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Abstract

The work of Kenneth Boulding is sometimes cited as being foundational to the understanding of how the economy interacts with the environment and particularly of relevance to ecological economists. The main reference made in this regard is to his seminal essay using the metaphor of planet Earth as a spaceship. In this paper that essay and related work is placed both within historical context of the environmental movement and developments in the thought on environment-economy interactions. The writing by Boulding in this area is critically reviewed and discussed in relationship to the work of his contemporaries, also regarded as important for the ecological economics community, such as Georgescu-Roegen, Herman Daly and K. William Kapp. This brings out the facts that Boulding did not pursue his environmental concerns, wrote little on the subject, had a techno-optimist tendency, disagreed with his contemporaries and preferred to develop an evolutionary economics approach. Finally, a sketch is offered of how the ideas in the Spaceship Earth essay relate to current understanding within social ecological economics. The essay itself, while offering many thought provoking insights within the context of its time, also has flaws both of accuracy and omission. The issues of power, social justice, institutional and social relationships are ones absent, but also ones which Boulding, near the end of his life, finally recognised as key to addressing the growing environmental crises.

Keywords: Kenneth Boulding, spaceship Earth, thermodynamics, entropy, limits to growth, ecological economics, Nicholas Georgescu-Roegen, Herman Daly.

¹ This discussion paper is a slightly revised version of a forthcoming book chapter that will appear in "Interdisciplinary Economics: Kenneth E. Boulding's Engagement in the Sciences" edited by Wilfred A. Dolfsma and Stefan Kesting; Routledge.

I. Introduction

In the essay entitled *The Economics of the Coming Spaceship Earth* we are presented by Boulding (1966) with an early overview and summary of the modern environmental crisis facing humanity and its roots in the total neglect of physical limits by economists. Boulding's distinctive contribution was to introduce aspects of entropy and highlight materials throughput from and to the environment, leading to a critique of the roles of growth and consumption as means of creating human well-being. He also questioned how future generations could be given voice. At the time he was amongst a small number of unassociated people making connections between social and economic systems and environmental degradation.

Almost 50 years later we are no longer in the luxurious position of being able to reflect in an abstract way about such issues, as if they only affected some distant future generation to come. The consequences of hitting the biophysical constraints are an all too present reality, leading to armed struggle for oil and increasing concerns over securing the supply of other resources seen as essential to national economic development. For this reason alone revisiting what Boulding had to say is of interest. Reflecting on what was recognised correctly already over half a century ago and where our knowledge has changed is also informative. This helps us gain some perspective with respect to modern social and environmental understanding. In doing so I will place the issues raised by Boulding within the context of the present field of social ecological economics.

I start by providing some background in terms of the state of environmental awareness in the United States of America (USA) at the time the essay was first published. This helps explain why it became a standard reading for those concerned about environment-economy interactions and was repeatedly cited and reprinted over the following decades. I then explain the central messages of Boulding's Spaceship Earth metaphor using both the

essay and related materials. This is followed by a section critically reflecting on the weaknesses of the essay as a modern environmental critique of economic systems. In the penultimate section I turn to the relationship with social ecological economics. First I question the links between Boulding and the ecological economics movement. Then I show how key concepts from Boulding's essay connect to current ideas in social ecological economics. I close with a few remarks relating on Boulding's presentation to the International Society for Ecological Economics at their inaugural conference in 1990, where he discussed the role of power in addressing environmental problems.

II. A Brief Historical Prelude

In the USA several elements of awareness about human society can be identified as finally coming together in the 1960s. These elements include realisation that natural systems can be devastated on a large scale by human action, fear that domestically available resources will prove inadequate, criticism of the power held by corporations and recognition of the downsides of a consumer society. Modern environmentalism then encapsulated all these different aspects which had previously remained isolated issues. However, the build-up to this synthesis was piecemeal and slow.

An event that should have triggered a greater environmental awareness was the Great Dustbowl of the 1930s. This was a prime example of human induced environmental degradation. The human misery it created was recounted by Steinbeck (1939) in his novel *The Grapes of Wrath*. In telling that story he pointed a finger directly at the faceless banking sector and modern agricultural practices. Yet, despite such a major environmental disaster, neither the exploitation of Nature nor the economic model of development were seriously brought into question. The problem of the Dustbowl was picked-up by economists in the

agricultural literature as how best to change farm management practices and prevent soil erosion (Ciriacy-Wantrup 1938; 1947).

