing. Remarkable civilizations—Maya is one example—crumbled away from history because their people were unable to migrate or to counteract by adequate technical progress the deterioration of their environment. Above all, there is the indisputable fact that all struggles between the Great Powers have not turned idly around ideologies or national prestige but around the control of natural resources. They still do.

Because mechanics recognizes no qualitative change but only change of place, any

[3] For a detailed discussion of the analytical representation of a process, see Georgescu-Roegen [32, ch. ix].

[4] If "land" appears as a variable in some standard production functions, it stands only for Ricardian land, i.e., for mere space. The lack of concern for the true nature of the economic process is also responsible for the inadequacy of the standard production function from other, equally crucial, viewpoints. See Georgescu-Roegen [27; 30; 33].

mechanical process may be reversed, just as a pendulum, for instance, can. No laws of mechanics would have been violated if the earth had been set in motion in the opposite direction. There is absolutely no way for a spectator to discover whether a movie of a purely mechanical pendulum is projected in the direction in which it was taken or in the reverse. But actual phenomena in all their aspects do not follow the story of the famous Mother Goose rhyme in which the brave Duke of York kept marching his troops up the hill and down the hill without giving battle. Actual phenomena move in a definite direction and involve qualitative change. This is the lesson of thermodynamics, a peculiar branch of physics, so peculiar that purists prefer not to consider it a part of physics because of its anthropomorphic texture. Even though it is hard to see how the basic texture of any science could be otherwise than anthropomorphic, the case of thermodynamics is unique.

Thermodynamics grew out of a memoir by a French engineer, Nicolas Sadi Carnot, on the efficiency of heat engines (1824). Among the first facts it brought to light is that man can use only a particular form of energy. Energy thus came to be divided into *available* or *free* energy, which can be transformed into work, and *unavailable* or *bound* energy, which cannot be so transformed.[5] Clearly, the division of energy according to this criterion is an anthropomorphic distinction like no other in science.

The distinction is closely related to another concept specific to thermodynamics, namely, to entropy. This concept is so involved that one specialist judged that "it is not easily understood even by physicists" [40, 37].[6] But for our immediate purpose we may be satisfied with the simple definition of entropy as an *index* of the amount of unavailable energy in a given thermodynamic system at a given moment of its evolution.

Energy, regardless of quality,[7] is subject to a strict conservation law, the First Law of Thermodynamics, which is formally identical to the conservation of mechanical energy mentioned earlier. And since work is one of the multiple forms of energy, this law exposes the myth of perpetual motion of the first kind. It does not, however, take account of the distinction between available and unavailable energy; *by itself the law does not preclude the possibility that an amount of work should be transformed into heat and this heat reconverted into the initial amount of work.* The First Law of Thermodynamics thus allows any process to take place both forward and backward, so that everything is again just as it was at first, with no trace left by the happening. With only that law we are still in mechanics, not in the domain of actual phenomena, which certainly includes the economic process.

The irreducible opposition between mechanics and thermodynamics stems from the Second Law, the Entropy Law. The oldest of its multiple formulations is also the most transparent for the nonspecialist: "Heat flows by itself only from the hotter to the colder body, never in reverse." A more involved but equivalent formulation is that the entropy of a *closed* system continuously (and irrevocably) increases toward a maximum; i.e.,

[5] The technical definition of available (unavailable) energy does not coincide with that of free (bound) energy. But the difference is such that we may safely ignore it in the present discussion.

[6] This judgment is vindicated by the discussion of the Entropy Law in [44, 17]. Even the familiar notion of heat raises some delicate issues, with the result that some physicists may go wrong on it, too. See *Journal of Economic Literature,* X (December 1972), p. 1268.

[7] Let us also note that even energy does not lend itself to a simple, formal definition. The familiar one, that energy is the capacity of a system to perform work, clashes with the definition of unavailable energy. We must then explain that all energy can in principle be transformed into work provided that the corresponding system is brought in contact with another which is at the absolute zero of temperature. This explanation has only the value of a pure extrapolation because, according to the Third Law of Thermodynamics, this temperature can never be reached.

the available energy is continuously transformed into unavailable energy until it disappears completely.[8]

In broad lines, the story is relatively simple: *All kinds of energy are gradually transformed into heat and heat becomes so dissipated in the end that man can no longer use it*. Indeed, a point that goes back to Carnot is that no steam engine can provide work if the same temperature, however high, prevails in the boiler and the cooler.[9] To be available, energy must be distributed unevenly; energy that is completely dissipated is no longer available. The classical illustration is the immense heat dissipated into the water of the seas, which no ship can use. Although ships sail on top of it, they need available energy, the kinetic energy concentrated in the wind or the chemical and nuclear energy concentrated in some fuel. We may see why entropy came to be regarded also as an index of disorder (of dissipation) not only of energy but also of *matter* and why the Entropy Law in its present form states that *matter, too, is subject to an irrevocable dissipation*. Accordingly, the ultimate fate of the universe is not the Heat Death (as it was believed at first) but a much grimmer state—Chaos. No doubt, the thought is intellectually unsatisfactory.[10] But what interests us is that, according to all the evidence, our immediate environment, the solar system, tends toward a thermodynamic death,[11] at least as far as life-bearing structures are concerned.

III. THE ENTROPY LAW AND ECONOMICS

Perhaps no other law occupies a position in science as singular as that of the Entropy Law. It is the only natural law which recognizes that even the material universe is subject to an irreversible qualitative change, to an evolutionary process.[12] This fact led some natural scientists and philosophers to suspect an affinity between that law and life phenomena. By now, few would deny that the *economy* of any life process is governed, not by the laws of mechanics, but by the Entropy Law [32, xiii, 191–194]. The point, as we shall now see, is most transparent in the case of the economic process.

Economists have occasionally maintained that, since some scientists trespass into economics without knowing much about the subject, they, too, are justified in talking about science, notwithstanding their ignorance in that domain [4, 328f]. The thought reflects an error, which unfortunately is general with economists. But whatever the economic expertise of other scientists, economists could not fare continuously well in their own field without some solid understanding of the Entropy Law and its consequences.[13] As I argued some years ago, thermodynamics is at bottom a physics of economic value—as Carnot unwittingly set it going—and the En-

[8] A system is closed if it exchanges no matter and no energy with its "environment." Clearly, in such a system the amount of matter-energy is constant. However, the constancy of this amount alone does not warrant the increase of entropy. Entropy may even decrease if there is exchange.

[9] There is no truth, therefore, in Holdren's idea [44, 17] that temperature measures "the usefulness" of heat. The most we can say is that the *difference* of temperature is a rough index of the usefulness of the hotter heat.

[10] One alternative, supported by statistical thermodynamics (Section VI), is that entropy may decrease in some parts of the universe so that the universe both ages and rejuvenates. But no substantial evidence exists for this possibility. Another hypothesis, set forth by a group of British astronomers, is that the universe is an everlasting steady state in which individual galaxies are born and die continuously. But facts do not fit this hypothesis either. The issue of the true nature of the universe is far from settled [32, 201f, 210].

[11] To preclude some erring, we should emphasize the point that a reversal of this trend would be just as bad for the preservation of life on earth.

[12] Rudolf Clausius coined "entropy" from a Greek word meaning "transformation," "evolution." See [32, 130].

