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NICHOLAS GEORGESCU-ROEGEN, 1906–1994

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Nicholas Georgescu-Roegen's long and productive career was marked by gradual but significant changes in his outlook, focus of research interest, and interpretation of the economic process. His publications reflect the unusual breadth of his education and work experience, and an innate intellectual curiosity which caused him to disregard the traditional boundaries between disciplines. He was an auto-didact in a wide range of areas, and his erudition showed at every turn. He moved easily from economics to philosophy, including the philosophy of science, and from the physical to the biological sciences. This makes it difficult for economists to evaluate his contributions adequately. Our task is somewhat lightened by the autobiographical notes which he wrote reflecting on the highlights of his professional development (Georgescu-Roegen, 1988, 1992*a*, *b*, 1993).

Georgescu was born in Constantsa, Romania in 1906 to a family in modest circumstances. He acquired a love for mathematics in primary and secondary school, and went on to study it at the University of Bucharest, where he graduated with a *licence ès mathématiques* in 1926. He then won a scholarship to the Sorbonne where he turned from mathematics to statistics. In Paris he took courses from the famous statistician Emile Borel and the economists Albert Aftalion and Jacques Rueff, thus receiving his first introduction to economics. He was granted the doctoral degree *avec les félicitations du jury* in 1930 after writing a dissertation on the discovery of latent cyclical components in time series. Another scholarship allowed him to continue his studies in London under Karl Pearson from 1930 to 1932, when he returned to Romania to become Professor of Statistics at the University of Bucharest, a position he held until 1946.

In 1934 Georgescu received a scholarship from the Rockefeller Foundation to visit Harvard University for two years. There he met Joseph Schumpeter who took an immediate interest in his dissertation, thinking he could apply the same methodology in the book he was writing on *Business Cycles*. Georgescu's encounter with Schumpeter was to have a pivotal influence on his subsequent career, effectively turning him into an economist. While at Harvard, he also began a friendship with Leontief which would last for the rest of his life. He wrote several papers which established his reputation as a first-rate mathematical economist. So impressed was Schumpeter with Georgescu that he asked him to be co-author of a treatise on theoretical economics and join the

* The first author of this essay is a former colleague of Nicholas Georgescu-Roegen, and the second a longtime student and admirer of his work. We have benefited from his friendship and many fruitful exchanges with him over the years. We thank Elton Hinshaw for his helpful comments.

Harvard faculty. Reflecting on his decision many years later, Georgescu believed he had been foolish to decline this invitation, but at the time felt an obligation to return to his native country. There he held a number of government positions and continued an active academic career.

In 1948, after the change of regime, Nicholas Georgescu and his wife Otilia escaped from Romania. He made his way back to Harvard, and in 1949 was invited to join the faculty of economics at Vanderbilt University in Nashville, Tennessee. He remained there for the rest of his career, becoming Distinguished Professor of Economics in 1969. Both before and after his retirement in 1976, he held visiting positions at several U.S. and foreign universities. He received many academic honours, including those of Distinguished Fellow of the American Economic Association, and Fellow of both the American Academy of Arts and Sciences and the Econometric Society. Georgescu died in Nashville in 1994. His wife Otilia provided unfailing support throughout his long career, facilitating his prodigious output of several books and 230 articles in English and several other languages (partial bibliographies of his writings are found in Tang *et al.* 1976; Dragan and Demetrescu, 1991; and Georgescu-Roegen, 1995).

Georgescu's scientific activity can be divided into two broad phases (Zamagni, 1987*a*; de Gleria, 1995). The first consists of his pioneering contributions to consumer theory and linear activity models of the Leontief type. The second was 'the product of a fundamental change in [his] orientation as an economist' (Georgescu-Roegen, 1976, p. ix), when he widened his attack on the shortcomings of the mechanistic epistemology underlying neoclassical economics. He turned his attention to a modelling of economic activity which takes account of the entropy law of thermodynamics, and eventually founded the field of bioeconomics. The watershed between these two phases is marked by a paper he presented at a conference of the International Economic Association in 1965 (Georgescu-Roegen, 1969), and by his 127-page introduction to *Analytical Economics*, his first book of collected writings (Georgescu-Roegen, 1966).

In this article we examine in turn Georgescu's epistemological orientation, his consumer theory, theory of production and pioneering of bioeconomics. As will be amply clear, there is a dialectical penumbra (to use one of Georgescu's favourite expressions) surrounding the borderlines between these categories, and they cannot be neatly separated. For lack of space, we must omit other areas such as agrarian economics (Georgescu-Roegen, 1960), which reflected his attempt to understand the nature of underdevelopment in his native country.

