Denying Herman Daly: Why Conventional Economics Will not Embrace the Daly Vision

or

"That’s not the right way to look at it"

by

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Introduction: The illusion of reality

This chapter contrasts key elements of the dominant neoliberal free market brand of economics with Herman Daly's steady-state ecological economics and provides a partial explanation of why the world prefers the former to the latter. To those who rigorously compare the two visions, there is little question that the Daly brand is more rational and better grounded in reality. Yet in half a century it has gained little traction in the minds of the public and policy makers alike.

This is no mere academic dispute. If pervasive influence is the measure, traditional neoliberal economists may well be the most universally acclaimed of performers on the global economic stage. Nevertheless, my starting premise is that for all the seeming elegance of their analyses, neoliberal economists are little better than master illusionists. The audience will therefore be excused for feeling betrayed—or merely silly—if the stage is left empty when the magician's mist of abstract equations has finally dissipated on the evening air.

Neoliberal economists should take no special offence at having their sleight-of-hand exposed. Technically speaking, all economists—even Herman Daly—are illusionists. In fact, everyone is. We can't help it. Humans necessarily conceive in metaphor and think from conceptual frames that may actually have little basis in reality. This is worth thinking about because metaphors, myths and models largely determine how individuals and whole cultures interact with each other and the rest of the material world. Indeed, my second premise is that the fate of civilization may well hinge on the content of contemporary conceptual models, particularly the economic models, that give force and direction to both national and global development policy.

Some people may find the assertion that society is illusion-driven difficult to accept. Hard-headed practical people in particular will claim that their thoughts, politics and actions spring from 'real-world' experience; no mystical musings or whimsical abstractions interfere with *their* judgment. The problem with this is that humans actually have little truly direct experience of even *physical* reality. The best we can say is that we base our actions on seasoned perceptions—and seasoned perceptions, like all perceptions, are only elaborate models.

"But wait", you protest, "surely we experience the physical world directly through our five senses. Vision, hearing, touch, taste and smell have evolved precisely to enable us to navigate safely through the material world!"

On one level this is true and, by all the evidence, the process has worked fairly well. But consider for a moment what is involved with just our power of sight and, by inference, our other senses.

The anatomy of primary illusion

Humans are visual animals with a well-developed optical system; vision is perhaps the most highly evolved of our senses. If you and I were sitting opposite each other at a well-lit table we would no doubt agree that each could 'see' the other (assuming, of course, that we are normally 'sighted'). Indeed, if encouraged, either could come up with a vividly elaborate verbal description of the other's physical being. (Add the interpretive freedom due artistic license and we might have the basis for an interesting party game!)

But would we actually be describing each other, the 'real (physical) thing'?

In fact, we would not. 'Seeing' does not provide the observer direct access to anything! We don't see objects *per se*, we detect light reflected off those objects, and this light contains only a tiny quantum of the total information about the object that might be revealed if we had sensory access to the entire electromagnetic spectrum. [1]

Fortunately, evolution has provided us with a very sophisticated instrument with which to extract that quantum of information. The human eye is a complex organ 'designed' to project a sharply-focused image of perceived objects onto a light-sensitive tissue at the back of the eye called the retina. Thus, we can claim to experience reality at least *indirectly* as represented by tiny images-in-light dancing on the backs of our eyeballs.

But even this is not quite true. Our brains cannot decode light *per se* no matter how well-focused and exquisitely detailed the retinal image (which, by the way, is upside down).The retina must first encode the image into electrical impulses, the only form of 'data' that the brain can understand. The optic nerve then conveys the impulses to various parts of the brain for processing and interpretation and only when the signal finally (but seemingly instantaneously) arrives at the primary visual cortex do we actually experience 'seeing'. (That said, just how the brain assembles the continuous cascade of optical data into a coherently comprehensive virtually real-time moving picture remains largely a mystery!)

What this technical romp reveals is that even our most vividly 'real' visual pictures are, in fact, nothing more (or less) than neural *reconstructions* of initially scanty data that are subsequently filtered by the mechanical eyeball and undergo at least two energy conversions in the retina before being fed to an unknown number of neuro-interpretive processes (all at what loss or tainting of information?) before finally emerging as sensory 'experience'. [2] In short, the sensory images that we use to regulate our interaction with the rest of the biophysical world (generally

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[1] There is a vast amount of electromagnetic energy out there that is not accessible to our senses but is as 'real' as what we can detect. For example, the signals of virtually every radio and television program being broadcast for hundreds of kilometres around and every cell-phone conversation in the vicinity are passing through your body unsensed right now. (Fortunately, one can only suppose.)

[2] See Regal (1990) for a detailed description of how "reality is always being tampered with by our nervous systems" and how "the construction of internal [i.e., 'subjective'] reality is a continual process in the human brain" (to which Regal refers as 'The Illusion Organ' [Chapter 3]).

quite successfully) are mere feeble abstractions—and we often submit even these to subjective interpretation based on our previous education, socialization and personality. Bottom line? Humans routinely operate from sensory *illusions* that are woefully incomplete and distorted shadows of corresponding physical reality. Sometimes the imperfections and omissions are hazardous to life. We cannot see the camouflaged predator, taste the toxins in our food or sense the high-energy radiation that eventually gives us cancer.

All of which poses an interesting question: If the brain's reconstructions of the physical world are such partial representations, how much more ethereal and potentially dangerous are concepts, myths and models that are entirely socially-constructed or that have few real-world touchstones? This is no trivial matter: a glance at the headlines reveals that religious dogma, political ideology, disciplinary paradigms (including economic paradigms) and all manner of cultural norms are more important determinants of how people behave as social beings than is their sensory experience.

Secondary Illusion and Dueling Paradigms

> All thinking about the world involves a degree of abstraction. Economics has taken this principle further than any other social science (Wolf 2010).

> Existing economics is a theoretical system which floats in the air and which bears little relation to what actually happens in the real world (Coase 1997).

Which brings us back to economics. Economics used to be concerned with what people did with and on 'the land' to acquire the material basis of their own existence. The 18th Century 'physiocrats' believed that land, particularly agricultural land, was the source of national wealth and valued agricultural labor as the means to extract it. Physiocracy, sometimes called the first body of organized economic thought, was also the last body of traditional economic thought to be so conceptually wedded to biophysical reality.

The divorce is virtually complete when it comes to the neo-liberal market economics that dominates global development thinking today. "Something strange happened to economics about a century ago. In moving from classical to neo-classical economics… economists expunged land — or natural resources" from their theorizing (Wolf 2010). Land and resources were quietly dropped from mainstream production functions as capital (including finance capital) and knowledge came to be perceived as the principal sources of wealth and drivers of growth.[3]

This abstraction could be maintained historically: 1) because the undervaluation of nature relative to other factors of production (no one pays the earth for the resources we extract) means that in 'advanced' economies land and resources *per se* often contribute only marginally to GDP and; 2) technology has succeeded until recently both in keeping the costs of extracting raw materials low and in finding substitutes for some resources that have become scarce (e.g., coal

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[3] This will seems odd to non-economists, because most people still participate in 'the economy' to acquire the material basis of their own existence.

substituted for wood as the primary fuel of the industrial revolution; fish-farms increasingly substitute for wild fish-stocksfertilizer substitutes for depleted soil in industrial agriculture). Bottom line? Most contemporary economic models still float free from biophysical reality, blind to the energy and material flows essential for human existence and to the 'natural capital' stocks that produce them (see Box 1).