[13] As we shall see later on, some highly interesting examples are provided by Harry G. Johnson [49] and, in an unceremonious, assertive manner, by Robert A. Solo [73]. As for Robert M. Solow, who at first also refused to swerve a hair from the standard position [74], he recently found it opportune to concede that "it takes economics and the law of entropy" to deal with the problem of resources [75, 11]. But at bottom, he still remained attached to his old creed.

tropy Law is the most economic in nature of all natural laws [29, 92–94; 32, 276–283].

The economic process, like any other life process, is irreversible (and irrevocably so); hence, it cannot be explained in mechanical terms alone. It is thermodynamics, through the Entropy Law, that recognizes the qualitative distinction which economists should have made from the outset between the inputs of valuable resources (low entropy) and the final outputs of valueless waste (high entropy). The paradox suggested by this thought, namely, that all the economic process does is to transform valuable matter and energy into waste, is easily and instructively resolved. It compels us to recognize that the real output of the economic process (or of any life process, for that matter) is not the *material flow* of waste, but the still mysterious *immaterial flux* of the enjoyment of life.[14] Without recognizing this fact we cannot be in the domain of life phenomena.

The present laws of physics and chemistry do not explain life completely. But the thought that life may violate some natural law has no place in science. Nevertheless, as has long been observed—and more recently in an admirable exposition by Erwin Schrödinger [71, 69–72]—life seems to evade the entropic degradation to which inert matter is subject. The truth is that any living organism simply strives at all times to compensate for its own continuous entropic degradation by sucking low entropy (negentropy) and expelling high entropy. Clearly, this phenomenon is not precluded by the Entropy Law, which requires only that the entropy of the entire system (the environment *and* the organism) should increase. Everything is in order as long as the entropy of the environment increases by more than the compensated entropy of the organism.

Equally important is the fact that the Entropy Law is the only natural law that does not predict quantitatively. It does not specify how great the increase should be at a future moment or what particular entropic pattern will result. Because of this fact, there is an entropic indeterminateness in the real world which allows not only for life to acquire an endless spectrum of forms but also for most actions of a living organism to enjoy a certain amount of freedom [32, 12]. Without this freedom, we would not be able to choose between eating beans or meat, between eating now or later. Nor could we aspire to implement economic plans (at any level) of our own choosing.

It is also because of the entropic indeterminateness that life does matter in the entropic process. The point is no mystical vitalism, but a matter of brute facts. Some organisms slow down the entropic degradation. Green plants store *part* of the solar radiation which in their absence would immediately go into dissipated heat, into high entropy. That is why we can burn now the solar energy saved from degradation millions of years ago in the form of coal or a few years ago in the form of a tree. All other organisms, on the contrary, speed up the march of entropy. Man occupies the highest position on this scale, and this is all that environmental issues are about.

Most important for the student of economics is the point that the Entropy Law is the taproot of economic scarcity. Were it not for this law, we could use the energy of a piece of coal over and over again, by transforming it into heat, the heat into work, and the work back into heat. Also, engines, homes, and even living organisms (if they could exist at all) would never wear out. There would be no economic difference between material goods and Ricardian land. In such an imaginary, purely mechanical world, there would be no true scarcity of energy and materials. A population as large as the space of our globe would allow could live indeed forever. An increase in the real income per capita could be supported in part

[14] It seems idle therefore to ask—as Boulding [8, 10] does—whether well-being is a flow or a stock.

by a greater velocity of use (just as in the case of money circulation) and in part by additional mining. But there would be no reason for any real struggle, whether intra-species or inter-species, to arise.

Economists have been insisting that "there is no free lunch," by which they mean that the price of anything must be equal to the cost; otherwise, one would get something for nothing. To believe that this equality also prevails in terms of entropy constitutes one of the most dangerous economic myths. *In the context of entropy, every action, of man or of an organism, nay, any process in nature, must result in a deficit for the entire system.* Not only does the entropy of the environment increase by an additional amount for every gallon of gasoline in your tank, but also a substantial part of the free energy contained in that gasoline, instead of driving your car, will turn directly into an additional increase of entropy. As long as there are abundant, easily accessible resources around, we might not really care how large this additional loss is. Also, when we produce a copper sheet from some copper ore we decrease the entropy (the disorder) of the ore, but only at the cost of a much greater increase of the entropy in the rest of the universe. If there were not this entropic deficit, we would be able to convert work into heat, and, by reversing the process, to recuperate the entire initial amount of work—as in the imaginary world of the preceding paragraph. In such a world, standard economics would reign supreme precisely because the Entropy Law would not work.

IV. ACCESSIBLE ENERGY AND ACCESSIBLE MATTER

As we have seen, the distinction between available and unavailable energy (generalized by that between low and high entropy) was introduced in order that thermodynamics may take into account the fact that only one particular state of energy can be used by man. But the distinction does not mean that man can *actually* use any available energy regardless of the place and form in which it is found. If available energy is to have any value for mankind, it must also be *accessible*. Solar energy and its by-products are accessible to us with practically no effort, no consumption of additional available energy. In all other cases, we have to spend some work and materials in order to tap a store of available energy. The point is that even though we may land on Mars and find there some gas deposits, that available energy will not be accessible to us if it will take more than the equivalent energy of a cubic foot of gas *accessible on earth* to bring a cubic foot of gas from that planet. There certainly are oil shales from which we could extract one ton of oil only by using more than one ton of oil. The oil in such a shale would still represent available, but not accessible, energy. We have been reminded ad nauseam that the real reserves of fossil fuel are certainly greater than those known or estimated [e.g. 58, 331]. But it is equally certain that a substantial part of the real reserves does not constitute accessible energy.

The distinction regards efficiency in terms of energy, not in terms of economics. Economic efficiency implies energetic efficiency, but the converse is not true. The use of gas, for example, is energetically more efficient than the use of electricity, but electricity happens to be cheaper in many instances [79, 152]. Also, even though we can make gas from coal, it is cheaper to extract gas from natural deposits. Should the natural resources of gas become exhausted before those of coal, we will certainly resort to the method that is now economically inefficient. The same idea should be borne in mind when discussing the future of direct uses of solar radiation.

Economists, however, insist that "resources are properly measured in economic, not physical, terms" [51, 663; also 3, 247]. The advice reflects one of the most enduring myths of the profession (shared also by others). It is the myth that the price mechanism can offset any shortages, whether of land, energy or materials.[15] This myth will be duly examined later on, but here we need only emphasize the point that from the point of view of the longrun it is only efficiency in terms of energy that counts in establishing accessibility. To be sure, actual efficiency depends at any one time on the state of the arts. But, as we know from Carnot, in each particular situation *there is a theoretical limit independent of the state of the arts, which can never be attained in actuality*. In effect, we generally remain far below it.

Accessibility, as here defined, bears on the fact that although mankind's spaceship floats within a fantastic store of available energy, only an infinitesimal part of this store is potentially accessible to man. For even if we were to travel in space with the greatest speed, that of light, we would still be confined to a speck of cosmos. A journey just to scout the nearest sun outside the solar system for possible, yet uncertain, earth-like satellites would take nine years! If we have learned anything from the landing on the moon, it is that there is no promise of resources in interplanetary, let alone intersidereal, travel.

