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On Economics as a Life Science

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There is no wealth but life.—JOHN RUSKIN
All flesh is grass.—Isa. 40:6

I. Introduction

The purpose of this essay is to bring together some of the more salient similarities between biology and economics and to argue that, far from being superficial, these analogies are profoundly rooted in the fact that the ultimate subject matter of biology and economics is *one*, viz., *the life process*. Most of biology concentrates on the "within skin" life process, the exception being ecology, which focuses on the "outside skin" life process (Bates, 1960, pp. 12–13). Economics is the part of ecology which studies the outside-skin life process insofar as it is dominated by *commodities* and their interrelations. In what follows the traditional economic (outside skin) and the traditional biological (within skin) views of the total life process will be considered, both in their *steady-state* aspect and in their *evolutionary* aspect. Finally an approach to a more general "general equilibrium" model will be suggested by considering the human economy from an ecological perspective.

II. Biological Analogies in Economics

Analogy is so fundamental to our way of thinking that the ability to recognize analogies is generally considered one of the criteria of intelligence. While there is a vast difference between analogy on the one hand and logical proof and empirical verification on the other, it by no means follows that the former belongs only to poetry and not to science. Analogy is the essence of the inductive side of science. Furthermore, the dominant mode of thought in economics today is the "analytical simile" (Georgescu-Roegen, 1966, pp. 114–24), the mathematical or geometric model based on a Pythagorean analogy between fuzzy, dialectical reality and well-defined, analytic number. The fruitfulness of this analogy for all science is obvious —but it is an analogy nonetheless, with its roots in the same insight which inspired the mystical Pythagorean brotherhood. That economists have also found biological analogies useful is only slightly less obvious. The circular flow of blood and the circular flow of money, the many parallel phenomena of specialization, exchange, interdependence, homoeostasis, and evolution are well known. In the opposite direction, economic analogies in biology are also common, as witnessed by Malthus' influence on Darwin and by the very etymology of the word "ecology." Finally, an ultimately central place for biological analogies in economics has been claimed by no less an authority than Alfred Marshall in this famous statement, "The Mecca of the economist lies in economic biology rather than in economic dynamics" (Marshall, 1920, Preface, p. 14), and in his further statement that "in the later stages of economics, when we are approaching nearly to the conditions of life, biological analogies are to be preferred to mechanical" (Marshall, 1925, p. 317). Among current economic theorists it would appear that only the works of Kenneth Boulding (1950, 1958, 1966) and Nicholas Georgescu-Roegen (1966) (both freely drawn upon here) reveal a disposition to take Marshall seriously on this point.

Perhaps the intellectual genealogy of the ideas to be developed in this paper can be more specifically indicated by a pair of quotations from two seminal thinkers of the early part of this century—one a biologist (A. J. Lotka) and the other an economist (J. A. Hobson).

Lotka (1956) informs us that "underlying our economic manifestations are biological phenomena which we share in common with other species; and...the laying bare and clearly formulating of the relations thus involved—in other words the analysis of the biophysical foundations of economics—is one of the problems coming within the program of physical biology."

Just what these "biophysical foundations" are, and how they support the economic superstructure, is in large part the subject of Section V.

From Hobson (1929) we learn that

> all serviceable organic activities consume tissue and expend energy, the biological costs of the services they render. Though this economy may not correspond in close quantitative fashion to a pleasure and pain economy or to any conscious valuation, it must be taken as the groundwork for that conscious valuation. For most economic purposes we are well-advised to prefer the organic test to any other test of welfare, bearing in mind that many organic costs do not register themselves easily or adequately in terms of conscious pain or disutility, while organic gains are not always interpretable in conscious enjoyment.

The "groundwork for conscious valuation" and the "organic test of welfare" are ideas with close counterparts in Section III, to which we now turn.

III. The Steady-State Analogy

The close similarity of the basic within-skin life process of metabolism (anabolism and catabolism) with the outside-skin life process of economics (production and consumption) is evident from Figure 1.

