Economics, Entropy and the Long Term Future: Conceptual Foundations and the Perspective of the *Economics of Survival*

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ABSTRACT

The present paper is a survey of the *economics of survival*, a branch of ecological economics that stresses the preservation of the opportunities of future generations over an extended time horizon. It outlines the main analytical foundation of the branch – in which the concept of entropy is a major building block – , and its analysis of the interaction between the economic system and the environment. Regarding its outlook of the future, we see that the founders of the branch were mainly concerned with the consequences of a serious depletion of natural resources – particularly the energetic capital of the earth. More recently, however, emphasis is being placed on problems that stem from the fragility of the global ecosystem in face of the disturbances caused by the entropic acceleration imposed by mankind. It is feared that the ongoing expansion of the scale of the economy may bring about irreversible damages to vital environmental functions, such as protection against undesirable consequences of solar radiation, maintenance of temperature within a range that will support life, and preservation of ecosystem resiliency.

KEY WORDS

Economic system and environment; entropy and sustainability; resilience; global system stability; energetic capital.

1. INTRODUCTION

In essence, the definition of *sustainable development* by the UN World Commission on Environment and Development encompasses the requirements that: (1)

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no one should lose welfare – not even the inhabitants of rich nations and regions; (2) an overriding priority be given to the basic needs 'of the world's poor'; and (3) the needs of today's rich and poor be met 'without compromising the ability of future generations to meet their own needs' (WCED, 1987, p. 43). It could be argued that the analytical vision of a strain of thought focusing the interaction between the economy and the environment should, to a some extent, comprise these central conditions. Assuming this to be true, a criterion for classifying a school of thought, be it in environmental or in ecological economics,[1] could be the emphasis it places on such requirements.

Based on this criterion, it is possible to show that neoclassical environmental economics accentuates elements of condition (1), above. Moreover, there are studies on the environmental problems of developing economies centring on aspects related to the second sustainability requirement.[2] And there is a relatively small but important group of authors and researchers which stresses the preservation of the opportunities of future generations. This paper focuses on the contributions of this group. It is an essay in the history of thought in ecological economics centred on a branch that, for reasons that will become obvious, we call the *economics of survival.* Contrary to neoclassical environmental economics, this branch of ecological economics is far from being organised and influential. It comprises a collection of authors and researchers that have erected their analyses of the sustainability of the current development pattern on the second law of thermodynamics – the entropy law.

There are two extreme views regarding the long term future of mankind: that of a posterity of abundance, warranted by advances in science and by swift social and institutional adjustments to obstacles; and that of a future threatened by the effects of growing material production, of uncontrolled demographic expansion, and of 'wrong' technologies. Neoclassical environmental economics tends toward the first, and the *economics of survival* toward the second view.

The paper examines the theoretical scaffold and the outlook regarding the future of the latter. The next section discusses reservations, inspired by this branch of ecological economics, concerning the environmental assumption that prevails in neoclassical environmental economics. Section 3 considers the conceptual framework of the *economics of survival*, and section 4 discusses the views of some of its main authors about the long term future of humanity, contrasting the perspective of its founders with that of more recent contributors.

2. PROBLEMS WITH THE ENVIRONMENTAL ASSUMPTIONS OF ECONOMIC ANALYSIS

Until recently, economic analysis regarded the economy as a self-contained system; thus, the environment was simply ignored. This began to change in the late 1960s, with the rise of neoclassical environmental economics, and with the contributions of the early authors of ecological economics.[3] The path followed by neoclassical environmental economics was set by Ayres and Kneese (1969); in a general equilibrium framework, the authors focused the economic system extracting natural resources from the environment, and depositing in it wastes from production and consumption.

Examining the environmental assumptions of economic analysis before the inception of environmental economics, Perrings (1987, p. 4–7) identified two classes of theories: those with a weak, and those with a strong environmental assumption. Classical political economy is an instance of the former. Its main contributors established a relationship between the economic system and its environment, but the latter was considered a largely benign and passive entity (Malthus and Ricardo were exceptions in this respect). The neoclassical mainstream, in turn, assumes an environment completely dominated by the economic system. The neoclassical mainstream growth theories, for instance, make economic expansion depend solely on capital accumulation, on the rate of growth of labour force, and on technical change. It is as if, as the economy expanded, natural resources would automatically materialise in the necessary amounts, and the residuals from production and consumption would simply vanish. According to Perrings' classification, they exhibit a strong environmental assumption.

As indicated, neoclassical environmental economics adopted a more realistic approach. But a close examination of its considerable contributions reveals that, in spite of the changes it brought about, it displays a *weak environmental assumption*. This branch of neoclassical economics considers the environment a passive entity, which accepts without commotion different degrees of degradation. In fact, since it is seen to affect, above all, the welfare of economic agents, environmental degradation is treated basically as a social problem. It argues that, if policy instruments are used to internalise the externalities of pollution and degradation, it is up to individuals and firms in society to determine the appropriate (the socially optimal) degree of degradation; and they do this based on their preference and cost functions. Moreover, in spite of recent neoclassical models including uncertainties, the uncertainties resulting from unexpected reactions of the environment to human aggression are rarely contemplated.

From the beginning the *economics of survival* took exception to the environmental assumption of the mainstream of economics. Georgescu-Roegen (1975, p. 348), for instance, reproved its stubborn reliance on an epistemology based on mechanics, 'a dogma that has been banished even from physics'. The economic process is treated as 'a mechanical analogue, consisting – as all mechanical analogues do – of a principle of conservation and a maximisation rule'; the environment is a restriction easily dealt with. A problem with this approach is that it overlooks the basic fact that the economic process 'cannot go on without a continuous exchange which alters the environment in a cumulative way and without being, in its turn, influenced by these alterations'. For Georgescu-

Roegen, in spite of the changes brought about by neoclassical environmental economics, its environmental assumption is still inadequate.

These objections were embraced by ecological economics. This school of thought rejects the neoclassical epistemology, and considers incomplete and misleading the innovations introduced by neoclassical environmental economics: incomplete because they treat superficially the interaction between the economy and the environment; and misleading because it hides behind a money veil central aspects of the interaction.

The epistemology and the approach and the environmental assumption of the *economics of survival* are completely different. They are examined in the following sections.

3. INTERRELATION BETWEEN THE ECONOMY AND THE ENVIRONMENT – THE APPROACH OF THE *ECONOMICS OF SURVIVAL*

This section explores, in broad terms, the approach of the *economics of survival* to the interaction between the economic system and the environment, emphasising the role the concept of entropy – borrowed from thermodynamics – plays in it.