Still narrower limits to the accessible energy are set by our own biological nature, which is such that we cannot survive at too high or too low a temperature or when exposed to some radiations. It is for this reason that the mining of nuclear fuel and its use on a large scale has raised issues which now divide laymen as well as authorities on the subject (Section IX). There are also limits set by some purely physical obstacles. The sun cannot possibly be mined even by a robot. From the sun's immense radiating energy, only the small amount which reaches the earth counts in the main (Section IX). Nor can we harness the immense energy of the terrestrial thunders. Unique physical obstacles also stand hopelessly in the way of the peaceful use of thermonuclear energy. The fusion of deuterium requires the fantastic temperature of 0.2 billion°F, one order of magnitude hotter than the sun's interior. The difficulty concerns the material container for that reaction. As has been explained in layman's terms, the solution now sought is similar to holding water inside a mesh of rubber bands. In this connection we may recall that the chemical energy of dynamite and gunpowder, although in use for a long time, cannot be controlled so as to drive a turbine or a motor. Perhaps the use of thermonuclear energy will also remain confined to a "bomb." [16] Be this as it may, with or without thermonuclear energy, the amount of accessible energetic low entropy is finite (Section IV).

Similar considerations lead to the conclusion that the amount of accessible material low entropy is finite, too. But although in both cases only the amount of low entropy matters, it is important that the two accounts be kept separate in any discussion of the environmental problem. As we all know, available energy and ordered material structures fulfill two distinct roles in mankind's life. However, this anthropomorphic distinction would not be compelling by itself.

There is, first, the physical fact that, despite the Einstein equivalence of mass and energy, there is no reason to believe that we can convert energy into matter except at the atomic scale in a laboratory and only for some special elements.[17] We cannot produce a copper sheet, for example, from energy alone. All the copper in that sheet must exist as copper (in pure form or in some chemical

[15] The evidence is ample [3, 240f; 4, 337f; 49; 51, 663, 665; 74, 46f; 80; 69, 9f, 14f]. The appeal of the myth is seen in that even many on the other side of the fence share it [58; 62, 65; 6, 10, 12; and Frank Notestein, quoted in 62, 130].

[16] The technical difficulties at the present moment are surveyed in [63]. On the other hand, we should remember that in 1933 Ernest Rutherford greatly doubted that atomic energy could be controlled [82, 27].

[17] The point is that even the formation of an atom of carbon from three atoms of helium, for example, requires such a sharp timing that its probability is astronomically small, and hence the event may occur on a large scale only within astronomically huge masses.

compound) beforehand. Therefore, the statement that "energy is convertible into most of the other requirements of life" [83, 412] is, in this unqualified form, apt to mislead. Second, no material macrostructure (whether a nail or a jet) whose entropy is lower than that of its surroundings may last forever in its original form. Even the singular organizations characterized by the tendency to evade the entropic decay—the life-bearing structures—cannot so last. The artifacts which now are an essential part of our mode of life have therefore to be renewed continuously from some sources. The final point is that the earth is a thermodynamic system open only with respect to energy. The amount of meteorite matter, though not negligible, comes already dissipated.

The result is that we can count only on the mineral resources, which, however, are both irreplaceable and exhaustible. Many of a particular kind have been exhausted in one country after another [56, 120f].[18] At present, important minerals—lead, tin, zinc, mercury, precious metals—are scarce over the entire world [17, 72–77; 56]. The widespread notion that the oceans constitute an almost inexhaustible source of minerals and may even become a link in a perpetual, natural recycling system [3, 239; 69, 7f] is denounced as mere hyperbole by geological authorities [17, 85–87].[19]

The only way we can substitute energy for material low entropy is through physico-chemical manipulations. By using larger and larger amounts of available energy we can sift copper out from poorer and poorer ores, located deeper and deeper in the earth. But the energy cost of mining low-content ores increases very fast [56, 122f]. We can also recycle "scrap." There are, however, some elements which, because of their nature and the mode in which they participate in the natural and man-conducted processes, are highly dissipative. Recycling, in this case, can hardly help. The situation is particularly distressing for those elements which, in addition, are found in very small supply in the environment. Phosphorus, a highly critical element in biological processes, seems to belong to this category. So does helium, another element with a strictly specific role [17, 81; 38].

An important point—apparently ignored by economists [49, 8; 69, 16, 42]—is that recycling cannot be complete.[20] Even though we can pick up all the pearls from the floor and reconstitute a broken necklace, no actual process can possibly reassemble all the molecules of a coin after it has been worn out.

This impossibility is not a straightforward consequence of the Entropy Law, as Solow believes [75, 2]. Nor is it quite exact to say, with Boulding [8, 7], that "there is, fortunately, no law of increasing material entropy." The Entropy Law does not distinguish between matter and energy. This law does not exclude (at least not in principle) a complete unshuffling of a *partial* material structure, provided that there is enough free energy to do the job. And if we have enough energy, we could even separate the cold molecules of a glass of water and assemble them into ice cubes. If, in practice, however, such operations are impossible, it is only because they would require a practically infinite time.[21]

V. DISPOSABLE WASTE

Since Malthus did not see that waste also raises some economic problems, it was normal for the schools of economic thought which ignored even the input of natural resources to pay no attention to the output of

[18] See the interesting story of the Mesabi Range in [14, 11f].

[19] The widespread notion that the oceans may be turned into an immense source of food also is a great delusion [13, 59f].

[20] Data on recycling are scarce and inadequate; a few are found in [12, 205; 16, 14]. For steel, see [14].

[21] All this proves that, even though the Entropy Law may sound extremely simple, its correct interpretation requires special care.

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]

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[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.[38]

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.[39] 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

[38] 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]

[39] 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].

sively on proving the impossibility of growth, they were easily deluded by a simple, now widespread, but false syllogism: since exponential growth in a finite world leads to disasters of all kinds, ecological salvation lies in the stationary state [42; 47; 62, 156–184; 6, 3f, 8, 20].[46] H. Daly even claims that "the stationary state economy is, therefore, a necessity" [21, 5].

This vision of a blissful world in which both population and capital stock remain constant, once expounded with his usual skill by John Stuart Mill [64, Bk. 4, Ch. 6], was until recently in oblivion.[47] Because of the spectacular revival of this myth of ecological salvation, it is well to point out its various logical and factual snags. The crucial error consists in not seeing that not only growth, but also a zero-growth state, nay, even a declining state which does not converge toward annihilation, cannot exist forever in a finite environment. The error perhaps stems from some confusion between finite stock and finite flow rate, as the incongruous dimensionalities of several graphs suggest [62, 62, 64f, 124ff; 6, 6]. And contrary to what some advocates of the stationary state claim [21, 15], this state does not occupy a privileged position vis-à-vis physical laws.

To get to the core of the problem, let S denote the actual amount of accessible resources in the crust of the earth. Let P_i and s_i be the population and the amount of depleted resources per person in the year i. Let the "amount of total life," measured in years of life, be defined by $L = \Sigma P_i$, from $i = 0$ to $i = \infty$. S sets an upper limit for L through the abvious constraint $\Sigma P_i s_i \leqslant S$. For although s_i is a historical variable, it cannot be zero or even negligible (unless mankind reverts sometime to a berry-picking economy). Therefore, $P_i = 0$ for i greater than some finite n, and $P_i > 0$ otherwise. That value of n is the maximum duration of the human species [31, 12f; 32, 304].

The earth also has a so-called carrying capacity, which depends on a complex of factors, including the size of s_i.[48] This capacity sets a limit on any single P_i. But this limit does not render the other limits, of L and n, superfluous. It is therefore inexact to argue—as the Meadows group seems to do [62, 91f]—that the stationary state can go on forever as long as P_i does not exceed that capacity. The proponents of salvation through the stationary state must admit that such a state can have only a finite duration—unless they are willing to join the "No Limit" Club by maintaining that S is inexhaustible or almost so—as the Meadows group does in fact [62, 172]. Alternatively, they must explain the puzzle of how a whole economy, stationary for a long era, all of a sudden comes to an end.

