ARE THE LEAST ACTION PRINCIPLE AND OTHER ECONOMIC LAWS LAWS OF NATURE?

by

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1. The question formulated by the title of this paper has acquired a pronounced topical interest as a result of the recent events that have brought to the surface the indissoluble relationship between the economic process and some laws of nature. It has been in order therefore to include a study of this relationship in a research program. But the particular form of the title alludes to an essential feature of that relationship. The intimation, however slight, is that some laws of nature may have been first thought up as laws of the economic domain. But one may see a hitch. In the general literature of today, the principle of least action appears as a law that originated in mechanics. Nonetheless, as I shall endeavor to show, the principle of least action is the example par excellence of the interdisciplinary influence from economics to laws of nature.

This particular point concerning the principle of least action is part and parcel of a more general theme which boils down to whether there are laws, independently of their origin, valid for some economic and for some natural phenomena. Any such law--as is best evidenced by the principle of least action--must by definition be bivalent. An inquiry about such a bivalent law may therefore proceed either from economics to natural sciences of from the latter to the former. This procedure is especially apposite for the repeated attempts at proving that some physical laws or concepts can be profitably transplanted into the economic domain. As I proceed I shall also take advantage of the symmetry of bivalence choosing one or the other phenomenological domain as a starting point according to the conditions at hand.

To avoid as much as possible the need for retroactive elucidations during the marshalling of the following argument it would be well to present now a clarification. It concerns the meaning of "nature" in opposition to "economics." Many a first-rank scholar does not favor any division of "nature." Even though "man's social and intellectual complexity is something new under the sun," argues G. G. Simpson (1963), "man remains a part of nature and is subject to all nature's laws," which is a forceful way of pressing the positivist dogma that all aspects of life are reducible to the laws of elementary matter alone.

No doubt, the concept of nature, like all concepts of fact, is not susceptible of an analytical definition (unless we conceive it as including absolutely every thing), that is, of being separated from its opposite by a vacuous boundary.[1] The problem whether or not going to one's place of religious worship or writing a love letter (for some telling examples) is an economic activity has been debated endlessly ever since the idea of historical materialism cropped up. We may see now why the argument in favor of historical materialism had to resort to dialectical concepts, that is, to concepts that are separated from their opposites by a connotational penumbra over which they overlap.[2]

Yet to keep any argument on a track of significant communication concept must be dubbed with some analytical definition. In view of the nature of the problem in discussion, if I propose to understand by natural law any law pertaining to the physical or chemical domain, I may establish a conceptual edict, perhaps an arbitrary but a necessary one.

2. Turning now to the principle of least action, I may recall that it was first formulated by Pierre-Louis Moreau de Maupertuis (1698-1759), "an eminent Frenchman" as described by Bertrand Russell (1967). But Maupertuis, whose name generally identifies the principle, is usually described as "mathematician and astronomer."[3] What most biographers have had in mind is that in 1735 Maupertuis headed a mission sent by order of Louis XV to Lapland for the purpose of measuring the length of one arc of a meridian near the pole. At the time the true shape of the Earth was hotly debated. According to René Descartes the Earth should be an elongated spheroid, according to Sir Isaac Newton, a flattened one. Maupertuis confirmed Newton's opinion, a fact that projected him among the scholarly celebrities and attracted immense praise from Voltaire: "notre plus grand poète comme notre plus grand mathématicien" (Callot, 1964). Astronomer (or rather geodesist) thus Maupertuis certainly was, as a few essays on the shape of the Moon and of the stars as well as a pamphlet on the comet of 1742 also reveal. However, as a mathematician he never attained a higher level than properties of curves. On the basis of his fame acquired after the Lapland expedition Maupertuis was invited by King Frederick II of

Prussia to reorganize the Berlin Academy (1744) and later to become its permanent president (1746).

For the issue under discussion it is crucial to realize that in spite of his foregoing manifestations Maupertuis was not a specialist in some particular field but a man characterized by an exceptionally broad spectrum of intellectual interests. In fact, his contributions of greatest impact were in domains other than astronomy or mathematics. Maupertuis' earliest publications belonged to biology: Observations et expériences sur une espèce de salamandre (1727), Expériences sur les scorpions (1731)--his most famous biological work.[4] With Venus physique, published in 1745, he opened new doors to the domain of heredity and dealt a mortal blow to the preformist dogma of animalcula developing instead the theory of epigenesis. It also contained for the first time the idea of biological evolution,[5] arguing, for example, that birds were once fish. Maupertuis also stretched over with remarkable success into some philosophical areas:[6] Réflections philosophiques sur l'origine des langues et la signification des mots (1748), which represents some first spadeworks in semantics, Essai de philosophie morale (1749), the earliest sounds of hedonism,[7] and Système de la nature (1751).