3.1. The economics of survival's approach to the interaction between the economy and the environment

Georgescu-Roegen's general flow matrix of the circulation of energy and matter provides a helpful illustration of the manner in which ecological economics regards the economy-environment interaction.[4] The matrix assumes a steady state economy, with a given endowment of fund factors of production (land, capital and labour) and with a set technological matrix; the economic process is seen as unfolding along a certain time interval, in which the fund factors provide productive services for the transformation of flows of inputs (inputs from nature, produced inputs, and maintenance) into final products.[5]

The matrix stresses the fact that the economic process requires energy and matter, gathered from the environment; and that the resulting production and consumption originate flows of waste, returned to the environment. We see the process beginning, in each period, with the extraction of energy and matter from the environment. This is done by specific sectors which transform environmental energy and matter into controlled energy and controlled matter; these are furnished to various sectors of the economy. Together with the above-mentioned extracting sectors they comprise a capital goods sector, which employs controlled energy and matter in the production of equipment and construction for all sectors; a sector producing consumption goods and services, which uses these elements to produce consumables, furnished to the consuming sector (to households); a sector that recycles part of the wastes generate by the economy, and another that depollutes some of the emanations of all sectors.[6] And importantly, the matrix stresses the fact that all sectors discharge into the environment dissipated energy, dissipated matter and wastes. Some do so more than others, but no sector is exempt from degrading the environment – not even the recycling and depolluting sectors.

As accentuated by Herman Daly, *ceteris paribus* the environmental impacts of the economic system are essentially determined by its scale – by the magnitude of its population and of its per capita income relative to the capacity of the environment to supply the system with basic resources and to absorb its pressures and wastes.[7] The impacts also have to do with the composition of output, with the prevailing production technologies, and with the stimuli and conditioning factors affecting behaviour regarding degradation. Moreover, the rates of both, output and population growth, together with technical change and environmental policies, condition the trends of these impacts.

Indubitably, environmental policies may lessen the impacts brought about by the economy but, as the matrix accentuates, even the most technically advanced and 'environmentally correct' society has to extract energy and matter from the environment, and will return dissipated energy and waste to it.

The *economics of survival* emphasises the fundamental role of a formal description of the relationship between the economic system and its environment, but considers this just a starting point. Focusing on the environmental effects of the ongoing expansion of the scale of the economic system it relies heavily on the entropy concept. Next we outline briefly the concept, and its use by this branch of ecological economics.

3.2. The role of the second law of thermodynamics

Currently the human use of energy exceeds, by far, the energy from the sun that can, directly or indirectly, be captured for human use. The portion of the energy of the sun that we can, even with the most advanced technology, employ is quite limited (Davis, 1991), and the exceptional economic expansion of the last two centuries was made possible by the endowment of energetic capital of our globe – the energy from fossil fuels.

The early authors of the *economics of survival* stressed the finitude of this fundamental resource; their concern was that the scarcity of non renewable energy might soon become acute, affecting mankind's long term prospects. More recent contributors, in turn, emphasise the effects of the degradation that stem from our prodigality in the use of energy. The work of both groups relies on physical laws that condition our use of energy: the laws of thermodynamics.

The first and second laws of thermodynamics. In 1865 Rudolf Clausius, one of the founders of thermodynamics, formulated as follows its two first laws*:*

- The energy of the universe is constant (1st law);
- The entropy of the universe increases toward a maximum (2nd law).[8]

According to the first law, energy can be neither created nor destroyed. This is the law of conservation of energy, also acknowledged by neoclassical environmental economics (Ayres and Kneese, 1969). However, as stressed by Georgescu-Roegen (1975, p. 351), with this law alone 'we are still in mechanics, not in the domain of actual phenomena, which certainly includes the economic process'. To get into this domain the law of entropy was regarded as essential.

Georgescu-Roegen pioneered the analysis of the role of the second law in the economic system.[9] The author acknowledges the complex nature of entropy; according to him, however, the story can be told in simple terms. It goes as follows: although constant, the energy of the universe can be divided in *available* (or free) energy, and *unavailable* (or bound) energy. Available energy is important to all living organisms – including our economy – because it can be transformed into work. To be available, energy must be distributed unevenly; only in this case will energy give rise to work, together with heat; but heat eventually becomes so dissipated that it can no longer generate mechanical work. Energy that is completely dissipated ceases to be available.[10] Although the universe's total energy is constant, the entropy law assures us that *available* energy is, continuously and irrevocably, being transformed into *unavailable* energy, the amount of which invariably increases, tending to a state in which there will be only energy unavailable to perform work – the situation of thermal death. Thermodynamics calls available energy, *low entropy* energy, and unavailable energy, *high entropy* energy.

The entropy law and open and closed systems. The classical formulation of the second law refers to the universe – an isolated system, containing all energy. What, however, is the meaning of the entropy law for open and closed systems – the systems of interest for the study of economics? Addressing this question, Nobel laureate Ilya Prigogine expressed the variation in a entropy, dS, over a minute time interval dt, as the sum of two terms: a term expressing exchange of entropy with the system's environment, d_eS; and a 'production' term, d_iS, that stem from processes inside the system. The law of entropy refers only to d_iS; it states that, as a result of irreversible phenomena inside the system, d_iS is always positive, except in the state of 'thermal death'; then $d_iS = 0$.[11] But what can be said about the sign of dS? In an isolated system, by definition, d_eS does not exist, so that dS is always positive; entropy increases continuously. However, open or closed systems tend to have a net, positive or negative, exchange of entropy with their environments, and dS may have either sign.

To underline the nature of the aforementioned variations, Prigogine and Stengers (1984, p. 118–119) made a similar decomposition for energy. Denoting energy by *E* and a variation in its amount over a very short time interval *dt* by *dE*, they show that '*dE* is equal to the sum of a term d_eE due to the exchange of energy and a term d_iE linked to the 'internal production' of energy [energy seized from the system's energetic capital]. However, the principle of conservation of energy states the energy is never 'produced' but only transferred from one place to another.' And to the energy 'production', d_iE, corresponds an increase in entropy, d_iS, which originates irreversible changes in the system.

