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End game: the economy as eco-catastrophe and what needs to change

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Prologue

In summer 2018-2019, Australia sizzled in record heat; every state simultaneously suffered temperatures of 40°C to 45°C for days at a time. A particularly searing week in late November killed thousands of spectacled flying-foxes as the mercury soared beyond 42°C, an unprecedented bat carnage that continued on and off through January. When temperatures finally eased in north Queensland at the end of that month, record rains and flooding drowned much of the region; 200,000 people were displaced (several died), hundreds of thousands of livestock drowned, and damage costs soared into the multi-millions.

Hardly anyone on the other side of the world noticed; people were distracted by their own problems. In North America, a weak and wobbly jet-stream allowed the Polar Vortex to bulge far south, engulfing much of Canada and the northern US east of the Rockies in a great amoeba-like lobe of frigid Arctic air. Record low temperatures were recorded at many sites. Late January temperatures in Winnipeg reached as low as −40°C (−40°F), −52°C (−62°F) with the wind-chill; Cotton, Minnesota was the coldest location in the US on 30 January with a low of −49°C (−56°F). At least 22 people across the continent died from the extreme cold.

Australia and North America may have been separated by 90 degrees, but extreme weather united their citizens in common concern over warming-induced global climate change. Indeed, all peoples now face a truly unprecedented communal challenge. We may perceive global warming, biodiversity loss, tropical deforestation, spreading marine dead zones, chronic air/water pollution, land/soil degradation, plummeting sperm counts, etc., as separate problems, but it is more realistic and potentially more productive to recognize that all are symptoms of a singular phenomenon, *gross human ecological dysfunction*. This is a genuine global meta-problem; it is potentially fatal to civilization and, paradoxically, entirely self-induced.

Which begs the question: how is it that the allegedly most intelligent and self-aware species on Earth is systematically destroying its own habitat, the only human-habitable planet in our solar system and the only planet most humans will ever know? The answer is, of course, multifaceted with roots in everything from what was once perfectly adaptive human behaviour, through Newtonian physics, to culturally inscribed (mis)representations of reality.

We cannot in a single chapter explore every dimension of the problem. However, we can show how several of the most important causal mechanism have come together to produce a global economic system whose conceptual framing, operating assumptions and *de facto* practices are pathologically incompatible with the very ecosystems that sustain it. In the circumstances, eco-destruction is inevitable. To understand this remarkable example of maladaptive behaviour we must begin with epistemology – how we know what we know – and a particularly quirky feature of human cognition.

We make it up as we go

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

Many people are startled to learn that most of what they believe to be true, most of what they think they know, is literally *made up*. Foundational cultural narratives and social norms may masquerade as reality but they are nevertheless products of the human mind, massaged or polished by social discourse and elevated to the status of received wisdom by custom or formal agreement. All cultural narratives, worldviews, religious doctrines, political ideologies, and academic paradigms are actually "social constructs".

Indeed, it is not much of a stretch to assert that all formal knowledge is socially constructed. One passively acquires the convictions, values, assumptions, and behavioral norms of his/her tribe or society simply by growing up in that particular milieu. By the time most people have reached maturity they will have adopted their culture's overall "narrative" and will subscribe, consciously or not, to any number of subsidiary religious, political, social, scientific or other disciplinary paradigms.

Some well-known constructs are *entirely* made up – "capitalism", "communism", "civil rights", and "democracy" for example, have no true analogues in the non-human world. These and similar concepts were birthed in words and given legs entirely through socio-political discourse. Other social constructs are created explicitly to describe corresponding real-world phenomena. For example, the domain of science encompasses anything measurable in time and space – gravity, light, energy, matter, etc. Science is unique among formal ways-of-knowing in that scientists explicitly test the validity of tentative constructs (hypotheses) about the real world through observation and experiment and adjust their understanding accordingly. When experimental results are reliably replicable, a hypothesis may be elevated to the level of accepted theory – a social construct that can be used for explanation and prediction concerning a particular entity or phenomenon.

Still other social constructs occupy a middle ground. For example, we can agree that "the economy" is that set of human activities involving the production, distribution and consumption of goods and services. That said, there are many ways of conceiving how an economy should be structured, each reflecting its followers' particular set of socially-constructed values and their beliefs/assumptions about the economy and its relationship to society, governance systems, ecosystems, etc. One approach may give prominence to concepts or activities that are marginalized or omitted altogether from another (e.g., private vs. state ownership, free vs. controlled markets). Things can get complicated – any economic paradigm is an elaborate socially-constructed model that may contain (or omit) other models that are themselves socially constructed.

By now it should be clear that much of what humans take to be "real" may or may not bear any relationship to anything "out there". More remarkably still, most people generally remain unconscious that their collective beliefs may be shared illusions – a cognitive enigma that may well determine the fate of humankind. No matter how well- or ill-founded, entrenched social constructs are perceptual filters through which people interpret new data and information; and, because our constructs constitute perceived reality, they determine how we "act out" in the real world. Millions of lives may be jeopardized if those in positions of authority cherry-pick data guided by some dangerously faulty but comfortable social construct (climate-change denial, anyone?).