- Box 1 near here -

The economy as self-fueling machine

This blindness is the target for one of Herman Daly's most pointed challenges to mainstream thinking. Consider that mother of all conventional economic models, the 'circular flow of exchange value' (Daly 1991, 195). Economic textbooks typically feature a standard circular diagram of the economic process as "a pendulum movement between production and consumption within a completely closed system" (Georgescu-Roegen, 1971). Value embodied in goods and services flows from firms to households in exchange for spending by households (national product). A supposedly equal value, reincarnated in factors of production (labor knowledge, finance capital), flows back to firms from households in exchange for wages, rents, dividend, etc., (national income).

Mainstream texts sometimes suggest that this stripped-down economy operates as a perpetual motion machine, generating a "flow of output that is circular, self-renewing, self-feeding" (Heilbroner and Thurow, 1981, p.127). From this perspective, economic growth is a spontaneous autocatalytic process. All the more miraculous because the circular flows model makes no reference whatever to the energy and resources to which value is added to produce the goods and to generate the income flows that the model does represent, nor to the waste outflows the system generates: "…the circle flow is an isolated, self-renewing system with no inlets or outlets, no possible point of contact with anything outside itself" (Daly 1991, p.196). Starting from self-generating flows and armed with bracing confidence in both market efficiency and human ingenuity, many mainstream economists face the challenges of global change with unabashed optimism.

The economy as super-organism

> In the later stages of economics, when we are approaching nearly to the conditions of life, biological analogies are to be preferred to mechanical (Marshall 1925, p.14).

If neoliberal economics casts the economy as lifeless machine, Daly's critique portrays it as living organism. He argues that studying the economic process in terms of self-generating circular flows without considering unidirectional throughput is akin to studying physiology in terms of the circulatory system with no reference to the digestive track. One might as well ask engineering students to fathom how "a car can run on its own exhaust" or biology students to accept that "an organism can metabolize its own excretia" (Daly 1991a, p.197) (see Box 2).

- Box 2 near here -

Daly's living system metaphor compares "the basic within-skin life process of metabolism (anabolism and catabolism) with the outside-skin process of economics (production and consumption)" (Daly 1993, orig. 1968). The value added by the metabolic process is the maintenance of life; the value added by the economic process is the maintenance and also the enjoyment of life. But in either case, "the only *material* output is *waste*" (Daly 1993, p.251,original emphasis).[4]

Some readers might protest this last assertion. Is not the entire purpose and major output of the economy to produce useful (and sometimes not so useful) goods and services? So it would seem, but this is a limited, static view. It does not recognize that usable energy can make only a single pass through the economy. With useful work extracted, 100% of the degraded infra-red residue radiates off the planet. As for material, only a fraction of the energy and material resources that enter the economy is actually converted to marketable products, and once these are consumed or worn out, the embodied material also joins the waste stream. Even with some recycling (which uses additional energy and at least some 'fresh' material), the *entire* stream of energy and resource inputs ultimately returns to 'the environment' as degraded waste.[5] Thus, from a purely 'outside-the-economy' biophysical perspective, economic activity is clearly much more a consumptive process than it is a productive process.

Dissipating the planet

This by no means exhausts the metaphor of the economy as super-organism. Seeing the economy as a generator of degraded energy and material cues us that, like all biological entities, the economy is subject to physical laws, particularly the second law of thermodynamics.

The second law is fundamental to all processes of energy and material transformation and is thus arguably the ultimate regulator of both biological and industrial metabolism. While the implications of this fact have been deemed irrelevant by neoliberal economists, Herman Daly (following his mentor Nicolas Georgescu-Roegen) has for decades led a small band of insurgents struggling to have the second law reflected in conventional analyses.

In its simplest form, the second law states that every spontaneous change in an isolated system increases the 'entropy' of the system (an isolated system that cannot exchange energy or matter with its environment). In general, this means that the system becomes increasingly 'random'—energy dissipates, material concentrations disperse, gradients disappear. In short, with time, isolated systems become increasingly degraded in an inexorable, irreversible descent toward

[4] This perspective has spawned the entire sub-discipline of "industrial metabolism" stimulated largely by the work of another renegade economist (and physicist) Robert U. Ayres (see Ayres & Simonis 2009 and Ayres & Warr 2009).

[5] The quantities can be prodigious. By the late 1990s, material waste output ranged from 11 metric tons per person per year in Japan to 25 metric tons per person per year in the United States. When so-called "hidden flows" were included—flows resulting from economic activity but which do not actually enter the production process, such as soil erosion, mining overburden, and earth moved during construction—total annual waste material output increased to 21 metric tons per person in Japan and 86 metric tons per person in the United States (WRI 2000). That's 86,000 kilograms (198,598 lbs) every year for every man, woman and child in the latter country!

thermodynamic equilibrium. This is a state of maximum entropy in which nothing else can happen.

In recent decades, science has recognized that the workings of the entropy law apply also to open, far-from-equilibrium systems. *Any* complex differentiated system tends to unravel and run down. Despite all reasonable attempts at maintenance, every shiny new car eventually becomes a junker. And this is invariably a one-way trip—no rusted-out shell has ever spontaneously reacquired its show-room splendor.

Readers may be quick to point out the many apparent exceptions. A newly-conceived fetus, an early-succession ecosystem, the world's great cities, indeed, the entire human enterprise all prove that, rather than sink toward equilibrium, *living* systems actually gain in mass and complexity over time. How such systems subvert the second law long puzzled philosophers and scientists. Physicist Erwin Schrödinger's resolved the conundrum only in 1945: "The obvious answer is: By eating, drinking, breathing and (in the case of plants) assimilating..." Like any other system, "…a living organism continually increases its entropy – [i.e., produces positive entropy] and thus tends to approach the dangerous state of maximum entropy… of death. It can only keep aloof from it, i.e. alive, by continually drawing from its environment negative entropy…" (Schrödinger 1945). ('Negative entropy' or 'negentropy' is free energy available for work). In other words, organisms thrive by exchanging high-entropy outputs (waste) for low-entropy inputs (resources). However, second law inefficiencies also dictate that the organism's gain in negentropy is only a fraction of the increase in global entropy. As Daly asserts, this statement "*…would hold verbatim as a physical description of the economic process*" (Daly 1993, p.253).

