COMMITTEE IV
A Critical Assessment of
the Achievements of the
Economic Approach

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ECONOMICAL PRINCIPLES IN NATURE

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DISCUSSION PAPER

on

Michael T. Ghiselin's

BIOLOGY, ECONOMICS AND BIOECONOMICS

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ECONOMICAL PRINCIPLES IN NATURE

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Commentary to Michael T. Ghiselin's

Biology, Economics and Bioeconomics

Economy and interdisciplinary sciences

Professor Ghiselin's paper is attractive to me since it presents a stimulating and partially unconventional view. Generally I am in favour of an interdisciplinary approach to biology because biology deals with very complex systems and it is likely that any such approach will reveal new aspects or even promote the emergence of entirely new theories. The growth of interdisciplinary sciences is a phenomenon that is rather characteristic for our own century. It may be sufficient to mention the impact of concepts such as information, codes or programmes onto the theoretical framework of a variety of sciences: from genetics and molecular biology to neurobiology and psychology. Anyhow, the development of new scientific disciplines is entirely justified by their contribution to a conceptual evolution, i.e. the change of outdated or false concepts into more adequate one (cp. Radnitzky, 1983).

Whether one wants to view economics as a branch of biology or the other way round, biology as a branch of general economics, is of course, a matter of one's main interest. Undoubtedly, the subjects are interrelated. From a biological point of view, the term bioeconomics seems to be appropriate.

The interconnection between different sciences varies, of course, greatly. As to mathematics, for example, it is a field of knowledge whose application has boosted the advance of many sciences. It is true, as Dr Ghiselin points out, that the application and development of many mathematical methods have been initiated by the particular needs of other sciences (among them physics and economics). Nevertheless, a similarity in mathematical formalism sometimes allows for comparisons which reflect more than superficial analogies. A number of essential mathematical discoveries concern abstract algebra and geometry, which at the time of their publication were thought to have little practical use. Nevertheless, they later on proved to be very essential tools. One may mention group theory, non-Euclidean metric spaces, Ricci (tensor) calculus or the theory of sets. Mathematics is basically a non-empirical, structural science. It is a surprising fact that entirely abstract mental constructs sooner or later have shown themselves to be essential tools for the description of our physical reality.

One may in this connection mention the Austrian physicist and philosopher Ernst Mach, who emphasized the economical function of science, in particular of mathematics. Mach obviously thinks in terms of comprehensiveness and parsimony of effort. Parenthetically, it may be mentioned that Mach inspired Einstein, but arose the indignation of Lenin (Newman, 1956). Mach mentions a number of factors which he regards as contributors to the economy of science, such as the universality of scientific symbolism, the common applicability of general rules to individual cases, the development of mathematical methods which save labour or allow for a better comprehension. This was written with the work of Charles Babbage in mind, half a century before the advance of electronic computers. Mach also emphasizes salient features of the brain, which reflect its economical way in the handling of information: affective classification of those aspects of reality which are important to us, the creation of simple auxiliary concepts which facilitate the comprehension of a complex reality, etc. (cp. Rignano, 1923).

There exist similar problems in both biology and economics which invite us to apply related methods of investigation. Examples would be network theory, particularly with respect to associative networks, the optimal distribution of raw material and energy resources in relation to variable or competing demands, the cost-benefit optimizing, etc.

Economical concepts and biology

Dr. Ghiselin's paper contains an extensive review of the topic. The following sections mainly endeavour to give some personal reflections on certain parts of it.

There are concepts which to me reflect economy in a proper sense, and others which do so partially, or reflect underlying economic principles. One may mention:

demand versus the availability of resources,

the cost-benefit relationship and profit,

competition with respect to limited resources,

cooperation and division of labour,

the principle of diminishing return,

reproductivity and survival rate,

criteria of fitness and efficiency of adaptation, etc.

As with most concepts which are borrowed from other sciences, one must expect that they are used in slightly different ways. Their connotation may overlap with that of other terms and they may slowly change during the course of time. This often evokes discussions about their meaning in different contexts. Examples will be given below.