Critical thinkers will recognize that, until proved otherwise: a) all constructs belong in the domain of "conjectural knowledge" and that; b) not all conjectures are created equal. Some conjectures will necessarily be "better" than others, particularly in terms of how well they represent biophysical reality. To reiterate, in science "Conjectures [hypotheses] are our trial balloons, and we test them by criticizing them and by trying to replace them, by trying to show that there can be better or worse conjectures, and that they can be improved upon" … "So long as a theory stands up to the severest tests we can design, it is accepted; if it does not, it is rejected" (Popper, 1972).

What does all this imply about economic thinking and "the economy"? Let's acknowledge that all economic theories/paradigms are elaborate conjectures and that none can contain more than a partial representation of biophysical, or even social, reality. If this is an important general limitation, we should be particularly concerned about today's dominant neoliberal economic paradigm (the economics of capitalism). Neo-liberal models incorporate a stinted caricature of human behavior, virtually ignore socio-cultural dynamics and make no significant reference to the biophysical systems with which the economy interacts. Moreover, as an economist colleague recently explained, mainstream economists generally do not operate in scientific mode. While natural scientists experiment and subsequently adapt their models better to represent reality, economists, particularly those enamoured with the idea of a self-regulating (free) market, would have the real economy adapt to fit their models.

Economics – a branch of human ecology (not!)

For present purposes, ecology might be defined as the scientific study of the cooperative and competitive relationships that have evolved among organisms in ecosystems and how these relationships serve to allocate energy and material resources among constituent species. Similarly, economics might be defined as the study of economic behaviour and the efficient allocation of scarce resources among competing users in human society. The parallels are obvious; moreover, since humans are of the ecosphere, and the economy extracts resources (energy and materials) from the ecosphere, economics should arguably be a branch of human ecology. Regrettably, the conceptual foundations of the two disciplines have diverged since their beginnings.

Neoliberal economics – not of this world

> "We cannot regulate our interaction with any aspect of reality that our model of reality does not include" (Beer, 1981).

The modern or "scientific" world-view that prevailed from the 18th through much of the 20th Century was framed by French philosopher René Descartes' mechanistic view of the universe as "a vast machine, wound up by God to tick forever" (Berman, 1984, p. 21). Descartes extended his model to include living organisms and even saw human thought as an iterative mechanical process by which the mind observes the world "out there" as separate object (hence the notion of "objective knowledge"). However, it was the genius of Sir Isaac Newton that effectively validated the Cartesian paradigm. Newton's *Principia* gave us apparently universal laws of mass and motion which describe the universe as a mechanical machine of unlimited dimensions behaving according to strict mathematical rules. At last, humans were potentially freed from religious superstition and other forms of unreason. For the first time, European society had a body of science that satisfied Descartes's mechanistic vision, including deterministic predictability, and promised humans the ability to manipulate nature indefinitely toward their own ends. This "scientific materialism" provided the technical foundation of industrial society, and helped entrench a new myth of human dominance over the natural world.

It also supplied a conceptual framing for modern economics. Contemporary neoclassical / neoliberal economics – which has enjoyed a remarkably uncritical sweep through the modern world over the past half century – finds its deepest roots in the concepts and methods of Newtonian analytic mechanics. Inspired by the unprecedented success of Newtonian physics, neoclassical economics was conceived in the late 19th Century as a sister social science in which market behavior could be modeled as "the mechanics of utility and self-interest" (Jevons, 1879). Its founders abstracted the economic process from nature, viewing it as an independent and "self-sustaining circular flow between production and consumption," in which "complete reversibility is the general rule, just as in mechanics" (Georgescu-Roegan, 1975, p. 348).[1]

From a human ecological perspective, this is pure aberration. It ignores extraction/ (over)harvesting, various material transformations, and the eventual discharge of the entire material flow back into the ecosphere as degraded waste (pollution). To interpret the economy as a self-generating circular flow without considering the unidirectional throughput of energy/material is akin to studying human physiology as a circulatory system with no reference to the digestive tract. One might as well ask biology students to accept that "an organism can metabolize its own excreta" (Daly, 1991, p.197). More generally, neoliberal theory lacks any realistic representation of the energy and resource constraints, functional dynamics, social relationships, interspecies dependencies and time-dependent processes at the heart of ecosystems thinking (see Christenson, 1991). There is no ecology in economics.

A related equally problematic construct is neoliberal confidence that resources are more products of human ingenuity than they are of nature. Theoretically, as scarcity forces up prices it will in turn both encourage resource conservation and stimulate the search for technological substitutes. "If [built] capital and natural resources are substitutes in production then neither can be limiting – if one is in short supply you just substitute the other and continue producing" (Daly, 2012). There are many historical examples of allegedly "near-perfect substitution" such as the partial displacement of dirty coal by solar photovoltaics in electricity generation. It has therefore become part of conventional wisdom that market factors are more than sufficient to overcome emerging resource scarcities (Victor, 1991). Indeed, neoclassical texts have long accepted that "exhaustible resources do not pose a fundamental problem" (Dasgupta and Heal, 1979, p. 205). Neoliberal economists have even dropped land/resources as a separate factor in their production functions, conflating it with finance capital (Wolf, 2010) and again implying that the contribution of nature *per se* to the economy is negligible.