I. A NEW EPISTEMOLOGICAL OUTLOOK

Georgescu's principal contributions to epistemology are synthesised in his two most important books (Georgescu-Roegen, 1966, 1971). One of the *leitmotivs* of his writings was the need to realise a union between reason and intellect, that is, between logic and an understanding of reality which cannot be encompassed by purely logical processes. What has prevented the realisation of a fertile alliance between the two spiritual forms which Pascal – an author specially dear to Georgescu – called *l'esprit de finesse* and *l'esprit géométrique*? Georgescu's answer: 'for the last two hundred years we have bent all our efforts to enthrone a superstition as dangerous as the animism of old: that of the Almighty Arithmomorphic Concept' (Georgescu-Roegen, 1971, p. 79).

To demolish this 'superstition' was one of Georgescu's primary aims. His concept of arithmomorphism was closely tied to the special definition he gave of theoretical science, namely 'a catalogue which lists known propositions in a logical – as distinct from taxonomic or lexicographic – order. In other words, we have a first equation "Theoretical science" = "Logically ordered description"' (Georgescu-Roegen, 1971, p. 26). However, the possibility of using logic cannot be taken for granted, since it requires that the Principle of Non-Contradiction (which asserts that '*B* cannot be both *A* and non-*A*') should apply to the object in question. Otherwise, no logical algorithm could ever be used, regardless of the specific object in question. The Principle of Non-Contradiction, as a presupposition for ascertaining the syntactic coherence of a language, can be invoked only insofar as the objects under consideration are clearly distinguishable, with the same properties as those enjoyed by numbers in arithmetic. The reason is that 'Logic can handle only a very restricted class of concepts, to which I shall refer as *arithmomorphic* for the good reason that every one of them is as discretely distinct as a single number in relation to the infinity of all others' (Georgescu-Roegen, 1971, p. 14). Arithmomorphic concepts are not only discrete but also neutral, in the sense that they express neither form nor quality. Their principal characteristic is that they never overlap. Hence they do not possess 'fuzzy edges', to use Wittgenstein's felicitous expression, not lend themselves to multiple interpretations due to the uncertainty of their semantic fields. Moreover, 'despite the use of the term "continuum" for the set of all real numbers, within the continuum every real number retains a *distinct individuality*.... Every arithmomorphic concept stands by itself...' (*ibid*., p. 45).

However, not all scientific knowledge falls within the scope of this mode of thought: sociology, biology and economics are disciplines (among others) whose conceptual categories cannot be neatly inserted in a logical scheme of reasoning, since qualitative differences and change characterise a large part of the phenomena which they investigate. What then are the consequences of the attempt to constrain all scientific research within an arithmomorphic scheme of thought? To be sure, the picture of a non-problematic science where black and white are rigorously distinct can be comforting. But it is the very fact that this picture is false which makes the history of scientific progress so fascinating.

The battle against the dogmatism of arithmomorphic concepts became for Georgescu a battle to reassert the motives which historically gave birth to those concepts. Scientific revolution has been an intrinsically democratic enterprise. The search for truth became open to all instead of being kept secret, as had happened from the times of ancient Egypt to those of 16th-century alchemists. Truth had become 'verifiable', as J. Dewey and others would later say. With no need for priestly mediation, people could look through a telescope and see for themselves the ruggedness of the moon. This led them to reject the Ptolemaic theory of crystal spheres. But with the passage of time, the undoubted advantages and historical successes of arithmomorphic rationality gradually transformed that democratic spirit into a dogmatic attitude, to the point of excluding from scientific reasoning anything which could not be reduced to number, mass or force. Science was dethroned in the name of scientific 'truth' itself.

One of the main themes of Georgescu's writings was his protest against the use of models inspired by Lagrangian dynamics, which assume that economic agents obey forces of conservation deducible from a potential function. The conceptualisation of the economic system as a homogeneous economic space, in which agents communicate with each other only via the mediation of the market, corresponds exactly to the model of Lagrangian equilibrium. One can hardly overestimate the importance of this model in physics and those disciplines, such as economics, to which it was exported. In fact it generalised Galileo's old idealisation of a world conceived on the model of a celestial physics. One of Georgescu's favourite targets of attack was the 'mechanistic dogma' which characterises neoclassical economics and assumes full reversibility of economic phenomena. It is curious that its importation into economics from physics occurred at a time when it no longer reigned supreme there (see Mirowski, 1989, 1992). It is embodied in the first law of thermodynamics, the law of conservation of matter and energy. Under its influence, economists have become conditioned to regard changes in economic events as akin to the movement of a pendulum, which returns qualitatively unchanged to any previous position.