This was the mind that thought up the principle of least action. Its interest certainly was not confined to physicochemical phenomena. To be sure, the preoccupations of some illustrious men with problems of an analogous nature must have stirred Maupertuis' curiosity. Although the problem had never constituted a center of attention, it had a very long tradition indeed. Hero of Alexandria (flourishing during the first century B.C.) found, among many other results fanciful ex post, that the ray of light reflected by a mirror follows the shortest of all possible paths.[8] Once it is established that a reflected light forms equal angles with the mirror, Hero's minimum proposition follows from a very elementary item of current geometry.

Hero's result attracted no attention for almost seventeen centuries, until in the 1650's one of the unusual mathematical geniuses, Pierre de Fermat, rediscovered Hero's proposition and, using the already known law of Willebrood Snell for a refracted ray of light, formulated a principle of minimum time: a light ray always pursues that path which takes the least time (Oeuvres, IV). But other famous scientists of the seventeenth century were also preoccupied with the brachistochrone problem, the problem of minimum time required for a given process. Galileo had believed that a segment of a circle was the brachistochrone path for the free fall of a weight from one position to another not on the same vertical. But in a 1697 essay Johann Bernoulli proved that the minimum time of descent corresponds to a cycloid.[9] Analogous problems of minima or maxima induced Leonhard Euler to set the foundation of a new field, the calculus of variations. It came as a natural offshoot of the recently created infinitesimal calculus. And as mathematicians generally do, many then took delight in finding novel uses for it. Newton, for example, in 1687 described the shape of the solid of revolution that would oppose the least resistance to a movement in a homogeneous fluid.[10]

Solving problems of minimum, not for a given point function but for a coordinate (such as the time needed for completion) of some possible motion, had become a characteristic feature of the intellectual endeavors by the time when Maupertuis first entertained the idea of least action. He certainly knew of Fermat's least time principle, to which he referred directly. Yet because of one particular circumstance Maupertuis' discovery was as independent a stroke of genius as any other in history. In all presentations of his principle Maupertuis, in contrast to the Bernoullis, Newton, Fermat and Euler, used no mathematics whatsoever and invoked no analytical law of mechanics. But, as I shall show presently, the strongest point in favor of my proposed thesis is the unexpected view that Maupertuis himself held about his principle.

Maupertuis' first mention of that principle was the object of a memoir presented on 15 April 1774 at the Paris Academy of Sciences: "Accord de différentes lois de la nature qui avaient jusqu'ici paru incompatibles."[11] A ray of light, he observes, can follow neither the shortest path nor that of the minimum time. Yet the actual path must present some advantage. This path is that "for which the quantity of action is the smallest." And Maupertuis goes on to explain that the action necessary for any movement "depends on the speed of the body and on the space it travels [hence] its quantity is proportional to the sum of the products of the spaces and the corresponding speeds." In anticipation of a possible wondering of a reader, Maupertuis adds between parentheses that since the case concerns a single body, the third coordinate, the mass, may be disregarded.

The whole argument is presented more carefully two years later in a second essay with a truly telling title: "Les lois du movement et du repos, déduites d'un principe de métaphysique."[12] This time the proposed measure of action is the product of the speed, the space, and the mass.[13] Maupertuis therefore did not intend to hide his opinion about the nature of his law, nor the intellectual process by which he had reached it. An indiscretion of his fundamental position is made by the title of one of his last essays: "Examen philosophique de la preuve de l'existence de Dieu employée dans l'Essai de Cosmologie."[14]

My own understanding of this whole story is as follows. After the Renaissance a definite turning point occurred in the attitude of people towards religion. For most of the intellectual stratum religion no longer consisted of a series of commandments and principles that had to be absorbed by simple, hence unvarying belief. Yet the idea of God, conceived as a Superior Being, infinitely intelligent and wise, became the basis of a new religious orientation. From Descartes to Newton, to Leibniz and to Euler, all scientists (with Voltaire exceptionally excepted) felt that the existence of such a Divine Being is absolutely necessary for accounting for those phenomena their own endeavors could not explain. Perhaps Leibniz's doctrine of preestablished harmony is the best illustration of that philosophical temper.[15] Given this outlook, it was only natural for many men of science to proceed the other way around, that is, to seek in Nature a proof of the existence of her divine maker and ruler. Leibniz, again, offers an admirable illustration of this very idea which, as we have just seen, also moved Maupertuis.[16] And I should not fail to mention that even a mathematical genius such as Leonhard Euler also trusted the searching of nature for proving the existence of God.[17]

Nature presents numberless features that the human mind marvels, for, as Albert Einstein said, who does not stand in awe in facing them is as good as dead. If one wanted to prove the existence of God on the basis of the splendid design that nature displays, one would have an unusually ample choice. As Johann Süssmilch taught, all is _die göttliche Ordnung_. One could point out, for example, that the existence of friction is part of the Divine Design for without it we could not control our walk or grasp anything. The question that comes up therefore is why did Maupertuis, the man of multiple expertise, think up the principle of least action and base his proof of the existence of God on it?