Neither is pollution a serious problem in the neoliberal paradigm. Economists define pollution damage costs not reflected in market prices as "externalities" – market imperfections – that

[1] In the circular flows model, firms pay wages/salaries/dividends to households in exchange for labour and investment; households spend the money on goods and services purchased from firms, enabling the cycle to repeat itself.

society can “internalize” if it *chooses* to get the prices right, through investment in improved technology, better regulation or pollution charges (e.g., carbon taxes). (This assumes – wholly unrealistically – that we can assign an accurate dollar value to ecological degradation.)[2] In general, society accepts ecosystems degradation as a necessary trade-off against economic growth. We pollute in exchange for jobs or income and see the point at which to stop largely as a matter of negotiated public choice, i.e., there are no unanticipated tipping-points-of-no-return or other serious risks. Significantly, any social construct that conceives of the economy as a self-sustaining system and rationalizes pollution neatly frees the human enterprise for perpetual growth.

H. sapiens as ecological entity

From the ecological perspective, human-induced global change – climate disruption, plunging biodiversity, etc.– is unambiguous evidence that our prevailing growth-based cultural narrative is seriously flawed. If we wish to re-construct the economy for sustainability our models must include a realistic representation of human behavioral ecology.

We can start by acknowledging that *H. sapiens* is a product of evolution and shares various adaptive genetic traits with other species. Consider bacteria dropped into nutrient broth or deer introduced to a food-rich predator-free island. Both species populations will expand exponentially, spread over the entire “habitat”, deplete their “new” resource base and finally collapse. *H. sapiens* is little different. Indeed, *unless or until constrained by negative feedback (e.g., disease, starvation, self-pollution), human populations, like those of all other species, will expand into any accessible habitat and use all available resources – even at the risk of collapse* (though in the case of humans collapse may be delayed since “available” is determined by the state of technology).[3] Evolutionary point: Individuals that employ strategies to secure the most suitable habitat and acquire the most essential resources, on average, survive longer and leave more viable offspring.

Natural selection also generally favors individuals who are most adept at satisfying short-term selfish needs whether by strictly competitive or in-group cooperative means (see Pratarelli, 2008). (If we don’t claim some perishable resource now, some competitor might take it.) Humanity’s well-known tendency to favor the here-and-now (i.e., to discount future benefits and costs) has almost certainly evolved through natural selection (and is one ecologically-significant behavioral trait that *has* been incorporated into economic methods and models such as cost-benefit analysis).[4]

Competition is clearly a major evolutionary driver. While not evident to modern urban-dwellers, humans compete, not only with other people, but also with other species for food and habitat. And we usually win – high intelligence and technology have ensured that *H. sapiens*’ capacity for habitat and resource domination vastly outstrip those of all other species

[2] Note that if full-cost pricing were possible, many people today could not afford at least some of what they perceive to be basic necessities.
[3] The exploitation of “tight” shale oil/gas, tar-sands, and deep sea drilling for petroleum are examples of advanced technology in pursuit of the last deposits of “available” energy resources. Consider, too, how constantly-evolving fishing technology (e.g., factory-freezer trawlers, sonar tracking) pursues various fish stocks to near-depletion. Credit cards are *virtual* resources that enable people to keep consuming after they have depleted real income.
[4] A genetic predisposition is not an inevitability. Rather, it is a propensity that is likely to play out in the absence of countervailing circumstances such as moral codes, cultural taboos, legal prohibitions, or other social inhibitors.

(Waring, 2010). Our species has the greatest geographic range of any ecologically comparable organisms – we have occupied all suitable, and sometimes even hostile, habitats; in terms of energy use, biomass consumption, and various other ecologically significant indicators, human demands on their ecosystems dwarf those of competing species by ten to a hundredfold. Human consumption of biomass, for example, exceeds the upper 95% confidence limits for biomass ingestion by 95 other nonhuman mammals by two orders of magnitude (Fowler and Hobbs, 2003). *H. sapiens* has become, directly or indirectly, the dominant macro-consumer in all major accessible terrestrial and marine ecosystems on the planet. Indeed, our species may well be the most voraciously successful predatory *and* herbivorous vertebrate ever to walk the Earth (Rees, 2010). (A remarkable degree of engagement for a species that sees its economy as floating free from the ecosphere.)

H. sapiens: "maximum power" exemplar

Austrian physicist Ludwig Boltzmann famously recognized that the Darwinian struggle for existence is effectively a competition for available energy to do useful work (Boltzmann, 1886/1974). Subsequently, ecologists Alfred Lotka (1922) and later Howard Odum formulated what is now known as the "maximum power principle": Successful systems are those that evolve to maximize their use of available energy per unit time in the performance of useful work (growth, self-maintenance and reproduction) (see Hall, 1995). "Maximum power" is arguably a fundamental organizing force in natural ecosystems.

Unsurprisingly, *H. sapiens* success in "maximum power" terms is unequalled. All species need energy to function and reproduce but most animals are restricted to the chemical energy they ingest in their food – endosomatic ("within body") energy. Humans have an evolutionary leg up in their near-unique capacity to employ "exosomatic" (outside the body) energy to do additional work from harvesting food to engineering the international space station. Thus, the technological history of *H. sapiens* is crudely marked by increasing exosomatic energy use per capita, from 20 giga-joules per year by hunter-gatherers, through 60 GJ/yr by early farmers to 200-300 GJ/yr in typical industrial societies (Fischer-Kowalski and Haberl 2007). At the upper end, this is equivalent to approximately 80 times human endosomatic energy use per person per year.