The near-homology of living systems and the economy has acquired a sharper edge in recent years with the development of self-organizing holarchic open (SOHO) systems theory. Systems scientists have recognized that self-producing systems exist as loose overlapping hierarchical structures where each component sub-system ('holon') is contained by the next level up and itself comprises a chain of linked sub-systems at lower levels (Kay and Regier 2000). (Consider that an individual organism is part of a community embedded in an ecosystem, and itself comprises a descending hierarchy of sub-systems from organs to cells). The critical point is that at every level in the hierarchy, the relevant holon can develop and maintain itself *only* by using available energy and material (negentropy) extracted from its 'host' system one level up and by exporting degraded energy and material wastes (entropy) back into that host.[6] In effect, all thermodynamically open self-producing sub-systems thrive—maintain themselves far-from-

[6] Because self-producing systems maintain themselves 'far-from-equilibrium' by degrading and dispersing imported energy and matter, they are called 'dissipative structures'. Prigogine suggested that distance from equilibrium would become as essential a variable in thermodynamic descriptions of nature as temperature is in classical equilibrium thermodynamics" (Prigogine 1997, Ch.2).

equilibrium—at the *expense* of their hosts (see Schneider and Kay 1994a,b; 1995; Kay and Regier 2000).[7]

The highest Earth-bound level in the SOHO hierarchy is the ecosphere, the macro-holon that comprises all subsidiary biomes, ecosystems and species. It follows that the structural and functional integrity of the ecosphere can be maintained only if the productivity and resilience of constituent ecosystems is sufficient to support indefinitely the development and maintenance of lower level holons (e.g., all consumer organisms, the economy) and to assimilate/dissipate the ecosystems' aggregate entropic output.

Normally within ecosystems, the rates of resource imports and waste discharge by any sub-system (e.g., a species population) fluctuate in the short term but are maintained by negative feedback within a range that is compatible with the overall rates of production and assimilation by the host ecosystem. Each lower holon therefore normally exists in a more or less 'steady-state' relationship with its host so the entire systems hierarchy retains its long-term structural and functional integrity. However, the hierarchical relationship among sub-systems and their hosts contains the seeds of potential pathology (Rees 2003). If any sub-system demands more than its host can produce, or discharges more waste than its host can assimilate, then further growth of that sub-system will necessarily deplete, degrade, and dissipate higher levels in the systems hierarchy.

Now it is undeniable that the economy (which is really the material manifestation of human ecology) is an Earthly entity, and therefore a sub-system of the ecosphere (actually, a sub-system of multiple ecosystems). But the two holons differ in one critical respect. The ecosphere evolves and maintains itself in far-from-equilibrium steady-state by assimilating and dissipating radiant energy from the sun, i.e., an extra-planetary source of negentropy (and, effectively, the next highest level in the thermodynamic hierarchy). The economy, however, can grow and maintain itself only by extracting and degrading resources extracted from ecosystems. As noted, an unavoidable consequence of the second law is that when any given subsystem expands and complexifies (i.e., rises further from equilibrium) its gain in negentropy is always less than the increase in global entropy.[8] It follows that, beyond a certain point, the expansion of the human enterprise *necessitates* the entropic depletion and dissipation of its host ecosystems (see Table 1). Fisheries collapses, landscape degradation, soil erosion, tropical forest deforestation and biodiversity loss, etc., are all symptoms of over-consumption by humans; marine dead zones, accelerated eutrophication, ocean acidification, ozone depletion, the toxic contamination of food-webs, greenhouse gas accumulations (climate change), etc., are all symptoms of waste sinks filled to overflowing. SOHO systems

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[7] In some cases, host systems can thrive without (some of) their sub-systems—the ecosphere would persist in the absence of humans, for example. In others, the subsystems and 'hosts' exist in a state of mutual dependence—think of the relationship between the nervous system and the entire body.

[8] Even photosynthesis converts only about two percent of available solar energy ('exergy') into biomass (negentropy); the rest is dissipated into space as low-grade infrared (heat) radiation, mostly through evapotranspiration. The negentropy gain by the ecosphere is trivial compared to the entropy gain of the universe.

framing clearly reveals today's perpetual growth economy to be an entropic black hole, thermodynamically positioned to consume and dissipate the ecosphere from within (Rees 1999).

- Table 1 near here -

The problem of scale and the steady-state

As Herman Daly has long recognized, the first corollary of any thermodynamic model of the economic process is the need to limit the scale (energy and material throughput) of the economic enterprise within the capacity of supporting ecosystems (e.g., several chapters in Daly 1991a; Daly & Farley 2004). In theory, an economy has achieved its optimal scale or size at the point where the (diminishing) marginal benefits of material growth just equal the (rising) marginal costs—including the (currently unaccounted) costs of depleted natural capital, capital substitution and pollution. At this point the total net benefits of economic growth to date (total benefits minus total costs) is at a maximum and, as Daly originally noted—and is frequently moved to remind us— any further growth actually makes us "poorer than richer" (e.g., Daly 1999). If intelligence and logic were the principal determinants of economic policy, the primary goal would be to ensure that growth slows as we reach the optimal scale and that the economy not exceed this optimal size.

There is a problem, however—several actually. The facts that our measures of benefits are flawed (e.g., GDP puts plus signs on both negative and positive entries), that we can neither identify nor monetize many of the costs (e.g., who knows the present value of some future climate change cost of which we are as yet unaware but which may already been triggered by historic and present actions?) and that changing circumstances constantly shift the exact 'location' of the optimal point, means that we could not actually perform a valid benefit/cost analysis of economic growth even if society were inclined to do so. But this in no way invalidates the basic point. There are real ecological and economic limits to sustainable global energy and material throughput. Politicians, heady from addiction to economic growth, should find it sobering that no mainstream economists can state with certainty that society is still below the optimal point and that numerous ecological economics indicators and biophysical studies suggest we may have long exceeded it (e.g., WWF 2008; Rockström et al. 2009).

The second corollary of economy-as-thermodynamic-process is that sustainability implies a steady-state economy. Our own bodies are steady state systems in which the daily inflows of energy and matter are, on average, quantitatively equivalent to the outflows. (Of course, the *quality* is diminished by the extraction of negentropy from the inputs.) Thus if "…we view capital as material extensions of the body, and we accept the fact that there are limits to the total number of human bodies supportable, then by the same logic we should recognize that the stock of extensions of human bodies is also limited and thus be led naturally to a steady-state perspective on the economy" (Daly 1991a, p.32).

The essential lesson is that after an initial phase of growth, all healthy living systems become steady-state systems, any propensity for further expansion constrained by negative feedback (e.g., incipient resource scarcity, disease). The ecosphere as a whole is in approximate steady-state limited by the constant solar flux and the geographically variable availability of water and nutrients. It follows that the economic sub-system, rapidly becoming the dominant subsystem of the ecosphere, must increasingly conform to the operational dynamics of the ecosphere *if it is to survive*. The operational dynamics of the ecosphere exemplify a dynamic steady-state.

Which is not to be confused with a static state. The economy needn't cease developing, it must merely stop growing. With luck and good management it could hover indefinitely in the vicinity of its 'optimal scale' while steadily improving human well-being. There are no limits on the capacity of human ingenuity to better quality of life, only on the quantity of throughput available to do it. And even within that constraint, new firms and even whole industrial sectors could both develop *and* grow even as their thermodynamic equivalents in obsolete or 'sunset' industries are phased out. Because it draws so many logical threads together, Herman Daly's pioneering development and persistent advocacy of the steady-state economy is perhaps his greatest overall contribution.

The Quest for the 'truer' economy

> You may say, if you wish, that all reality is a social construction, but you cannot deny that some constructions are 'truer' than others. They are not 'truer' because they are privileged, they are privileged because they are 'truer.' (Postman 1999, p.76).