This is the reductionist image of science which the advent of thermodynamics in the last century placed in a state of acute crisis. That image did not incorporate an aspect which had been suppressed in its formulation of dynamics: the notion of a process or transformation which modified an object, making it impossible to bring it back to its former state. All processes which Newtonian physics describes are symmetric with respect to time. No phenomenon takes place which this physics does not allow in reverse, given different starting conditions. Past and future play exactly the same role, that is, no role at all. The definition of a state in terms of the location and velocity of the particles which compose it already contains the past and future of the system. Every state can indifferently be the initial or the final state of a long evolution. Change is nothing but the unfolding of a sequence of essentially equivalent states.

The starting-point of Georgescu's approach was to demonstrate that, in many common situations, the idea of determining the initial conditions of the trajectories to be followed by a given system is incompatible with the implications of the dynamic law describing its motion. This is the case when the situations are described by processes which, like the economic one, do violence to matter and are irreversible, depending on past history. The notion of evolution, exorcised by means of mechanical analogs, re-entered through the front door via the law of entropy. Time and irreversibility were reunited. A thermodynamic description of time, introducing what Sir Arthur Eddington has felicitously described as 'time's arrow', replaced a mechanical description of time which tied it to movement.

II. CONSUMER THEORY AND CRITIQUE OF THE RATIONALITY PARADIGM

The theory of consumer behaviour, an area which Georgescu investigated over four decades (1935–73), offers some initial cues for his epistemological orientation. Because qualitative attributes like preferences are continuous in a sense which cannot be represented mathematically, any attempt at their quantification, such as by means of a utility metric, can never eliminate a qualitative residuum hidden within their structure. This arises from the fact that human wants are of endless variety (Georgescu-Roegen, 1954). Moreover, since actual choices are always partly the result of hysteresis phenomena, learning processes in consumption activity should be explicitly taken into consideration. This led Georgescu to analyse the role of time in economic inquiry, and make a fundamental distinction between dynamic *vs.* historical time on the one hand, and qualitative *vs.* mechanical change on the other.[1] After showing that a preference ordering does not necessarily imply a measure (even an ordinal one) of these preferences, Georgescu became convinced that a purely logical method of investigation could not be applied to economics because of the need to resort to dialectical concepts. He called 'ordinalist fallacy' the failure to note the important difference between comparability and measurability, and the consequent belief that the former always implies the latter: 'it was under the influence of the idea "there is a number in everything" that we have jumped to the conclusion that "where there is 'more' and 'less' there is also quantity"' (Georgescu-Roegen, 1971, p. 83).

A great 'utilitarian' such as J. S. Mill had already recognised the lexicographic nature of utility: 'It is quite compatible with the principle of utility to recognize the fact that some kinds of pleasure are more desirable and more valuable than others. It would be absurd that, while in estimating all other things quality is considered as well as quantity, the estimation of pleasure should be supposed to depend on quantity alone' (Mill, 1882, p. 14). Yet the great theoretical advantage of representing an individual's preference set by means of a utility index function gained the upper hand over the analytical difficulties introduced by the indifference postulate. This procedure represented the development in an empirical era of the idea, largely accepted by neoclassical economists by the late 19th century, that different needs can be related to utility understood as generic satisfaction, an indifferentiated flux of

[1] The crucial role played by time in the maximisation of utility from consumption is one of the main reasons why Georgescu admired Gossen's book *The Laws of Human Relations*, as evidenced by the long and profound introduction he wrote for its English translation (Georgescu-Roegen, 1983).

enjoyment yielded by the consumption of commodities. Consumption is thus an activity not directed to the satisfaction of a spectrum of needs but, more reductively, one with a single 'output': utility.

The abstraction of utility from the satisfaction of multiple needs causes the physical characteristics which distinguish different consumption goods to lose all relevance, so that only their capacity to produce 'utility' counts. The existence of a hierarchy of wants implies instead that the arithmomorphic representation of preferences becomes discontinuous. However, 'to argue that preference is discontinuous because its arithmomorphic simile is so, is tantamount to denying the three-dimensionality of material objects on the ground that their photographs have only two dimensions' (Georgescu-Roegen, 1971, p. 79). Since qualitative attributes like preferences are continuous in a sense which cannot be represented mathematically, their quantification can never eliminate a qualitative residuum hidden within their metric structure and expressible in the form of a discontinuity: 'the dialectical spectrum of human wants (perhaps the most important element of the economic process) has long since been covered under the colourless numerical concept of "utility" for which, moreover, nobody has yet been able to provide an actual procedure of measurement' (*ibid.*, *p.* 52).[2]

Conventional consumer theory faces a further difficulty. Leaving aside the plausibility of its axioms, how can we be sure that individuals maximise (or act as if they maximise) a utility function? This is the 'mysterious' problem of integrability in demand theory. Exorcised for a long time as a pseudo problem by mainstream economic theory, it was a *leitmotiv* for Georgescu, who established that the integral curves derived from the differential equation expressing a consumer's equilibrium do not necessarily represent indifference curves. Moreover, the whole question of integrability is 'without any meaning outside the transitivity condition [in the field of preferences]' (Georgescu-Roegen, 1936, p. 568). He thereby cast doubt on whether demand theory can serve as a bridge connecting the analysis of consumer behaviour to observable reality, and on the possibility of providing an empirical foundation for pure consumer theory.