The answer that I wish to submit also pierces the question of my title. For some time already, probably without a precise point in the evolution of our thought, the idea propounded by such illustrious scholars as Leibniz and Euler (Tort, 1980), that nature never makes anything in vain, was a popular conviction. (Süssmilch put it most strongly). The divine architect could not make an inefficient, wasteful world. Nor did God make His own image, man, an inefficient creature, a squanderer. Does not every normal human (and even other animal for that matter) take the straight line whenever possible for moving from one place to another? Of course, the list of the ways in which humans reveal the efficient quality of the blueprint of our race is too long to be printed anywhere. Man is thus an economical animal. Seventy years before Maupertuis' first presentation of the least action principle, Nicolas Malebranche (1674-1675) maintained that nature is economical.[18] Economics as a special intellectual discipline was then just coming to life. Even though Maupertuis was an astronomer with substantial knowledge of physics and chemistry, the source of his inspiration for the principle of least action was the economical quality of nature and man, not some purely physicochemical phenomenon. No wonder then that the principle ended by becoming the foundation of economic behavior. Minimum cost means least action. And since least action is tantamount to maximum effect, Maupertuis' principle has eventually become the main pillar of both utility and production theories.[19]

3. In Maupertuis' presentation of his principle there is no recourse to mathematical diction. The only mathematical ingredient was his simple formula for the measure of action. Euler, who was in close relation with Maupertuis during the latter's presidency of the Berlin Academy, naturally saw that one could develop analytically the crude formula of his friend. He replaced Maupertuis' principle Action = mvs = minimum (with m standing for mass, v for speed, and s for distance) by

$$\delta\int v ds = 0 \quad \text{or} \quad \delta\int v^2 dt = 0.$$

Euler did not clearly justify the change. (Probably, like Maupertuis in 1744, he abstracted from mass.) But he did produce a few highly interesting applications.

The form in which Euler expressed the principle of least action raised an entirely new problem. Until then, problems of extremum consisted of finding one point among a set of points represented by an ordinary point function. The least action principle meant instead determining which path (function) among all possible paths on which a given system may move from, say, time t_1 to time t_2. Like the extremum problem for a point function, the new problem, too, requires that the first differential be null (as Euler's formula expressed). A new chapter of mathematics, the calculus of variations, thus took shape thanks to Euler's inspired spadework.[20]

Euler's results attracted the attention of Lagrange, who proposed a definition of action, S, connected with two essentially mechanical concepts:

$$S = \int_{t_1}^{t_2} (K-T)dt,$$

where K stands for kinetic and T for potential energy.[21] The integral is to be taken along a path that the system may follow between the same positions during the given interval (t_1, t_2). Just as in Euler's formula, for the path of minimum action it is required that

$$\delta S = 0.$$

The final touches to the principle of least action (regarded as a principle of analytical mechanics) were applied by Sir William Hamilton. His great fame is based on his proof that for a conservative mechanical system (i.e., for which total energy $H = K + T$ is constant), the Lagrange differential equation is always valid. It was with this result that the principle of least action was replaced by the principle of stationary action.[22]

By now the reason is an elementary matter. The condition that the first differential be equal to zero, as Euler and Lagrange set it, is only necessary for an extremum, but it is not also sufficient to reveal the kind of the extremum. As we know, the answer to this last question depends on the sign of the second differential, $\delta^2 S$. In economics it is possible in almost all cases to find out this sign on the basis of the general assumption of convexity (one way or the other). But in mechanics the determination of that sign is very rarely possible.

It was Euler who first drew the right conclusion and expressed it at the same time with his deistic conviction (Kline, 1972):

> For since the fabric of the universe is most perfect and the work of a most wise Creator, nothing takes place in the universe in which some rule of maximum or minimum does not appear.

As an instructive example we may cite the following case: the path of a ray of light corresponds to the least or the greatest time depending on whether the curvature of the reflecting (or refracting) surface is smaller than the aplanatic (free from aberration) surface tangential at the point of incidence.

The fate of Maupertuis' principle even in natural sciences has not been outstanding. We have just seen that its sharpest cutting edge has been dulled by its transformation into the dualist form of the stationary action. Hear the old verdict of 1833 by Sir William Hamilton:

> "although the law of least action has thus attained a rank among the highest theorems of physics, yet its pretensions to a cosmological necessity, on the ground of economy in the universe, are now generally rejected. And the rejection appears just, for this, among other reasons, that the quantity pretended to be economized is in fact lavishly expended."[23]

In its original form Maupertuis' principle has continued to serve well in that domain which constituted its source of inspiration: in economics, even though Maupertuis' name is hardly mentioned at all in the economic literature. The economists speak only of the various labels that have been applied to that principle.