In the 1940s, World War II boosted employment and economic growth. After the war domestic resource security was a recognised policy problem. The cold war exacerbated the paranoia over securing national resource supplies in the USA and boosted military spending. This meant resource scarcity became an important priority and in 1951 President Truman established the President's Materials Policy Commission. As Jarrett (1966 p.vii) notes: "The Commission's main assignment was to inquire into whether there would be enough food and industrial raw materials at reasonable prices over the next twenty-five years to support continued economic growth and meet the requirements of national security." Amongst other things, the final report (Paley 1952) led to the establishment of the economic think tank Resources for the Future. This organisation later became a key focus for American research on economy-environment interactions during a period when concern change from resource quantity to environmental quality. In the 1950s consumerism and technological optimism were still the order of the day. There was no questioning of economic growth, merely concern over how to secure its continuance.

However, aspects of discontent over the modernist preoccupation with economic growth were already clear in criticisms of and warnings about the consumer society. The problems with consumerism can be found being debate in the late 1800s (e.g., Devas 1899), and at that time Veblen (1991 [1899]) had created the phrase "conspicuous consumption". In the 1950s Galbraith (1969 [1958]) published a popular book about the newly affluent American society and its failings. This included exposing the influence of companies in creating consumer wants and the failings of a society focussed on promoting private wealth to provide for the social good. Galbraith criticised the prevalence of private affluence and public squalor in the USA and pointed out some aspects of the resulting environmental

degradation. As Dubos (1966 p.32) notes, by the mid-1960s the affluent society was being called the 'effluent' society.

Environmental issues appeared in modern form, and with a public profile, after the astounding publicity surrounding Rachel Carson's (1987 [1962]) *Silent Spring*, which focussed on the use of pesticides in agriculture. This had actually been shortly preceded that year by a far wider reaching environmental critique *Our Synthetic Environment* by Lewis Herber (1962), alias Murray Bookchin. The book by Carson avoided directly addressing political and economic root causes in preference for a story centred on human-Nature relationships and the need for ecological balance. The products and chemical companies responsible for the damages she was denouncing were not even named (except Army Chemical Corps). Those unfamiliar with the period should remember criticism of the American way of life or its industry was subject to investigation by Hoover's FBI and libel to accusations of communism, just as today environmental activism is being branded and treated as terrorism (Potter 2011).

In contrast to Carson, in *Our Synthetic Environment* Bookchin was directly concerned with how the social and economic system in the USA created pollutants and lifestyles damaging to human health and the environment. In Chapter 1, under the subtitle "man and the natural world", Bookchin stated:

"The needs of industrial plants are being placed before man's need for clean air; the disposal of industrial wastes has gained priority over the community's need for clean water. The most pernicious laws of the market place are given precedence over the most compelling laws of biology." (Herber 1962)

His book basically disappeared and is largely unknown, Carson's is world renowned (for a comparison and explanation see Garb 1995). Questioning of the economic model of development from an apolitical science based environmentalist position was apparently

radical enough. Certainly in the early 1960s few professional economists can be found raising any environmental concerns.

There are two notable exceptions, Siegfried von Ciriacy-Wantrup and K. William Kapp. In his main life's work Ciriacy-Wantrup (1952), having worked on soil erosion (see above), was mainly concerned about resource conservation, but defined resources as a very broad set including many aspects of the wider environment. A legacy of that work was the proposition of a safe-minimum standard beyond which depletion of flow resources (e.g., soil, water, plants and animals) should not go lest irreversible losses result. Kapp's work, amongst other things, explained pollution as a feature of both capitalist and socialist business enterprise, and by the early 1960s had already exploded the myth that such a prevalent phenomena could be treated as external to the economic system, rather than an inherent aspect of modern production and consumption (1950; 1963). In addition, Kapp (1961) advocated the integration of knowledge and had identified the failure to connect the biological and social sciences as in need of attention. Both Ciriacy-Wantrup and Kapp explored the institutional aspects of resource and environmental problems.

This was the context into which Boulding's essay fits and indeed why it was itself insightful. In 1965, when Boulding first presented his ideas, behind the essay, on environment-economy interactions, the literature on the topic was sparse and the connection to thermodynamics seemed lost in the past (Martinez-Alier 1990). Boulding did not attempt a literature review, giving just four references, nor did he cite any of the above literature, despite having favourably reviewed Galbraith's book (Boulding 1959). What Boulding did was to contribute a wide ranging semi-journalistic essay, using a powerful metaphor, at a very formative time for the debate on how economics needed to relate to environmental reality.

Boulding (1965) originally presented the ideas behind the essay to the Committee on Space Sciences as a short 3 page address 10th May 1965 at Washington State University.² That version entitled "Earth as a Space Ship" is very tight, critical and to the point; it also ends deriding "low-priority achievements like putting a man on the moon", which must have gone down well with the Committee! Ten months later, 8th-9th March 1966, Resources for the Future held a workshop at their headquarters in Washington, D.C., where Boulding presented a fuller version of his ideas. After revision of the presented papers an edited volume appeared (Jarrett 1966), in which the more extended and commonly known version of Boulding's essay was the opening chapter (Boulding 1966). The earlier 3 page address explicitly uses the term "Space Ship" as an analogy drawing direct comparisons with Earth systems. By the time the full essay was published a year later the term is now "Spaceship", which has changed into being a metaphor, i.e. the spaceship as an expression not literally applicable to Earth.