In either process the only *material* output is *waste*. The purpose (value produced) of the metabolic process is the maintenance of life. The purpose (value produced) of the economic process is the maintenance and enjoyment of life. An accounting balance equation of the life process in value terms would state that the value of life enjoyment plus the value of material waste (zero) equals the sum of the values of all the matter and energy upon which the total life process is based. The total value of life (our subjective estimate thereof) is *imputed* to the total quantity of things necessary for its enjoyable maintenance.[1] The Austrian economists have taught us that this imputation also determines the *relative* values (prices) of individual things according to the principle of diminishing marginal utility, which for Böhm-Bawerk was "the key-stone of all economic theory" (1891, p. 149). Since commodities are priced according to their diminishing marginal utilities, the sum of all goods in the economy valued at their marginal utilities (or prices) would be very small relative to the total utility of all goods (total life value), which is probably infinite.[2] The infinite difference between the finite sum of prices of all goods and the infinite sum of total utility of all goods is an infinite "global consumers' surplus." Hence, insofar as economics concentrates on value in exchange (marginal utility) to the exclusion of value in use (total utility)—to that extent it is concerning itself with only an infinitesimal portion of total life value. This is not meant to minimize the importance of exchange values, since it is precisely by considering margins that we maximize totals. The point is that, while margins are reliable means for *maximizing* totals, they are very treacherous means for *evaluating* totals, as any student who has pondered the diamonds-water paradox must realize. Any sort of economic numerol-

[1] Value is not permanently imputed to the (non-material) technology within which matter and energy are used, unless that technology is made artificially scarce by patents. Following Schumpeter we can say that a new technology, while it is temporarily scarce by virtue of its novelty, will earn a temporary profit but will not receive a permanent imputed share of total value produced.

[2] To say that "total life value" is infinite is not to say that it is *ultimate*—"For whosoever will save his life shall lose it: and whosoever will lose his life for My sake shall find it. For what is a man profited, if he shall gain the whole world and lose his own soul? Or what shall a man give in exchange for his soul?" (Matt. 16:25, 26). On the commonsense infinitude of total utility, see Böhm-Bawerk (1891, Book III, pp. 147–53).

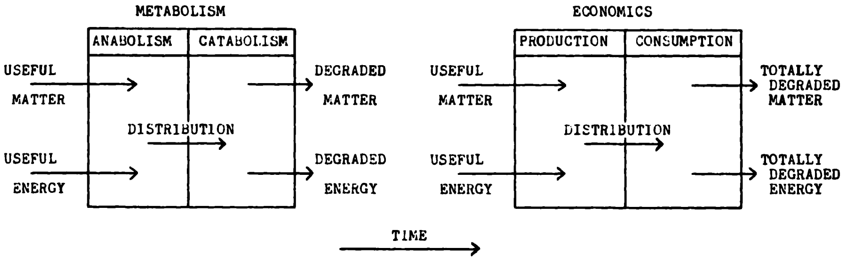

FIG. 1

ogy which, with one-eyed devotion to Pythagoras, insists on glossing over this treachery deserves a thorough dunking in the satirical acid of Jonathan Swift's *A Modest Proposal*.[3] Perhaps Hobson's "organic test of welfare" is simply the idea that it is better to make imprecise statements about unmeasurable but relevant magnitudes (use value, total utility) than to make more precise statements about the measurable but irrelevant magnitude (for evaluating total welfare) of exchange value. Economists shy away from thinking too much about total utility mainly because it is unmeasurable and dependent on value judgments—both embarrassing for a "positive science." But perhaps, as Joan Robinson suggests (1962, p. 54), this aversion to total utility also stems from its tendency to make one question "an economic system in which so much of the good juice of utility is allowed to evaporate out of commodities by distributing them unequally"; furthermore "this egalitarian element in the doctrine was sterilized mainly by slipping from utility to physical output as the object to be maximized." But as we have seen, the ultimate *physical* output of the economic process is waste, and there is no sense in maximizing that!