Human "maximum power" ascendance was kick-started about 10,000 years ago when agriculture generated the first major food energy surpluses. This enabled "civilization" – the emergence of social structure, governments and ruling classes, division of labor, specialization, etc., – and accelerated technological innovation in everything from agriculture through metal-work, and boat-building. Ponting (2011) documents how, for subsequent millennia, humans were able to explore and plunder terrestrial and marine ecosystems over virtually the entire planet, using animal (including human slavery), wood-fire, water, and wind energy alone. These are exosomatic energy sources, but are all derived from contemporary solar energy. It wasn't until the wide-spread use of fossil-fuels (vast stocks of stored ancient solar energy) that the human enterprise was able fully to exercise its "maximum power" muscle.

The effect was spectacular, unprecedented – and likely to be short-lived. It took 99.9% of modern humans' 200,000 year history for our population to reach one billion in the early 19th century. In just the next 200 years (1/1000th as much time) it ballooned to 7.7 billion by 2018.

This was an extra-somatic energy revolution.[5] From 1800 to 2016, globally fossil energy use increased over 1300 fold![6] By 1997 (when annual consumption was 40% less than in 2018) humanity was already burning fossil fuel containing about 422 times the net amount of carbon fixed by photosynthesis globally each year, or 73 times the global standing stock of carbon in vegetation (Dukes, 2003). (This won't end well.)

Meanwhile, between 1800 and the present, real global GDP increased over 100-fold and average per capita incomes by a factor of 13 (rising to 25-fold in the richest countries) (Roser, 2018). Inevitably, material consumption and attendant pollution have more than kept pace (see graphs in Steffen, et al., 2015), driving an all-too-evident parallel degradation of air, land and water all over the planet. It is particularly worth noting that, with exponential growth, half the fossil energy ever used (and half of the fossil CO_2 ever produced), has been burned / emitted in just the past 25-30 years! (Climate change can only accelerate.) During the 20th Century – economists' "separatist" fantasies aside – H. sapiens' maximum power "success" made our species not only the dominant ecological entity but also the major geological force changing the earth.[7] (It is testament to short cultural memory that people today take the recent spurt of growth to be the norm when it actually defines the most anomalous few decades in 200 millennia of human history.)

The "second law"

The global degradation accompanying the "great acceleration" underscores why the ecologically relevant flows through the economy are not economist's circular money flows but rather the unidirectional transformations of energy and matter. These transformations are governed not by static mechanics but rather by thermodynamics, in particular the second law of thermodynamics (the entropy law). In simplest terms: every spontaneous change in an isolated system (one that cannot exchange energy or matter with its "environment") increases the entropy (randomness or disorder) of the system; more generally, *every* material transformation irreversibly degrades useable (high-grade) energy/matter to a more disordered, less available, entropic state.

The second law regulates all energy and material transformations in all subsystems of the ecosphere, including the human economy. As Georgescu-Roegen (1975; 1977) tried unsuccessfully to impress on fellow economists, this means that an expanding economic process is ultimately self-destructive: it feeds on useful energy/matter first produced by nature and returns it to the ecosphere as useless waste. A should-be-obvious corollary of second law is that all economic "production" is mostly consumption. Because of second law inefficiencies, the bulk of the energy/matter that enters the production process is emitted almost immediately as (often toxic) land air or water pollution; only a small fraction is embodied in marketable goods and services (and even this eventually joins the waste stream). Again, without reference to this one-way entropic throughput, it is virtually impossible to relate the economy to the environment, yet the concept is virtually absent from economics today (Daly, 1991).

[5] Abundant cheap energy is the means by which humans acquire food and all the other resources needed to grow and maintain the human enterprise.
[6] The contribution from coal grew from just 97 terawatt hours in 1800 to 43,403 TWh in 2016; petroleum and natural gas were not used at all until later in the 19th century, but by 2016 they were contributing 50,485 and 36,597 TWh respectively to global energy supplies (Richie and Roser, 2019).
[7] It is sadly ironic that destructive global change is actually evidence of humanity's evolutionary success.

The human enterprise as dissipative structure

Consistent with the second law, an *isolated* system becomes increasingly randomized and disordered with each successive internal transformation: energy dissipates, concentrations disperse and gradients disappear. Eventually, the system reaches at least local thermodynamic equilibrium, a state of maximum entropy in which nothing further can happen. That said, we are all familiar with real-world systems that are evidently not sliding toward equilibrium. Living organisms and other complex systems "self-organize" in ways that resist the inexorable drag of the second law; they maintain themselves in high-functioning, low entropy, "far-from-equilibrium" states because they are open systems able to exchange energy/matter with their "environments". Consider the ecosphere, a self-organizing, highly-ordered, multi-layered system of mind-boggling structural complexity represented by millions of distinct species, differentiated matter, and accumulated biomass. Over geological time, its biodiversity, systemic intricacy, and energy/material flows have been increasing – i.e., the ecosphere has been moving ever further from equilibrium. This may well be the measure of life. As Prigogine (1997) asserts, "distance from equilibrium becomes an essential parameter in describing nature, much like temperature [is] in [standard] equilibrium thermodynamics".