III. The Spaceship Earth Metaphor

The original 3 page address contains the key elements of concern over economic growth and the consumerist society we find today in ecological economics. The basic problem is that humanity has increased the scale of its activities to a level where pollution and resource extraction can no longer be regarded as unimportant. We cannot move to another place to escape our waste, or find new resources, as we now cover the entire planet. This has specific consequences. Societies based upon increasing consumption rates using technologies which burn fossil fuels and disperse ores, without any concern for recycling or reuse, are wasteful and short lived (Boulding 1965, mentions a few hundred years).

² Kenneth E. Boulding Papers, Archives (Box # 38), University Libraries, University of Colorado, Boulder, USA.

A different technology is necessary to achieve a stable circular-flow of materials. Natural systems are part of the means by which materials can be concentrated. As Boulding (1965) states: "The stable high-level technology will have to rely on the oceans and the atmosphere as a basic resource from which materials may be concentrated in sufficient quantity to overcome their diffusion through consumption." Yet basic physical laws, and entropy in particular, mean continuous energy inputs are required to maintain order. As fossil fuels run out we need new inputs of energy (he notes solar and possibly nuclear fusion). In terms of ecological systems, a symbiotic relationship with all other elements and populations of the world is recommended, although this might involve animal domestication and wildlife preserves.

In terms of social systems the implications are noted to be far from clear. Boulding (1965) mentions that we cannot have "cowboys and Indians" or a "cowboy ethic", a theme expanded upon in the full essay (discussed below). He rejects both unrestrained conflict and unrestricted national sovereignty. At this point he notes the comparison of Earth with a spaceship breaking-down, because a relatively small space craft is run along military lines where society is planned with a dictator in charge, and necessarily so in his opinion. In a world of ten billion a different social and political structure is necessary and desirable. He allows for the possibility of pricing and a market system, but "of a limited and controlled kind". Institutions are required which combine the need for overall control with individual freedom and mobility. The enforcement of overall control is in reference to maintaining the social system within constraints such as population limits, while controlling for conflict and "perverse social dynamic processes" (not explained but perhaps, in light of Boulding 1991, p.27, a reference to such things as fashion, financial speculation and war).

Boulding is particularly critical of the poor state of human knowledge about environmental issues. He reflects on our level of ignorance about Earth systems and amongst

other things notes the failure to resolve the question of impacts from human activity on global temperature (i.e. the enhanced Greenhouse Effect). He is particularly critical of the state of ecology as a discipline, which he refers to as hardly beyond the level of bird-watching. He is also concerned that:

"when it comes to understanding the world social system or the sociosphere, we are not only ignorant but proud of our ignorance. There is no systematic method of data collection and processing, and the theory of social dynamics is still in its first infancy." (Boulding 1965)

Today the level of understanding of all but the social seems to have made some considerable progress. Ecology, Earth systems and climatology have all undergone major developments over the intervening half century.

In the full length essay Boulding (1966) expands on these basic themes. There he introduces two similes: the cowboy economy of the past which is contrast with the spaceman economy of the future. The former is wasteful of resources and involves continually moving-on, leaving environmental degradation in its wake. It is associated with "reckless, exploitative, romantic, and violent behavior" (Boulding 1966 p.9). The spaceman economy is limited in both sources of materials and pollution sinks and requires humanity living within "a cyclical ecological system which is capable of continuous reproduction of material form even though it cannot escape having inputs of energy" (Boulding 1966 p.9). The distinction is drawn-out further by a comparison of attitudes towards consumption. In the former throughput, and so consumption, is good, but in the latter stock maintenance for minimal input is desired, not throughput.

"This idea that both production and consumption are bad things rather than good things is very strange to economists, who have been obsessed with the income-flow concepts to the exclusion, almost, of capital-stock concepts." (Boulding 1966, p.10)

This does raise some problematic issues for Boulding in terms of how to relate to human well-being which derives in part from the joy of throughput (see comment by Daly 1981). In this regard he favours something which might now be regarded as a needs based approach (e.g., see Max-Neef 1992).

Boulding framed his primary concern about biophysical limits as a long-term problem. That is, the impact, he believed, would fall mainly, or most severely, on future generations. The question is then how current consumers of scarce resources and low entropy energy stocks can be convinced to take the needs of future generations into account? How can the unborn be given voice? No real answer is provided in the essay, but rather the issue is flagged-up requiring more attention.