An adaptation of Prigogine's entropy decomposition. The analysis of the process of energy degradation in our globe – a closed system in which the economy, an open system, is imbedded – is central to the *economics of survival.* According to Georgescu-Roegen (1971, p.6), 'If the entropic process were not irrevocable, i. e., if the energy of a piece of coal ... could be used over and over again ad infinitum, scarcity would hardly exist in man's life.' The problem, however, is that, once used, energy is irrevocably dissipated. It is possible, therefore, to say that the entropic process is the taproot of scarcity.

Georgescu-Roegen employed Prigogine's decomposition to clarify the role of entropy in economics; this was done in his answer to a line of neoclassical criticism, according to which, since the entropy law refers to the universe (an isolated system), and not to the open or closed systems relevant to economics, it was immaterial to the analysis of long run resource scarcity.[12] After all, since in open and closed systems dS may have any sign, it is even possible to have a decrease in entropy in the open economic system.

Assessments such as this, however, are founded on a mistaken perception of the entropy law. It is true that the law was first conceived for an isolated system but, as pointed out above, Prigogine extended it to the domain of closed and open systems. It is also true that 'the systems of our experience are all either *closed* (in which case energy but not matter may be exchanged with the outside), or *open* (in which case both energy and matter may be so exchanged). Obviously, in these last systems entropy may very well decrease.' (Georgescu-Roegen, 1986, p. 4). However, it is wrong to conclude that this can occur in *today's economic system* – an open system, inserted in a closed system – that of our globe.

Elaborating on this, Georgescu-Roegen (1977, p. 302–3) adapted the Prigogine decomposition. According to the author, the basic idea is elementary.

> The change in the entropy of an open system breaks down into two components:
>
> $\Delta S = \Delta S_e + \Delta S_i$,[13]
>
> where $\Delta S_i > 0$ is the entropy 'produced' within the system by its irreversible processes, and ΔS_e is [the exchange of entropy with the environment of the system].

And, in spite of the fact that ΔS_i is always positive, ΔS may have either sign, depending on the magnitudes of ΔS_i and ΔS_e. Thus, if the low entropy net import of the system is larger than the entropy 'produced', $\Delta S < 0$; the entropy of the system declines.

Considering today's economic system, however, we have to keep in mind that the magnitude of the entropy the system originates in a period, ΔS_i, is much larger than that which could be sustained from ΔS_e, the net inflow of low entropy captured from the sun. This inflow is essential for the maintenance of life on earth, but only a relatively small portion of this energetic 'income' can be captured by modern industrial society to attend to its needs.[14] The difference is being covered with energy from its stock of fossil fuels – the 'capital' of low entropy energy accumulated in our globe. This is what allows the enormous 'production' of entropy, ΔS_i, by today's economic system. However, the rate of depletion of our energetic capital is large and increasing. Since it is not being renovated in any significant sense, the energy depletion increases scarcity.

In other words, for today's economic system ΔS_i is much larger than the absolute magnitude of ΔS_e, and the sign of ΔS is necessarily positive. The net increase in the entropy of the system is equal to a huge ΔS_i minus a comparatively small net inflow of low entropy, ΔS_e.[15] For the *economics of survival* the current magnitude and the rate of expansion of ΔS_i is doubly disturbing: first, in a long term perspective it suggests a steady increase in the scarcity of energy resources (and of other natural resources); and second, this entropy generation means both, a considerable disruption of ecosystems and huge emanations of residuals and effluents, with potentially destabilising impacts. This theme is explored further below.

Entropy, matter and environmental degradation. Initially Georgescu-Roegen focused the entropy of energy; then his analysis stressed what he termed, 'clean thermodynamics'. Later on he perceived that, to be converted into work energy needs a material base, and that matter is also subject to irrevocable dissipation.[16] According to the author, the need to simplify caused thermodynamics to neglect the entropy of matter; but we should not forget that, due to friction – which science often assumes away – a machine that converts energy into work is always far from its maximum theoretical efficiency. Moreover, friction brings about the entropy of matter. Thus, 'matter also exists in two states, available and unavailable, and just like energy, it degrades continuously and irrevocably from the former to the later state'. (Georgescu-Roegen, 1986, p 7). Thus, as in the case of energy, mankind is also generating rapid degradation of matter.

Binswanger (1993) argues that Georgescu-Roegen's extension of the entropy law to matter resulted from that author's insistence in remaining within the limits of classical thermodynamics. This led him to redefine entropy to describe irreversible processes occurring within a closed system. As a result, however, entropy became 'purely qualitative'; thus, it 'cannot be related directly to the entropy term of classical thermodynamics'. (p. 214). As discussed below, the recent strains of the *economics of survival* got around the problem by adopting Prigogine's theory of 'dissipative structures', for open systems far from thermodynamic equilibrium.

According to Binswanger (1993), however, the new thermodynamic approach must be seen as providing an essentially heuristic base for the analysis of the interactions between the economic system and the environment. This is how the concept of entropy is considered in the remainder of this paper.

The concept of entropy applied to matter assumes importance in recent approaches of the *economics of survival* (see below). Georgescu-Roegen used the concept to highlight the impending scarcity of certain materials essential to our industrial society. To the recent approaches, however, our huge entropy production means not only an increase in scarcity but also the generation of massive and growing amounts of wastes and pollution, which obviously incorporate dissipated matter. They stress the role of these emissions in today's growing environmental degradation.

In the following section, we examine the outlook of the *economics of survival* regarding the future of human society, grounded on the heuristic foundation of the entropy law.

4. THE *ECONOMICS OF SURVIVAL* AND THE FUTURE OF HUMAN SOCIETY

The view of the long term future of this branch of ecological economics is far less optimistic than that of neoclassical environmental economics, notably after Solow's evaluation of the early 1970s,[17] but there is a difference in emphasis between the approach of its founders, and that of more recent authors. The first focused on the exhaustion of strategic resources while the latter stress the impacts of the entropic acceleration on the stability of ecosystems.

4.1. Outlook of earlier contributors

Although relying on the conceptual basis discussed above, the work of the main initial contributors – Nicholas Georgescu-Roegen and Kenneth Boulding – shows differences in emphasis regarding the effects of the entropic acceleration.

Boulding's somewhat hopeful outlook. This author's more popular contribution is that of his often reprinted 1966 paper; in it he rebukes the stubborn resistance of modern society in turning away from the 'cowboy economy' – an economy that presupposes no natural resources limitations – , in favor of a 'spaceman economy' – an economy that emphasises a wise management natural resources; this change is considered imperative for the survival of 'spaceship earth'. However, as will become obvious, his contributions go much further.