Georgescu's truly remarkable contribution in this area was to raise the following dilemma. To ensure integrability of the demand functions in an economic sense, conditions must be introduced which, whatever the chosen mathematical approach, cannot be subject to empirical verification. On the other hand integrability, as an economic problem, should allow us to decide, after empirical testing, if consumers act 'as if' they are guided by the principle of instrumental rationality. Georgescu's contribution was to show that neoclassical consumer theory is empirically unacceptable.

[2] Dissatisfaction with traditional consumer theory on the part of other economists has led to attempts to reformulate it. Lancaster (1971) argued that commodities are endowed with heterogeneous characteristics which enter preference functions. More explicitly as a result of Georgescu's criticisms, Ironmonger (1972) postulated that goods satisfy qualitatively different needs, and that preference functions should be defined over needs rather than commodities.

III. THEORY OF PRODUCTION AND THE FLOW–FUND MODEL

The second phase of Georgescu's scientific orientation, marked by an attempt to take into account evolution, the accompanying qualitative changes and the entropy law, began in 1965 with his analysis of the production process (Georgescu-Roegen, 1969). His paper 'Process in farming versus process in manufacturing' is, in our view, one of the most lucid and insightful contributions ever made to the theory of production. In 1969 he delivered the prestigious Richard T. Ely lecture 'The economics of production' at the meetings of the American Economic Association (Georgescu-Roegen, 1970), and followed this up with a spate of papers (most of them reprinted in Georgescu-Roegen, 1976) elaborating on this theme.

The first casualty of Georgescu's new formulation of production theory is the still dominant concept of economic activity as a purely circular process. As Schumpeter has pointed out, the discovery of the latter coincided with the birth of modern economic analysis. The notion of a closed circular process was a progeny of 18th-century science and a hallmark of the writings of Cantillon and Quesnay, followed by Smith and Ricardo. Viewing the 'economy of society' by analogy to the 'economy of nature', it inaugurated systematic economic discourse. The thermodynamic revolution started by Sadi Carnot radically changed this conceptual framework. It implied that the economic process, like the biological one, should be viewed in unidirectional terms, no longer circular ones. With his usual perspicacity, Marshall had already reached this conclusion when he showed that all long-term supply curves are irreversible because of the orthogenetic nature of innovations.

Georgescu began by criticising the production function first proposed by Wicksteed and then adopted by neoclassical economists, where output is made a function of several factors of production, sometimes defined as stocks, other times as factor service flows.[3] He went on to formulate a new analytical representation of the process of production, his flow–fund model. He defined a process of production by the finite interval of time over which it occurs, the analytical boundary separating it from its environment, and the timing and nature of the elements crossing this boundary in either direction. Georgescu divided process elements into flows, which appear only as inputs or outputs, and funds, which appear as both inputs and outputs.[4] Thus 'in a reproducible process, the fund elements are the immutable agents that transform some input flows into output flows' (Georgescu-Roegen, 1970, p. 4).[5] Input flows include natural resources, produced inputs and inputs earmarked for maintenance, while output flows consist of commodities and waste. Funds include the

[3] Had he looked for them, Georgescu would have found some useful allies among the Cambridge (UK) economists, who were busy at about the same time criticising the neoclassical production function from a very different perspective (see Harcourt, 1972).

[4] The fact that tools come out of a process more worn than when they entered it, just as workers enter it fresh and exit it tired, raises the issue of the qualitative change of fund factors. Georgescu resolved this difficulty by assuming that activities inside plants or households maintain them at their original efficiency.

[5] There is no correspondence between fund and flow factors on the one hand, and fixed and variable factors on the other. Likewise there is no equivalence between the notion of funds and that, similar in appearance, of stocks.

classical trio of capital, labour and Ricardian land, as well as inventories and goods in process.

Georgescu's flow–fund model forces us to ponder over two important theoretical issues. One is the still widespread belief that it is possible, and even convenient, to keep in separate compartments an analytical core made up of the technical properties of production, and the sphere of economic decisions proper such as those determining the levels of employment and output, which are not independent of the institutional setting. The flow–fund model clearly shows that such separability is not possible. The reason is that the representation of technology in terms, say, of Leontief or von Neumann matrices does not exhaust the set of data required. For example, the vector of labour coefficients indicates the flows of labour-hours per unit of output, but not the way in which labour is organised. Yet the same number of labour-hours can correspond to different ways of organising work, consistent with the prevailing state of technical knowledge but leading to different consequences.