The full essay also adds a relatively lengthy discussion about knowledge, its creation and loss. Knowledge is stated to be more important for humans than energy or materials (p.6). The concept of knowledge being employed is very broadly and loosely defined and hard to grasp. As will be discussed in the next section, the explanation is far from clear or convincing and comes across as rather unscientific, speculative reflection compared to the discussion on materials and energy. Knowledge and its importance for development was something Boulding later pursued in relation to his ideas on evolutionary economics.

IV. Shortcomings of Boulding's Essay

There are actually several aspects of the essay which do not seem particularly well thought through or able to sustain some reflection. One of these is the opening claim that there has always been a frontier in the human mind and this represents a belief in an unoccupied, safe, physical place to which humans can go when things get too difficult. This seems more appropriate to North American white settler mythology than a general or universal truth. The frontier did not even actually exist in North America because the country was already settled

by native Americans who had to be wiped-out to create the myth of an empty country full of unexploited potential (Brown 1970). Boulding then appears to have adopted the myths of his new homeland and forgotten the European culture from whence he came, where historically most people had remained tied to local communities unless dislocated by war or extreme persecution. Even under the 20th Century's despotic regimes, totalitarianism and fascist persecution people in their millions were reluctant to flee and millions died. Frontiers as welcoming is then more likely the perception of a successful immigrant *a posteriori*, and one who has been lucky enough to manage the risks and avoided the traditional dangers (e.g. disease, starvation, poverty, unemployment, imprisonment, exploitation, religious and racial discrimination) and get past any language and cultural barriers.

In later revisiting the Spaceship metaphor Boulding (1980 [1973]) himself recognised societies were historically isolated and this was one reason for his concern over what is now termed globalisation. Collapse of one society need not affect another if they are isolated from one another. As he states: "the collapse of the Mayan Empire, an early example of a Club of Rome report, affected Charlemagne or the Emperor of China not at all. They knew nothing of it." (Boulding 1980 [1973] p.266). Human development has not then always been a matter of trashing the environment and then moving-on in order to survive, as Boulding claims in his cowboy economy simile.

Indeed the fear of instability in modern society may be exactly because we have a fear of the unknown, frontiers, leaving home and hearth. Outside the local boundaries of our daily lives the world is uncertain. Historically this is reflected in stories of dark places, inhospitable lands and strange peoples. Going out into the big wide world has traditionally been threatening: "Beware! There be monsters". While globalisation, cheap flights and package holidays abroad, have broken down such barriers for many, this relaxation is a relatively recent phenomena (and not prevalent in the early 1960s). If there is an awareness

in the collective unconscious of frontiers it is that they are not welcoming places to go when the crisis comes, and they are as likely to bring death as be life sustaining.

This takes on more importance when we look at Boulding's technological optimism. In a short piece revisiting his metaphor he seriously advocates colonising space (Boulding 1980 [1973]).³ As per the long running television programme Star Trek, space is the final frontier for the North American colonising spirit. So, when Boulding advocates space colonies as a real, if highly uncertain, potential future for humanity, he is doing nothing more than appeasing the critics of biophysical limits with a scientific fantasy. In doing so he readily derides the potential for solar power on Earth because in space energy flows from the sun 24 hrs a day and energy transport costs are lower away from Earth's gravity. He neglects to note that, without massive material and energy inputs, space is neither an easy place to get to nor an environment in which humans can naturally survive. Boulding does himself and environmental reality no favours by such flights of fancy and would have been better-off remembering his own words concluding the 3 page address, that putting a man (or two) on the moon was a low priority achievement. Indeed, the impetus for humanity sending a handful of people into space was an imperial struggle supported by the military-industrial complexes of the contestants.

The rise of nuclear power as an energy source has similar roots and, given Boulding's Quaker peace activism, his willingness to consider this option seems strange. The promise of nuclear fusion is mentioned without any caveats and fission is merely remarked upon as being limited by the available supply of fissionable materials. There is nothing about the

³ Boulding (1980 [1973]) is not being cynical at all, as some might at first think given the contrast with his Spaceship Earth essay. He is deadly serious because of the considerable public and media optimism created around the potential of space exploration after the 1969-1972 series of six Moon landings. He states that we have seen "the development of reasonably serious proposals for space colonies. This may sound like science fiction ... The idea is not, however, absurd".

inherently unsafe nature, toxic waste and weapons proliferation potential of nuclear energy as we know it. In a later presentation Boulding (1975 p.18) does briefly make these connections and is more critical.

"At the moment we seem to have put all our eggs into the rather dirty basket of the breeder reactor. I must confess I have grave doubts whether this is wise, not only because of the costs and dangers of the reactors themselves, but because of the enormous increase in the quantity of plutonium, the most deadly substance known to man, is not one that can be contemplated with any satisfaction, especially in light of the possibility that small organizations could make nuclear weapons."