We have described two competing 'social constructions' or conceptual models of the workings of the economic process. The dominant neoliberal paradigm treats the economy as an independent entity, an open growing system whose productive cycle is virtually unconstrained by any biophysical reality outside itself. By contrast, ecological economists see the economy as an open, growing but also fully contained and dependent sub-system of the finite, non-growing and materially closed earth ecosystem (Daly 1990, p.45). This latter framing also recognizes that the bio-metabolism of the ecosphere and the industrial metabolism of the economy are both governed by inviolable biophysical laws. In the critical context of sustainability the critical question is which of these conceptual models provides a 'truer' representation of biophysical reality.

Who can dispute that in today's world the economy interacts with and seriously affects the productivity and behavior of ecosystems? Nevertheless, the mainstream economic models used to govern/regulate national economies and international development remain insensitive to the structure and function of the ecosystems upon which the economy draws, and of the time- and space-dependent processes that characterize ecosystem behavior. Indeed, the simple, reversible, mechanistic behavior of the economy implicit in mainstream models and derivative analytic tools (e.g., benefit/cost analysis) is quite inconsistent with the complexity, irreversibility, lags, thresholds and positive feedback dynamics of the complex energy, information, and ecosystems with which the economy interacts in the real world (Christensen 1991). Even more remarkably, the modeled behavior is inconsistent with that of the real economies the models supposedly represent (as was clearly revealed, yet again, by the financial collapse of 2008). On all these grounds, a reasonable person would be justified in dismissing mainstream sustainability analyses as fatally illusory from an ecological perspective. The structural and relational assumptions framing the dominant economic models behind global development today disqualify them from generating useful insights into humanity's relationship with nature.

Contrast this with the relative structural integrity of the Dalyesque vision and the insights accessible to it. Seeing the economy as a growing dependent subsystem of the non-growing ecosphere enables one to surmise from the outset that at some point—even after accounting for human ingenuity—the economy will eventually be hobbled by scarcity and begin to suffocate in its own detritus. And what if the economy and the ecosphere really are far-from-equilibrium dissipative structures and the former is nested within the latter? This allows the equally rational conjecture that the ever-growing economy must inevitably degrade and dissipate the ecosphere in the manner of a malicious parasite. Virtually every so-called 'environmental' problem today, from collapsing fisheries and biodiversity loss, through peak oil and potential food shortages to contaminated food webs, accumulating greenhouse gases, climate change and ozone depletion is predictable or explicable from Daly's 'contained system' framing of the economic process.

Finally, ecological economic economics recognizes that complex systems—social systems, ecosystems and economic systems—are characterized by non-linear (discontinuous) behavior, particularly lags and thresholds. The latter represent 'tipping points'—if key variables of the system are pushed beyond these (by, for example, overexploitation) the entire system may 'flip', potentially irreversibly, into an new stability domain where conditions are hostile to human purposes. (The collapse of the North Atlantic cod stocks in 1992 serves as a memorably tragic example—and warning.) Indeed, complex systems may have multiple possible equilibria or stable regimes whose existence is unknowable before the fact. These qualities together speak to the need to carefully monitor resource exploitation for any sign that that the system is being over-stressed and to limit the overall scale of the human enterprise within cautiously safe limits.

Given present circumstances and global trends, Daly's organismic/thermodynamic model of the human enterprise is clearly less reassuring than the mainstream perspective. Nevertheless, one suspects that if ordinary people were given an opportunity to dissect and assess these two conceptual 'constructions', most would judge Daly's version on the evidence as being a 'truer' representation of economy-environment relationships. Daly's construction is therefore the one that should be 'privileged' in the economic policy arena.

"That's not the right way to look at it"

Despite the growing cascade of data supporting this conclusion many practicing economists still do not agree. Their resistance has a cumulative history. Consider just one well-known example (Daly 2008). The first draft of the World Bank's 1992 *World Development Report* (which focused on sustainable development) contained a diagram called 'the relation of the economy to the environment'. All it showed was a rectangle labeled 'economy' with an in-bound arrow labeled 'inputs' and an exit arrow labeled 'outputs'.

As senior economist in the bank's environment department, it fell on Herman Daly to critique the draft. Daly observed that this drawing should be revised to include 'the environment'. As matters stood the economy was exchanging inputs and outputs with nowhere. Always helpful, Daly suggested that the next version of the diagram show the economy as contained within a circle labeled 'ecosystem'. This would make clear that the economy was a subsystem, that the input arrow represented resources extracted from the ecosystem, and that the output arrow represented waste returning to it as pollution. Daly suggested that this would stimulate fundamental questions, such as how large the economy could grow before it overwhelmed the total system.

The second draft of the report duly showed the original figure enclosed in a large unlabelled rectangle but this prompted Daly to complain that, incompletely labeled, the diagram changed nothing. The third draft omitted the diagram altogether. The bank apparently recognized that something was wrong with that diagram but preferred to omit it rather than deal with the inconvenient questions it raised.

Sometime later Daly had an opportunity to question Lawrence Summers, Chief Economist at the World Bank (under whom the report was being written) about the same issue. Did the Chief economist consider the question of the size of the economy relative to the total ecosystem to be an important one? Did he think economists should be asking the question: What is the optimal scale of the economy relative to the ecosphere? Summer's reply was "immediate and definite: '*that's not the right way to look at it*'" (quoted in Daly 1996, p.6). Apparently, "The idea that economic growth should be constrained by the environment was too much for the World Bank in 1992, and still is today" (Daly 2008).

Other rogue economists have advanced similar critiques of modern growth fetishism. According to Julie A. Nelson, economists show "dogged allegiance to a narrow set of epistemological ideals, methodological framing and substantive assumptions" in their application of endogenous growth theory (EGT) (Nelson 2005. P.9). EGT explores the role of technological innovation and other sources in GDP growth, but "no matter how tortured the logic, [the explanations] lead back to a source in economic fundamentals." Apparently, the word 'endogenous' is a signal that the model is closed off from historical developments or other considerations that might undermine its validity. Evidence that violate its assumptions is set aside. "And in line with the vast majority of economic theorizing about growth, the ecological implications of a ceaseless expansion of production are totally ignored." (Nelson 2005, p.9).

Mainstream economists are not doing much better in formally acknowledging the potentially devastating impacts of complexity theory on prevailing economic dogma. This makes economists and finance managers culpable in the 2008 collapse of the global finance system

(Ormerod 2010). The latest attempt to explain business cycles and 'booms and busts' from the 'rational agents using rational expectations' view of the world goes by the term 'dynamic stochastic general equilibrium' models (DSGE). DSGE models contain all the key microeconomic assumptions of orthodox economic theory. Acting under the illusory fog thrown up by this framing, "the authorities" assumed, falsely, that brokers and agents had used the 'correct' model in setting prices, i.e., that the massive volumes of loans and debts being traded in the market had been "priced rationally and hence optimally". Had this been the case, and institution 'A' defaulted on a loan:

> "sufficient provision via the optimal pricing of the loan [would have] been made to cover the loss arising from any such default. There was no need to tie up capital unnecessarily in liquid assets when it could be lent out at a profit. Across a portfolio of many such loans, the default of a single loan simply could not cause a problem" (Ormerod 2010, p.14).