There is also a balance equation of the life process in physical units, based on the law of conservation of matter-energy. But more significant than the physical balance, from an economic viewpoint, is the one-way, non-circular, irreversible nature of the flow of matter-energy through all divisions of the life process. Since useful (low entropy) matter-energy is apparently finite, the total life process could be brought to a halt by what Boulding has called "the entropy trap." Thus one of the ultimate natural sources of scarcity, and hence of economic activity, is the second law of thermodynamics (Georgescu-Roegen, 1966, pp. 66–82). Indeed, if one were perversely to insist on a real-cost theory of value, it would seem that entropy, rather than labor or energy, should be the source of value. Even in the subjective theory of value, however, entropy, the common denominator of all forms of scarcity, determines the locations of the margins and

[3] In which, using exchange-value calculations, Swift logically demonstrates the "economic desirability" of eating children!

hence enters into the determination of marginal utilities and exchange values.

Erwin Schroedinger (1945) has described life as a system in steady-state thermodynamic disequilibrium which maintains its constant distance from equilibrium (death) by feeding on low entropy from its environment—that is, by exchanging high-entropy outputs for low-entropy inputs. *The same statement would hold verbatim as a physical description of the economic process.* A corollary of this statement is that an organism cannot live in a medium of its own waste products. With this principle in mind, one can better appreciate the significance of the following recent observation by J. J. Spengler (1966) in his presidential address to the American Economic Association, "Witness here in America the endless dumping of trash (four pounds per person per day)....Indeed, some hold, J. K. Galbraith had better labeled ours an effluent society than an affluent one." This four pounds per person per day does not disappear—it becomes a part of the physical environment in which we must live. Great stress has been put on the reciprocal nature of the relation of fitness between organism and environment by L. J. Henderson (1958). If the organism fits the environment, then it is also the case that the environment is fit for the organism. Henderson argues that there must have been some not-yet-understood process of physical evolution prior to the emergence of life in order for the environment to attain the rather exacting preconditions for supporting life. Thus man's newly acquired ability to degrade his material environment at the rate of four pounds per person per day is likely to be even more dangerous than commonly realized, in view of our ignorance of ecological relations.

How do the economic and metabolic processes fit together? Clearly metabolism is partly contained within the economic subprocess of consumption. Many of the material inputs into metabolism are economic products, and some outputs of metabolism are generally not totally degraded and thus can be further consumed—for example, manure fertilizer and carbon dioxide. But the ultimate physical output of the economic process *is* totally degraded matter-energy, in Marx's term, "devil's dust." Continuing in Chinese-box fashion, the total economic process is itself a subprocess on the consuming side of the total ecological life process, the producing side of the latter consisting mainly of photosynthesis carried on by green plants, which draw their inputs from the physical environment of air, soil, water, and sunlight.

Both the within-skin and outside-skin life processes have a permanently maintained physical basis which undergoes continual replacement over relatively short time periods (steady-state aspect) and which is capable of qualitative change and reorganization over long periods (evolutionary aspect). In other words "capital" represents "exosomatic organs" and biological organs represent "endosomatic capital." In each case, we observe both short-term depreciation and replacement and long-term technological change. Physical capital is essentially matter that is capable of trapping energy and channeling it to human purposes. Hence, in a very real sense the entire physical environment is capital, since it is only through the agency of air, soil, and water that plant life is able to capture the solar energy upon which the whole hierarchy of life (and value) depends. Should not these elements receive the same care we bestow upon our other machines? And is not any theory of value that leaves them out rather like a theory of icebergs that fails to consider the submerged 90 per cent?

IV. The Evolutionary Analogy

The material basis of the life process grows when the rate of production (anabolism) exceeds the rate of consumption (catabolism). Growth merges into development as alterations in the rates of increase of different parts give rise to new proportions, new qualitative relations, and new technologies. Although development is not well understood by either science, the subtle influence of size on organization has led both biologists and economists to the concept of a proper or optimum scale for a given organizational plan. That Marx, who emphasized this dialectic interplay of quantity and quality, also tended to view economics as a part of natural history is evident in the following quotation (1967, I, 372):

"Darwin has interested us in the history of Nature's Technology, that is, in the formation of the organs of plants and animals, which organs serve as instruments of production for sustaining life. Does not the history of the productive organs of man, of organs that are the material basis of all social organization, deserve equal attention?"