But there is a wrinkle. Systems biologists recognize that living systems exist in overlapping nested hierarchies in which each component system is contained by the next level up and itself comprises a chain of linked sub-systems at lower levels (see Kay and Regier, 2002). Each sub-system in the hierarchy grows, develops and maintains itself by extracting usable energy and material (negentropy) from its "environment", i.e., its host system one level up. It processes this energy/matter internally to produce and maintain its own structure/function and exports the resultant degraded energy and material wastes (entropy) back into its host. In short, living organisms maintain their local level of organization as far-from-equilibrium-systems at the expense of increasing global entropy, particularly the entropy of their immediate host system (Schneider and Kay, 1994; 1995). All such self–organizing systems are called "dissipative structures" because they self-produce and thrive by continuously extracting, degrading and dissipating available energy/matter (Prigogine, 1997).

Modern interpretations of the Second Law powerfully inform thinking about sustainability. Both the economy and the ecosphere are self-organizing far-from-equilibrium dissipative structures – but with an important difference. Green plants (the *producer* components of the ecosphere) self-produce using photosynthesis to "feed" on an extra-planetary source of high-grade energy, the sun. They use this energy to reassemble carbon dioxide, water, a few mineral nutrients into energy-rich plant biomass upon which most other life depends. Photosynthesis is thus the thermodynamic engine of life, the most important productive process on Earth and the ultimate source of all bio-resources used by terrestrial and marine life, including the human economy.[8] The animal (macro-consumers) and bacterial/fungal (micro-consumer / decomposer) components of ecosystems self-produce by feeding on plant biomass or on each other. Intra-systems negative feedbacks – e.g., predator-prey relationships, disease, temporary scarcities – keep populations of both producer and consumer organisms in check, so the whole system functions in a dynamic far-from-equilibrium "steady-state". Significantly, after bacterial decomposition of dead organic matter, the material elements of life – oxygen, carbon, hydrogen and trace nutrients – recycle completely, perpetuating the system, while degraded energy dissipates off the planet. In short, the ecosphere, an extraordinary assembly

[8] This should be old news to economists. As Daly (2012) points out, "Nobel Laureate in chemistry and underground economist, Frederick Soddy… argued [almost 90 years ago] that mankind ultimately lives on current sunshine, captured with the aid of plants, soil, and water."

of self-perpetuating local order, exists at the expense of increased entropy *elsewhere in the universe*.

By contrast, the human enterprise (human metabolism plus industrial metabolism) functions as a rogue super-consumer. As a fully-contained, growing, sub-system of the non-growing ecosphere, industrial society self-produces by over-exploiting that same ecosphere, super-charged by fossil fuels and the maximum power imperative. Moreover, technology has – at least temporarily – eliminated negative feedback, so growth of the human sub-system is unconstrained. Global society thus elevates itself to a highly-ordered, intricately-structured far-from-equilibrium *non*-steady state by consuming energy/matter extracted from its supportive ecosystems at an ever-increasing pace, and dissipating a growing torrent of entropic waste energy/matter back into the ecosphere. Much of the waste stream is non-recyclable previously unknown synthetics, often toxic or otherwise hostile to life. In short, the admittedly spectacular local order represented by the human enterprise is purchased at the expense of the *entropic disordering of the ecosphere.*

Net primary production by producer species (mostly green plants) has always been more than adequate to sustain the world's entire complement of consumer organisms, including pre-industrial humans. However, *H. sapiens*' growing populations and ever-increasing material demands have become dangerously destabilizing. Any society that dissipates/pollutes its host ecosystems faster than they can regenerate/assimilate is inherently self-destructive. In fact, as a sub-system of the ecosphere, the human enterprise has become parasitic on Earth. This predicament is not merely a matter of bad management that can be addressed through simple reform. There are no exemptions from the 2^{nd} law – beyond certain thresholds, a materially growing economy *necessarily* consumes and disorders the ecosphere; it cannot *not* increase net global entropy.

Complexity, chaos and catastrophe

Consider a final relevant aspect of complex systems dynamics. Both theoretical and empirical studies reinforce the idea that the interaction of the simple laws of physics, chemistry and biology can produce extraordinarily complex systems behaviour. Indeed, "complexity theory" projects a view of nature that, while basically deterministic, is relentlessly non-linear and full of surprises.

Dynamical systems such as the climate and ecosystems are governed by strict rules such that the state of the system at any point in time unambiguously determines the future state of the system. Theoretically, then, if we know the rules and the precise state of a system "right now", we should be able to predict what it will look like at any point in the future. In a model system, this simply requires performing an iterative sequence of calculations; the outcome of each iteration determines the subsequent state (which is the starting point for the subsequent iteration).

In modeling many real-world phenomena, however, analysts find that the state of the model *after just a few iterations* bears no evident relationship to its corresponding external reality. The interplay of even strictly deterministic laws generates patterns of behaviour that are inherently unpredictable even with near-perfect knowledge of the initial state of the system. Complex systems dynamics ensures that the smallest of measurement errors (or seemingly negligible differences in starting conditions) "feed back" and are amplified with each iteration. This means that eventually *any* inaccuracy will confound the model – the tiniest, unavoidable, measurement error can render even a perfect construct useless in predicting real-world systems behavior much in advance.