The real economy, however, is a complex system that behaves little like a DSGE model whether or not its assumptions have been satisfied. Complex systems theory, specifically network theory, "tells us that in an interconnected system, the same initial shock can, if we could replay history many times, lead to dramatically different outcomes". Uncertainty is large and essentially irreducible. It may be that most of the time, "shocks are contained and do not spread very far through the system. But in principle a shock of identical size can trigger a cascade of global proportions." Unfortunately, as noted in other contexts, is that "The economics profession in particular has become very insular and hostile to scientific work outside its own field." Accordingly, "...economists are largely ignorant of the large amount of work carried out on cascades in interconnected systems by a whole range of disciplines over the past decades such as control engineers, computer scientists, physicists, and mathematicians". Result? "In the brave new world of DSGE, the possibility of a systemic collapse, of a cascade of defaults across the system, was never envisaged at all" (all quotes from Ormerod 2010, p.14-15).

James K. Galbraith extends his critique of modern economics to include even the domain that it *does* purport to encompass. He argues that the empirical evidence "flatly contradicts" the five leading ideas of modern economics and interprets this disconnect from the real world as evidence that "modern economics… seems to be, mainly, about *itself*'" (Galbraith, 2000, p1, original emphasis). He goes on: "But self-absorption and consistent policy error are just two of the endemic problems of the leading American economists. The deeper problem is the nearly complete collapse of the prevailing economic theory… It is a collapse so complete, so pervasive, that the profession can only deny it by refusing to discuss theoretical questions in the first place" (Galbraith, 2000, 4).

The triumph of illusion

How can we explain this seeming abandonment of reason, the wide-spread hiding of heads in the sand? Humans pride themselves on being evidence that the universe is coming to self-awareness and intelligence. We claim to be a science- or at least a knowledge-based society. Why is it, then, that in so many domains, modern humans seem to act out of habit, ignore contrary data and happily embrace illusory fantasies?

Such illogical behavior could be part of a contemporary cultural trend. More than a half-century ago (at about the time economic growth began to push its way to prominence on the policy agenda) German philosopher Martin Heidegger observed that "...man today is *in flight from thinking*" (Heidegger, 2003, p.89). By "thinking" Heidegger did not mean the day-to-day calculative thought processes at which technological society actually excels. Rather, he believed that modern society was 'in flight' from the deeper kind of critical, questioning or, in his terms, "meditative" thinking, the tool of the philosophers and ordinarily contemplative people alike. Such generalized thoughtlessness (as reflected in the quality of the Evening News?) is characterized by our failure to ponder, to observe, to question and even to show awareness of what is actually taking place around us and within us. From Heidegger's perspective, contemporary society is thus allowing to "lie fallow" one of our great and most uniquely human abilities. With intellectual blinkers on, the world is being swept away in the techno-material tide, guided, if at all, by careless whims and sheep-like adherence to prevailing myth and ideology.

On the other hand, perhaps nothing has changed. Heidegger may merely be observing most people for what they are. And it seems people have always been lazy thinkers, preferring skilful illusionists to realists in politics as in art. Consider French behavioral psychologist Gustave Le Bon's observation in his 1895 classic study of 'group-think':

> "The masses have never thirsted after truth. They turn aside from evidence that is not to their taste, preferring to deify error, if error seduce[s] them. Whoever can supply them with illusions is easily their master; whoever attempts to destroy their illusions is always their victim" (Le Bon 1895).

Le Bon's observation is no mere curiosity. The 'deification of error' and resultant behavioral inertia—or deviance—at the top can determine the fates of nations. Pulitzer Prize winning American historian, Barbara Tuchman, details the tragic effects of self-delusion on entire societies through millennia in her 1984 classic, *The March of Folly*. According to Tuchman 'folly' involves "the pursuit of policy contrary to the self-interest of the constituency or state involved". To qualify as true folly a particular course of action must be pursued even though a "feasible alternative course of action [is] available". In addition, the action or policy must generally be "that of a group" (not merely an individual leader) and "persist beyond any one political lifetime" (Tuchman 1984, p.5). So defined, political folly or "wooden-headedness":

> "...plays a remarkably large role in government. It consists in assessing a situation in terms of preconceived fixed notions [e.g., ideology] while ignoring any contrary signs. Itis acting according to wish while not allowing oneself to be deflected by the facts" (Tuchman 1984, p.7).

My point? Le Bon and Tuchman are describing seemingly universal perceptual blocks and behavioral intransigence—even in the face of imminent danger—that are exhibited by people who have developed deeply entrenched systems of belief that have long shaped and directed their lives. (More on this to follow.)

Let's return to the present context but assume that the global community is *not* perceptually handicapped, i.e., we are able to act decisively in a spirit of collective engagement and high intelligence in the face of global ecological change. This means that national and global policies for sustainability would have to be consistent with the scientific evidence that ecosystems and the climate system are in stress, including the fact that the human enterprise is currently in a state of overshoot (drawing down even self-producing natural capital and filling critical waste sinks to overflowing). The world would also have to recognize: 1) that the economy is a dependent subsystem of the ecosphere subject to thermodynamic laws, i.e., for the economy to grow and maintain itself 'far-from-equilibrium, it necessarily 'feeds' on its supportive ecosystems and uses them as waste dumps; and 2) there are limits to the regenerative and assimilative capacity of ecosystems. Corollary: for sustainability, there must be caps on aggregate energy and material flows and thus constraints on the scale of the material economy so that it operates safely within the means of nature. Let's also assume that as good global citizens, we express our compassion for others—basic equity considerations require formal recognition that today's levels of gross material disparity are intolerable.

In these circumstances, rich countries would accept that it is their responsibility to initiate programs to *shrink* of their national economies toward a globally viable energy and material steady-state (*a la* Herman Daly). North Americans, for example, would have to reduce their ecological footprints by about 80%, from around nine global average hectares (gha) *per capita* to our 'fair Earth-share' of two gha (Rees 2006, WWF 2008). Such contraction at the top is necessary to make room for needed growth in the developing world given that Earth is a finite planet already in overshoot (Rees 2008, Victor 2008). These may seem to be unreasonable demands and impossible goals, but analysis shows that we actually have the technology to enable a 75%-80% reduction in energy and (some) material consumption (Weizsäcker *et al*. 2009) while improving quality of life in both rich and poor countries. (Remember that people in wealthy countries were actually happier on average with less than half of today's average per capita income.) In any case, as Daly and other analysts have shown, aggregate global growth itself has already likely become uneconomic and self-defeating.

The most politically plausible alternatives to such a 'steady-state with redistribution' strategy are the *status quo* or some technologically engineered variant. But if our best science is correct, the increasingly likely outcome of these alternatives is ecosystemic collapse, resource wars and geopolitical chaos. This dismal outcome underscores that it is actually in everyone's long-term interest to give up on continuous material growth and learn to share the earth's existing bounty. For what may be the first time in human history, *individual and national self-interest has converged with humanity's collective interests* (Rees 2008).

Of course, as matters stand, 'steady-state with redistribution' is off the table.[9] Instead, the dismal alternative is in play. Far from considering a planned economic contraction, all national government and mainstream international organizations (e.g., the United Nations and the World Bank) subscribe to a mythic vision of unlimited global expansion inspired by neoliberal economics, fuelled by globalization and expanded trade, and inflated by overweening confidence in efficiency gains and technological hubris. Popular support is assured by the single most successful program of social engineering in history, the purposeful global promulgation of consumer culture. A multi-billion dollar 'public relations' and advertising sector has converted virtually whole nations of potentially engaged citizens into passive consumers.[10] Little wonder that the concept of 'contraction' does not resonate in society's collective consciousness—it is not the narrative people have been conditioned to hear. In effect, we live from a socially-constructed materialistic world-model sustained by the smoke, mirrors and pixie dust sent aloft by professional illusionists of all stripes, prominent among whom are growthist economists.