The same idea has been expressed by Lotka (1956, p. 208), viz., "Man's industrial activities are merely a highly specialized and greatly developed form of the general biological struggle for existence," and further in a passage (1956, p. 369) that would have pleased Marx:

> The most singular feature of the artificial extensions of our natural body is that they are shared in common by a number of individuals. When the sick man consults the physician, who, we will say, makes a microscopic examination, for example, the patient is virtually hiring a pair of high power eyes. When you drop a nickel into a telephone box, you are hiring the use of an ear to listen to your friend's voice five or ten miles distant. When the workingman accepts a wage of forty dollars for his weekly labor, he is in fact paying to his employers an undetermined amount for the privilege of using his machines as artificial members to manufacture marketable wares.
>
> The modern development of artificial aids to our organs and faculties has exerted two opposing influences.

> On the one hand, it has in a most real way bound men together into one body: so very real and material is the bond that society might aptly be described as one huge multiple Siamese twin.
>
> On the other hand, since the control over certain portions of this common body is unevenly distributed among the separate individuals, certain of them may be said in a measure to own parts of the bodies of others, holding them a species of refined slavery, and though neither of the two parties concerned may be clearly conscious of the fact, it is often resented in a more or less vague way by the one less favored.

In biological evolution genes transmit the "knowledge" of organic forms over time, and gene mutations introduce occasional modifications, resulting in the success of the forms best suited to the environment. In economic evolution, culture transmits knowledge over time, and new ideas produce mutant organizations from which competition again determines the fittest. Indeed, Teilhard de Chardin (1959) argues that "cultural evolution" is simply a new evolutionary mechanism that superseded the old mechanism in importance.

A natural history of economic evolution might be built around the theme of "economic surplus" and its progressive growth and cultivation. The original surplus was produced by plants, since they capture more solar energy than that necessary for their own maintenance. Animal life depends on this surplus, and perhaps man's greatest discovery was that he could cultivate and expand that upon which his existence depended, thus "exploiting niggardly nature."[4]

As soon as this primary activity became efficient enough to produce a surplus above the maintenance needs of those engaged in primary production, it became possible to evolve secondary economic activities, etc. Although economic activity moves far away from direct contact with nature, the "biophysical foundations of economics" remain ever present in the background, and it is to these foundations that we now direct our attention.

V. The Human Economy in Ecological Perspective

Although the life process is essentially one, it seems that for many analytical purposes the most convenient boundary by which to divide the process is the natural boundary of skin. The outside-skin life process is the subject of ecology, but ecologists abstract from the human economy and study only natural interdependences, while economists abstract from

[4] And, Marx would argue, man even discovered that he could "cultivate and extract" an analogous surplus from other men in the factory "hothouse."

nature and consider only interdependences among commodities and man. But what discipline systematically studies the interdependences which clearly exist between the natural and human parts of the outside-skin life process? Marston Bates, a biologist, addresses himself to this point in the following quotation (1960, p. 247):

> Then we come to man and his place in the system of life. We could have left man out, playing the ecological game of "let's pretend man doesn't exist." But this seems as unfair as the corresponding game of the economists, "let's pretend that nature doesn't exist." The economy of nature and ecology of man are inseparable and attempts to separate them are more than misleading, they are dangerous. Man's destiny is tied to nature's destiny and the arrogance of the engineering mind does not change this. Man may be a very peculiar animal, but he is still a part of the system of nature.

Any attempt to isolate a segment of reality is always somewhat misleading, but not for that reason less necessary. Our purposes dictate the manner in which we abstract from reality, and as economists well know, many useful purposes can be served by partial analysis—that is, studying one industry in abstraction from its matrix of interconnections with the rest of the economy. While this is a useful procedure for studying the peanut industry, no economist would want to study the automobile industry under such limitations. Too many important feedbacks from the rest of the economy would be left out. Until recently the economy of man was "peanuts" in the total economy of nature. Now it is more like the automobile industry, and to continue *ceteris paribus* treatment of nature (even in general-equilibrium analysis) is indeed dangerous to our purpose if that purpose is to say something about how human wants can best be served.