Still, in the Spaceship Earth essay he remains ready to consider this and other interventionist and synthetic technologies at face value. Hence we find reference to what has become biotechnology as a possible means of harnessing energy. He refers to the biological revolution providing possible solutions by developing artificial organisms for solar energy transformation and running machines with methane-producing algae (Boulding 1966 p.8). This technological optimism rather runs counter to the sufficiency argument he presents for making do with what we know are the current capacities of humanity within set biophysical limits.

A related area in which the essay is open to criticism is the discussion of knowledge. This is initially compared to energy and materials, and entropy is directly stated to be applicable if "used in a somewhat loose sense". How there is meant to be some equivalence to the Laws of Thermodynamics that might cover knowledge is a mystery, and this speculation just leads to muddying the waters of scientific understanding. The discussion seems mainly to be aimed at justifying the treatment of knowledge as something of an accounting concept within a language of stocks, flows and depreciation. In fact, this accountancy approach underlies Boulding's writing in the essay. The treatment of Nature as

capital, and indeed the modern penchant for treating everything as readily substitutable capital, does little to address environmental problems (Spash and Clayton 1997). Indeed buying into a neo-liberal economic ideology, where the world becomes a collection of capital assets, allows the discourse of money, banking and finance to predominate over other values, which are then more easily lost rather than preserved (Spash 2009a; 2011a). So here Boulding does the environmental movement no favours.

In several respects Boulding would not be seen as having provided the full range of arguments and concerns of modern environmentalists. For example, he does not address the social and political factors or structural issues driving economic growth and environmental degradation. Those are actually the key issues of concern today. Understanding amongst social ecological economists of the basic biophysical constraints laid out by Boulding has also improved and is more precise than in his essay.

V. Connecting Boulding, his Spaceship and Social Ecological Economics

The modern heterodox field of ecological economics arose to fill the gap between social and biological sciences as identified by Kapp (1961). The direct connection to Boulding's essay is the specific concern to develop the social and economic implications of biophysical reality and in particular entropy. Establishing ecological economics as a professional association took another thirty years and involved a long diversion via neoclassical resource and environmental economics (Spash 1999). Boulding was not particularly involved in that journey, despite some early reflections on the relationships between ecology and economics (Boulding 1950). Nor was he engaged in the decade of events during the 1980s that established ecological economics by bringing North American and European ecologists and socio-economists together; for example, he was absent from the key 1987 foundational meeting in Barcelona (Røpke 2004).

On the basis of the Spaceship Earth essay one might have expected greater cooperation and association with like-minded others, such as Georgescu-Roegen and Herman Daly. Yet, this did not happen and Boulding (1981 p.191) himself explains why, as follows:

"Herman Daly, Nicholas Georgescu-Roegen and I, indeed, once thought of forming a society of heretics like ourselves, but it never got under way because we could not agree on the name for it, which perhaps revealed that our heresies were rather different. Georgescu-Roegen being concerned with entropy, Herman Daly with the stationary state, and I with a sustainable social evolution. This difference has persisted over the years, though in no way was it a detriment to our friendships."

However, the situation does not seem to have been quite so amicable, amongst all parties, as Boulding tries to claim here.

In 1971 a major work on entropy and economics was published by Georgescu-Roegen (1971) and this has since been heavily cited and regarded as foundational for ecological economics. That major work included but a brief and highly critical mention of Boulding. Referencing a section of a textbook by Boulding (1955, Chapter 28), Georgescu-Roegen (1971: p.235) states that Boulding's understanding of production functions encapsulates "almost every misleading notion that surrounds the conception of process in the economic literature".

The following year, Boulding (1972: pp.280-281) wrote an article which devoted just four paragraphs to dismissing the contents of Georgescu-Roegen's major work. This included remarks apparently contradicting his own earlier Spaceship Earth essay (not referenced in the article) and denying the implications of entropy for economics. The comments lack depth and appear somewhat rhetorical, so that determining what exactly is being dismissed is far from straight forward. For example, his comments deriding a concern about the creation of disorder (as expected to arise from the traditional understanding of the entropic process)

appear senseless and empty. His other criticisms have little to do with the implications of entropy for economic systems, and actually involve a denial of an entropy theory of value. This is an unjustified criticism of Georgescu-Roegen's work on the part of Boulding. In Chapter X of the major work, which possibly Boulding had not read (?), Georgescu-Roegen (1971) explicitly argues against such a reduction of economic value to a physical variable such as energy (see also Georgescu-Roegen 1979).