To be fair, growth-based economics has been remarkably successful in improving the material well-being of a significant minority of the human population in what started out as an 'ecologically empty' world (Daly 1991b). This provides superficial support for the prevailing mode of thinking. Why spoil what could be a luxury cruise for all if human ingenuity promises to maneuver the ship around any shoals thrown up in what is now an 'ecologically full' world? Privileged elites with the greatest personal stake in the *status quo* thus sit at the Captain's Table and insist we stay our course through the fog of illusion; middle-class passengers, even those nervous about the voyage, seem willing to sacrifice uncertain but major long-term gain (i.e., global survival) to avoid the certain but minor short-term pain of having to adapt their lifestyles; and the folks in steerage have little choice but to go along for the ride, clinging hopefully to the expansionist myth as to a life-raft in effective denial of their lived reality.

Exposing the roots of denial

> No one is immune to it; in some respects it is the foundation of our lives. Magical thinking is a universal affliction. We see what we want to see, deny what we don't (Monbiot 2010) .

How can we explain this behavioral conundrum? What motivates the perversely illogical politics described by Le Bon, Tuchman and others? Whenever people possess knowledge that should be powerfully motivating or profess a strong commitment to some belief or social ethic yet persistently ignore or violate it, there is a good possibility that some innate predisposition is unconsciously directing their actions (Pinker 2002). This section argues that not only do illusory social constructions confound human intelligence, but that genetically-determined "biological

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[9] And is likely to remain so. What military or economic superpower has ever voluntarily relinquished its privileged position in the geopolitical hierarchy? For that matter, even most ordinary citizens as presently 'programmed' would see such a plan as a threat to their survival and respond accordingly.

[10] To this extent, Heidegger was right—the corporate sector has exploited both humans' natural tendency to intellectual laziness and their hidden wants and fears to sideline meditative thinking from the public domain.

drives . . . can [also] be pernicious to rational decision-making… by creating an overriding bias against objective facts . . .” (Damasio 1994, p. 192).

Understanding the innate predispositions that affect individual and group behavior requires reference to the evolutionary biology of cognition. The latter involves both the evolved structure (nature) and the experiential development (nurture) of the human brain. First, consider that the human brain is a complex organ with a long and complex evolutionary history. Indeed, MacLean (1990) argued that the organization of the human brain roughly recapitulates three broadly overlapping phases of vertebrate evolution. Successive anatomical developments were added to and integrated with pre-existing structures thus retaining original functions while enhancing the organism’s overall fitness. In effect, the human brain has three quasi-independent sub-systems each having distinct functions, memory, ‘intelligence’ and limitations:

1. The reptilian brain (the brainstem and cerebellum) is the seat of sensory perception and related coordinated movement; autonomic functions associated with the body’s physical survival (e.g., circulation and breathing); instinctive social behavior (e.g., pertaining to territoriality, social stature, mating and dominance). It also executes the fight or flight response and controls other mainly hard-wired instinctive behaviors.
2. The limbic (or paleo-mammalian) system is the primary locus of emotions (e.g., happiness, sorrow, pleasure, pain) and related behavioral responses (e.g., sexual behavior, play, emotional bonding, separation calls, fighting, fleeing). It is also the location of affective (emotion-charged) memories and the source of value judgments and informed intuition.
3. The neo-cortex (neo-mammalian or ‘rational brain’) is the most recent (and least experienced) addition, but occupies over two thirds of the human brain by volume. It is the seat of consciousness and the locus of abstract thought, reason, logic and forward planning; it controls voluntary movement and actions.

Of course, the normal healthy brain acts as an integrated whole—the three sub-brains are inextricably interconnected, each continuously influencing the others. The emergent behavior and overall personality of the individual is therefore generally a seamless melding of thoughts, emotions and instincts. However, since awareness springs largely from the neo-cortex the individual may not be conscious that s/he is also under the influence of neural and chemical (hormonal) stimuli originating in other parts of the brain.

This interplay of motivations is of more than passing interest. It implies that *H. sapiens* is inherently a conflicted species. In some circumstances, emotional/instinctive predispositions (e.g., overt aggression, passionate hatred, abject fear, sensual desire) originating beneath consciousness may well override reason and when this happens the individual may not be aware that a ‘lower’ part of the brain has seized control. Sometimes we crave the emotional boost that comes from being certain even when we are dead wrong! (Burton 2008). Even if our actions are guided *mainly* by emotions, we often lie to ourselves (rationalize) that we are being entirely reasonable. Everyone is aware of situations in which *endogenous* factors generate irreconcilable tensions between our rational minds and our emotional/instinctive control centers. The ‘circumstances’ can range from trivial to life-changing. What dieter has not found him/herself unable to resist that third helping from the all-you-can-eat buffet? The statistics on marital infidelity are witness enough to the frequency with which people’s conscious will and professed morality yield to raw sex drive and emotions when the opportunity arises. Whether reason or emotion/instinct wins out in a particular case depends on myriad factors including previous experience (e.g., socialization, education and religious training) and the native personality of the individual. The main point is that whether or not one is conscious of what is going on, “There are indeed potions in our own bodies and brains capable of forcing on us behaviors that we may or may not be able to suppress by strong resolution” (Damasio, 1994, p.121).

Irresolvable conflict may also develop between the individual’s sense of stability and *exogenous* factors. In these circumstances the universal human predisposition to lie may come into play. People are often not psychologically equipped to bear the burden of reality. Confronted by an overwhelming problem with no satisfying solution at hand, the natural human reaction is to paper it over, to lie about it to ourselves and to others. In some situations lies are psychologically necessary “because without them many deplorable acts would become impossibilities” (Jensen 2000, p.2). (The same would apply to stupid or irrational acts.) Psychologist Dorothy Rowe suggests that “Lying gives us the temporary delusion that our personal and social worlds are intact,… above all, that we are not likely to overwhelmed by the uncertainty inherent in living in a world we can never truly know” (Rowe 2010).

Perhaps the most complex and consequential form of self-deception is deep systemic denial by whole sub-groups within society. Consider the well-funded and highly-organized climate denial movement or continuing over-the-top resistance to the fact of evolution on the part of the religious right[11] (see MacKenzie 2010). Systemic denial generally emerges in situations where an individual’s or group’s core beliefs and values are under siege. It is clearly reflected in such phenomena as unyielding loyalty to the established order of things in the face of overwhelming contrary data (e.g., economists’ continued defense of growth-based economics) or in situations where there is clear acknowledgment of “a dire problem yet no volition to address it” (Pratarelli & Aragon 2008) (e.g., the failure of the November 2009 Copenhagen climate change conference).