A rather dramatic example of this kind of danger has been indicated by Dr. Edward Teller (1965), who pointed out that since the Industrial Revolution the tremendous consumption of carbon fuels has resulted in an increased concentration of carbon dioxide in the atmosphere. Since this gas increases the heat retention of the atmosphere, thus raising the average temperature, it may well be that the ultimate effect of the Industrial Revolution will be the melting of the polar ice cap and the inundation of large parts of the world. The more concrete case of the unintentional destruction wrought on the environment by chemical insecticides has been forcefully documented by Rachel Carson (1962). Also, we know that the entire chain of life depends heavily on bacteria—for example, nitrogen fixation and decomposition of dead organisms. Is it not possible that some export from the human economy (for example, detergents) could prove lethal to certain of these organisms? Conversely, might not some human exports be highly beneficial to the propagation of particular disease-causing bacteria? And one need only mention the problem of radioactive fallout. At a less dramatic but increasingly serious level, we have ubiquitous instances of air and water pollution plaguing the world's cities, not to mention the problems of deforestation, soil erosion, and noise.

Such phenomena have long been recognized (grudgingly) in economic theory under the heading of *externalities*—that is, interrelations whose connecting links are external to the economists' abstract world of commodities but very much internal to the world in which we live, move, and have our being. Perhaps "non-market interdependence" is a more descriptive term.

It would be easy to liken this concept to a *deus ex machina* lowered into the scene by our theoretical playwrights to save an awkward plot, but it is by no means easy to suggest a better treatment. A better treatment is called for, however, since externalities are spending more time on center stage and less time in the wings than previously. Or, changing the metaphor, to continue theoretical development via continued ad hoc introduction of externalities is reminiscent of adding epicycles and in the long run will lead only to Ptolemaic complications in economic theory. Our economic cosmos is not one of uniform circular motion of commodities among men but one of eliptical orbits through interdependent ecological sectors.

How does one integrate the world of commodities into the larger economy of nature? Perhaps this is a problem in which economics can provide a useful analogy. Leontief's input-output model has proved useful in dealing with phenomena of interdependence, and it may offer the most promising analytical framework within which to consider the above question.[5] Just as the annual flow of gross national product, or *final* commodities, requires a supporting matrix of flows of *intermediate* commodities, so does the annual flow of all economic commodities (final and intermediate) require a supporting matrix of flows of physical things which carry no price tag but nonetheless are necessary complements to the flows of those things which do carry price tags.

In its simplest input-output representation the total economy can be divided into its human and non-human sectors, as in Table 1.

Cell or quadrant (2) is the domain of traditional economics, that is, the study of inputs and outputs to and from various subsectors within the human-to-human box. Cell (4) represents the traditional area of concern of ecology, the inputs to and outputs from subsectors in the non-human–

[5] The Leontief input-output model derives from a line of thought beginning with Francois Quesnay's "tableau economique," which was described by Mirabeau as "the great discovery which glorifies our century and will yield posterity its fruits." (For an exposition see Leontief, 1966.) It is more than coincidental that we should find the input-output model relevant to economics considered as a life science, since Quesnay (a physician) and the physiocrats emphasized the supremacy of nature and the biological analogy.

TABLE 1

From	To: Human	To: Non-Human
Human	(2)	(1)
Non-human . . .	(3)	(4)

to–non-human box. Cells (1) and (3), respectively, contain the flows of inputs from human subsectors to non-human subsectors and from non-human subsectors to human subsectors. All of the items exchanged in (2) are *economic commodities*, by which we mean that they have positive prices. All items of exchange in cells (1), (3), and (4) may by contrast be labeled *ecological commodities*, which consist of free goods (zero price) and "bads" (negative price). The negative price on bads is not generally observed, since there usually exists the alternative of exporting the bad to the non-human economy, which cannot pay the negative price (that is, charge us a positive price for the service of taking the "bad" off our hands, as would be the case if it were transferred to another sector of the human economy). Ecological commodities that are bads are bad in relation to man, not necessarily to the non-human world. The difficulty, however, is that these more than gratuitous exports from the human economy in cell (1) are simultaneously inputs to the non-human economy and as such strongly influence the outputs from the non-human back to the human sector—that is, cell (1) is connected to cell (3) via cell (4), and cell (3) directly influences human welfare.[6] These relationships will perhaps be more evident in Table 2, which is an expansion of Table 1, with the four quadrants corresponding to the quadrants of Table 1. Note that in both tables the basic vision is still a "world of commodities," although a bigger world that now includes both economic commodities (the q_{ij} in quadrant [2]) and ecological commodities (the q_{ij} in quadrants [1], [3], and [4]). The q_{ij} in quadrants (1), (3), and (4) are the "biophysical foundations of economics."