Apparently, the advocates of the stationary state equate it with an open *thermodynamic* steady state. This state consists of an *open* macrosystem which maintains its entropic structure constant through material exchanges with its "environment." As one would immediately guess, the concept constitutes a highly useful tool for the study of biological organisms. We must, however, observe that the concept rests on some special conditions introduced by L. Onsager [50, 89–97]. These conditions are so delicate (they are called the principle of *detailed* balance) that in actuality they can hold only "within a deviation of a few percent" [50, 140]. For this reason, a steady state may exist in fact only in an approximated manner and over a finite duration. This impossibility of a macrosystem not in a state of chaos to be perpetually durable may one day be explicitly recognized by a new thermodynamic law just as the impossibility of perpetual motion once

[46] The substance of the argument of *The Limits* beyond that of Mill's is borrowed from Boulding and Daly [8; 9; 20; 21].

[47] In *International Encyclopedia of the Social Sciences*, for example, the point is mentioned only in passing.

[48] Obviously, any increase in s_i will generally result in a decrease of L and of n. Also, the carrying capacity in any year may be increased by a greater use of terrestrial resources. These elementary points should be retained for further use (Section X).

was. Specialists recognize that the present thermodynamic laws do not suffice to explain all nonreversible phenomena, including especially life processes.

Independently of these snags there are simple reasons against believing that mankind can live in a perpetual stationary state. The structure of such a state remains the same throughout; it does not contain in itself the seed of the inexorable death of all open macrosystems. On the other hand, a world with a stationary population would, on the contrary, be continually forced to change its technology as well as its mode of life in response to the inevitable decrease of resource accessibility. Even if we beg the issue of how capital may change qualitatively and still remain constant, we would have to assume that the unpredictable decrease in accessibility will be miraculously compensated by the right innovations at the right time. A stationary world may for a while be interlocked with the changing environment through a system of balancing feedbacks analogous to those of a living organism during one phase of its life. But as Bormann reminded us [7, 707], the miracle cannot last forever; sooner or later the balancing system will collapse. At that time, the stationary state will enter a crisis, which will defeat its alleged purpose and nature.

One must be cautioned against another logical pitfall, that of invoking the Prigogine principle in support of the stationary state. This principle states that the minimum of the entropy produced by an Onsager type of open thermodynamic system is reached when the system becomes steady [50, ch. xvi]. It says nothing about how this last entropy compares with that produced by other open systems.[49]

The usual arguments adduced in favor of the stationary state are, however, of a different, more direct nature. It is, for example, argued that in such a state there is more time for pollution to be reduced by natural processes and for technology to adapt itself to the decrease of resource accessibility [62, 166]. It is plainly true that we could use much more efficiently today the coal we have burned in the past. The rub is that we might not have mastered the present efficient techniques if we had not burned all that coal "inefficiently." The point that in a stationary state people will not have to work additionally to accumulate capital (which in view of what I have said in the last paragraphs is not quite accurate) is related to Mill's claim that people could devote more time to intellectual activities. "The trampling, crushing, elbowing, and treading on each other's heel" will cease [64, 754]. History, however, offers multiple examples—the Middle Ages, for one—of quasi stationary societies where arts and sciences were practically stagnant. In a stationary state, too, people may be busy in the fields and shops all day long. Whatever the state, free time for intellectual progress depends on the intensity of the pressure of population on resources. Therein lies the main weakness of Mill's vision. Witness the fact that—as Daly explicitly admits [21, 6–8]—its writ offers no basis for determining even in principle the optimum levels of population and capital. This brings to light the important, yet unnoticed point, that *the necessary conclusion*

[49] The point recalls Boulding's idea that the inflow from nature into the economic process, which he calls "throughput," is "something to be minimized rather than maximized" and that we should pass from an economy of flow to one of stock [8, 9f; 9, 359f]. The idea is more striking than enlightening. True, economists suffer from a flow-complex [29, 55, 88]; also, they have little realized that the proper analytical description of a process must include *both flows and funds* [30; 32, 219f, 228–234]. Entrepreneurs, as far as Boulding's idea is concerned, have at all times aimed at minimizing the flow necessary to maintain their capital funds. If the present inflow from nature is incommensurate with the safety of our species, it is only because the population is too large and part of it enjoys excessive comfort. Economic decisions will always forcibly involve both flows and stocks. Is it not true that mankind's problem is to economize S (a stock) for as large an amount of life as possible, which implies to minimize s_i (a flow) for some "good life"? (Section XI).

of the arguments in favor of that vision is that the most desirable state is not a stationary, but a declining one.

Undoubtedly, the current growth must cease, nay, be reversed. But anyone who believes that he can draw a blueprint for the ecological salvation of the human species does not understand the nature of evolution, or even of history—which is that of a permanent struggle in continuously novel forms, not that of a predictable, controllable physico-chemical process, such as boiling an egg or launching a rocket to the moon.

IX. SOME BASIC BIOECONOMICS[50]

Apart from a few insignificant exceptions, all species other than man use only *endosomatic* instruments—as Alfred Lotka proposed to call those instruments (legs, claws, wings, etc.) which belong to the individual organism *by birth.* Man alone came, in time, to use a club, which does not belong to him by birth, but which extended his endosomatic arm and increased its power. At that point in time, man's evolution transcended the biological limits to include also (and primarily) the evolution of *exosomatic* instruments, i.e., of instruments produced by man but not belonging to his body.[51] That is why man can now fly in the sky or swim under water even though his body has no wings, no fins, and no gills.

The exosomatic evolution brought down upon the human species two fundamental and irrevocable changes. The first is the irreducible social conflict which characterizes the human species [29, 98–101; 32, 306–315, 348f]. Indeed, there are other species which also live in society, but which are free from such conflict. The reason is that their "social classes" correspond to some clear-cut biological divisions. The periodic killing of a great part of the drones by the bees is a natural, biological action, not a civil war.

The second change is man's addiction to exosomatic instruments—a phenomenon analogous to that of the flying fish which became addicted to the atmosphere and mutated into birds forever. It is because of this addiction that mankind's survival presents a problem entirely different from that of all other species [31; 32, 302–305]. It is neither only biological nor only economic. It is bioeconomic. Its broad contours depend on the multiple asymmetries existing among the three sources of low entropy which together constitute mankind's dowry—the free energy received from the sun, on the one hand, and the free energy and the ordered material structures stored in the bowels of the earth, on the other.

The *first* asymmetry concerns the fact that the terrestrial component is a *stock,* whereas the solar one is a *flow.* The difference needs to be well understood [32, 226f]. Coal *in situ* is a stock because we are free to use it all today (conceivably) or over centuries. But at no time can we use any part of a future flow of solar radiation. Moreover, the flow rate of this radiation is wholly beyond our control; it is completely determined by cosmological conditions, including the size of our globe.[52] One generation, whatever it may do, cannot alter the share of solar radiation of any future generation. Because of the priority of the present over the future and the irrevocability of entropic degradation, the opposite is true for the terrestrial shares. These shares are affected by how much of the terrestrial dowry the past generations have consumed.

Second, since no practical procedure is available at human scale for transforming energy into matter (Section IV), accessible material low entropy is by far the most critical element from the bioeconomic viewpoint.

[50] I saw this term used for the first time in a letter from Jiří Zeman.

[51] The practice of slavery, in the past, and the possible procurement, in the future, of organs for transplant are phenomena akin to the exosomatic evolution.