The second issue regards the close connection which the flow–fund model establishes between the division of labour and production efficiency. Whether fund factors are indivisible or not, in general they are not utilised throughout the process of production. Their idleness is therefore an unavoidable necessity, although the way in which elementary processes can be combined, whether in series, in parallel or in line, can aim to minimise such idleness. When demand for a product is low, only an arrangement in series is economically viable. An arrangement in parallel means that a number of elementary processes begin and end at the same time, as is usually the case in agriculture where the seasons dictate the times of sowing and harvesting. This may reduce the idleness of some indivisible funds shared among several processes. But the most advantageous arrangement is that in line, where processes are staggered so as to minimise fund idleness. This is exemplified by an assembly line and illustrates the great advantages of the factory system, which 'deserves to be placed side by side with money as the two most fateful economic innovations for mankind' (Georgescu-Roegen, 1970, p. 8).[6] Since the last arrangement is associated with a large output, it is viable only if demand exceeds a minimum threshold. Hence the consideration of fund factors allows one to explain the passage to more efficient techniques based on a larger volume of output.[7] The temporal structure of Georgescu's representation of a production process elicited another implication of the factory system. Since the length of the working day (hence the number of shifts) is one of the determinants of daily output, lengthening the working day allows the capital–output ratio to be

[6] For examples of the economies achieved by the arrangement of processes in line, see Zamagni (1987*b*, ch. 6). Morroni (1992) presents a model of production as a sequential process directly based on Georgescu's flow–fund model.

[7] There is no need to stress that Georgescu's manner of considering the relation between efficiency and scale of production stands in marked contrast to the conventional neoclassical view, according to which this relation is seen as a special case of the law of variable proportions, given one or more indivisible factors. His method contrasts sharply not only with the neoclassical one but also with two alternative representations of the production process, Leontief's input–output model (whether of the static or dynamic kind) and Sraffa's (1960) *Production of Commodities by Means of Commodities*, whose very title implies a different and less complete depiction of the process of production.

reduced in an inexpensive way. From this follows Georgescu's advice to developing economies: 'let the factory operate around the clock' (Georgescu-Roegen, 1970, p. 8).

IV. BIOECONOMICS

The Entropy Law and the Economic Process (Georgescu-Roegen, 1971) is Georgescu's *magnum opus*. This challenging book expands on his introduction to *Analytical Economics* (Georgescu-Roegen, 1966) and is the most complete expression of his scientific thought. It deals as much with physics (and the 'object lessons' to be drawn therefrom) as with economics, but also includes a fair sprinkling of evolutionary theory and of the philosophy of science. The focus is of course on the entropy law, which Georgescu had mentioned in his earlier writings. The science of thermodynamics 'began as a physics of economic value', and its second law (the entropy law) is described by Georgescu as 'the most economic in nature of all natural laws' and 'the taproot of economic scarcity'. Entropy is a measure of a system's energy which is unavailable for mechanical work, and also an index of degradation or disorder. Both a faster extraction of the earth's natural resources and the infusion of waste products into the environment quicken the increase of entropy. The changes engendered are irreversible and qualitative in nature, as exemplified by the burning of a piece of coal. Its available energy becomes 'bound' or irretrievably lost to the environment and cannot be recycled, even though there is no overall loss of matter or energy.

As we saw above, an important feature of Georgescu's flow–fund model is the inclusion of two important flows connected with the environment, the inflow of natural resources and the outflow of waste or pollution. He incorporated these elements into the production process well before it became fashionable to do so. Natural resources were added by neoclassical economists as inputs of production as an afterthought, after the oil shocks of the seventies and the foreboding implications of the Club of Rome's *The Limits to Growth* (Meadows *et al.* 1972) had attracted attention to their exhaustibility. At the same time, problems of pollution and a greenhouse effect with potentially catastrophic effects for the world's ecosystem made economists aware of the flow of waste materials into the environment.