In his discussion of the long term future Boulding replaced the conventional entropy notion with a less precise, but 'much more illuminating concept': that of entropy as *negative potential.*

> What we detect in the history of the human race is the constant interplay of two processes interacting in opposite directions, of which one sometimes dominates and sometimes the other. One process is the entropy process interpreted as the principle of exhaustion of a given potential. [... but this tends to be] offset by the process of the recreation of potential. (Boulding, 1980, p. 184)

The author submits that, since we are dealing with a 'system very different from Newtonian mechanics and the prediction of eclipses', the uncertainties regarding the future are considerable, but he places hope in the working of the principle of *autopoiesis.* This principle states that,

> in a stochastic system an event of given probability will eventually happen if we wait long enough, no matter how improbable the event. When an event happens, this changes the probability of events, at least in the immediate neighborhood, simply because the structure of the system is changed by the event actually taking place. (Boulding, 1980, p. 187).

Boulding was especially concerned with the rapid depletion of the earth's energetic capital, promoted by the economic system. This exhaustion seemed unavoidable and, in spite of the advances of science, he did not see alternative sources of energy about to be discovered to replace the currently employed when they became exhausted. Based on the principle of *autopoiesis*, however, the author allowed for the possibility of the recreation of the potential lost by our depletion of the non renewable energetic resources. But he reminds us that *autopoiesis* presupposes the passage of a certain time span – the extension of which we do not know. If it reaches too far into the future, or if a wasteful use of low entropy resources quickly reduces our stock of energetic capital, the recreation of potential may not materialise in time. To reduce the chance of this happening, therefore, it is essential that we manage wisely the finite low entropy resources at our disposal, in an effort to redirect evolution 'towards salvation rather than destruction' (Boulding, 1980, p. 188).

Georgescu-Roegen's pessimistic view. The behaviour of mankind regarding natural resources led Georgescu-Roegen towards an extremely pessimistic outlook; he went as far as to predict the human society's downfall in a not too distant future. In his words,

> Perhaps, the destiny of man is to have a short, but fiery, exciting and extravagant life rather than a long, uneventful and vegetative existence. Let other species – the amoebas, for example, which have no spiritual ambitions – inherit an earth still bathed in plenty sunshine. (Georgescu-Roegen, 1975, p. 379)

More recently, however, the author accepted the possibility, although remote, of the discovery of what he calls a 'Promethean technology'.

Defining *technology* as a recipe to do something, the author shows that there are feasible recipes (those that allow us to perform), and nonfeasible ones (which, although desirable, are unavailable); among the former, we are only interested in viable recipes. They compose society's technology matrix. However,

> since no recipe exists to create energy or matter any viable technology needs a continuous supply of environmental low entropy. For this it must include some recipe … that converts environmental energy and matter into energy and matter at our disposal for other activities. (Georgescu-Roegen, 1986, p. 15)

With respect to energy, history shows that such technologies are very difficult to come by; this is so because they need to satisfy a strict condition: that the technology generates more energy than that used in the extraction process, passing the excess to other technologies of the matrix. Georgescu-Roegen calls *promethean* the technology that meets this condition.

The author reminds us that mankind has had access basically to two *promethean* technologies: the mastery of fire, (Prometheus I); and the discovery of forms of converting heat into motion with heat engines (Prometheus II).

Transforming combustible materials into thermal energy and allowing a chain reaction (a spark may start a blaze), the control of fire enabled mankind

> not only to keep warm and cook ..., above all, to smelt and forge metals, to bake bricks, ceramics and lime. ... During the technological era, supported primarily by fuel from wood, new recipes of all sorts were invented at an increasing pace,

allowing rapid economic expansion. However, 'the ensuing development depleted its own support just as rapidly'. At the eve of the Industrial Revolution, forests were disappearing all over Europe and a severe crisis appeared inevitable. (Georgescu-Roegen,1986, p. 15).

However, the crisis was preempted by Prometheus II, technologies which made it possible to derive motor power from a more abundant and far more powerful source: the energy of mineral fuels. At the beginning the most important of such fuels was coal. Coal was known long before the rise of Prometheus II, but by the end of the eighteenth century, the deposits of coal near the surface had been virtually exhausted, and the extraction of coal through underground mining was seriously restricted by flooding. The discovery of the heat engine made possible the use of fuel to propel pumps which removed water from the mine shafts, permitting the extraction of far more coal than that employed in removing the water. And this surplus coal was made available to existing and new viable technologies, accelerating progress considerably. Later other fossil fuels were made available, and we still are in the Prometheus II era. However, the development resulting from this technology accelerated 'the depletion of its very support (so that, we) are now approaching a new technological crisis, an energy crisis' (Georgescu-Roegen,1986, p.16).

Initially the author considered this inevitable, but more recently he acknowledged the possibility of the discovery of a Prometheus III – a new source of energy with the Promethean attribute. This would postpone the crisis associated with the scarcity imposed by the entropy law. Using Boulding's approach, Georgescu-Roegen accepted the possibility of the recreation of potential, although he considered this highly unlikely. In fact, the author expressed concern with the prevailing complacency, based on what he calls false promethean recipes, such as nuclear power and the wholesale capture of solar energy (Georgescu-Roegen,1986, p. 17).

Summing up, affected by the oil crises of the 1970s, the originators of the *economics of survival* saw in the depletion of the energetic capital of the earth a major threat to the survival of human society. In their work both showed awareness of the threats imposed by growing pollution and degradation, but the depletion of the capital of non renewable low entropy energy of our globe was considered far more critical.

4.2. The more recent approaches

Recently research groups began emphasising the effects of the reduction, caused by human entropic acceleration, in the capacity of the environment to absorb disturbances. These groups are concerned with the exhaustion of a different kind of basic resource – the carrying capacity of the environment – which, they feel, is being pushed to the limit. After summarising the conceptual scaffold they employ, we examine the approaches of two of these research groups.

Conceptual framework of the new approaches. The concern of the *economics of survival* with lasting development is evident. Moreover, for this branch the meaning of development is aligned, not with *growth* – as in the neoclassical growth models (Perrings, 1987, ch. 1) – but with *evolution* in the context of a particular conception of dynamic equilibrium. It is also obvious that the future of mankind is, to a large extent, linked to the *stability* of development. And a central notion relating *development* to *stability* is that of *quasi-equilibrium*.