[52] A fact greatly misunderstood: Ricardian land has economic value for the same reason as a fisherman's net. Ricardian land catches the most valuable energy, roughly in proportion to its total size [27, 508; 32, 232].

True, a piece of coal burned by our forefathers is gone forever, just as is part of the silver or iron, for instance, mined by them. Yet future generations will still have their inalienable share of solar energy (which, as we shall see next, is enormous). Hence, they will be able, at least, to use each year an amount of wood equivalent to the annual vegetable growth. For the silver and iron dissipated by the earlier generations there is no similar compensation. This is why in bioeconomics we must emphasize that every Cadillac or every Zim—let alone any instrument of war—means fewer plowshares for some future generations, and implicitly, fewer future human beings, too [31, 13; 32, 304].

Third, there is an astronomical difference between the amount of the flow of solar energy and the size of the stock of terrestrial free energy. At the cost of a decrease in mass of 131×10^{12} tons, the sun radiates annually 10^{14}Q—one single Q being equal to 10^{18}BTU! Of this fantastic flow, only some 5,300 Q are intercepted at the limits of the earth's atmosphere, with roughly one half of that amount being reflected back into outer space. At our own scale, however, even this amount is fantastic; for the total world consumption of energy currently amounts to no more than 0.2 Q annually. From the solar energy that reaches the ground level, photosynthesis absorbs only 1.2 Q. From waterfalls we could obtain at most 0.08 Q, but we are now using only one tenth of that potential. Think also of the additional fact that the sun will continue to shine with practically the same intensity for another five billion years (before becoming a red giant which will raise the earth's temperature to 1,000°F). Undoubtedly, the human species will not survive to benefit from all this abundance.

Passing to the terrestrial dowry, we find that, according to the best estimates, the initial dowry of fossil fuel amounted to only 215 Q. The outstanding recoverable reserves (known and probable) amount to about 200 Q. These reserves, therefore, could produce only two weeks of sunlight on the globe.[53] If their depletion continues to increase at the current pace, these reserves may support man's industrial activity for just a few more decades. Even the reserves of uranium-235 will not last for a longer period if used in the ordinary reactors. Hopes are now set on the breeder reactor, which, with the aid of uranium-235, may "extract" the energy of the fertile but not fissionable elements, uranium-238 and thorium-232. Some experts claim that this source of energy is "essentially inexhaustible" [83, 412]. In the United States alone, it is believed, there are large areas covered with black shale and granite which contain 60 grams of natural uranium or thorium per metric ton [46, 226f]. On this basis, Weinberg and Hammond [83, 415f] have come out with a grand plan. By strip-mining and crushing all these rocks, we could obtain enough nuclear fuel for some 32,000 breeder reactors distributed in 4,000 offshore parks and capable of supplying a population of twenty billion for millions of years with twice as much energy per capita as the current consumption rate in the USA. The grand plan is a typical example of linear thinking, according to which all that is needed for the existence of a population, even "considerably larger than twenty billion," is to increase all supplies proportionally.[54] Not that the authors deny that there also are non-technical issues; only, they play them down with noticeable zeal [83, 417f]. The most important issue, of whether a social organization compatible with the density of population and the nuclear manipulation at the

[53] The figures used in this section have been calculated from the data of Daniels [22] and Hubbert [46]. Such data, especially those about reserves, vary from author to author but not to the extent that really matters. However, the assertion that "the vast oil shales which are to be found all over the world [would last] for no less than 40,000 years" [59, 99] is sheer fantasy.

[54] In an answer to critics (*American Scientist,* LVIII, No. 6, p. 619), the same authors prove, again linearly, that the agro-industrial complexes of the grand plan could easily feed such a population.

grand level can be achieved, is brushed aside by Weinberg as "transscientific" [82].[55] Technicians are prone to forget that due to their own successes, nowadays it may be easier to move the mountain to Mohammed than to induce Mohammed to go to the mountain. For the time being, the snag is far more palpable. As responsible forums openly admit, even one breeder still presents substantial risks of nuclear catastrophes, and the problem of safe transportation of nuclear fuels and especially that of safe storage of the radioactive garbage still await a solution even for a moderate scale of operations [35; 36; especially 39 and 67].

There remains the physicist's greatest dream, controlled thermonuclear reaction. To constitute a real breakthrough, it must be the deuterium-deuterium reaction, the only one that could open up a formidable source of terrestrial energy for a long era.[56] However, because of the difficulties alluded to earlier (Section IV), even the experts working at it do not find reasons for being too hopeful.

For completion, we should also mention the tidal and geothermal energies, which, although not negligible (in all 0.1 Q per year), can be harnessed only in very limited situations.

The general picture is now clear. The terrestrial energies on which we can rely effectively exist in very small amounts, whereas the use of those which exist in ampler amounts is surrounded by great risks and formidable technical obstacles. On the other hand, there is the immense energy from the sun which reaches us without fail. Its direct use is not yet practiced on a significant scale, the main reason being that the alternative industries are now much more efficient economically. But promising results are coming from various directions [37; 41]. What counts from the bioeconomic viewpoint is that the feasibility of using the sun's energy directly is not surrounded by risks or big question marks; it is a proven fact.

The conclusion is that mankind's entropic dowry presents another important differential scarcity. From the viewpoint of the extreme longrun, the terrestrial free energy is far scarcer than that received from the sun. The point exposes the foolishness of the victory cry that we can finally obtain protein from fossil fuels! Sane reason tells us to move in the opposite direction, to convert vegetable stuff into hydrocarbon fuel—an obviously natural line already pursued by several researchers [22, 311–313].[57]

Fourth, from the viewpoint of industrial utilization, solar energy has an immense drawback in comparison with energy of terrestrial origin. The latter is available in a concentrated form, in some cases, in a too concentrated form. As a result, it enables us to obtain almost instantaneously enormous amounts of work, most of which could not even be obtained otherwise. By great contrast, the flow of solar energy comes to us with an extremely low intensity, like a very fine rain, almost a microscopic mist. The important difference from true rain is that this radiation rain is not collected naturally into streamlets, then into creeks and rivers, and finally into lakes from where we could use it in a concentrated form, as is the case with waterfalls. Imagine the difficulty one would face if one tried to use *directly* the kinetic energy of some microscopic rain drops as

[55] For a recent discussion of the social impact of industrial growth, in general, and of the social problems growing out of a large scale use of nuclear energy, in particular, see [78], a monograph by Harold and Margaret Sprout, pioneers in this field.

[56] One percent only of the deuterium in the oceans would provide 10^8 Q through that reaction, an amount amply sufficient for some hundred millions of years of very high industrial comfort. The reaction deuterium-tritium stands a better chance of success because it requires a lower temperature. But since it involves lithium-6, which exists in small supply, it would yield only about 200 Q in all.

[57] It should be of interest to know that during World War II in Sweden, for one, automobiles were driven with the poor gas obtained by heating charcoal with kindlings in a container serving as a tank!

they fall. The same difficulty presents itself in using solar energy directly (i.e., not through the chemical energy of green plants, or the kinetic energy of the wind and waterfalls). But as was emphasized a while ago, the difficulty does not amount to impossibility.