But the calculus of variations, the mathematical byproduct of the mechanical interpretation of Maupertuis' law, did ultimately find its way into economics as the economists' belief in the value of the mathematical tool approached its apogee. That calculus comes in quite naturally if one wants to find out, for example, which distribution of a *given* income over a *given* time interval maximizes the spender's total utility.[24,25]

4. What deserves our unparsimonious attention in connection with the foregoing analysis is the fact that our interest in the essence of the principle of economic action, that is, in the economical actions of any sort has never deserted us; if anything, it has become even more pressing. To recall, Ernst Mach (1895) spoke of the necessity of practicing the economy of thought. For that he recommended various means for disburdening the memory through numerical tables, mathematical symbolism, etc. (but naturally not computers). Mach did hint at the idea--expanded by his disciple, Karl Pearson (1937)--that the greatest economy of thought is achieved by theoretical science, that is, by knowledge filed in a *logical* (not taxonomical) order (Georgescu-Roegen, 1966).

Recently, a Harvard linguist, George K. Zipf (1949) advanced a new principle of "least effort" somewhat analogous to Mapertuis'. It purports to explain a general feature of human behavior by an assumed law that combines a physical with a cultural basis. Each culture develops some pertinent tools to be used by its members. The use of any such tool imposes an effort on the user. Plausibly, as several authors have insisted, even an animal would seek to minimize its effort in achieving an end. According to Zipf, the individual minimizes his effort if the frequency of the tool used is such that the city ranked n-th in the population of a country is as great as 1/n of the most populous one. Zipf's argument marshalled in a volume of more than 500 pages studded with supporting examples drew much attention at first. Some strong counterexamples caused interest in it to peter away.[26]

5. Another salient principle akin to that of Maupertuis is that advanced by Henri Louis Le Chatelier, in the sense that it rules in both natural and economic science. However, no economic consideration presided over its contriving. Le Chatelier was a versatile chemist, the author of numerous discoveries in applied chemistry. But after becoming acquainted with the work of Sadi Carnot and of Josiah W. Gibbs, he fell in love with thermodynamics, a symptom of which is the section "Thermodynamics" in (probably) his last publication (1936). The first step toward his principle was made in an 1884 communication to the <u>Académie des Sciences</u>, where we read

> <u>Any system in chemical equilibrium when subject to an exterior cause which tends to change either its temperature or its condensation (pressure, concentration, number of molecules per unit of volume) totally or only partially, can undergo solely interior modifications, which, if produced by them-</u>

> selves, would cause a change of temperature or of condensation of opposite sign to that produced by the exterior cause.[27]

Reference is generally made to the final version which appeared four years later, Le Chatelier (1888), but which is not as explicative.

The root of the Le Chatelier principle was certainly in chemical thermodynamics. The proof is that in his 1884 paper Le Chatelier cites a classic work of a famous thermodynamicist, J. H. van't Hoff (1896), the first Nobelite for chemistry. Van't Hoff wrote,

> Every equilibrium between two different conditions of matter (systems) is displaced by lowering the temperature, at constant volume, toward that system the formation of which evolves the heat.

My contention that the birthplace of the Le Chatelier principle was thermodynamics is further evidenced by the fact that virtually only thermodynamicists still speak of it. The importance of that principle is that it determines the direction in which a reaction (chemical or physical) will proceed. Its quintessence is most clearly expressed by Enrico Fermi in his little monograph Thermodynamics (1956):

> If the external conditions of a thermodynamical system [in equilibrium] are altered, the equilibrium of the system will tend to move in such a direction as to oppose the change in the external condition,

But the most expressive formulation is that the equilibrium state of thermodynamic system is stable because it involved a restoring mechanism to take care of any small disturbance. Naturally, great disturbances may destroy the system beyond any repair.

It stands to reason that besides chemical thermodynamicists only biologists should have felt great enthusiasm for the Le Chatelier principle. A host of illustrations from biology have been adduced about regeneration, the common property of all living creatures.[28] Of course, this interpretation does not always hold water. All wounds would regenerate, but only if they are moderate. Also, reactions to the ingestion of medicine do not always move in the same direction: some may lead to immunity, others to increased sensitivity.

To my knowledge no economist, except Paul Samuelson, has referred to a possible role of the Le Chatelier principle in economics. Samuelson dealt with that principle on several occasions. The first time it was in his unmatched Foundations (1947). There he dealt with the form that is basic in both consumer and production theory

$$f(x_1, x_2, \dots , x_n) - \Sigma p_i x_i .$$

From this he derived the relation established by Sir John Hicks (1939), probably the most admirable in all mathematical economics

$$\Sigma \Delta x_i \Delta p_i < 0.$$

This inequality indeed relates to the relation $\Sigma L_i X_i > 0$, where X_i are generalized forces and L_i generalized flows, which expresses a fundamental property of a stable thermodynamic system. In Hicks' inequaltiy, p_i are the forces and x_i, the flows. Samuelson came back to this interpretation in terms of flows and forces in his heavy-punching Nobel

Prize address (reprinted in Samuelson, 1972). There he explained the economic import of the principle with the help of a diagram of two families of curves, one for the force, the other for the flow.