There are two meanings of dynamic quasi-equilibrium: that of cybernetic equilibrium, e.g., the equilibrium of a stable ecosystem (a forest; a wetland), where 'there is birth, death, cooperative and competitive relationships of populations, but [where] there is a state of the system that can at least be called a quasi-equilibrium, in which a change in any population would lead to the restoration of its original value.' The other meaning is associated with the process of development. In essence, most of the fundamental changes brought about by development do not involve return to a previous state. Thus, the relevant meaning of quasi-equilibrium is that of *evolution*, 'a process of ongoing change [within] some stable patterns or parameters'.[18] Development brings about, not only the exhaustion, but also the recreation of potential; and the latter opens up new niches which are then filled, originating still more niches, 'and so on, the system constantly being transformed ...'. What we have is 'complexity, control, and consciousness emerging out of chaos by processes' related to autopoiesis (Boulding, 1980, p.187).

Characterising development as evolutionary transformation, it is reasonable to expect that evolutionary parameters experience changes; and that some of these changes may be catastrophic. Biological evolution offers instances of catastrophes that altered evolutionary parameters. An evolutionary catastrophe is

> [an] improbable event, whether an external catastrophe or some improbable mutations, [bringing about drastic alterations, creating] new niches, new species, and perhaps widespread extinction of old species, after which things settle down again as evolution slows down.

Mankind has been imposing disturbances which approach the category of evolutionary catastrophe. The arrival of *Homo sapiens* has 'shifted evolution on this planet into a new gear and proved ecologically catastrophic for many older species' (Boulding, 1991, p.23–24). We have invaded almost all ecosystems of the earth, and produced vast amounts of artifacts – both inanimate and biological – many of which now occupy extended niches in the global ecosystem, reducing the populations of previous biological artifacts; and we are extensively poisoning the environment.

At this point, it is appropriate to refer to the connection, established in section 4, between the extent of human aggression to the environment and our endowment of energetic 'capital'. The point is that, without the latter, mankind would not be able to colonise the planet, transforming it into a virtually single ecosystem; and we would not be increasing the likelihood of evolutionary catastrophes.

In general terms, this is the analytical framework of the recent approaches; following, we review their use of the entropy concept. They do this in the context of Prigogine's theory of dissipative structures.[19] Finding classic thermodynamics, developed for isolated systems, inadequate for the study of open systems, Prigogine developed the theory of far-from-equilibrium 'dissipative structures'; structures which, once formed, achieve certain stability of their own. His approach was formulated to describe the emergence of complex structures in physics and chemistry, but it was subsequently extended to other fields – including that of the study of the interaction between the economic system and its environment.

For the far-from-equilibrium approach, a living organism is an open system which evolves by feeding on low entropy from the larger system in which it is enclosed; doing this it is able to reduce its internal entropy by continuously dissipating energy and matter. In other words, as the living organism evolves, it is able to maintain itself in a stable condition far from equilibrium, thanks to irreversible thermodynamic processes that dissipate energy and matter from the larger system (the environment), increasing the entropy of this system. (Binswanger, 1993, p. 216).

This approach constitutes the heuristic basis of recent strains of the *economics of survival*. In their analyses they tend to employ a convenient abstraction – that of the global ecosystem, a closed, dynamic, self organised system, composed of a set of interdependent and vulnerable subsystems. Processes in the global system compose 'a closed-loop system of material cycles in which matter is continuously recycled. These material cycles are powered by dissipation of solar energy, which is finally radiated into the universe' (Binswanger, 1993, p. 221). These biologically assisted material cycles – the ecocycles – contribute to the circulation of materials and to the auto-regulation and self-maintenance of the global system. They are essential to the preservation of life.

The global system is, therefore, in a far-from-equilibrium stable state. For the recent approaches, however, this is just one of various possible states of local equilibrium. If the entropy created by living systems becomes overwhelming, the larger system may flip from the current state of local equilibrium to another, with unpredictable consequences. And, being able to generate evolutionary catastrophes, human society is a living system capable of destabilising the global system, pushing it to another far-from-equilibrium stable state.

Exploring the nature of destabilisation, let us assume a system such as that of our globe, but without the human species. Thanks to the operation of the ecocycles powered by solar energy, the system would tend to remain stable. On the energy side, the 'production' of entropy, ΔS_i, would be largely compensated by the inflow of low entropy energy ΔS_e, and ΔS would be close to zero; matter would also be recycled. The inflow of solar energy would enable a great variety of complex species to evolve in a large number of local ecosystems, resulting in a sustainable and a highly efficient system.[20]

Inserting the current human society into the picture, since it is unable to function only with the energy from the sun, it would have to use growing amounts of low entropy energy from the energetic capital of the global system. As a result, human society would 'produce' entropy far beyond the maximum it could originate using exclusively the energy 'income' from the sun. Being out of line with the system of ecocycles, this 'production' of high entropy (heat, pollution, solid wastes) would not be adequately assimilated. And if the process were carried on much further, the result could be destabilisation. The global system has self-regulating mechanisms which assure its resilience in face of moderate disturbances but they might be incapable of enduring very large disturbances.

Of the recent approaches, one focuses the potential for destabilisation of the intoxication generated by modern industrial society; the other emphasises possible impacts of the persistent elimination of biodiversity promoted by our civilisation. Next we examine their views.

Entropy and the impacts of growing environmental intoxication. In a seminal article with Allen Kneese, Robert Ayres laid the ground for neoclassical environmental economics (see Ayres and Kneese, 1969). However, apparently uneasy with the approach followed by that school, Ayres faded from the neoclassical circuit. Recently he came to lead a research team which investigates the effects of the toxic emissions resulting from the entropic acceleration.

Ayres regards our planet as a dynamic, self organising system, operating through a series of physical and chemical processes, thanks to which it

> ... maintains itself in a dynamic pattern of continuous change, within a stable envelope. ... In certain respects, the earth system as a whole is like an individual organism: it is maintained in a stable state, far from ... thermodynamic equilibrium, by a steady supply of external energy from the sun.