This form of denial actually has a physical basis and involves yet another layer of nature/nurture interaction. Recent studies in human cognition show that, in the course of individual development, repeated sensory experiences and continuous exposure to fixed cultural norms (e.g., religious doctrines, political ideologies and disciplinary paradigms) literally help to shape the brain’s synaptic circuitry in quasi-fixed patterns that reflect and embed those experiences. In short, *H. sapiens* has evolved in such a way that the brain is pre-adapted *to record for playback*

[11] Many levels of motivation are at play. For big oil and coal, for example, it may seem rational in the economic short term to turn the public against effective carbon emissions reduction policies, but if the climate science is correct this strategy of denial is against everyone’s longer term interests.

critical beliefs and behavioral norms shared by members of the individual's group. (The automatic inscription in juvenile brains of tribal/cultural norms that have proved successful to date would presumably be highly adaptive in a relatively static biophysical environment.) The critical point in the present context is that once a synaptic circuit has formed, people tend to seek out *compatible* beliefs and experiences to reinforce the associated cultural pre-sets and, "when faced with information that does not agree with their [preformed] internal structures, they deny, discredit, reinterpret or forget that information" (Wexler, 2006).

Cognitive neurobiology thus provides a multi-layered bio-social basis for understanding individual behavioral intransigence and wider cultural inertia in the context of accelerating global change. Once a person's synaptic pathways are well-entrenched and adapted to particular circumstances it is difficult for that individual to accept subsequent changes in their socio-cultural or biophysical environments. Even when one accepts that 'reprogramming' is necessary, the process can be lengthy and unpredictable. Re-establishing cognitive consonance' between peoples' programmed perceptions and new environmental realities thus requires that all parties engage wilfully in the restructuring of their own neural pathways and psychological states (Wexler 2006).

In these circumstances, achieving sustainability may require that global society engage in a world program of social re-engineering. There may be no other way to assert humanity's collective intelligence and reason over people's predisposition to defend the *status quo*. Certainly creating a global mind-set receptive to planned dramatic change is the only way to implement anything like the 'steady-state with redistribution' strategy for sustainability outlined earlier. [12]

As part of the above we will certainly have to discard many of the 'pre-analytic visions' associated with the political ideologies, religious doctrines and academic paradigms that are helping to create the (un)sustainability crisis. Consider the dominant conception of the economy as an open, growing, self-producing system floating free from the biophysical world. This vision is so fundamentally at odds Herman Daly's more realistic vision of the economy as an open, growing but fully contained and totally dependent sub-system of the non-growing ecosphere, that no reconciliation is possible. However, fully consistent with denial, or perhaps the subconscious need for familiar certainty, mainstream economists have generally tended "to deny, discredit, reinterpret or forget" the Daly alternative rather than accept the collapse of their fundamental models. Given the pace of global change, Max Planck's interpretation of the general problem is particularly sobering:

[12] Those who recoil at the thought of social engineering for the common good should keep in mind that the present generation has already been socially engineered for the corporate good. The alternative is to wait until widespread disaster knocks large numbers of people off their comfortable cognitive perches. This will also force them to reconstruct their internal 'realities' (perceptions) but in much less agreeable ways.

> "… a new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it" (Planck1949, p.33).

(Of course, even this won't turn the trick if the universities keep churning out thought-clones of Lawrence Summers rather than Herman Daly think-alikes).

Epilogue: Herman Daly and cultural evolution

I started out by arguing that humans have no choice but to live according to socially-constructed models of reality and that, in the unconscious construction of these abstractions, we tend to be seduced by 'magical thinking'. I have also argued that this is not necessarily a hopeless situation—society could choose to engage in the *conscious* re-writing of its core cultural narratives. Certainly we need a new deliberately-structured model of the economy that recognizes both humanity's *de facto* ecological niche as a consumptive 'dissipative structure' and people's complex relationships in community.

We already consciously create physical and abstract models in many domains of human activity from architecture to zoology. Invariably, the purpose is to simplify certain aspects of reality while retaining the essential character and behavior of the entity being modeled. We hope that understanding how carefully-constructed models behave when we manipulate key variables or parameters will provide reliable insights into how the real world might behave under similar circumstances. This is why good experimental science proceeds cautiously, continuously testing its assumptions and hypotheses against the real world. When a hypothesis fails, scientists restructure the model accordingly, each time hoping to nudge the model's behavior closer to that of the reality it purportedly represents.[13]

It is worth noting too that bio-evolution proceeds in precisely this 'trial and error' fashion. In effect, every genetic mutation represents an experimental 'hypothesis' about the relevant organism's environment. Mutations that increase an individual's survivability or 'fitness' are retained and accumulate in its offspring, i.e., in future 'models' of the organism. Failed hypotheses are 'selected out' and eventually disappear from the population.

Shouldn't society apply this understanding of both the creative role of models and the evolutionary process to the great economic experiment presently playing out in the material world? As we test the neo-liberal economy against external reality, we are performing an uncontrolled and potentially dangerous experiment in human evolution. However, as the results come in we are showing little willingness to adapt the model to its 'environment'.

This is particularly disappointing. The fact that human evolution is more driven by cultural than by biological factors gives us a potential advantage over other species. It is common knowledge that 'genes' are the basis of biological evolution. Genes are heritable bits of genetic information

[13] It has been argued that economist do the opposite, asking the real world to conform to their models!

that interact with 'the environment' to determine the physical and behavioural phenotype (the 'appearance') of the individual. Less familiar is the concept of 'memes'. Memes are heritable units of cultural information—persistent myths, economic models, or working technologies—that influence the 'phenotype' of the society of concern (Dawkins 1976). Memes are thus the basis of cultural evolution; they have a leg-up over genes in that memes can spread rapidly among living individuals in the *same* generation or population. This means that human evolution, particularly the cultural component, is potentially much faster than biological evolution.

But only potentially. Memes, like genes, are subject to natural selection. If a previously successful meme or meme complex (e.g., growthist economics) becomes maladaptive under changing environmental circumstances it may be eliminated by that environment. Thus, while memetic evolution is theoretically faster than the genetic variety, it may not always be fast enough. Whole cultures that refused to abandon maladaptive meme-complexes—core values and beliefs—have foundered and collapsed (see Diamond 2005).

With this in mind, a truly rational society would quickly adopt Herman Daly's steady-state economics on the evidence that neoliberal economics is about to be 'selected out' and that the Daly brand provides a better map of contemporary biophysical reality. Simply put steady-state economics offers humanity superior fitness and greater survival value.

While we're at it, we might consider improving the social dimensions of economic life. In addition to logical intelligence, humans also have unmatched capacity for empathy (with both other people and species), to exercise moral judgement, and to use all of these traits in planning for their future. Neoliberal economics ignores most dimensions of human intelligence, eschews moral and ethical considerations and dismisses long-term planning. Once again, by contrast, Herman Daly's political economy of displays all these qualities in abundance (see Daly and Cobb 1994) and all are necessary if global civilization is to achieve an equitably sustainable 'steady-state' relationship with the ecosphere.

Wake up world! It would be a tragic irony if modern *H. sapiens*, that self-proclaimed pinnacle of self-conscious intelligence and earthly evolution were to be unceremoniously ejected by the ecosphere because of a lingering, maladaptive propensity for political and economic folly based on self-deception and 'magical thinking'.

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3ox 1: The Constant Capital Stocks Criterion for Sustainability

/Iuch contemporary discussion of 'sustainability' hinges on the concept of 'Hicksian income' after the British conomist, Sir John Hicks. Hicks defined true income as the maximum level of consumption that an individual or nation) can consume over a given time period while leaving wealth-producing capital intact (Hicks 1946). In ther words, living on true income means 'living on the interest'— not tempting poverty by depleting capital ssets.