Certain natural resources are unique among factors because their stock is not only finite but irrevocably exhaustible. Even with a given stock of accessible resources, there would be no true scarcity but for the fact that, thanks to the entropy law, energy and matter degrade from a state where they are utilisable to one where they are not.[8] This is true whether the resources are exploited or not, though obviously their exploitation accelerates entropic degradation (just as technical progress may slow it down). By focusing on the first characteristic of natural resources, their scarcity, Ricardo arrived at his well-known formulation of the stationary state. According to him, land though scarce is

[8] As well as borrowing from physics, Georgescu has even boldly loaned to it by formulating a 'fourth law of thermodynamics' which asserts that unavailable matter increases irrevocably, just as unavailable energy does according to the entropy law (Georgescu-Roegen, 1977).

blessed with 'original and indestructible powers'. Only later was it realised that a closed system such as the earth is subject to entropic degradation with regard to both energy and matter.[9]

The growth of world output has placed increasing demands on the limited stock of low-entropy resources and led to greater pollution. In Marxian fashion, Georgescu predicted that the struggle for low-entropy resources would result in the outbreak of social conflict, a trend aggravated by the pressure of population on the land. This has impelled farmers to grow food on land previously used to raise fodder for draught animals, and led to the increasing mechanisation of agriculture, fed by low-entropy resources from the earth's crust instead of the energy previously supplied by the animals and ultimately derived from the sun. Yet the earth's stock of recoverable reserves of fossil fuels contains as much energy as that produced by only a few days of sunlight.

These issues were elaborated by Georgescu in his paper 'Energy and Economic Myths' (Georgescu-Roegen, 1975). Here he re-entered the fray with a vigorous attack on those who deny that there are any limits to economic growth, and rely on the price system or an increasingly sophisticated technology to alleviate any impending resource scarcities. Even allowing for substitution between different types of resources and for the discovery of hitherto unknown ones, Georgescu denied the possibility of continued exponential growth in the absence of the discovery of a new source of energy, which may or may not be part of man's 'Promethean destiny'. Prometheus I launched the Wood Age by revealing to man the burning of wood as an energy source. Increasing deforestation required a Prometheus II, who came in the form of the inventors of the coal-fired steam engine. The increasing scarcity of coal and other fuel reserves leads us now to await hopefully the arrival of Prometheus III (Georgescu-Roegen, 1986).

While we wait, even J. S. Mill's stationary state is a fanciful and unattainable goal. Georgescu's Spartan prescription is that 'the most desirable state is not a stationary, but a declining one' (Georgescu-Roegen, 1976, p. 25). He urges the present generation to husband the current finite stock of resources, so as to satisfy its needs as well as those of generations yet unborn. His paper concluded with eight recommendations for a 'minimal bioeconomic program', including the complete prohibition of weapons production and the consequent beating of swords into ploughshares to be provided as aid to developing countries, a lower world population maintained by organic agriculture, regulation of the energy waste caused by 'overheating, overcooling, overspeeding, overlighting', reduced consumption of high-technology luxury items, greater durability of consumer durables, and more intense recycling. His motivation is the welfare of future generations, or 'love thy species as thyself!' (Georgescu-Roegen, 1980, p. 269).[10]

[9] This cannot be controverted by invoking Einstein's famous equivalence between mass and energy. As Georgescu has pointed out, it is only in a laboratory and only for a few subatomic particles that matter can be produced from energy (photons) alone.

[10] Georgescu's bioeconomic programme is epitomised by the title of a collection of his essays in French, *La Décroissance* [contraction] (Georgescu-Roegen, 1995). See also the excellent monograph by Dragan and Demetrescu (1991) on Georgescu's bioeconomic paradigm.

V. A MEASURE OF THE MAN

It is difficult to take the measure of a man as complex and as sceptical of the scope of measurability as Nicholas Georgescu-Roegen. Even his philosophical orientation escapes any easy classification.[11] He is the founder of a school of thought rather than the adherent of any existing school.

In the course of his career, Georgescu earned accolades from some of the world's foremost economists, eight of whom (including four Nobel laureates) presented papers (collected in Tang *et al.* 1976) to honour his seventieth birthday and retirement from Vanderbilt University. One of them, Paul Samuelson, a decade earlier had written a foreword to *Analytical Economics* (Georgescu-Roegen, 1966), describing it as 'a book to own and to savor'. He praised Georgescu as 'a pioneer in mathematical economics' as well as 'a scholar's scholar, an economist's economist'. In spite of the recognition he has received, it is somewhat paradoxical that Georgescu seems to be better known outside than inside his adopted country, the United States.[12] While *The Entropy Law and the Economic Process* stands as a monument to his scholarship and the crowning glory of his career, it is regrettable that his projected books on *Bioeconomics* and on *Production and Institutions in Agriculture* never saw the light of day. Georgescu was frequently mentioned as a possible candidate for the Nobel Prize in economics. In our view, the novelty and importance of his contributions warranted this recognition. That he never received it may be partly due to the unorthodox ideas he displayed in the second half of his professional life, which set him on a collision course with the neoclassical establishment. His attempts to convert economists to his ideas were not helped by his propensity to refer to them (including several Nobel laureates) as 'standard economists' and use them occasionally as whipping boys to illustrate the wide dissemination and authoritative sanctioning of 'erroneous' ways of thinking. The poor health he experienced towards the end of his life and his somewhat irascible personality compounded his bitter feelings.