The general problem is called "sensitive dependence on initial conditions" and the behaviour it produces in both models and real systems – even simple ones – is called "chaos". With vastly increased computing power, analysts have shown that "chaos is everywhere. It is just as common as the nice simple behavior so valued by traditional [simple mechanical] physics" (Cohen and Stewart, 1994, p. 190). Chaos explains why even the best computer models cannot predict the weather next week with complete confidence.

A second related relevant phenomenon is the unexpected, dramatic (i.e., "catastrophic") change that can occur in previously stable systems under stress. Key variables of complex systems, including ecosystems, may range considerably within broad domains or "basins" of stability (e.g., the mean surface temperature on Earth has varied within a few degrees of 15 degrees Celsius for tens of millions of years). We have learned that, within these domains, a variable will normally tend to converge toward a centre of gravity called an "attractor". Initially modellers conceived of attractors as predictable single equilibria (point attractors) or as repeating cycles (periodic attractors). A chaotic systems variable, however, may trace a complex pattern of *individually unpredictable paths* that collectively define a "strange attractor" as internal feedback continually changes the system's internal dynamics. A chaotic system will nevertheless retain its overall structure and behaviour *as long as key variables remain under the influence of their customary attractors*.

And therein lies a potential problem. Although not evident from any previous history, dynamical systems may be characterized by several attractors separated by unstable ridges or "bifurcation points" (picture a terrain of watersheds isolated from each other by irregular hills). "Catastrophe" occurs when a key systems variable, driven by some persistent pressure, is displaced far from its usual attractor. If the variable reaches a bifurcation or tipping-point (the top of a ridge), it may be captured by an adjacent attractor (valley) instead of returning to its familiar domain. There will be large discontinuous breaks in the system's behaviour; its characteristics and quality change dramatically.

Such catastrophic "collapse" may result from incrementally small changes in key variables. As pressure builds, a final marginal change in temperature, pressure, population, or (?), may flip the whole system into a new stable domain, a different attractor. Most significantly, the new domain may be hostile to human interests and there is *no guarantee that the system will ever return to its former state*.

Complex systems ranging from commercial fisheries and disease control, to the Gulf Stream, global climate, and even the economy seem prone to catastrophic behaviour. Indeed, it is precisely the fear of catastrophic tipping points that has stimulated climate scientists to warn: "....even if the Paris Accord target of a 1.5°C to 2.0°C rise in temperature is met, we cannot exclude the risk that a cascade of feedbacks could push the Earth System irreversibly onto a 'Hothouse Earth' pathway" (Steffen et al., 2018; see also Drijfhout et al., 2015). Similar grave concerns were evident in the Intergovernmental Panel on Climate Change special report (IPCC, 2018) on the consequences of 1.5°C mean global warning (which is now virtually inevitable). We ignore such findings at considerable risk to the human enterprise. As the dominant force in global ecological change, humans may well be driving key biophysical variables toward unknown strange attractors.

End game

> "So, let us not be afraid of the truth. We don't need to avoid our reality… We don't know whether we will survive. We may. But if we do, it will be in an utterly different world, with almost no other living creatures to keep us company, poor food, rampant disease and a wildly uncomfortable environment" (James, 2019).

Our dominant econo-cultural narrative of perpetual growth and ever-progressing technology sees the natural environment as little more than a static aesthetic backdrop to human affairs. It relies on analytic models based on reductionist assumptions about resources, people, firms, and technology that bear little relationship to their counterparts in the real world; in effect, society views the economy as a separate system functioning independently of the ecosphere. Relieved of limiting frictions, mainstream economists and politicians equate "sustainable development" with sustained economic growth abetted by technological progress. We may acknowledge "environmental" problems but as only one of many equivalent sets of competing values and interests. Within a broadly anthropocentric utilitarian framework, society can arrive at a satisfactory (i.e., politically acceptable) trade-off between ecosystem integrity and growth through power-brokering, negotiation, and compromise. Certainly biophysical absolutes have no seat at the bargaining table.

The ecological perspective describes a more dynamic and potentially dangerous world in which the human enterprise is a fully embedded completely dependent sub-system of the ecosphere. Both the economy and the ecosphere are dissipative structures subject to the entropic drag of the Second Law. However, while the ecosphere produces and maintains itself in a far-from-equilibrium more or less steady-state by dissipating solar energy, the human enterprise expands relentlessly by consuming and dissipating the ecosphere. The recent energy-fed/capitalist-led explosion of the human subsystem has made us both the dominant consumer and greatest geological force on Earth. Scientists are concerned that continued incremental growth may push key variables beyond "tipping-points" into unfamiliar domains that might well be catastrophic for civilization. In this framing, the need to maintain ecospheric integrity (climate stability, adequate biodiversity, etc.) is an absolute and, while the boundaries might be fuzzy, there are clearly limits to material growth.