The relationship of the Le Chatelier principle with economic systems of the type considered in mathematical economics is beyond question. Samuelson's insistence on it proves that his excellent (and lucky) flair did not desert him.[29] From Hicks' relation it simply follows that if $\Delta x_i \, \Delta p_i = 0$ for $i > 1$, then $\Delta x_1 \, \Delta p_1 < 0$. This is an elementary proposition: if the equilibrium of demand and supply is disturbed, then a new (or the old) equilibrium is reached by opposite changes of price and quantity as the 1884 formulation of Le Chatelier would have. Yet, just as in biology, the application of the Le Chatelier principle may meet with refutal. Think of the case of an unstable equilibrium for which $\Delta p_1 \, \Delta x_1 > 0$.

Both principles, of Maupertuis and of Le Chatelier, have their legitimate places in natural sciences, the first in Newtonian mechanics, the second in thermodynamics. They both find frequent individual applications outside those domains, but they also failed to almost the same extent. Their claim for attention in science has only a metaphysical basis, as Maupertuis openly recognized from the outset. The economist should ponder over the fact that Joseph A. Schumpeter in his encyclopedic and authoritative History of Economic Analysis did not mention even once those presumed general principles. Yet, without doubt, he must have known a great deal about them.

6. As has often been remarked, two different fields of inquiry may be serviced by the same theoretical patterns. For a sharp yet

simple example, let us take the basic axioms of the elements of all plane geometries, p and D: (1) two normal p's determine only one D, and (2) two D's determine only one p. These propositions may represent also a situation in which D is some club, and p some possible club member (Georgescu-Roegen, 1966). The idea is responsible for several attempts at establishing some bridges between social and natural domains somewhat akin to the bivalence of the two principles discussed above.

One may believe that the title Physics and Politics of the best contribution of Walter Bagehot (1879) announces such an attempt. However, what Bagehot did in that volume was to try to establish an excursion through economics after the theoretical itinerary proper to natural science, which meant to proceed on pure logic from one set of propositions to the next. It is only the ill-suited title that prompted me to mention it in this group.[30]

An endeavor to reduce an economic phenomenon to a specific natural law--probably the first of this nature--was that of none other than Irving Fisher (1925). As it seems, Fisher believed that any mathematical system in economics must correspond to some physical process, a belief justified by the concepts economics had already imported from analytical mechanics. Accordingly, he constructed an apparatus consisting of several communicating vessels of different profiles. Each profile was determined in such a way that the hydraulic equilibrium of all vessels should bring in each vase an amount of water proportional to the utility of some quantity purchased from a given income.[31] Clearly, Fisher connected the famous hydraulic principle of Blaise

Pascal, according to which water would reach the same level in all freely communicating vessels, with the process by which one spends income optimally.

7. There are two famous instances of homomorphism between economics and other sciences. The first is the theory of Walter Eucken (1950), which may be described, perhaps not quite exactly, as the chemical doctrine of society. In a nutshell, Eucken claimed, first, that all forms of society are analyzable into a finite number of immutable elements, and, second, that society can possess no other property than those inherent in its elements. To wit, the ancient city of Babylon, the Golden Horde, medieval Florence, or twentieth-century USSR, would not be different "animals," but only different cocktails mixed from a finite number of ingredients. In a most cogent manner, Eucken insisted that these ingredients fall into three categories: the control, the market, and the monetary conventions.

To make his epistomological position clear, Eucken uses an analogy: the most different musical compositions are only combinations of a limited number of musical tones. Yet musical tones and scales have evolved and new ones are certainly in store. Furthermore, even in the inanimate world combinations bring about novelties. The elementary properties of oxygen, for example, are not recognized in water. And if we pass to the organic world, certainly, no one can by any logical process derive the way, say, an elephant behaves if one knows only the properties of the elementary chemical elements that enter into the soma of the elephant. As Peter Medawar observed, "a gene is known by its performance, not by its substantive properties." This point would be even truer in the superorganic domain (Georgescu-Roegen, 1966). Yet when all is said and done Eucken's perspective constitutes a very helpful schablone for attacking a practical problem.

The second instance is a homomorphism between economics and biology. I expect any reader to think immediately of Alfred Marshall. Was not Marshall who told economists that biology, not dynamics, is their Mecca? True, he repeated the same idea in another form and also likened the representative firm with the representative tree of a forest. But that was all.