Fifth, solar energy, on the other hand, has a unique and incommensurable advantage. The use of any terrestrial energy produces some noxious pollution, which, moreover, is irreducible and hence cumulative, be it in the form of thermal pollution alone. By contrast, any use of solar energy is *pollution-free*. For, whether this energy is used or not, its ultimate fate is the same, namely, to become the dissipated heat that maintains the thermodynamic equilibrium between the globe and outer space at a propitious temperature.[58]

The *sixth* asymmetry involves the elementary fact that the survival of every species on earth depends, directly or indirectly, on solar radiation (in addition to some elements of a superficial environmental layer). Man alone, because of his exosomatic addiction, depends on mineral resources as well. For the use of these resources man competes with no other species; yet his use of them usually endangers many forms of life, including his own. Some species have in fact been brought to the brink of extinction merely because of man's exosomatic needs or his craving for the extravagant. But nothing in nature compares in fierceness with man's competition for solar energy (in its primary or its by-product forms). Man has not deviated one bit from the law of the jungle; if anything, he has made it even more merciless by his sophisticated exosomatic instruments. Man has openly sought to exterminate any species that robs him of his food or feeds on him—wolves, rabbits, weeds, insects, microbes, etc.

But this struggle of man with other species for food (in ultimate analysis, for solar energy) has some unobtrusive aspects as well. And, curiously, it is one of these aspects that has some far-reaching consequences in addition to supplying a most instructive refutation of the common belief that every technological innovation constitutes a move in the right direction as concerns the economy of resources. The case pertains to the economy of modern agricultural techniques.

[58] One necessary qualification: even the use of solar energy may disturb the climate if the energy is released in another place than where collected. The same is true for a difference in time, but this case is unlikely to have any practical importance.

X. MODERN AGRICULTURE: AN ENERGY SQUANDERER

Given the extant spectrum of green plants and their geographical distribution at any one time, the biological carrying capacity of the earth is determined, even though we could compute it only with difficulty and only approximately. It is within this capacity that man struggles with other life-bearing structures for food. But man is unique among all species in that he can influence, within limits, not only his share of food but also the efficiency of the transformation of solar energy into food. With time, man learned to plow deeper, to rotate the use of land, to fertilize the soil with manure, and so on. In his farming activity, man also came to derive an immense benefit from the use of domesticated draft animals.

Two evolutionary factors have influenced farming technology over the years. The oldest one is the continuous pressure of population on the extant land under cultivation. Village swarming, at first, and later migration, were able to relieve the pressure. Means of increasing the yield of land also helped ease the tension. The main source of release, however, remained the clearing of vast tracts of land. The second factor, a by-product of the Industrial Revolution, was the extension to agriculture of the process by which low entropy from mineral sources was substituted for that of biological nature. The process is even more conspicuous in agriculture. Tractors and other agricultural machines have taken the place of man and draft animals, and chemical fertilizers, that of manuring and fallowing.

However, mechanized agriculture does not fit small family farms which have at their disposal a large supply of free hands. Yet even in this case it had to come. The peasant who practices organic agriculture, who uses animals for power and manure as fertilizer, must grow not only food for his family but also fodder for his helpers. The increasing pressure of population thus forced even the small farmer, practically everywhere, to do away with the beasts of burden so as to use his entire land for food [27, 526; 31, 11f; 32, 302f].

The point beyond any possible doubt is that, given the pressure of population in the greater part of the globe, there is no other salvation from the calamities of undernutrition and starvation than to force the yield on the land under cultivation by an increasingly mechanized agriculture, an increasing use of chemical fertilizers and pesticides, and an increasing cultivation of the new high-yield varieties of cereal grains. However, contrary to the generally and indiscriminately shared notion, this modern agricultural technique is in the longrun a move against the most elementary bioeconomic interest of the human species.

First, the replacement of the water buffalo by the tractor, of fodder by motor fuels, of manure and fallowing by chemical fertilizers substitutes scarcer elements for the most abundant one—solar radiation. Secondly, this substitution also represents a squandering of terrestrial low entropy because of its strongly decreasing returns.[59] What modern agricultural technique does is to increase the amount of photosynthesis on the same piece of cultivated land. But this increase is achieved by a more than proportional increase in the depletion of the low entropy of terrestrial origin, which is the only critically scarce resource. (We should note that decreasing returns in substituting solar for terrestrial energy would, on the contrary, constitute a good energetic deal.) This means that, if half of the input of terrestrial energy (counted from the mining operation) required by modern agriculture for one acre—cultivated, say, with wheat—is used each year, in two years the less industrialized agriculture would produce more than twice as much wheat from the same piece of land. This diseconomy—surprising as it may seem to the worshipers of machinery—is especially heavy in the case of the high-yield varieties which earned their developer, Norman E. Borlaug, a Nobel Prize.

A highly mechanized and heavily fertilized cultivation does allow a very large population, P_i, to survive, but the price is an increase of the per capita depletion of terrestrial resources s_i, which *ceteris paribus* means a proportionally greater reduction of the future amount of life (Section VIII). In addition, if growing food by "agro-industrial complexes" becomes the general rule, many species associated with old-fashioned, organic agriculture may gradually disappear, a result which may drive mankind into an ecological cul-de-sac from which there would be no return [31, 12].

The above observations bear upon the perennial question of how many people the earth could support. Some population experts claim that there would be enough food even for some forty billion people at a diet of some 4,500 kilocalories provided that the best farming methods were used on every acre of potentially arable land.[60] The logic rests on multiplying the amount of potentially arable land by the current average yield in Iowa. The calculations may be as "careful" as boasted—they represent, nonetheless, linear thinking. Clearly, neither these authors nor those less optimistic have thought of the crucial question of *how long* a population of forty billion—nay, even one of only one million for that matter—can last [31, 11; 32, 20, 301f]. It is this question which, more

[59] Between 1951 and 1966, the number of tractors increased by 63 percent, phosphate fertilizers by 75 percent, nitrate fertilizers by 146 percent, and pesticides by 300 percent. Yet the crops, which may be taken as a good index of yield, increased by only 34 percent! [6, 40]

[60] This position has been advanced, for example, by Colin Clark in 1963 [see 31, 11; 32, 20], and very recently by Revelle [70].

than most others, lays bare the most stubborn residual of the mechanistic view of the world, which is the myth of the optimum population "as one that can be sustained indefinitely" [6, 14; also 62, 172f; 74, 48].

XI. A MINIMAL BIOECONOMIC PROGRAM

In "A Blueprint for Survival" [6, 13], the hope is expressed that economics and ecology will one day merge. The same possibility has already been considered for biology and physics, with most opinions agreeing that in the merger biology would swallow up physics [32, 42]. For essentially the same reason—that the phenomenal domain covered by ecology is broader than that covered by economics—economics will have to merge into ecology, if the merger ever occurs. For, as we have seen in the preceding two sections, the economic activity of any generation has some influence on that of the future generations—terrestrial resources of energy and materials are irrevocably used up and the harmful effects of pollution on the environment accumulate. One of the most important ecological problems for mankind, therefore, is the relationship of the quality of life of one generation with another—more specifically, the distribution of mankind's dowry *among all generations*. Economics cannot even dream of handling this problem. The object of economics, as has often been explained, is the administration of scarce resources; but to be exact, we should add that *this administration regards only one generation*. It could not be otherwise.

There is an elementary principle of economics according to which the only way to attribute a relevant price to an irreproducible object, say, to Leonardo's Mona Lisa, is to have absolutely everyone bid on it. Otherwise, if only you and I were to bid, one of us could get it for just a few dollars. That bid, i.e., that price, would clearly be parochial.[61] This is exactly what happens for the irreproducible resources. Each generation can use as many terrestrial resources and produce as much pollution as its own bidding alone decides. Future generations are not, simply because they cannot be, present on today's market.