Iicksian income so defined is at the heart of the so-called 'constant capital stocks criterion for sustainability'. As night be expected, there two competing versions (Victor 1991). The dominant version reflects neo-liberal conomists' dismissal of the unique contributions of resources (particularly self-producing natural capital) to the conomy and human well-being (Pearce & Atkinson 1993, Victor *et al*. 1995). This so-called 'weak' version of he constant capital stocks criterion can be stated as follows:

> *An economy is sustainable if the aggregate value* ***per capita*** *of its stocks of manufactured and natural capital (or the money-income derived from those aggregate stocks) remains constant or grows from one accounting period to the next.*

'his definition obviously assumes the commensurability and substitutability of different forms of capital. As ong as the aggregate market *value* of different forms of capital remains unchanged (or increases), society is eemed to be sustainable. It horrifies ecologists to observe that the weak sustainability criterion assumes all is vell provided that the rising market value (i.e., increasing scarcity value) of natural capital (or the income erived therefrom) increases to compensate for the depletion of the physical stocks.

Ecological economists therefore subscribe to an alternative 'strong' version of the constant capital stocks riterion as follows:

> *An economy is sustainable if its physical stocks of both manufactured capital and natural capital* ***per capita*** *are held constant or grow in separate accounts from one accounting period to the next.*

3y this definition, manufactured and natural capital are not commensurable and substitution is at best imperfect. /Ioney valuation does not enter the picture. (Money is itself an abstraction.) Herman Daly has championed the dea that in many circumstances, manufactured capital and natural capital are complements not substitutes— nore fish boats do not compensate for the collapse of the fish stock (e.g., Daly 1991a, Ch.13; Daly 1994). ndeed, a moment's reflection reveals that some form of natural capital is a *prerequisite* for all forms of nanufactured capital and their functioning.

Vhy does this dispute matter? Because self-producing 'natural capital' maintains the life-support functions of he ecosphere, the risks associated with its depletion are unacceptable, and there may be no possibility for echnological substitution. Meanwhile, the prevailing system of costs, prices, and market incentives fails bsolutely to reflect ecological scarcity or help determine appropriate levels of natural capital stocks. Even some airly mainstream environmental economists have therefore observed that "*conserving what there is* could be a ound risk-averse strategy" (Pearce *et al*. 1990,7 [emphasis added]).

as young, nervous, and naïve, and had been struggling to adapt concepts from bio-ecology to land use planning . ways that my students (mostly geographers and economists) could understand. I opted to present a crude odel of the human carrying capacity of the Vancouver region (the Lower Mainland of British Columbia) ɔinting out that the region was already living well beyond its biophysical limits.

fter my presentation (which was received politely enough) I was invited to lunch by a senior colleague who just ıppened to be a prominent resource economist. Very gently, with the greatest of professional respect and ɔurtesy, he advised me that should I persist in pursuing research on human carrying capacity, my academic ıreer would likely be a Hobbesian "nasty, brutish, and short." He argued that economists had effectively ɛgated all such neo-Malthusian thinking. Why should the population or economy of a given region or country be onstrained by local shortages of anything? Any region could simply trade services or surpluses of resource 'a' ır needed supplies of resource 'b', thus freeing itself (and presumably its trading partners) from local limits to rowth. And, in any event, technology could substitute for nature. He ended by suggesting that I bone up on trade eory, the power of the marketplace, the emerging service economy, and technology's role in increasing 'factor roductivity'.

ly economist friend had delivered his verdict with intimidating assurance and conviction. These were new ideas ır me. My formal training had not stretched far beyond the disciplinary boundaries of biology; I had never had) much as an introductory course in economics. I left the lunch deflated, discouraged, and depressed, tail lodged rmly between my legs.

ut there was something incomplete about my colleague's prescription. The farm-boy and ecologist in me could ɔt conceive of a *H. sapiens* so detached from nature. This question became the worm in the apple of my mind, ıawing away beneath the surface struggling to emerge. Even so, an embarrassing length of time passed (given e simplicity of the insight) before I had my 'eureka' experience. Part of the problem was with the standard ɛfinition of carrying capacity as 'the average maximum population of a given species that can occupy a ırticular habitat without permanently impairing the productive capacity of that habitat'. Since humans engage in ade and are capable of increasing resource productivity, local limits apparently dissolve and economists could deed argue that 'carrying capacity' had no useful meaning applied to humans.

ut what happens if we invert the carrying capacity ratio? Rather than asking what population can be supported . a given area, the relevant—and answerable—question becomes how much ecosystem area is needed to support given population on a continuous basis, *wherever on Earth the land and water is located and whatever the chnological sophistication of the population*. This simple shift in perspective re-established people's direct ɔnnection to 'the land'. It also led to my conceiving 'ecological footprint analysis'(EFA) as a tool to estimate e eco-system area effectively appropriated by any specified population to produce the resources it consumes ıd to assimilate its wastes. Human carrying capacity was firmly back on the agenda.

ut what really restored my confidence in studying *H. sapiens* as an ecologically significant species was ıcountering Herman Daly's insistence that the economy is indeed embedded in nature and that the economic rocess is subject to natural law, particularly the second law of thermodynamics. (A population's eco-footprint ın also be defined as the photosynthetic surface required, on a continuous basis, to regenerate the biomass quivalent of the negentropy being consumed and dissipated by that population.) EFA has subsequently shown at most high-income consumer societies are running ecological deficits relative to domestic biocapacity and erefore living, in part, on imports. It also suggests that there is insufficient capacity elsewhere in the world to ɔver these deficits (only a few countries have surplus biocapacity). Trade has enabled the world as a whole to go to overshoot and, despite humanity's technological wizardry, the per capita eco-footprint is still expanding. As erman Daly has long suggested, the human enterprise now grows by drawing down natural capital and the latter ıs become the scarce factor of production. This reality imposes formidable limits to growth.

Table 1: A 'Second Law' Comparison of Human-less and Human-Dominated Ecosystems

Ecosystems without humans	**Human-dominated econo-ecosystems**
Evolve and develop by assimilating, degrading and dissipating available solar energy (exergy) using photosynthesis and evapotranspiration.	Grow and develop by extracting, degrading and dissipating energy-rich 'resource stocks' that have accumulated in the ecosphere, including other species, entire ecosystems and fossil hydrocarbons.
Anabolic processes (production of biomass) marginally exceed catabolic processes (degradation and dissipation).	Catabolism (consumption and dissipation of energy and material resources) exceeds anabolism (the production of humans and their artifacts).
Biomass accumulation dominates; species proliferate, complexity increases; stocks of available energy and matter (resource gradients) accumulate.	Humans and their artifacts accumulate; ecosystems are simplified or eliminated, biodiversity declines; resource stocks are depleted and dissipated.
Materials recycle through ecosystems (biogeochemical 'nutrient' recycling); waste heat dissipates off-earth; the entropy of the universe increases.	Material wastes (economic throughput), often novel and toxic, accumulate in the ecosphere; waste heat dissipates off-earth; functional integrity of ecosystems is lost; the entropy of ecosphere (ultimately the universe) increases.