Georgescu's concern with the biological aspects of economic theory and the dependence of economic activity on the biosphere has increasingly attracted the attention of environmental economists (see Perrings, 1987). It is premature

[11] While Georgescu's world view owes much to past and present thinkers, he never hesitated to point out where they fell short. For instance, while he was fond of citing Marx and using his insights, he criticised him and his followers for paying no more attention to natural resources (viewed by them as a free gift of nature) than their neoclassical *confrères*. Georgescu has been labelled a neo-Malthusian, since both he and Malthus have stressed the interconnection between the biological growth of the human species and the finite volume of natural resources available. But though he paid tribute to Malthus, Georgescu followed this with a critique of his 'implicit assumption that population may grow beyond any limit both in number and time *provided that it does not grow too rapidly*' (Georgescu-Roegen, 1976, p. 22). Georgescu singled out Jevons as the archetype of the mechanistic dogma which he deplored, but praised his first book, *The Coal Question*, for drawing attention to the imminent (as he saw it) exhaustion of coal reserves in Great Britain. Marshall, of course, received top grades from Georgescu for paying attention to the evolutionary aspects of the economic system and pointing out that 'the Mecca of the economist lies in economic biology rather than in economic dynamics' (on Marshall and Georgescu, see Foster, 1993).

[12] However, mention should be made of his former student Herman Daly, who adopted many of Georgescu's ideas and developed them in *Steady-State Economics* (Daly, 1977). As stated above, however, Georgescu thought that even a stationary economy is a quixotic goal. For a thoughtful salute to Georgescu, see Daly (1995).

to try to assess the place he will occupy in the wider community of economists. But it is already clear that his scientific thought is not an isolated phenomenon, but a vital component of an intellectual renaissance which is gradually sloughing off dogmas inherited from the 19th century. The history of science in the course of the past century is marked by the breach of frontiers separating disciplines, and reveals that scientifically challenging issues are often those which straddle several disciplines, and establish contact between fields which our positivist culture had tried to isolate. From this viewpoint, Georgescu represents a connecting link. He has narrowed the gulf separating us from recent findings in the thermodynamics of processes and in economic disequilibrium. It is probably too early to tell if he has succeeded in demonstrating that a reconciliation between man and nature is indeed possible. But his bioeconomic perspective represents a clear intellectual challenge to traditional economic theory which, because of its mechanistic epistemology, tends to ignore phenomena linked to the passage of historical time. While others may go beyond Georgescu's conclusions, they will need to take them into account even if they do not begin from them.

The statement of a problem is often more important than its solution, which may be a question of mere mathematical or empirical skills. The ability to pose new problems, point to new possibilities and allow oneself to be guided by insights into the yet-unseen is what really transforms the intellectual scene and marks real scientific progress. If these considerations are correct, then any new and radical departure which can breach the wall of complacence built around the present-day economic paradigm should be welcomed and made better known to our profession.

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References

Daly, H. E. (1977). *Steady-State Economics*. San Francisco: Freeman 2nd ed., 1991.

Daly, H. E. (1995). 'On Nicholas Georgescu-Roegen's contributions to economics: an obituary essay.' *Ecological Economics*, vol. 13, pp. 149–54.

De Gleria, S. (1995). 'Nicholas Georgescu-Roegen: a mind that thought above his time.' *Economia Internazionale*, vol. 48, pp. 3–32.

Dragan, J. C. and Demetrescu, M. C. (1991). *Entropy and Bioeconomics: The New Paradigm of Nicholas Georgescu-Roegen*, 2nd ed. Rome: Nagard.

Eatwell, J., Milgate, M. and Newman, P. (eds.) (1987). *The New Palgrave: A Dictionary of Economics*, vol. 2. London: Macmillan.

Foster, J. (1993). 'Economics and the self-organisation approach: Alfred Marshall revisited.' ECONOMIC JOURNAL, vol. 103, pp. 975–91.

Georgescu-Roegen, N. (1936). 'The pure theory of consumer's behavior.' *Quarterly Journal of Economics*, vol. 50, pp. 545–93.

Georgescu-Roegen, N. (1954). 'Choice, expectations and measurability.' *Quarterly Journal of Economics*, vol. 68, pp. 503–34.

Georgescu-Roegen, N. (1960). 'Economic theory and agrarian economics.' *Oxford Economic Papers*, n. s., vol. 12, pp. 1–40.

Georgescu-Roegen, N. (1966). *Analytical Economics: Issues and Problems*. Cambridge, MA: Harvard University Press.