To be sure, the demand of the present generation reflects also the interest to *protect* the children and perhaps the grandchildren. Supply may also reflect expected future prices over a few decades. But neither the current demand nor the current supply can include even in a very slight form the situation of more remote generations, say, those of A.D. 3,000, let alone those that might exist a hundred thousand years from now.

Not all the details, but certainly the most important consequences of allocation of resources among generations by the market mechanism may be brought to the fore by a very simple, actually a highly simplified diagram. We shall assume that demand for some mineral resource already mined (say, coal-on-the-ground) is the same for each successive generation and that each generation must consume at least one "ton" of coal. The demand schedule is also assumed to include the preference for protecting the interests of a few future generations. In Figure 1, D_1, D_2, $\ldots D_{15}$ represent the aggregate demands of successive generations, beginning with the present one. The interrupted line *abcdef* represents the average cost of mining the deposits of various accessibilities. Total reserves amount to 15 tons. Now, if we ignore for a moment the effect of the interest rate on the supply of the coal *in situ* by the owners of the mines, then the first generation will mine the amount *a′b′*, the shaded area representing the differential rent of the better mines. We may safely regard *aa′* as the price of the coal contained in these mines. The second generation will mine the amount *b′c′*. But

[61] Yet the economist's myth that prices reflect values in some generally relevant sense is now shared by other professions as well. The Meadows group, for example, speaks of the cost of resource depletion [62, 181], and Barry Commoner, of the cost of environmental deterioration [18, 253f and *passim*]. These are purely verbal expressions, for there is no such thing as the cost of irreplaceable resources or of irreducible pollution.

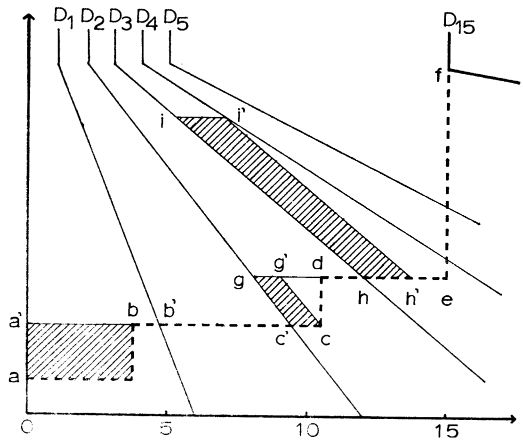

FIGURE 1

since no mine will earn a differential rent, the price of the coal *in situ* will be zero. During the third generation, the marginal cost of mining will be at the level of h; the quantity mined will be gh, with the quantity $c'c = gg'$ earning the rent shown by the shaded area. Finally, the fourth generation is left with the amount hh' (determined by the condition that $g'd = h'e$), which will earn a pure scarcity rent, represented by the shaded area $hh'i'i$. Nothing will be left for the following generations.

Several things are now obvious. First, the market mechanism *by itself* results in resources being consumed in higher amounts by the earlier generations, that is, faster than they should be. Indeed, $a'b' > b'c' > gh > hh'$, which confirms the dictatorship of the present over the future. Should all the generations bid from the outset for the total deposit of coal, the price of coal *in situ* will be driven up to infinity, a situation which would lead nowhere and only explode the entropic predicament of mankind. Only an omniscient planner could avoid this situation by simply allocating one ton of coal *in situ* to each of the first fifteen generations, each ton consisting of the same qualitative composition.[62]

Bringing in the interest rate modifies the picture somewhat and allows us to see even more clearly the impotence of the market to prevent the excessive depletion of resources by the earlier generations. Let us consider the case which I earlier called a bonanza era. Specifically, it is the situation in which the best quality of coal mine suffices to satisfy the present demand as well as that of the future generations *as far as the* present economic time horizon goes. Within this horizon, then, there is no rent at any time and hence no inducement to save coal *in situ* for future generations. Coal *in situ* can thus have no price during the present generation.

The question ignored by the few economists who have recently tackled some market aspects of natural resources [e.g., 75] is why resources *in situ* may, after all, have a positive price even if there are no self-imposed restrictions by the mine owners. The answer is that if present resources have a price, it is not ordinarily because of present scarcity, but because of some expected differential scarcity within the present time horizon. To illustrate the rationale of this process, let C_1, C_2, C_3 be coal mines of different qualities, the costs of mining one unit of coal being $k_1 < k_2 < k_3$, respectively. Let us further assume that C_1 is expected to be exhausted during the third generation after the present one, when C_2 will become economically efficient. Let us also assume that C_2, in turn, will be exhausted during the second generation thereafter, and that C_3 will then suffice for the remainder of the time horizon. During the third future generation, C_1 will prove to enjoy a differential rent $r_1 = k_2 - k_1$ with respect to C_2, and after two more generations the differential rent of C_2 over C_3, $r_2 = k_3 - k_2$, will become manifest. Only C_3 has no differential rent, and hence, as we have seen in the previous paragraph, its price is zero throughout. On the other hand, because C_2 necessarily earns a rent in the fifth generation from now, it must have a present positive price, namely, $p_2{}^0 = r_2/(1 + i)^5$, where i is the interest rate (assumed constant throughout the time horizon). In the j-th

[62] In a pioneering work [45], Hotelling demonstrated once for all that one cannot speak of optimum allocation of resources unless the demand over the entire future is known.

generation from now, the price will be $p_2{}^j = r_2/(1 + i)^{5-j}$. A similar logic determines the present price of C_1. Only, we must observe that during the generation when the differential rent of C_1 becomes manifest, the price of C_2 is $p_2^3 = r_2/(1 + i)^2$. The rent must therefore be added to this price. Hence, the present price of the coal of C_1 is $p_1{}^0 = (r_1 + p_2^3)/(1 + i)$.[3]

The formulae just established show that the effect of the interest rate in the presence of a qualitative spectrum of mines is to extend the use of coal mined from more accessible sources (in comparison to the quantities determined by Figure 1). In some rather idle way, we may say that the existence of the interest rate helps the economy of resources. But let us not ignore the far more important conclusion of the foregoing analysis, which is especially striking in the case of an era of bonanza. Serious scarcities may become effective (as will certainly happen) beyond the present time horizon. That future fact can in no way influence our present market decisions; it is virtually inexistent as far as these decisions are concerned.

Nothing need be added to convince ourselves that the market mechanism cannot protect mankind from ecological crises in the future (let alone to allocate resources optimally among generations) even if we would try to set the prices "right." [63] The only way to protect the future generations, at least from the excessive consumption of resources during the present bonanza, is by reeducating ourselves so as to feel some sympathy for our *future* fellow humans in the same way in which we have come to be interested in the well-being of our *contemporary* "neighbors." This parallel does not mean that the new ethical orientation is an easy matter. Charity for one's contemporaries rests on some objective basis, namely, the individual self-interest. The difficult question one has to face in spreading the new gospel is not "what has posterity done for me?"—as Boulding wittily put it—but, rather, "why should I do anything for posterity?" What makes you think, many will ask, that there will be any posterity ten thousand years from now? And indeed, it would certainly be poor economics to sacrifice anything for a nonexistent beneficiary. These questions, which pertain to the new ethics, are not susceptible of easy, convincing answers.