These economic and ecological narratives are virtual polar opposites and it matters greatly which is the "truer" social construct. The empirical evidence is unambiguous and provides a crude test – consider just climate change, biodiversity loss and the direct human demand for biocapacity:

- There is no dispute that the 'greenhouse effect' is real and the main anthropogenic greenhouse gas is carbon dioxide (the greatest industrial metabolic waste by weight of industrial economies). Now increasing by 3 parts per million (ppm) per year, atmospheric CO_2 readings in January 2019 averaged over 410.83 ppm (NOAA, 2019). This is a human-induced increase of 47% above pre-industrial levels and takes atmospheric carbon to its highest levels in 800,000 years; other greenhouse gases (GHGs) such as nitrous oxide and methane are increasing as fast or faster. As a result, mean global temperature has risen by almost 1.0 Celsius degree, mostly since 1980. A statistically improbable 18 of the 19 warmest years in the instrumental record have occurred in this young century: the five warmest years were the last five – 2016 was the warmest; followed by 2015, 2017, 2018 and 2014" (CC, 2019).

- Our best science tells us that the world is currently on track to experience three to five °C warming. There is no dispute that five degrees would be catastrophic, likely fatal to civilized existence. Even a "modest" three degrees implies disaster – enough to destroy economies, destabilize geopolitics and empty cities. As noted, scientists are concerned that even the more difficult Paris target (to limit warming to 1.5°C above pre-industrial levels) may be sufficient to tip the climate down just such a hothouse earth pathway. This should be particularly worrisome since, even if 2019 GHG concentrations are held steady (in fact, they are rising), they are sufficient to commit the world to an additional 0.3 to 0.8 C°C degrees in coming decades (Hansen, 2018).

- Meanwhile, humans are competing with all other vertebrate life for Earth's finite livable space and "surplus" plant biomass – and, thanks to technology, we are "winning". It is, however, a Pyrrhic victory – the human harvest of ten to 100 times more biomass than our ecological competitors is destroying wild nature. With only 0.01% of total earthly biomass, H. sapiens has eliminated 83% of wild animal and 50% of natural plant biomass. From a fraction of one percent ten millennia ago, humans now constitute 36%, and our domestic livestock another 60%, of the planet's mammalian biomass compared to only 4% for all wild species combined. Similarly, domestic poultry now comprises 70% of Earth's remaining avian biomass and the oceans are being depleted by commercial fishing (at the expense of rapidly declining marine mammals) (Bar-On, et al., 2018). "Competitive displacement" of non-human species can be territory-related as when humans appropriate grassland habitats at the expense of wild ungulate ecosystems or more directly energy-related as when over-fishing starves marine mammals and birds: "Fisheries generate severe constraints for seabird populations on a worldwide scale... Indeed, seabirds are the most threatened bird group, with a 70% community-level population decline across 1950–2010" (Grémillet et al., 2018). Overall, the World Wildlife Fund reports an "astonishing" 60% decline in the populations of mammals, birds, fish, reptiles, and amphibians in just over 40 years (WWF, 2018). Other plant and animal groups are also under siege from climate change, habitat loss, insecticide and industrial contamination – even insects are experiencing "Armageddon" (and systemically linked insect-dependent birds, mammals and amphibians are not far behind) (Carrington, 2019; Lister and Garcia, 2018; Hallmann et al., 2017).

- Direct human appropriation of ecosystems (biocapacity) can be estimated using ecological footprint analysis (Rees, 2013). EFA shows that society is in severe "overshoot. The average high-income citizen requires four to 10+ hectares of global average productive ecosystems (gha) to produce the bioresources s/he consumes and assimilate just his/her carbon emissions. Even the average human eco-footprint is 2.8 gha when there are only about 1.7 ha/capita of productive land and water ecosystems on the planet. To sustain just the 2014 world population at North American, European or global average material standards with prevailing technology, we would need four, 2.8 and 0.69 additional earth-like planets respectively (data from GFN, 2019). That is, even at the 2014 global average standard of living, the human enterprise exceeded long-term global human carrying capacity by 69%. This is further proof that growth and maintenance of the human system "far-from-equilibrium" is being financed by the liquidation of accumulated stocks of essential natural capital (forests, soils, fish, etc.).

The most important "take-away" from the above is that the data and trends are consistent with and generally predictable from basic ecological constructs. Since the scale of, and demands by, the human enterprise are steadily increasing, and the ecosystems upon which they depend are not, it is inevitable on a finite planet, that material consumption would eventually exceed sustainable rates of production even as the resultant pollution (climate change is a waste management issue) and plunging biodiversity undermine remaining productive capacity.

By contrast, in the absence of ecological content, the true state of the ecosphere remains invisible to neoliberal theory and analyses. Economists' narrow perspective, fixation on growth and rejection of biophysical limits are particularly troublesome. As if to illustrate the point, in a determined show of disciplinary unity, 3333 US economists – including 27 Nobel Laureates – issued a statement on 16 February 2019, asserting that the "most cost-effective lever to reduce carbon emissions" is an escalating carbon tax (WSJ, 2019). This would substitute for "cumbersome regulations", "encourage technological innovation" stimulate the production of "carbon-efficient goods and services", and facilitate the shift to renewables while "promoting economic growth". To "maximize fairness and political viability" (not to mention minimal economic disruption), "all the revenue should be returned directly to US citizens through equal lump-sum rebates" to spend as they will; the majority of families would "receive more in "carbon dividends" than they pay in increased energy prices.