Solar energy drives a system of biochemical processes that provide support to our oxygen-nitrogen atmosphere; and there are several other biochemical cycles, all of which are essential in supporting life. But '

> every closed cycle ... is an inherently non-equilibrium phenomenon, in the sense that it can only be maintained by a continuous flow of available (free) energy from the sun. This statement is an obvious consequence of the second law of thermodynamics (the entropy law), which states that entropy increases in every irreversible process in an isolated system. (Ayres, 1993, p. 202–204; see also Ayres, 1994, and 1995)

Contrary to other living organisms, however, human society operates outside this cycling mechanism. The question is: to what an extent can the global system endure the continued expansion of human aggression? Dealing with it, Ayres employs the notion of *metabolism*, borrowed from physiology. Metabolism comprises the internal processes of a living organism responsible for its maintenance, reproduction and growth. It involves the extraction of energy and matter from the environment of the organism, and the discharge into it of dissipated energy and degraded matter. In an analogy, the author employed the concept of *industrial metabolism*, which comprises '...all materials/energy transformations that enable the economic system to function, i.e., to produce and consume' (Ayres and Simonis, 1994, p. xi). As a result of such transformations, the system returns energy and matter to the environment in a state of irreversible high entropy.

The analogy between the economy and a living organism cannot, however, be carried too far. In nature the emanations of one life form are usually essential to others. Plants produce biomass employing solar energy, water, nutrients, and carbon dioxide; and emanate oxygen as a residual. But oxygen is essential for aerobic animals, and the latter issue carbon dioxide as a residual, closing the cycle. However, our economy does not operate this way; its metabolism issues not only residuals such as carbon dioxide that, by far, exceed the requirements of other living organisms, but also large flows of toxic residuals, highly damaging to most forms of life.

According to Ayres and collaborators, these emanations are dangerously altering the self-regulating mechanisms of the global system, threatening its stability. They do not deny that the global system is, to some extent, able to absorb toxic elements and recover, but they maintain that human activities are producing such elements ‘far more rapidly than natural processes can cope with...’ (Ayres, 1995, p. 3).

The potential of exhaustion of natural resources – the main concern of the early authors – is not ignored. Ayres recognises that a continual expansion of human population and of material production in a finite world cannot persist indefinitely (Ayres, 1995, section 3). However, his main concern is with the destabilising impacts of the industrial metabolism; at current rates of emissions, the impacts of toxic wastes are likely to become critical before the depletion of nonrenewable resources is strongly felt.

The industrial metabolism approach rejects the neoclassical assumption of an environment which can be polluted to a greater or lesser degree, with predictable and reversible reactions. This assumption clashes with the conception of the global system as

> an extremely non-linear self-organising system ... in a quasi-stationary state from which sudden and unpredictable excursions may occur. [A system which] when perturbed sufficiently–may ‘flip’ to other steady states, or even ‘flip-flop’ between two or more states. (Ayres, 1995, p.8)

To illustrate his argument Ayres developed topographical analogies of the main perceptions regarding the capacity of the environment to resist anthropogenic disturbances. (Ayres, 1995, p. 8–9). The outlook of neoclassical modelling is illustrated with the aid of panel (a) of Figure 1. The stability of the global system is regarded similar to that of a ball inside a tall glass. Initially the glass is at rest, but a jolt makes the ball move; however, as soon as the glass rests again, the ball returns to its original position. Similarly, human produced disturbances affect the environment, but when the disturbances are reduced, it tends to recover. This outlook assumes a robust nature, endowed with a considerable capacity of self-regeneration. Panel (b), in turn, shows the ball placed at the bottom of an upside-down glass at rest, so that a small jolt would make it fall and roll away. This is in line with the view of environmentalists such as Erlich (1988); for them the environment is prone to react catastrophically to disturbances. This representation is in line with conceptions of a highly vulnerable nature.

For Ayres, however, the relevant analogy is that of the ball inside, say, a bucket with a wavy bottom – see panel (c). A moderate bump moves the ball but, as the bucket rests, it returns to its initial state. However, a sufficiently strong jolt would shift the ball from its initial equilibrium position, to another position of

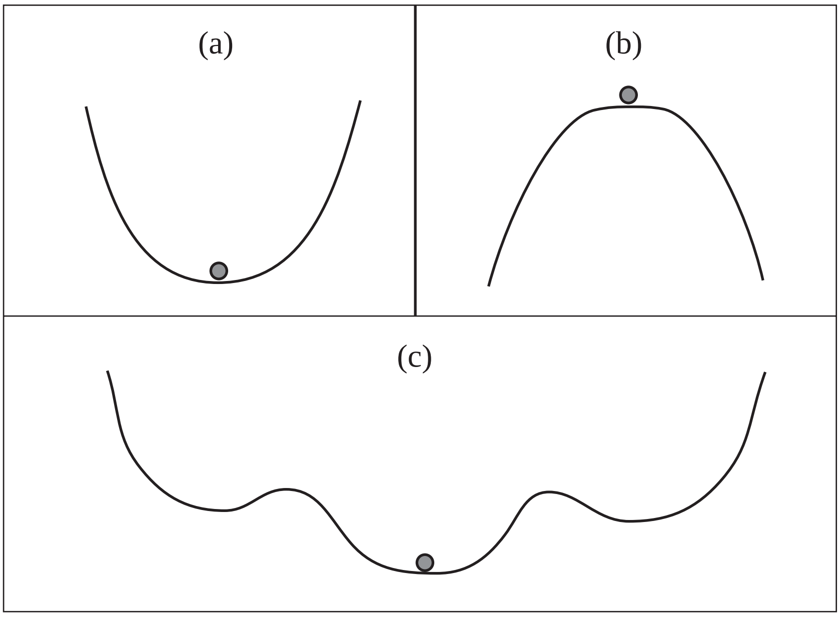

FIGURE 1. Topographic illustrations of views on the stability of equilibrium of the global system

local equilibrium in the bucket's bottom. This is considered a more realistic illustration of the behaviour of ecosystems in face of aggression.

Taking the above as an effective illustration of the limited capacity of the global system to assimilate the impacts from growing flows of toxic residuals, the relevant question is: how much of such disturbances can the system absorb? 'How much perturbation does it take to 'kick' it out of its stationary state into another one?' (Ayres, 1995, p. 9). The author argues that we are far from having convincing answers to this question. Considering that

> we do not know the stabilising mechanisms for the climate or the various cycles in detail, we *cannot* know how big a perturbation it would take to move to another quasi-stable state, or even to begin an irreversible slide towards the true equilibrium state which would not sustain life. We can reasonably assume that anthropogenic perturbations that are small compared to observed fluctuations in the past will not destabilise the system. However, with respect to some materials (such as greenhouse gases) the perturbations attributable to human industrial activity in the next century could easily exceed any historical counterpart. This is a very dangerous situation. (Ayres, 1993, p. 205)

In that case, what should be done? For Ayres (1993, p. 205), the only prudent course of action is to curtail anthropogenic interference that threatens the overall stability of natural processes.

