An Ecological Economics of Growth:
Learning from nature when to turn

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Abstract

Organized human and natural systems generally develop by an observable process of growth, with a beginning, middle, and end. Examples range from the growth of organisms, cultures, and ecologies to that of businesses, social movements, weather systems, even personal and social relationships, and many more. Close observation reveals the growth of organized systems to be a progressive process of self-organization. Most recognizable are its recurring three shifts in direction, each followed by a more organizationally stable period, a pattern recognizable as a series of milestones along an "S" curve assembly line, that can guide the study of a growth system's design. That common model allows useful comparison of all kinds of natural and human-designed growth systems, using a diagnostic as opposed to a deterministic research method, keeping what "ought to be" in close association with "what is." Discussed are the historical roots of the field, a set of pattern recognition tools, three brief pedagogical case studies, and an eco-economy view of the human world and when to turn.

Electronic supplementary material

Supplementary topics: http://synapse9.com/_pub/EcoEconOfGrowth-Supl.pdf (pending)

Figures Slide set: http://synapse9.com/_pub/EcoEconOfGrowth-figs.pdf (pending)

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How living systems develop their complex organizational designs by processes of rapidly evolving growth has fascinated scientific observers for millennia. However, natural growth also still resists scientific definition.

Perhaps the delay comes from scientists asking the wrong questions, such as looking for deterministic rules for nature's creative processes rather than generative patterns of natural design.

This paper offers a new diagnostic approach to observing and working with the growth processes by which organized systems develop of all kinds, among other properties generally observed to:

1) proceed by an accumulative self-organizing building process,
2) creating an individual center of emerging design,
3) with different internal and external systems of relationships, and
4) beginning and ending with unobservably small events.

Examples include ecologies, plants and animals, cultures, communities, businesses, industries, societies, movements, families, and relationships. Many kinds of non-living energy using systems also display periods of accumulative self-organization, too, such as convection, weather, fluid flows, and crystallization. The most familiar examples are probably our own adaptive "give and take" work methods, with efforts that expand then contract toward a discovered finished end (Henshaw 2018). In many cases, one can watch it as it happens. Tasks like cooking, design, labor, and others, typically proceed by accumulatively larger starting steps that lead to successively smaller finishing steps, with adaptive design occurring in the process. It is a universal pattern for self-organization on any scale we can observe as also having:

5) energetic rising, then falling action
6) notable non-linear continuity and momentum of connecting steps
7) a three-stage differentiation of beginning, middle, and end, and
8) composed of a shift in direction and a more organizationally stable periods
9) usually with coordinating multi-level design,
10) observed wherever nature or people are doing something new.

The rising and falling action of growth also allows its time-series measures to be a useful proxy for its rates of organizational change, and order of successive events that together highlight what to study. The individuality of each growth system and many of its qualitative features are among the observable features that resist mathematical definition. Others include the growth stages of germination (nucleation), differentiation, and maturation. Those have to do with properties we can only describe as qualitative, having to do with organizational development, not numerical, and concerning relationships between whole individual systems and their environments.

Familiar studies taking somewhat similar approaches, focused on the recurring patterns of growth, are those by Brian Goodwin (1982) and D'Arcy Thompson (1942). Equations for growth can be relatively simple, and a useful companion, but one still needs to study the multi-level complexity of organization that underlies emerging growth. So this study is organized around recognizing recurring and connecting patterns, which sometimes yield useful numerical diagnostic indicators. One of the most useful observations (#5 above) is that physical measures of growth appear to exhibit mathematical-like derivative continuity. That appears to be a visible result of the necessary physical continuity of natural processes, producing progressive steps of change that necessarily build up and then build down again.

Context of Growth Studies

Methods

The original field research that began this study was a two year 1977-8 instrumented field study of the microclimates of homes. Recordings of numerous temperature and airflow sensors over 24 hr periods combined with using smoke tracers to help watch individual air currents develop exposed how whole systems of airflow grew and faded successively throughout the day (Henshaw 1978). That study required learning how to read dynamic shapes of swelling and subsiding change for information on organizational change, leading to studies of many other kinds of growth systems, exploring universal patterns of organizational development (Henshaw 1979, 1985a 1985b). In the late 1980s and 90s, the focus of research switched to developing data-driven mathematical pattern recognition methods for growth systems, applied to time-series data from published sources for ecological, astronomical, environmental, and economic systems (Henshaw 1995, 1999, 2007). General theory papers followed, focusing increasingly on the evidence of active learning exhibited by whole ecological and economic growth systems (Henshaw 2008, 2010a, 2010b, 2011, 2015, 2018).