Perhaps we should not then be surprised to find, some years later, Georgescu-Roegen (1979 p.1026) attacking Boulding for his inconsistency and lack of understanding of the importance of material flows. For his part, Boulding appears primarily concerned with promoting his own evolutionary ideas at the expense of others, including any ecological economic synthesis. As Martinez-Alier (1990 p.2) states: "That there was no concerted action to create a school of ecological economics is made clear by Boulding's inane critique of Georgescu-Roegen (Boulding 1972)".

Daly can also be found, rather gently, chastising Boulding for weakening his position with respect to his critical understanding of mainstream economics. This occurred over the years between the Spaceship Earth essay and his "ecodynamics" book on evolutionary theory (Boulding 1978). During a written exchange Daly (1981) criticises Boulding's work for offering inadequate explanations on stock/funds, flows and time. Rather amazingly, Boulding (1981 pp.191-192) confesses he has no adequate reply to make on these points. However, he does not appear particularly concerned by this failing.

Boulding's move away from environmental concerns is also evident in an address entitled "Energy and the Environment", given in 1975 at the University of Wyoming, where he makes hardly any connection to environmental issues, or indeed energy, and is almost totally preoccupied with knowledge and evolutionary analogies applied to social and economic systems (Boulding 1975). These ideas undoubtedly leading to his ecodynamic

theory (Boulding 1978). Perhaps there is then a case to be made for Boulding's work on evolutionary economics being a basis for claiming a foundational status for him in ecological economics. However, this would require not just showing his importance in terms of the development of evolutionary economics and establishing that evolutionary economics has been important for ecological economics, but claiming the substantive import and influence of Boulding's brand of evolutionary thinking in ecological economics. None of these claims seems unambiguous, and the third least credible of all.

In the absence of counter evidence, the sometimes noted claim of Boulding being a founder of modern ecological economics appears to be based more on wishful thinking. Any such assessment would certainly seem unsustainable on the basis of his professional engagement. The claim generally relies upon appeal to the single Spaceship Earth essay, while ignoring the fact that Boulding himself basically abandoned the subject and approach in his preoccupation with evolutionary ideas. Yet, despite what Boulding himself thought, or did later, an interesting question is how far and in what ways the contents of the essay itself can be seen as linked to the ideas of other researchers, especially within the context of ecological economics.

An important contribution of the essay was to raise the profile of the Laws of Thermodynamics as relevant for economists. Their role in bounding social and economic systems seems undeniable. The First Law establishes the principle of the conservation of energy, namely that energy can neither be created nor destroyed but appears in different forms (e.g., heat, work, chemical, electrical). The Second Law concerns entropy (or unavailability of thermal energy for work) and states that in any isolated system entropy increases when energy is transformed. So, more simply, this means when using energy we irreversibly downgrade it and make it unavailable. At the same time matter becomes dispersed, degraded or disordered.

Boulding's (1966) essay was quoted in the booklet by Kneese, Ayres and d'Arge (1970) which developed a materials balance theory of the economy, and attempted to take some account of the First Law of Thermodynamics. Like energy, mass can neither be created nor destroyed in an isolated system. Einstein's theory of relativity equates energy to mass. The implications are simply that the mass of material inputs to the economy do not disappear upon consumption but rather are transformed into an equivalent mass of waste. As Boulding (1966 p.5) recognised:

"From a material point of view, we see objects passing from the noneconomic into the economic set in the process of production, and we similarly see products passing out of the economic set as their value becomes zero. Thus we see the econosphere as a material process involving the discovery and mining of fossil fuels, ores, etc., and at the other end a process by which the effluents of the system are passed out into noneconomic reservoirs—for instance, the atmosphere and the oceans—which are not appropriated and do not enter into the exchange system."

The materials balance theory as applied to economics by Kneese, Ayres and d'Arge (1970) showed that all the prices in the economy were in need of adjustment as everything had a related externality in neoclassical economic terms. The all pervasive nature of pollution destroyed the myth of a free unplanned market economy because prices do not reflect real resource costs and most fundamentally the wastes from production and consumption. Boulding however failed to make the connection to the all pervasive nature of pollution and, near the end of his essay, recommended internalisation of externalities using taxes as the solution to what he saw as the immediate pollution problems arising from imperfections in the pricing system. He was apparently unfamiliar with the work published 15 years earlier by Kapp (1950). He also fails to recognise that appropriation of Nature and

the incorporation of all aspects of the environment into the exchange system are part of the problem not the solution.