Functional biodiversity and the resilience of the global system. Another recent approach stems from the work of the Biodiversity Program of the Beijer Institute[21] – a research program in which economists and ecologists collaborate with other natural scientists in studying the role of biodiversity in the stability of ecosystems. This collaborative effort also rejects the hypothesis of a neutral and passive environment; and it also makes use of the theory of dissipative structures. Its primary concern lies not with the extinction of particular species with potential for the satisfaction of human needs, a common consideration regarding the damage to biodiversity, but with the loss of resilience of ecosystems that may result from this damage. It stresses important ecological functions of biodiversity as a whole.

According to Holling et al.(1995), ecology has two conceptions of resilience: that of *systems ecology*, which considers resilience in terms of the resistance of an ecosystem to disturbances, and of the speed of its returns to equilibrium once they cease. Disturbances bring about dislocations around a globally stable equilibrium position, as illustrated in panel (a) of Figure 1. The other conception, that of the *ecology of communities*, considers the ecosystem in a situation of multiple equilibria, as illustrated in panel (c) of Figure 1. For this conception, resilience is the amount of disturbance that an ecosystem can absorb before fundamental changes in its *structure of control* take place, bringing about a dislocation, from one situation of local stability to another. This is the conception stressed by the Biodiversity Program.

For the Beijer group there are two main roles of biodiversity in an ecosystem: it mediates energy and matter flows – the ecocycles – determining the functional properties of the system; and, it provides the system with *resilience* in face of extraordinary events. Sustaining biophysical cycles in the context of a hierarchy of ecosystems, biodiversity is an essential element of the self-organising mechanism of the global system and, therefore, of its capacity to withstand anthropogenic pressures – of its resilience (Perrings et al., 1995, p. 1–4).

Thus, special attention should be given to the impacts of the widespread destruction of species; but we do not even perceive fully the extent of this destruction. It has been going on for a long time, in connection with human occupation of space. Modern agriculture, extensive pasture formation, inadequate management of the extraction of renewable resources on land and in the sea, widespread drainage of wetlands, the expansion of cities, industries and infrastructure, all have had a role in biodiversity loss. It has also been affected by the intoxication of habitats by chemical fertilisers and pesticides and by industrial wastes.

Without changing the way we manage natural systems, the continued increase in the scale of the world economy will intensify biodiversity loss.

Ecologists have documented countless cases of disastrous anthropogenic alterations in ecosystems, many involving dislocation from one situation of local stability to another; cases of dense forests turned into savannas, of desertification, of irreversible erosion, of destruction of marine ecosystems, of the collapse of fisheries, among others (See Holling et al, 1995, part 2.2).

The Beijer group stresses the dynamics of ecosystem alteration. The suggested pattern is the following: human produced simplification and inadequate management bring about a loss in the functional biodiversity of the ecosystem which, in turn, leads to a decline of resilience. Initially the process unfolds slowly but a point is eventually reached when drastic, and usually irreversible, changes take place, leading the ecosystem to another position of local equilibrium. Anthropogenic activities produce

> changes in soils, hydrology, disturbance processes and keystone species complex, [and, as a result, the] (c)ontrol of ecosystem function shifts from one set of interacting physical and biological processes to a different set. (Holling, 1995, p.53)

The dynamics of change can be illustrated with the aid of panel (c) of Figure 3. Before the process of biodiversity destruction begins, the ecosystem is in a local quasi-stationary equilibrium state. The process starts, and progressively biodiversity destruction reaches a stage in which the organisational structure of the system begins to change. In the diagram, it is as if disturbances began altering the shape of the bucket’s wavy bottom. As human impacts intensify, these alterations become larger, so that progressively smaller additional disturbances are needed to shift quasi-stationary equilibrium from one region to another. Eventually a situation is reached in which this shift in equilibrium state takes place; after this, there is no return to the old quasi-stationary equilibrium position.

Such behaviour has been observed in individual ecosystems.

> Real ecosystems ... are non linear, discontinuous, and complex in their time-behaviour. There is no reason to believe that they will reconverge on a well-defined equilibrium (the climax state) following perturbation during the course of economic exploitation. (Perrings et al., 1995, p. 9–10)

The question is: does this mechanism also operate in the global ecosystem, composed of many subsystems experiencing shifts in equilibrium positions? The answer seems to be yes. According to Holling (1986), the resilience of the larger system could also become critically affected, increasing – as a result of irreversible changes in the parameters of the system – the likelihood of a shift in the equilibrium state.

For the Beijer group, we should be especially concerned with our ignorance about the extent of the damages that the global ecosystem can withstand as a result of a widespread biodiversity destruction. The process has already reached considerable proportions, but we do not yet know the extent of the damages it has inflicted on the organisational structure of the system. Much of public opinion does not even understand the nature of the problem, but there are extremely pessimistic predictions regarding this (e.g., Erlich, 1998). Thus, a high priority should be given to research on ways to preserve the resilience of ecological systems on which humanity depends.

It is easy to see that the perspectives of the biodiversity and the industrial metabolism approaches are largely confluent. Both view the global system as a highly non-linear self-organised system in a state of quasi-stationary equilibrium, in which the economy is inserted. Both argue that, if the current pattern of economic expansion persists, this non-linear system may become so perturbed that it will flip to another region of quasi-stationary equilibrium, with presumably dramatic consequences. The differences between the two approaches are more of emphasis. The industrial metabolism approach stresses the effects of the intoxication resulting from industrial excretions; and one of such effects may be the destruction of species that are important to the operation of ecocycles. Moreover, the Beijer group certainly recognises the impacts, in terms of biodiversity loss and otherwise, of a growing intoxication of ecosystems.

5. CONCLUDING REMARKS

There seems to be reasons to believe that the present trends of natural resources extraction and environmental degradation cannot be maintained over the long run. This is the central topic addressed by the *economics of survival*. The early authors of this branch of ecological economics were mainly concerned with the swift depletion of non renewable resources, especially those of the earth's energy capital. Recent approaches, in turn, emphasise the effects of anthropogenic interferences on environmental functions that are vital for the stability of the global system. They are especially uneasy about our still substantial ignorance of the limits of nature. We do not know the extent of the regeneration capacity of the environment, nor the degradation it can endure before extreme discontinuous changes take place. A strategy for sustainability should, therefore, strive for adequate protection of the resilience of ecosystems on which humanity depend.