The economist who proved that there is a strong homomorphism between economics and biology was Joseph A. Schumpeter (Georgescu-Roegen, 1977). It is beyond my comprehension why this important part of Schumpeter's contribution has not been remarked. The explanation may be that, contrary to Marshall, Schumpeter never preached the biological homomorphism. He only reasoned on a biological line, but that he did in a supreme manner. I may recall his concept of innovation which, exactly like biological mutations, moves the economic evolution on. In explaining what he understood by an innovation, Schumpeter specified that an innovation must not be just a small change, something like enlarging the display windows or painting a new color on the streetcars. Innovations so small can have no impact on the march of economic evolution. The thought, we should mark well, corresponds in toto to the objections to Charles Darwin's tenet that evolution proceeds by imperceptible phylogenetic changes. Curiously, it was also an economist, an older one, Fleeming Jenkin (1887), who first raised that objection. Darwin was disturbed by Jenkin's argument (Francis Darwin, 1958), but the Neo-Darwinists simply swept them under the carpet.

Schumpeter placed that issue in an incontrovertible light. First, in a clearly dialectical way he forestalled one possible objection to his non-analytical concept of small innovation. About this he remarked that it is absurd to deny the existence of entrepreneur just because we cannot say when that notion begins and ends. And second, most important of all, he invited us to ponder over one thought, an immortal one:

> Add successively as many mail coaches as you please, you will never get a railway [engine] thereby (Schumpeter, 1934).

An almost unbelievable event, thirty years after Schumpeter described how economic evolution slides on the unpredictable series of large mutations, a highly respected biologist (Goldschmidt, 1940) vexed his contemporary Neo-Darwinists by arguing, that speciation requires the emergence of a "successful monster." This was exactly Schumpeter's view of evolution: for, certainly, a railway engine is a monster in comparison to a horse cab, yet a successful one indeed as its history has proved.[32]

The identity of the elements on which evolution depends in biology and economics--both domains of life manifestations--and of the two evolutionary processes is a valuable finding which belongs to an economist, to Joseph Schumpeter. After all, economics is not always a dismal science.

8. The last but probably the most fateful association between a natural law and economics has been brought to the attention of virtually all of us by the events of the last ten years or so, hinging on the

supply of oil. However, the knot concealed in this phenomena had already formed the preoccupation of a small circle of natural scientists one hundred years ago. They held a particular view of the material basis of reality which became known as "energetics" because it denied the existence of anything else besides energy, of atoms especially.

It is hard to find the reason why the energetists became interested in economics. The most assertive energetist was Wilhelm Ostwald, a vigorous and prolific pundit in chemistry. Friedrich von Hayek (1952) mentioned with a vigorous protest Ostwald alongside with Frederick Soddy and Ernest Solvay, as the energetists who advocated a reduction of economic value to energy. However, only Solvay (1902) was guilty of a strange hereticism, strange because he proposed the equivalence of economic value with energy by using an imputation logic similar to that used by Karl Marx for the labor theory of value.[33] Soddy did not insist for long on an energetic explanation of value, and, just like Ostwald, never argued for the equality of energy and economic value.[34] Ostwald (1908) stated as clearly as possible that "we would err if we measured value only in proportion to the amount of free energy." But the idea of the equivalence must have been in the air, for none other than Frederick Engels (1954), the exponent of the materialist interpretation of reality, protested in 1875: "Let someone try to convert any skilled labor into kilogram-meters and then determine wages on this basis!"[35] What Ostwald and Soddy wanted to propound was the fact that energy plays a preponderant role in man's struggle for existence, hence, in man's economic activity of production and consumption. Relatively recently, their theme was taken up by Leslie A. White (1954) who has written intensively on it. On the basis of the entire evolution of mankind marked by impulses caused by innovations of more efficient uses of energy, White maintained that "culture develops . . . as the amount of energy harnessed and put to work per capita per year is increased." But his enthusiasm for this conception pushed him to add that "energy is a universal measure of culture," an extravagant claim that has attracted strong protests such as that of Hayek. Yet a weaker form of that idea is without reproach. Each technological saltation means the adaption of a novel system of production or trade, which calls for a different appropriate system of guidance and control. A new elite, in the Paretoan sense, emerges by necessity to perform the new duties. The best example is the priesthood aristocracy of Ancient Egypt, whose role was to guide the agricultural activity (Georgescu-Roegen, 1971). This seems to me to be an acceptable part of historical materialism first propounded by Richard Jones, and later by Karl Marx.

At the time of the oil embargo, 1973/74, the field of the dependence of all economic activity on natural resources was a no man's land. That event seems to have caused a literary run like the traditional Oklahoma run. Hosts of writers, especially economists, came only then to realize that vital natural resources are, after all, exhaustible, and set out to propose alternative ways for solving the menace. However, the problem is grounded in thermodynamics, the most intricate physical discipline, which, according to some thermodynamicists, is not well understood even by many physicists.