The term efficiency is sometimes used in a way which reflects a principle of economy. Basically, the concept relates to the problem of energy conversion and denotes the ratio of "useful energy" (that part which is directly converted into an equivalent amount of work) and the total amount of input energy:

$$\eta = \frac{\text{useful energy}}{\text{total input energy}}$$

The number η (a dimensionless number) is an engineering concept which reflects the economy of a motor or engine. Nevertheless, our thinking is influenced by a group of related concepts. There exists a class of (now outdated) energy conversion numbers that were used as a kind of "exchange rate" between different <u>types</u> of energy, i.e. they give the numerical equivalent between different units. Examples would be:

1 cal = 4.19 Joule (J) ; 1 J = 0.239 cal

with respect to energy, or

1 horsepower (hp) = 736 W ; 1 kW = 1.36 hp

with respect to power.

The introduction of the International Standard System (SI eliminated redundancy and reduced the number of units and symbols to about 25% of the original one. This, in itself, is a measure of economy. Today all energy is expressed in Joule and power in Watt. The expression:

1 J = 1 Ws = 1 Nm (Newtonmeter)

gives the equivalent amount of work. The earlier notations, however, have to be available in order to facilitate the reading of older literature.

A rather difficult concept which is related to efficiency is called entropy. It was originally coined by Rudolf Clausius in order to characterize possible thermodynamical processes i relation to the extent to which heat energy under given conditions can be used to produce mechanical work. Today one uses the term exergy to denote this amount of energy. Exergy is formally defined as the product of the negentropy of a system and the absolute temperature (T) of its environment. Negentropy here denotes the difference between the actual and the maximum entropy of the system (cp. Nordling, 1982). It may be added that the term negentropy is used in a slightly different way in connection with information theory (for details, see e.g. Higatsberger, 1986).

Parenthetically, it may be mentioned that the attempt to introduce the notion of entropy to the realm of economics has initiated a critical debate at several ICUS meetings. The arguments, however, differed between the participants. While some physicists doubted the applicability of the concept to systems of macroscopic elements, economists mainly were reluctant to adopt new concepts that did not seem to enhance the explanatory power of economic theory.

Now "efficiency" has a wider connotation which is reflected in the differentiation of langauge. In German, for example, the more general term is "Effektivität", while the factor η is more specifically called "Wirkungsgrad". We speak of "efficiency" if a task is performed correctly for a minimum amount of time. One may compare alternative procedures of problem solving or methods of productions with respect to their "economy" (the use of a minimum amount of time, energy, steps or elements). This applies to chemical processes within biological organisms as well. One may, of course, reformulate these examples in terms of the cost-benefit principle.

In order to speak of the economy or parsimony of a process, one has to relate this statement <u>both</u> to a certain achievement or "goal" <u>and</u> to the given initial conditions. If one speaks of "goals" in a biological context, one has, of course, to be very careful to avoid an unintentional introduction of teleological arguments. This has also been mentioned in Dr. Ghiselin's paper. There are subtle differences in the way in which economic concepts are used. Normally one presupposes an "external" observer who judges the "economy" of a process (for example. the cost-benefit ratio) under given conditions. This means either a post factum analysis of a given process or a comparison of the outcome of thought experiments. Anyhow, the judgement is made a posteriori and implies a thought process or its electronic equivalent. A modern computer may use a high level program to evaluate the "economy" of a lower level program and to modify the latter with respect to external criteria of efficiency.

Radnitzky in a similar way applies the cost-benefit principle to an analysis of the methodology of research (Radnitzky, 1987).

One may now ask if economical principles exist that govern the behaviour of natural systems? What then is the nature of these principles? First of all, one has to define the system which is studied. Any automatically acting system such as an organism usually needs feedback criteria of success or information about the cost-benefit ratio relating to the action. This means that information has to be recorded and stored in different types of memory. Ultimately, the survival of an individual, a group or a species, indicates a success. All organisms are dependent on trial-and-error learning to a varying degree. Simpler organisms are, furthermore, to a higher extent subjected to the influence of chance events, since usually they are unable to anticipate any event.