Boulding (1966 p.13) expresses concern over the lack of any serious work on the durability of products and how this might relate to the environmental impact over their economic life. The general area of the relationship of production and consumption to materials and energy has since developed e.g., in the practice of product life-cycle analysis. Ayres (1996) moved from materials balance theory to help develop the field of industrial ecology, and to explain in greater depth the connection between economic growth and useful energy or exergy (Ayres 1998; Ayres and Warr 2005). Others have pursued the concept of social metabolism which traces energy and materials flows through the economy and explains the process of industrialisation as exploitation of fossil fuels (Fischer-Kowalski and Haberl 2007; Sieferle 2001).

The Second Law concerning entropy was something explored more fully by Georgescu-Roegen (1966 pp.66-82; 1971; 1975). Both Boulding and Georgescu-Roegen influenced Daly (1968) towards his advocacy of a steady-state economy (Daly 1972; 1974; 1977). Georgescu-Roegen himself took a quite pessimistic stance in which the inability to recycle materials meant falling back to an agrarian society dependent upon organic agriculture and solar energy. Daly's position can be described as embracing our inevitable extinction but with the proviso of aiming for longevity on the basis of an ethic of Christian stewardship (Daly 1974). A negative relationship between longevity and societal throughput means the higher economic growth, as we know it, the shorter humanity can be expected to survive. The idea of taking biophysical limits as serious constraints on economic activity has today become reflected in ecological economics by the concept of degrowth (Kallis 2011; Martinez-Alier et al. 2010).

In the discussions of the implication of biophysical limits Boulding is guilty of a loose approach to language (and as already noted with respect to correspondences drawn between entropy and knowledge). More generally the spread of inaccurate and imprecise terminology has been blamed for causing a period of considerable confusion in the ecological economics literature that took some time to clear-up (Baumgärtner 1996). Boulding (1966) refers to closed and open systems but without direct correspondence to physics or the Laws of Thermodynamics. Although what he states is broadly correct there are instances of inaccuracy. For example, the term closed systems occurs when discussing systems without any exchange of energy or matter. These are actually isolated systems in thermodynamics. Closed systems exchange energy but not matter. Earth is in practice basically (though not strictly) a closed system. Open systems exchange both materials and matter with other systems. Boundary distinctions are important because different systems have different properties. For example, while Earth is basically closed, economic and social systems are open. Boulding's (1966 p.9) discussion of cowboy vs. spaceman economies confuses these boundaries and different systems. Clarifying such boundaries means taking into account the impacts of social and economic systems on other systems and their dependency on those systems (e.g., ecosystem, solar system).

Boulding (1966 p.7) correctly identifies the important role of ecosystems in recycling and concentrating chemical elements and organic substances and creating low entropy materials, something Georgescu-Roegen got wrong (see also reconfirmation of this point by Bianciardi et al. 1993). More recent developments have reflected the role of self-organising systems in creating order from dissipated and solar energy, but also in releasing energy through major dynamic system changes (Kay et al. 1999). This links ecosystems structure and functioning to thermodynamic theory. The changing dynamic of systems is seen as highly important and especially how systems may flip due to different attractors becoming

dominant. Self-organising systems may then show spontaneous coherent behaviour but suddenly change when reaching a 'catastrophic' threshold (Kay et al. 1999). This introduces concerns over strong uncertainty (ignorance and social indeterminacy), thresholds, non-linearity and irreversibility.

Boulding recognises that physical laws have implications for society, but regards what humanity chooses to do as an ethical question. So here Boulding is raising the role of ethics in social and economic conduct. Picking-up on this line of reasoning means that ecological economics has an essentially social (i.e., political and distributional) aspect, as now being made more explicit (Spash 2011b). The issue Boulding (1966) specifically touches upon in this context is the treatment of future generations. Near the end of the essay, he gives a stark warning as to the consequences of failing to act ethically towards the future:

"This whole problem is linked up with the much larger one of the determinants of the morale, legitimacy, and "nerve" of a society, and there is a great deal of historical evidence to suggest that a society which loses its identity with posterity and which loses its positive image of the future loses also its capacity to deal with present problems, and soon falls apart." (Boulding 1966 p.11)

In Boulding's essay, the inevitable implication of entropy and materials dispersion is that modern consumerist economies face biophysical and social limits. Resources for the essential needs of future generations are being squandered on luxuries for the current rich. He might have added the current poor into the story and the failure to do so is actually a strong criticism of the essay (as is his weak claim that 'others' are addressing today's problems). Social inequity and harm of the innocent is not something that is only relevant if we are concerned for the future. Geographical myopia seems as prevalent as the temporal myopia which Boulding criticises. So the use of ordered forms of energy by the present rich is at the expense of the needs of the present poor, future poor and future rich.