The *economics of survival* rejects the conception, common in neoclassical modelling, of an economic system interacting with a fundamentally passive environment. It insists on the need to conside explicitly the complex interactions between the economy and the global system, and the concept of *entropy* is a fundamental tool in the investigation by this branch of these interactions. And entropy plays a special role in its recent approaches. They consider the economy a system which expands by irreversibly increasing the entropy of its environment; and that if this continued entropic acceleration remains unchecked, a loss of stability of the global system may ensue with potentially dire consequences.

All approaches of the *economics of survival* reject emphatically the notion that economic freedom and rapid growth can be the principal elements of a long term environmental policy. The importance of policies built on market mechanisms in dealing with short run, localised environmental problems is not denied, but such policies should not be the main building blocks of a strategy aimed at improving the chances of future generations. As stressed by Ayres (1993), many of the resources the degradation of which negatively affect the prospects of future generations are outside the domain of markets. They include

> soil fertility, clear fresh water, clear fresh air, unspoiled landscapes, climatic stability, biological diversity, biological nutrient recycling and environmental waste assimilative capacity. There are no plausible technological substitutes for these. The irreversible loss of species and ecosystems, and the buildup of greenhouse gases in the atmosphere, and of toxic metals and chemicals in the topsoil, groundwater and in the silt of lake-bottoms and estuaries, are not reversible by any technology that could appear in the next few decades. Finally, the great nutrient cycles of the natural world – carbon, oxygen, nitrogen, sulfur and phosphorus – require constant stocks in each environmental compartment and balanced inflows and outflows. These conditions have already been violated by large-scale and unsustainable human intervention. (p. 189–190).

It is difficult to see how market stimuli and incentives could be devised to revert, or even to attenuate the long term impacts of this state of affairs.

NOTES

[1] It is usual to call the school which analyses the interaction between the economy and the environment from the theoretical perspective of neoclassical economics ‘environmental economics’, and that based on a systemic approach, in which the economy is seen as a living organism inserted in its environment, ‘ecological economics’.
[2] For an assessment of neoclassical economics based on the sustainability criterion see Mueller, 1996. A survey of studies stressing environmental problems of less developed nations is in Mueller, 1994.
[3] Ayres and Kneese, 1969 is a seminal paper for neoclassical environmental economics; instances of the earlier contributions to ecological economics are in Boulding, 1966; and Georgescu-Roegen, 1966.
[4] See Georgescu-Roegen, 1977; the analytical foundations are in Georgescu-Roegen, 1971, chapter IX.
[5] See Georgescu-Roegen (1969) for a more detailed exposition of the author’s approach to the functioning of the economic process, which is also a part of his general matrix.
[6] To undertake recycling and depollution, the recycling and depolluting sectors also use controlled energy and matter; and they also issue wastes and pollution.The importance of these two sectors in a particular economy depends on factors such as the possibilities and costs of recycling and depolluting; the prices of recycled materials; sanctions on

degradation – pollution taxes, fines; and on legal-institutional factors requiring and conditioning recycling and depollution.

[7] See Daly, 1991. This author emphasises the negligence of mainstream macroeconomics in considering the scale of the economy. Due to this, mainstream economics gives the erroneous impression that there are no environmental limits to growth.

[8] Rudolf Clausius, *Ann. Phys.*, vol. 125, 1865, p. 353; *apud* Prigogine and Stengers, 1984, p. 119.

[9] The reference section lists some of the author's main contributions. Regarding the entropy law, deserves especial emphasis Georgescu-Roegen, 1971; but see also Georgescu-Roegen 1975, 1977 and 1986. The following excerpt by Boulding (1980, p.184) illustrates the prevailing view regarding that author's role: 'The concept of entropy had very small impact on economics until Nicholas Georgescu-Roegen's remarkable book on *The Entropy Law and the Economic Process*.'

[10] Georgescu-Roegen, 1975 (p. 352); and 1977 (p. 294). The unavailable nature of high entropy energy is illustrated by a ship in the ocean; although the latter contains an enormous amount of dissipated energy the ship cannot navigate on this immense deposit of energy without low entropy energy from another source.

[11] See Prigogine and Stengers, p. 118. The decomposition of the variation of entropy in two terms was introduced by Prigogine in 1947, in his thesis to the Faculté des Sciences de l'Université Libre de Bruxelles. *Apud* Prigogine and Stengers, 1984, note 18 to chapter IV.

[12] For a lucid instance of such criticism see Young, 1991, p. 178–179. There are also misplaced or irrelevant attempts in this direction; see, for instance, Burness et al., 1980).

[13] Georgescu-Roegen considers the variation of entropy of a time interval consistent with the human experience. He works with the summation of infinitesimal entropy variations in the period to get the entropy change in that time interval.

[14] Considering that mankind uses only a small portion of the solar energy that reaches the earth, one may be tempted to argue that the way out of the scarcity threat is to increase the proportion of energy captured from the sun. However, given prices and costs, and the state of the arts, the possibility of increasing significantly this proportion is still very small. Mankind still depends crucially on the extraction and use of fossil fuel energy.

[15] It is possible to imagine a primitive society in which the use of energy from the sun is below its potential and in which the extraction of low entropy energy from its stock of energetic capital is minute. In this case, the stock of energetic capital might even increase – accumulating, for instance, in expanding forests. In such a society, DS would be negative. But, contrary to what is implied in the neoclassical criticism, in modern industrial society this cannot occur.

[16] In his seminal work, however, the author already acknowledged the entropy of matter; see Georgescu-Roegen, 1971, p. 13. For the author's more recent discussion on the subject, see Georgescu-Roegen, 1975, p. 352; and 1977, p. 300–304.

[17] For a summary of this optimistic evaluation see Solow, 1974.

[18] Boulding, 1991, p. 23; see also Boulding, 1981.

[19] Prigogine and Stengers, 1984, ch. 5; see also Binswanger, 1993, and Perrings et al., 1995, ch. 4. The early authors were aware of Prigogine's theory. Georgescu-Roegen (1986, p. 7), for instance, refers to Prigogine's extension of the domain of thermodynamics to open systems; Boulding (1980, p. 187) acknowledges Prigogine's theory of dissipative systems. However, these authors did not explore its implications.

[20] See Binswanger (1993, Part 4.2). The ecological concept of efficiency is similar to that of economics. It is the maximum of biomass that can be maintained from a given inflow of low entropy energy.
[21] The Beijer Institute of Ecological Economics is sponsored by the Royal Swedish Academy of Sciences.

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