One may argue that economical principles are most typically applied to groups rather than to individuals. While Dr Ghiselin's paper does not state this explicitly, one may draw this conclusion from the given examples. The natural variability of properties between individuals as well as between species, is a precondition for differences between individuals with respect to successful competition. Dr Ghiselin mentions an interesting point in that he correctly asserts natural selection to the reproductive competition between individuals of the same species. Due to natural differences between individuals, there is a selection of the fittest (for example, individuals with high immunological efficiency) who deliver their genes to the next generation. It might be that the Spencerian notion "survival of the fittest" directs one's thoughts too much towards "stable" properties of individuals or groups of individuals, neglecting the genetic aspect. One should not forget, however, that a more detailed understanding of the nature of genetic variability and polygenetic heredity were not available during his time. Still, there are many details of the mechanisms of adaptation which are insufficiently known today.

The living organism, during its life, maintains a high level of negentropy (information content). This is made possible by the use of energy-rich components which are extracted from the environment and by the expenditure of an excess of energy. Thus, living organisms have to be open systems whose negentropy is maintained by a corresponding increase of the entropy (disorder) in their environment. This means that local information is gained by processes which selectively filter away noise. The increase of environmental entropy is the price which has to be paid in order to maintain the living state of the organism. This is part of the energy and waste problem of mankind.

Now, phylogenetic evolution may be described as an information process, featuring a chain of discrete feedback steps. In the words of Dobzhansky: "Adaptation and emergence of new genotypes if a feedback process within a reproductive group, natural selection is homeostasis within a relatively isolated biotic system. The result of these two processes operating together is the evolution of established species" (Dobzhansky, 1955, p. 131).

A mark of success of an organic form in evolution is the ability to achieve stability within their environment. This amounts to a persisting ability on the part of the organism to feed on the negentropy of its immediate environment (Schrödinger, 1951). Sayre coins, in this connection, the term negentropic flexibility: "In speaking of flexibility in the assimilation of negentropy, I refer to the capacity of an organism to establish efficient couplings with its environment under a range of different conditions, through which negentropy can be obtained to support growth and metabolism and to control its response to environmental contingencies. Let us name this capacity negentropic flexibility" (Sayre, 1976, p. 117).

Thus, in my view reproductive competition and successful adaptation in the above mentioned sense represent complementary phenomena that both relate to economic principles. Competition is a rather complex phenomenon, which always implies an interaction between individuals with respect to limited resources (food, sources of energy, space, attractive objects or, in the case of human beings, money). The behaviour may reflect the role of a "consumer" or a "seller" or both. The ability to compete efficiently is one mark of successful adaptation. However, efficiency here is not merely a quantitative concept in the engineering sense, but it means different things in different situations. First of all, an organism has to perform a multitude of different tasks at the same time which may make it necessary to make use of the same functional sub-systems for different purposes in a kind of time sharing procedure. The organism must be able to control the use of internal resources with respect to some priority schedule which may change over a period of time. The efficiency of an external behavior is, hence, dependent on the internal state of the organism in a rather complex way.

Efficiency in competition may relate to speed and agility but in the case of animals of prey (including man), also to aggression. These elements of behavior depend on very complexly controlled sensory motor functions. The interaction between behavioural components may even be "counterproductive". One may observe two sea-gulls or sparrows fighting for the same piece of attractive food, while a third one "gets the whole cake".

However, efficient competition may be based on other qualities such as intelligence, a suitable strategy or the ability to attract a "customer" or "client". This may be part of a larger pattern of interaction, using both active and passive qualities. The attractiveness of certain flowers to particular groups of insects ensures an adequate pollination and illustrates a type of mutual adaptation with respect to an interaction between different species. A similar view holds with respect to symbiosis.

At the human level, one may think of the subtle differences between individuals with respect to aesthetic preferences which may determine the production of works or art as well as the attractiveness of the latter to potential customers.

A paradoxical example on competition regards the loss of an ability, which might be advantageous to an organism under certain specific conditions. Linus Pauling (1970) reports a finding by Zamenhof & Eichhorn that a strain of bacterium subtilis (common hay bacterium) that has lost the ability to synthesize the aminoacid tryptophan, displaces a normal strain within an environment which supplies tryptophan in an optimal quantity.