Thermodynamics provides the most firm bridge between the natural and the economic domain. As Sadi Carnot set it going, thermodynamics is a physics of economic value and its most intriguing (and also highly popular) law, the entropy law, is the root of economic scarcity (Georgescu-Roegen, 1966, 1971). Indeed, scarcity means some immutable limitations. One type of scarcity, the least pressing on our species, is the limitation of Ricardian land. This economic factor, the prototype of economic fund, is limited but is not consumed by use. The worst type of scarcity is constituted by the economic flows of available matter and available energy. These flows are both limited in quantity which, unlike the Ricardian land, is continuously and irrevocably degraded by use. Let me draw your attention to these two terms, available and unavailable, essential in phenomenological thermodynamics. For they reveal the strong anthropomorphic origin of that discipline.

The point I have insisted on is that the economic process is entropic in every one of its <u>material</u> fibers, it is a process by which valuable, vital available resources are transformed into unavailable forms, valueless waste. But I hastened to add that without taking account of the basic human propensities that compose the enjoyment of life <u>we are not in the economic domain</u>. How some material flows produce in us pleasure or disgust is still a mystery. But the supply of valuable materials is an element on which thermodynamic considerations can throw invaluable light.

To present just the most relevant points for the relation of thermodynamic laws and the economic process, I have proposed the analytical representation of this process by the multi-process matrix based on an extension of the Leontief input-output table. In the attached table, the analytic representation of the whole economic process is divided into the following processes (Georgescu-Roegen, 1979):

P_0: transforms matter in situ, MS, into controlled matter, CM;

P_1: transforms energy in situ, ES, into controlled energy, CE;

P_2: produces maintenance capital, MK;

P_3: produces consumer goods, C;

P_4: recycles the garbojunk, GJ;

P_5: maintains the population, H.

For a steady-state process (the kind that every analysis must consider first) the sum of the first five flow lines must be null: the amounts of all produced commodities must equal their consumption. The matrix also explains that the net product energy is $x_{11} = \Sigma x_{1i}$, and the net product of matter is $x_{00} = \Sigma x_{0i}$. There always must be a surplus in any process in which man participates, whether in agriculture, as pointed out first by Xenophon, or in the production activity, as explained by Karl Marx.

The other observation, a direct consequence of the entropy law, is that the energy that leaves every individual process, d_i, is no longer available, it is, as Lord Kelvin said, as if it were lost for us. But this is what the classical law of entropy states, for thermodynamicists, so it seems, felt embarrassed to say anything about friction, one of the two thieves of available energy. Friction is a common phenomenon that still awaits a mechanical explanation. The truth is that available mater, too, continuously and irrevocably degrades because of friction, cracking, fatigue and general wear-and-tear. Therefore, even in a steady-state economy--the solution advocated by Herman Daly for the energy crisis--would not work indefinitely. The impossibility of the perpetual motion of the third kind, which I have defined as a process that cannot be supplied from outside with available matter, prevents it.

One may want, as many have done, to find out how much energy or how much matter is embodied in every commodity. The project is legitimate and is known as energy (or matter analysis). But the concentration of most economists or specialists in operation research on the menacing energy crisis have caused some to go so far as to set a claim denounced more than one hundred years ago by Engels, Ostwald and Soddy. On an obviously misunderstanding of the structure represented by Table A, Costanza (1980) has come out with the fantastic conclusion that embedded energy = economic value. Accordingly, a dollar's worth of caviar should represent the same amount of embodied energy as a dollar's worth of potatoes.

A far more important conclusion follows from Table A and my remarks about the necessary existence of a surplus. Not all recipes can produce a surplus, only those that I have called Promethean, Promethean because they represent a <u>qualitative</u> transformation that can keep going as long as its supporting fuel is forthcoming. In the whole history there have been only three: agriculture, fire, and the steam engine. No technology can be viable if it does not rest on a Promethean recipe, a point completely ignored by all who are now busy to sell the salvation by an alternative technology. The most frequently mentioned is the direct use of solar energy. At present, however, no system of solar cells is capable of producing enough energy for its reproduction <u>and</u> for use for other purposes. That recipe is not Promethean.

8. In this paper I have tried to bring into focus the nature, the intensity, and the relevance, theoretical or practical, of the bridges, I know, between natural laws and the human activity known as economics. I believe that according to the prevailing intellectual temper, I may be accused of having dealt with a straw problem. Everything, many may remind me, is determined by what the quarks want to do. On this, I recall that St. Augustine once said that God made the Inferno, too, exactly for those who asked undesirable questions. But I believe the St. Augustine said it in stride, otherwise he should be found there now.