Georgescu-Roegen, N. (1969). 'Process in farming versus process in manufacturing: a problem of balanced development.' In *Economics Problems of Agriculture in Industrial Societies* (U. Papi and C. Nunn eds.). London: Macmillan.

Georgescu-Roegen, N. (1970). 'The economics of production.' *American Economic Review*, vol. 60, pp. 1–9.

Georgescu-Roegen, N. (1971). *The Entropy Law and the Economic Process*. Cambridge, MA: Harvard University Press.

Georgescu-Roegen, N. (1975). 'Energy and economic myths.' *Southern Economic Journal*, vol. 41, pp. 347–81.

Georgescu-Roegen, N. (1976). *Energy and Economic Myths: Institutional and Analytical Economic Essays*. New York: Pergamon.

Georgescu-Roegen, N. (1977). 'The steady state and ecological salvation: a thermodynamic analysis.' *BioScience*, vol. 27, pp. 266–70.

Georgescu-Roegen, N. (1980). 'Afterword.' In *Entropy: A New World View* (J. Rifkin, with T. Howard). New York: Viking.

Georgescu-Roegen, N. (1983). 'Hermann Heinrich Gossen: his life and work in historical perspective.' Introduction to H. H. Gossen, *The Laws of Human Relations and the Rules of Human Action Derived Therefrom* (trans. R. C. Blitz). Cambridge, MA: MIT Press.

Georgescu-Roegen, N. (1986). 'Man and production.' In *Foundations of Economics: Structures of Inquiry and Economic Theory* (M. Baranzini and R. Scazzieri eds.), pp. 247–80. Oxford: Blackwell.

Georgescu-Roegen, N. (1988). 'An emigrant from a developing country: autobiographical notes. I.' *Banca Nazionale del Lavoro Quarterly Review*, no. 164, pp. 3–31.

Georgescu-Roegen, N. (1992*a*). 'Nicholas Georgescu-Roegen about himself.' In *Eminent Economists* (M. Szenberg ed.), pp. 128–59. Cambridge: Cambridge University Press.

Georgescu-Roegen, N. (1992*b*). 'Nicholas Georgescu-Roegen (born 1906).' In *A Biographical Dictionary of Dissenting Economists* (P. Arestis and M. Sawyer eds.), pp. 179–87. Aldershot, Hants: Edward Elgar.

Georgescu-Roegen, N. (1993). 'An emigrant from a developing country: autobiographical notes. II.' *Banca Nazionale del Lavoro Quarterly Review*, no. 184, pp. 3–30.

Georgescu-Roegen, N. (1995). *La Décroissance: Entropie – Écologie – Économie*. With an introduction by J. Grinevald and I. Rens. Paris: Sang de la Terre, 2nd edition.

Harcourt, G. C. (1972). *Some Cambridge Controversies in the Theory of Capital*. Cambridge: Cambridge University Press.

Ironmonger, D. S. (1972). *New Commodities and Consumer Behaviour*. Cambridge: Cambridge University Press.

Lancaster, K. (1971). *Consumer Demand: A New Approach*. New York: Columbia University Press.

Meadows, D. H. *et al.* (1972). *The Limits to Growth*. New York: Universe Books.

Mill, J. S. (1882). *Utilitarianism*. London: Longmans, Green.

Mirowski, P. (1989). *More Heat than Light: Economics as Social Physics, Physics as Nature's Economics*. Cambridge: Cambridge University Press.

Mirowski, P. (1992). 'Nicholas Georgescu-Roegen.' In *New Horizons in Economic Thought* (W. J. Samuels ed.), pp. 86–105. Aldershot: Edward Elgar.

Morroni, M. (1992). *Production Process and Technical Change*. Cambridge: Cambridge University Press.

Perrings, C. (1987). *Economy and Environment: A Theoretical Essay on the Interdependence of Economic and Environmental Systems*. Cambridge: Cambridge University Press.

Sraffa, P. (1960). *Production of Commodities by Means of Commodities*. Cambridge: Cambridge University Press.

Tang, A. M., Westfield, F. M. and Worley, J. S. (eds.) (1976). *Evolution, Welfare, and Time in Economics: Essays in Honor of Nicholas Georgescu-Roegen*. Lexington: Heath.

Zamagni, S. (1979). *Georgescu Roegen: I Fondamenti della Teoria del Consumatore*. Milan: Etas Libri.

Zamagni, S. (1987*a*). 'Georgescu-Roegen, Nicholas (born 1906).' In Eatwell *et al.* (1987), pp. 515–6.

Zamagni, S. (1987*b*). *Microeconomic Theory: An Introduction*. Oxford: Blackwell.