Analogies sometimes convey a slightly different meaning. The competitive exclusion principle of Gause states that two different species in the long run cannot occupy the same ecological niche. The analogy regards two companies that are said to be unable to compete with identical products. This is not quite clear to me. Notwithstanding the problem of trademarks that always introduce a trivial difference between products which otherwise may be identical with respect to quality, it is difficult to see why the companies could not compete. In fact, this was common before the spread of trademarks. One could buy starch, kerosene, pure alcohol or salt with comparable quality from different manufacturers at the same store and without a label of origin. This means that different producers may compete with the same product, but I am aware that the price and personal relations may favour one of the competitors. The question is, of course, if one can regard the price as a quality of the product itself. I may, however, have missed the point.

There is a special class of problems which is related to an efficient utilization of given, internal resources. This concerns living organisms in general.

It is often observed that a high economy in this sense is a mark which characterizes highly sophisticated mechanisms. The mammalian eye may serve as an example. Initially, one has to make a distinction between anatomical structures and functional systems. Essentially, there exists a multiple (many to many) relationship. Crick (1979) speaks of associative nerve nets that are able to create very efficient couplings between any set of input and output channels needed in the handling of a certain problem, The participating anatomical elements, however, may somewhat later on be used for different tasks. An example may illustrate this. If one phones a person, a specific and temporary communication channel is created by the interconnection of existing wires with the aid of a set of relays. The relays are activated in a sequence which is determined by a number of coded signals until the desired communication line is established. After the call is finished, the communicating channel ceases to exist, but its material components are available for renewed use.

The retina of each human eye contains approximately 130 million receptor cells (rods and cones), the optic nerve about 1 million nerve fibres. The retina is functionally a peripheral part of the brain, but anatomically a part of the eye. The first part of visual information processing including the choice of suitable input lines is already performed within the retina.

Still more fascinating is the way in which patterns are analyzed. Retinal receptors cooperate in so-called receptive fields. Some of these fields have the shape of "bars". The field ultimately transmits its message in convergent lines to cortical cells in the area striata of the "visual cortex". There are receptive fields of different orientation and different position in the retina. Each field reacts to either light bars, dark bars or edges of "correct" orientation, which means that each receptive field has a preference for a specific linear stimulus of correct orientation. (Hubel, 1963; Hubel & Wiesel, 1979).

This picture, however, is probably too simple. A receptive field may rather be viewed as a narrow window (slit) to the visual world. A set of parallel slits may be said to constitute a grid, which perform a spatial Fourier analysis across stripes of light which enter the eye. Details will be omitted here.

Now each simple retinal receptor is simultaneously part of functionally different receptive fields with different orientation. This results in a mechanism which would be impossible in terms of normal optical grids (parallel arrays of mechanical slits). The eye seems to perform, for each part if the retina, a simultaneous spatial Fourier analysis, covering all possible orientations, which means that the eye in a way simulates the effect of a superposition of non-interactive optical grids. (For different details, see Pribram et al, 1981, De Valois & De Valois 1980; Sekuler & Blake, 1985). This very elegant solution of an extremely difficult optical task is at the same time an example of extraordinary economy regarding the use of functional elements.

The limitation of available space prevents the discussion of further examples. It may be sufficient to say that nature supplies ample numbers of phenomena to which economic principles apply. Let me, finally, emphasize the fact that human beings are living organisms and part of the large ecological system of earth. Our biosphere is a giant flow system which incorporates millions of subsystems, each one interacting with others and with their physical environment in an exchange of energy, matter and entropy. Any major disturbance to this delicately balanced system may have serious consequences to life on earth. Man in his selfish actions does not always show sufficient insight into the consequences of the former. Still worse are the effects of short-sighted greed which are often "justified" with reference to "economic necessity". The latter then mainly receive the role of a cover up.

It would be one of the most essential contributions of bioeconomics to prove convincingly that common economics and the welfare of human beings are critically dependent on the undisturbed ecological balance of the biosphere to which we all belong.

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