TABLE A

The Relationship Between the Economic Process and the Environment

ements	(P_0)	(P_1)	(P_2)	(P_3)	(P_4)	(P_5)
			Flow Coordinates			
CM	x_{00}	*	$-x_{02}$	$-x_{03}$	*	*
CE	$-x_{10}$	x_{11}	$-x_{12}$	$-x_{13}$	$-x_{14}$	$-x_{15}$
MK	$-x_{20}$	$-x_{21}$	x_{22}	$-x_{23}$	$-x_{24}$	$-x_{25}$
C	*	*	*	x_{33}	*	$-x_{35}$
RM	*	*	$-x_{42}$	$-x_{43}$	x_{44}	*
ES	*	$-e_1$	*	*	*	*
MS	$-M_0$	*	*	*	*	*
GJ	w_0	w_1	w_2	w_3	$-w_4$	w_5
DE	d_0	d_1	d_2	d_3	d_4	d_5
DM	s_0	s_1	s_2	s_3	s_4	s_5
R	r_0	r_1	r_2	r_3	r_4	r_5
			Fund Coordinates			
pital fund	K_0	K_1	K_2	K_3	K_4	K_5
ple	H_0	H_1	H_2	H_3	H_4	H_5
ardian land	L_0	L_1	L_2	L_3	L_4	L_5

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FOOTNOTES

[1]An analytical boundary of a concept must be vacuous because otherwise it would not be a valid boundary for the opposite concept as well (Georgescu-Roegen, 1966).

[2]Ibid.

[3]E.g., La Grande Encyclopédie and The Columbia Encyclopedia (New York: Columbia University Press, 1956).

[4]Ostoya (1954).

[5] Venus physique suivie de La lettre sur le progrès des sciences is a recent reprint by Aubier Montaigne (Paris, 1980). About it, see the authoritative evaluation by Bentley Glass (1947).

[6]Grossman (1960).

[7]In that volume, Maupertuis discussed the opposition between plaisir (pleasure) and peine (pain) and the role that these feelings have in life. His strange conclusion was that over the whole life the sum of evil, of unhappiness, is greater than the sum of pleasures.

[8]A significant passage from the fragments of Hero's Catoptrics is quoted by Yourgrau and Mandelstam (1968).

[9]Kline (1972), which is a competent and highly informative volume.

[10]Newman (1956), vol. I.

[11]Published in Mémoirs de l'Académie des Sciences, 1744, and reprinted in Oeuvres, IV. A few paragraphs are reproduced by Callot (1964).

[12]Mémoirs de l'Académie de Berlin, 1746.

[13]This last definition is also found in several other of Maupertuis' contributions, all reprinted in Oeuvres.

[14]Mémoirs de l'Académie de Berlin, 1756. The Essai de Cosmologie, published in 1750 and reprinted in Oeuvres, I, expatiates on the least action principle. Its Part I deals with "the proofs of the existence of God derived from the marvels of nature." See the reprint in Callot (1964).

[15]Bertrand Russell (1937).

[16]From all that one may gather, Voltaire's discovery that Maupertuis did not favor the reduction of all natural processes to Newton's fundamental law and that in reality he believed in the reality of a divine architect, caused him to substitute Voltairean ridiculing for his former praises. That ridiculing undermined Maupertuis' deserved scientific reputation, a blow from which there has been no recovery. Maupertuis probably is the most striking exception to Max Planck's rule that the true value of a scholar's achievements is recognized only after his contemporary foes have died.

[17]As he revealed through several writings, most of which were intended to intervene in favor of Maupertuis during the latter's nasty conflict with Samuel Koenig, a former student, who falsely accused Maupertuis of having stolen the least action principle from Leibniz. Yet the accusation, supported by Voltaire, left unfortunate traces. Hermann von Helmholtz (1887) insisted that Leibniz knew the argument. Max Planck (1968) also held that opinion.

[18]Curious though it may seem, although Malebranche's verdict has never been questioned, it has hardly been openly advertised. Paul

Samuelson (1972) is an exception, for in an enlivening paper of 1965 he categorically endorsed Malebranche: "Nature is a great Economist, or economizer." But on that occasion he also was eager to perpetuate the old animosity toward Maupertuis by decrying the latter's "mystical notion of teleology." The principle is great, but its author, sordid!

[19]For finding the minimum or the maximum, economists usually resort automatically to the additional parameters invented by Joseph Louis Comte de Lagrange. However, the automatic application of Lagrange multipliers, the darling mathematical artifact of the economist, bypasses the most frequent situations (the corner cases) in which the maximum (or the minimum) is not located by that method.

[20]The so-called Euler's equation has become a basic item of the calculus of variations (Kline, 1972).

[21]$L = T - V$ is now known as the Lagrange function.

[22]A convenient, uncomplicated presentation of Sir Hamilton's fundamental contribution is offered by Menzel (1961).

[23]Quoted from Dublin University Review by Kline (1972).

[24]This particular problem formed the object of one of the analogous papers by Gerhard Tintner (1936). Interestingly, that problem recalls the guiding idea of H. H. Gossen's vision of the economic process. But Gossen solved it in a truly imaginative way and on the basis of one of his laws which has strangely been totally overlooked (Georgescu-Roegen, 1983).

[25]For economics that was also the momentum of its dynamisation initiated by the works of Griffith C. Evans, Charles F. Roos, and Harold T. Davis.