Moreover, there is the other side of the coin, also ethical and even more urgent, on which Kaysen [51] and Silk [72], in particular, have rightly insisted. The nature of Mohammed-men being what it is, if we stop economic growth everywhere, we freeze the present status and thus eliminate the chance of the poor nations to improve their lot. This is why one wing of the environmentalist movement maintains that the issue of population growth is only a bogy used by the rich nations in order to divert attention from their own abuse of the environment. For this group, there is only one evil—inequality of development. We must proceed, they say, toward a radical redistribution of productive capacity among all nations. Another view argues that, on the contrary, population growth is the most menacing evil of mankind and must be dealt with urgently and independently of any other action. As expected, the two polarized views have never ceased clashing in useless and even violent controversies—as happened especially at the Stockholm Conferences in 1972, and, quite recently, at the Bucharest Conference on Population.[64] The difficulty is again seated in human nature: it is mutual, deep-rooted

[63] The economist's characteristic confidence in the omnipotence of the price mechanism (Section IV, note 15) led many of my auditors to counter that the choice between satisfying present or future needs, with the usual reward for postponing consumption, will set the prices right for optimal use of resources. The argument fails to take into account precisely the limitation of our time horizon, which does not extend beyond a couple of decades [10, 10]. Even Solow, in an illustration defending the standard position [74, 427], assumes a horizon of thirty years only.

[64] For a highly interesting account of the crosscurrents at the Stockholm Conference, see [2].

mistrust—of the rich that the poor will not cease growing in numbers and of the poor that the rich will not stop getting richer. Sane reason, however, invites us to recognize that the differential gradient between the poor and the rich nations is an evil in itself, and although closely connected with continuous population growth, it must be dealt with directly as well.

Because pollution is a surface phenomenon which also strikes the generation which produces it, we may rest assured that it will receive much more official attention than its inseparable companion, resource depletion. But since in both cases there is no such thing as the cost of undoing an irreparable harm or reversing an irrevocable depletion, and since no relevant price can be set on avoiding the inconvenience if future generations cannot bid on the choice, we must insist that the measures taken for either purpose should consist of quantitative regulations, notwithstanding the advice of most economists to increase the allocation efficiency of the market through taxes and subsidies. The economists' plank will only protect the wealthy or the political protégés. Let no one, economist or not, forget that the irresponsible deforestation of numerous mountains took place because "the price was right" and that it was brought to an end only after quantitative restrictions were introduced. But the difficult nature of the choice should also be made clear to the public—that slower depletion means less exosomatic comfort and that greater control of pollution requires proportionately greater consumption of resources. Otherwise, only confusion and controversies at cross-purposes will result.

Nor should any reasonable ecological platform ignore the basic fact that, from all we know about the struggle for life in general, man will probably not let himself down, when pressed for his needs, natural or acquired, by sparing his competitors (including future humans). There is no law in biology stating that a species must defend the existence of others at the cost of its own existence. The most we can reasonably hope is that we may educate ourselves to refrain from "unnecessary" harm and to protect, even at some cost, the future of our species by protecting the species beneficial to us. Complete protection and absolute reduction of pollution are dangerous myths which must be exposed as such (Section V).

Justus von Liebig observed that "civilization is the economy of power" [32, 304]. At the present hour, the economy of power in all its aspects calls for a turning point. Instead of continuing to be opportunistic in the highest degree and concentrating our research toward finding more economically efficient ways of tapping mineral energies—all in finite supply and all heavy pollutants—we should direct all our efforts toward improving the direct uses of solar energy—the only clean and essentially unlimited source. Already known techniques should without delay be diffused among all people so that we all may learn from practice and develop the corresponding trade.

An economy based primarily on the flow of solar energy will also do away, though not completely, with the monopoly of the present over future generations, for even such an economy will still need to tap the terrestrial dowry, especially for materials. The depletion of these critical resources must therefore be rendered as small as feasible. Technological innovations will certainly have a role in this direction. But it is high time for us to stop emphasizing exclusively—as all platforms have apparently done so far—the increase of supply. Demand can also play a role, an even greater and more efficient one in the ultimate analysis.

It would be foolish to propose a complete renunciation of the industrial comfort of the exosomatic evolution. Mankind will not return to the cave or, rather, to the tree. But there are a few points that may be included in a minimal bioeconomic program.

First, the production of all instruments of war, *not only of war itself,* should be prohibited completely. It is utterly absurd (and also hypocritical) to continue growing tobacco if, avowedly, no one intends to smoke. The nations which are so developed as to be the main producers of armaments should be able to reach a consensus over this prohibition without any difficulty if, as they claim, they also possess the wisdom to lead mankind. Discontinuing the production of all instruments of war will not only do away at least with the mass killings by ingenious weapons but will also release some tremendous productive forces for international aid without lowering the standard of living in the corresponding countries.

Second, through the use of these productive forces as well as by additional well-planned and sincerely intended measures, the underdeveloped nations must be aided to arrive as quickly as possible at a good (not luxurious) life. Both ends of the spectrum must effectively participate in the efforts required by this transformation and accept the necessity of a radical change in their polarized outlooks on life.[65]

Third, mankind should gradually lower its population to a level that could be adequately fed only by organic agriculture.[66] Naturally, the nations now experiencing a very high demographic growth will have to strive hard for the most rapid possible results in that direction.

Fourth, until either the direct use of solar energy becomes a general convenience or controlled fusion is achieved, all waste of energy—by overheating, overcooling, overspeeding, overlighting, etc.—should be carefully avoided, and if necessary, strictly regulated.

Fifth, we must cure ourselves of the morbid craving for extravagant gadgetry, splendidly illustrated by such a contradictory item as the golf cart, and for such mammoth splendors as *two-garage* cars. Once we do so, manufacturers will have to stop manufacturing such "commodities."

Sixth, we must also get rid of fashion, of "that disease of the human mind," as Abbot Fernando Galliani characterized it in his celebrated *Della moneta* (1750). It is indeed a disease of the mind to throw away a coat or a piece of furniture while it can still perform its specific service. To get a "new" car every year and to refashion the house every other is a bioeconomic crime. Other writers have already proposed that goods be manufactured in such a way as to be more durable [e.g. 43, 146]. But it is even more important that consumers should reeducate themselves to despise fashion. Manufacturers will then have to focus on durability.

Seventh, and closely related to the preceding point, is the necessity that durable goods be made still more durable by being designed so as to be repairable. (To put it in a plastic analogy, in many cases nowadays, we have to throw away a pair of shoes merely because one lace has broken.)

Eighth, in a compelling harmony with all the above thoughts we should cure ourselves of what I have been calling "the circumdrome of the shaving machine," which is to shave oneself faster so as to have more time to work on a machine that shaves faster so as to have more time to work on a machine that shaves still faster, and so on *ad infinitum.* This change will call for a great deal of recanting on the part of all those professions which have lured man into this empty infinite regress. We must come to realize that an important prerequisite for a good life is a substantial amount of leisure spent in an intelligent manner.

Considered on paper, in the abstract, the foregoing recommendations would on the whole seem reasonable to anyone willing to examine the logic on which they rest. But one thought has persisted in my mind ever since

[65] At the Dai Dong Conference (Stockholm, 1972), I suggested the adoption of a measure, which seems to me to be applicable with much less difficulty than dealing with installations of all sorts. My suggestion, instead, was to allow people to move freely from any country to any other country whatsoever. Its reception was less than lukewarm. See [2, 72].

[66] To avoid any misinterpretation, I should add that the present fad for organic foods has nothing to do with this proposal, which is based only on the reasons expounded in Section X.

I became interested in the entropic nature of the economic process. Will mankind listen to any program that implies a constriction of its addiction to exosomatic comfort? Perhaps, the destiny of man is to have a short, but fiery, exciting and extravagant life rather than a long, uneventful and vegetative existence. Let other species—the amoebas, for example—which have no spiritual ambitions inherit an earth still bathed in plenty of sunshine.

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