The connection of biophysical reality to its economic, social and ethical implications was later drawn far more forcefully by Georgescu-Roegen (1975). Indeed, Boulding's essay at one point offers an orthodox economic discussion of discounting which contrast with, and appears as an attempt to constrain, the concern for ethics and values. Mainstream economists, such as environmental economists, attempt to impose such time constraining ethical restrictions on the debate, but these are rhetorical exercises which try to avoid the fundamental value conflicts and power struggles in society (e.g., for a discussion in the context of climate change see Spash 2002; Spash 2007). Monetary valuation and pricing reduces all things to a single metric and discounting replaces a discourse over ethical behaviour with the language and priorities of investment banking and accountants.⁴ The rise of the field of environmental ethics, since the early 1970s, has provided an extensive literature on understanding plural values and how they should be addressed in environmental policy (O'Neill et al. 2007). Hence, research on ethics and value pluralism form central parts of social ecological economics (Spash 2009b), and their relevance extends far beyond issues of economic discounting, temporal myopia or intergenerational resource allocation. In contrast the future generations discussion in the essay is rather limited.

VI. Concluding Remarks

A Spaceship Earth metaphor provided an easily understandable and brief account of some key aspects of the concern, becoming increasingly acknowledge in the early 1960s, that there were some serious downsides to the American modernist technological optimism of a materialist hedonic nirvana delivered to your door by free-market enterprise. Boulding's essay is far from perfect and contains many speculative elements and aspects which,

⁴ Boulding has something of a weakness for the concepts of accountants, which are evident in the essay.

sometimes conforming to mainstream economic thinking and/or an accountancy approach, prevent a clear vision of environmental and social problems. Still one of the attractions of Boulding's writing is his often successful attempt to be thought provoking, and the speculative elements at least add to that. The essay is also wide ranging and includes many ideas. The drawback of a short essay of this sort is the brevity of coverage given to those ideas. This problem was unfortunately compounded because of Boulding's failure to return in any depth to the environmental challenges facing modern economic systems as raised in the essay.

Despite drawbacks, the essay appears to have taken on a life of its own in stimulating others and providing an early accessible overview of the implications for human economic activity of biophysical reality. The essay can be seen as complementing the more substantive work by Georgescu-Roegen and Daly. It also provides a reference point for the development of industrial ecology and research on social metabolism.

After writing the essay Boulding seems to have moved-on to different interests, such as evolutionary economics, and did not help establish ecological economics. Indeed, he dismissed the work of Georgescu-Roegen, in a rather off-hand and ill-informed fashion, while seemingly being uninterested in addressing problems with his own evolutionary approach as raised by Daly. However, Boulding did attend the inaugural conference of the International Society for Ecological Economics in 1990, where he gave a plenary speech. His plenary address mainly concerned the potential for legitimate institutions of governance and good leadership to arise in time to tackle the impending environmental crises (Boulding 1991). The conclusion looked towards "integrative power" by which he meant "the power of legitimacy, loyalty, respect, affection, love, truth, and so on". He concluded that in order to address environmental problems, population growth and the exhaustion of fossil fuels:

"the major element unquestionably will be integrative power, based first on the widespread knowledge that we all live on the same fragile planet, which we have now seen from outer space and to which we owe a common loyalty and affection. Unless this view is very widespread, legitimacy will not be granted to those frequently painful processes which may be necessary to prevent catastrophe." (Boulding 1991 p.30)

So, despite not having been active in, or contributing directly to, the development of ecological economics, he maintained a strong environmental concern and in the end saw the need for serious and substantive action in a political arena.

As the current political economy justifies pouring billions into stabilising financial and banking sectors, waging wars in oil rich countries and extracting energy from the most damaging and dangerous sources, the type of institutions and leadership required to prevent social and environmental catastrophe seem particularly lacking. Governments hark on about scientific uncertainty and call for more research rather than tackle human induced climate change. When action occurs it is minimal and does not address fundamental causes. The causes of Greenhouse Gas emissions go to the roots of the modern economic systems' failings. The biophysical basis of those failings were outlined by Boulding's essay. The social, structural and institutional aspects were largely neglected.

Social ecological economics aims to bring all these elements together and make them explicit in order to help understand and aid the necessary transformation facing humanity. The reality of the functioning of the economy within society and society within biophysical constraints is set against the fantasy of economic growth forever. The outlines of this hierarchical ontology can be found in Boulding's essay, and others have since added much to understanding the reality of economy-environment interactions. However, in the half a century since the essay first appeared, little has been done in policy circles to address

biophysical or social constraints to traditional economic growth, and little action seems likely without on-going crises. As Boulding recognised, at the end of his life, power is a key issue.

Changing social and economic systems means challenging existing structures and relationships. A variety of institutionalised arrangements empower societal actors and organisations benefiting from, and perpetuating, the current system of accelerating social inequity, environmental degradation and resource exploitation. Yet a lack of legitimate means confronts those wishing to challenge and achieve peaceful transformation of the dominant exploitative regime.

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