In Table 2, quadrant (2) is the simplest form of the usual Leontief input-output table, with two transforming sectors (agriculture and industry) and one primary sector (households). Agriculture consists of living transformers of matter-energy, and industry consists of non-living transformers of matter-energy. The non-human economy has likewise been divided into the "transforming sectors" of animal, plant, and bacteria (living sectors)

[6] If the reader will pardon the liberties taken with Luke 11:24–26 we may say that sometimes a bad cast out of cell (2) wanders through the waterless places of cells (1) and (4) seeking rest. And finding none it gathers seven new bads, which then descend upon the well-garnished human household through the back door of cell (3). And the last state of that household is worse than the first.

TABLE 2

OUTPUT FROM	INPUT TO: Agri-culture (1)	Industry (2)	Households (Final Consump-tion) (3)	Ani-mal (4)	Plant (5)	Bac-teria (6)	Atmosphere (8)	Hydro-sphere (8)	Lytho-sphere (9)	Sink (Final Consump-tion) (10)	TOTAL
	Quadrant (2)			Quadrant (1)							
1. Agriculture	...	q_{12}	...	...	...	...	q_{17}	...	...	...	Q_1
2. Industry	q_{21}	(q_{22})	q_{23}	...	...	...	q_{27}	...	...	...	Q_2
3. Households (primary services)	...	q_{32}	...	...	...	...	q_{37}	...	...	...	Q_3
	Quadrant (3)			Quadrant (4)							
4. Animal	...	...	...	...	...	...	q_{47}	...	...	...	
5. Plant	...	...	...	...	...	...	q_{57}	...	...	...	
6. Bacteria	...	...	...	...	...	...	q_{67}	...	...	...	
7. Atmosphere	q_{71}	q_{72}	q_{73}	q_{74}	q_{75}	q_{76}	(q_{77})	q_{78}	q_{79}	$q_{7,10}$	Q_7
8. Hydrosphere	...	...	...	...	...	...	q_{87}	...	...	...	
9. Lithosphere	...	...	...	...	...	...	q_{97}	...	...	...	
10. Sun (primary services)	...	...	...	...	...	...	$q_{10,7}$	...	...	...	

and of atmosphere, hydrosphere, and lithosphere (non-living sectors). In addition, in row 10 we have a primary-service sector providing the ultimate source of low-entropy matter-energy, the sun, and, in column (10), the great thermodynamic sink into which finally consumed high-entropy matter-energy goes, forever degraded as devil's dust.[7] The annual flow of low entropy consists of direct solar energy currently received, plus a running down of the stock of low entropy that came from the sun in the distant past. The table records the passage of low-entropy matter-energy through its life-supporting input-output transformations into high-entropy waste. These transformations are not all known or understood, but certainly the scope they offer for non-market interdependence far exceeds the standard examples of externalities in the literature, "somewhat bucolic in nature, having to do with bees, orchards and woods" (Scitovsky, 1954).

Table 2 has thus far been considered only as a descriptive catalogue for economically filing vast amounts of information about the exchanges of economic and ecological commodities making up the total economy of life. Any realistic table would probably have to have at least one hundred sectors, and the resulting ten thousand cells would be pigeonholes for storing measured data about the ten thousand most important exchanges in the total economy of life. Would it be possible to convert the table from a descriptive and heuristic device to a statistical tool, a matrix of technical coefficients useful for planning and prediction—that is, could one do with the whole table what Leontief has done with quadrant (2)?

Each row of Table 2 can be stated as a physical balance equation, thus:

$$\sum_{j=1}^{n} q_{ij} = Q_i; \qquad i = 1, \ldots, n,$$

where i = row and j = column.