This is simplistic, unreformed, compartmentalised thinking stuck on mechanical market "levers" and technology to solve the climate "problem" and maintain the growth-based *status quo.* There is no hint that climate change is just one symptom of gross human (econo-) ecological dysfunction, no targets, no tipping points and no limits. It rashly assumes the availability of, and a smooth transition to, viable substitutes for fossil fuel. At best the economists' statement is a tiny step forward and a giant (rebate) step back. And why not? The statement displays the same level of ecological (un)sophistication that qualified for the 2018 (pseudo-) Nobel Prize in Economics (see Hickel, 2018).

The ecological framing also raises important questions that would not occur to growth-bound economists: What is the probability that the ecosphere can withstand another doubling of human energy/material demand as is expected before mid-century? Can we devise new social constructs that override rather than reinforce peoples' innate expansionist tendencies and selfish myopia? What might be done globally to avoid resultant tipping points and systemic collapse? Below are some steps that address this last question, all consistent with the evidence. In particular, they recognize that the era of material growth will soon end either through systems implosion or a planned descent. The world community should:

- Acknowledge that collapse is a finite possibility and the usual outcome for societies whose leaders ignore evidential warning signs or are too corrupt or incompetent to act accordingly (Tainter, 1984; also Kemp, 2019);
- Admit the theoretical simplicity and conceptual flaws in neoliberal market economics and capitalist expansionism;
- Embrace the need to "socially construct" a new foundation for economics that is consistent with bio-physical reality, beginning with today's emergent ecological economics (e.g., Daly and Farley, 2010; Victor, 2019);
- Recognize that humans are bio-ecological beings, the most ecologically significant entity in all Earth's ecosystems and subject to ecological and biophysical principles;
- Acknowledge that economic behaviour and processes qualify economics as a branch of human ecology;
- Accept that the human enterprise is a fully-contained dependent sub-system of the non-growing ecosphere;

- Abandon relatively mechanical, linear, single equilibrium models for more dynamic, non-linear multiple equilibrium constructs of the integrated human eco-economic system;
- Forge economic theory that is consistent with the physical, chemical, and bio-ecological concepts governing both economic and ecological material transformations in the ecosphere;
- Accept the limitations of technology – in general, natural capital and manufactured capital are complements, not substitutes; some forms of "natural capital" are essential and non-substitutable;
- Accept that there are "fuzzy" biophysical limits to growth that may not be evident and whose location (tipping points) may be shifting with changes in both natural conditions and exploitation rates. (This implies liberal application of the precautionary principle.);
- Acknowledge that no economy that grows or even maintains itself by depleting essential capital is sustainable;
- Shift the primary emphases of economic planning from quantitative growth and efficiency (getting bigger) toward qualitative development and equity (getting better). At present, the US and many of its OECD allies are growing but un-developing;
- Acknowledge that the vast majority of humans will never leave this planet and that species survival depends on maintaining the functional integrity of the ecosphere. Key controlling variables must remain within the historic "basins of attraction" [stability domains] that enabled human evolution and the emergence of civilized existence;
- Understand that (un)sustainability is a collective problem requiring collective solutions and an unprecedented level of international cooperation, sacrifice and sharing;
- Commit to devising and implementing policies consistent with a "one Earth" civilization;
- Establish as overall goal an ecologically stable, economically secure "steady-state" society (Daly, 1991) whose citizens live more or less equitably within the biophysical means of nature.
- Accept that today's gross and growing income/wealth inequality[9] is a major barrier to sustainability and that one-Earth living requires mechanisms for fair redistribution;
- Recognize that Earth is over-populated even at average material standards. A one-earth life-style for 7.3 billion people requires that humans learn to thrive on the biocapacity represented by 1.7 global average productive hectares per capita (compared to the eight gha/capita require by contemporary North America);
- Begin the public cultural, social and economic discussions and formal planning necessary to reduce fossil energy and material consumption (economic throughput) by up to 69% globally (at least 80% in high-income countries).[10] This is consistent with achieving the IPCC (2018) goal of almost 50% fewer carbon emissions by 2030 and requires six percent per year reductions beginning immediately;
- Conceive and implement a global fertility strategy to reduce the human population to the 2-3 billion people that might be able to live in material comfort on this already much-damaged single planet Earth.

These will seem outrageously radical demands to contemporary economic strategists, invested capitalists, politicians and even most ordinary citizens attuned to the growth imperative and human technological wizardry. Nevertheless, it is time for the world to admit that continued adherence to prevailing socially-constructed illusions risks fatal catastrophe. Untransformed, our present system *will* crash. We really have no choice but to act upon what

[9] Oxfam estimates that the world's richest 26 billionaires control as much wealth as the poorest half of humanity, or at least 3.6 billion people (Elliott, 2019).
[10] This is technically achievable (von Weizsäcker, et al., 2009).

our best science has been telling us for decades. And we have to act urgently: “Effective planetary stewardship must be achieved quickly, as the momentum of the Anthropocene threatens to tip the complex Earth System out of the cyclic glacial-interglacial pattern during which *Homo sapiens* has evolved and developed” (Steffen et al., 2011).

That said, we do have to ask: what is the probability that in the present “post-truth” era, our delusional, leaderless and increasingly fractious world community will be able to agree on the diagnosis advanced here let alone on implementing effective solutions? Some problems may not be solvable. There is certainly no easy solution to humanity’s econo-ecological predicament and without an agreed emergency plan for cooperative action there may be no solution at all.

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