Technical coefficients could be defined as $a_{ij} = q_{ij}/Q_j$.

The a_{ij} in quadrant (2) are the usual technical coefficients of the Leontief system, and the a_{ij} in the remaining quadrants are natural technical coefficients. For example, if i is water and j is alfalfa, then a_{ij} would be nine hundred, since it takes nine hundred pounds of water to produce one pound of dried alfalfa (Storer, 1954, p. 96). Assuming all a_{ij} are known, and noting that $q_{ij} = a_{ij}Q_j$, we have the following n equation in n unknowns:[8]

$$\sum_{j=1}^{n} a_{ij}Q_j = Q_i; \qquad i = 1, \ldots, n.$$

[7] Cf. Lotka's (1956, chap. xxiv) concept of the "world engine."

[8] If we separate out household consumption as having no meaningful "technical" coefficients, then we would have n equations in $2n$ unknowns (n of the Q_j and n of the q_{ik}, where k is the household sector). Arbitrarily setting any n of these magnitudes determines the remaining n unknowns. This corresponds to the "open" Leontief model. The assumption of technical coefficients for the household sector would give the "closed" model.

These equations are formally identical to Leontief's quantity table, in which we can sum across rows but not down columns. The assumptions by which Leontief breathes usefulness into this formalism are discussed below and are shown to present no greater theoretical problems for the whole Table 2 than for quadrant (2). To begin, Leontief's basic assumption of constant (slowly changing) technology over time seems to be much closer to the facts for Table 2, since in the non-human economy technical change (evolution) is much slower than in the human economy. Linearity or constant-costs assumptions (a_{ij} constant with respect to Q_j) would seem to be at least equally appropriate as a first approximation. Perhaps this assumption, too, is closer to reality for Table 2, since biological populations grow by adding identical units—hence input-output relations of biological populations are more likely to be proportional to scale (linear) than are such relations for populations of firms (that is, industries) in which new members are never such close replicas of old members. The assumption of single production processes with no joint products appears, at first sight, to be less true for nature than for the human economy. However, this is not all clear, especially if we include bads and free goods as outputs in our traditional production functions. In general, aggregation and classification criteria used in input-output models (similarity of input structure and fixity of proportions among outputs) would remain applicable in the larger table. Certainly no single classification would give a complete representation of the exquisitely tangled web of physical life relations—but then the usual input-output model is also a very incomplete picture of economic relations. Different classifications can be used to serve different limited purposes.

Although there appear to be no theoretical problems in extending the input-output model in this way, there is the obvious practical difficulty that most of the q_{ij} and a_{ij} in quadrants (1), (3), and (4) have never been measured. Nevertheless they all seem to be measurable or at least subject to indirect calculation. Probably the major reason this information has not been acquired is that we have not had many theoretical pigeonholes into which it would fit. Also, the model does not really require a Laplacian knowledge of the universe, as it may appear from the presentation. Application can be confined to a given spatial or conceptual region, with an export row and an import column summarizing relations with the "rest of the world." In any case, application appears rather less utopian than "cost-benefit analysis," which on the slender reed of exchange-value calculations attempts to "maximize the present value of all benefits less all costs, subject to specified restraints" (Prest and Turvey, 1965, p. 4). In fact, something like Table 2 would be necessary for indentifying "all" costs and benefits in the organic sense of Hobson. The construction of such a table would require the co-operation of many disciplines—which may be a point in its favor.

In conclusion, to summarize and support the point of view taken here, I can do no better than to remind the reader of the introductory aphorisms from Ruskin and Isaiah and to quote Lotka (1956, p. 183) one last time:

> For the drama of life is like a puppet show in which stage, scenery, actors and all are made of the same stuff. The players indeed, "have their exits and their entrances," but the exit is by way of translation into the substance of the stage; and each entrance is a transformation scene. So stage and players are bound together in the close partnership of an intimate comedy; and if we would catch the spirit of the piece our attention must not all be absorbed in the characters alone, but must be extended also to the scene, of which they are born, on which they play their part, and with which, in a little while, they merge again.

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