Over the years, the research method that developed was to use the most observable universal patterns of growth as the general norm, such as shown in Fig 3 and 4. Those universal patterns would then, by contrast, expose the distinguishing details of individual cases. That method exposed more and more of how particular growth systems uniquely emerge, differentiate, and develop. That helped generate well-grounded hypotheses and tests for individual cases, making a seemingly successful observational diagnostic method. Understanding individual cases then helped clarify the common patterns, as a learning feedback loop, leading to reporting on a great many more common elements (Henshaw 2015). Learning to read recorded time-series data as a history of organizational development also helped create useful lifecycle storylines for helping find how detailed observations connect (Henshaw 2018).

Literature

Many other scientists have also noticed growth as a fundamental phenomenon of nature that needed study. It seems, however, that since instances of growth vary so much, are so complex, dynamically transient and generally not determined by external forces, the commonalities displayed were slow to be recognized. Scientists who took an interest in the study of growth, and helped lay the groundwork for this work, included Thomas Malthus (1809), W. Stanley Jevons (1877, 1885), John M Keynes (1935) Alan Turing (1952), Kenneth Boulding (1953), Albert Bartlett (2004), Walter Elsasser (1987), Robert Rosen (1991, 1993), and Stewart Kauffman (2008).

Malthus was surely not the first observer to notice the natural instability and urgent need look for where growth curves would climax. That awareness of 'things erupting' seems essential for the success of any shepherd, farmer, cook, entrepreneur, leader, banker, or any parent too. However, Malthus did find a new way to connect the mechanics of unconstrained growth with the social trap of overpopulation. The problem persists too, but now more urgently for both boundless growing wealth. Malthus's observation that compound growth of any physical system is inherently self-limiting was incomplete, however. Compound growth is also the beginning of all stable systems too. In those cases, growth becomes self-limiting without causing chaos, pointing to what our world needs to learn about now. If one looks, one finds people remarkably skillful in responding to natural limits of all sorts, and so needs to expand on that talent.

Jevons' famous so-called "paradox" that industrial efficiency most often increases rather than decreases industrial resource consumption (1885) illustrates how humans are confused by growth systems in another way. No one is hiding the fact that businesses use efficiency to help expand output and increase profits. Virtually worldwide, though, people have latched onto the hope that efficiency would also reduce resource use, even as the global data is remarkably clear that the opposite is happening[1]. That makes popular faith in using efficiency for solving economic problems misplaced. The increase in unit efficiency is what lowers the price and allows a business to multiply the units produced, its impact on the environment and income.

A less well known but equally important contribution of Jevons was his earlier work describing the scientific method (1887). His view was that the progress of science rests first on recognizing natural phenomena of interest to study, driving scientific progress by asking the right questions. That defines science as being nature-centered, relying on:

> "…a rare property of mind which consists in penetrating the disguise of variety and seizing the common elements of sameness [..] which furnishes the true measure of intellect." (Jevons 1877, p5 The Powers of Mind concerned in the Creation of Science)

Jevons' view rests the progress of science squarely on forming hypotheses that illuminate nature. That differs considerably from Popper's (2002) general view, exemplified by modern physics, that the progress of science rests on the rigor of data analysis. Most working scientists would want to have both, of course, but for a long time, there has been a split.

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[1] Evidence of Decoupling Still Zero, Henshaw research notes: https://synapse9.com/signals/2018/06/18/evidence-decoupling-still-zero/

Keynes (1935) is most famous for devising the modern government role for trying to stabilize the constant boom and bust behavior of the unregulated free-market economy. His least known contribution may be laying out how the economy could shed its instability more generally, in his chapter on "Sundry Observations on the Nature of Capital," when forced by natural limits to end its endless compounding of financial capital. Some further discussion of it will come near the end of the paper.

Among the relatively rare studies considering growth as a universal natural phenomenon were those of H. S. Reed (1924) and Ken Boulding (1953). They both recognized growth as a progression that had very different structural and quantitative dimensions and emphasized how representing growth mathematically differed fundamentally from characterizing the emergence of its working designs and structures. Particularly forward thinking and useful are Reed's following observations of:

a) the irreversibility of growth,
b) the flowing continuity of growth and development,
c) the conservation of energy regulating growth processes,
d) the frequently evident self-regulation and autonomy of growth systems, and that
e) the continuity and regularity of growth were often independent of adverse conditions.

Boulding's observations on the study of growth (1953) include remarking on how mathematical growth laws were not very useful due to growth system behaviors arising from their internal structures. That defect becomes an advantage, however, as he quotes Dr. S. A. Courtis pointing out:

> "an empirical growth law which fits many cases has at least the virtue that it calls attention to possible unknown sources of disturbance in cases where it does not fit - just as the law of gravity led to the discovery of the outer planets." (quoted in Boulding, 1953)

That diagnostic use of general theory to highlight local departures for further study is indeed a valuable tool for both research and practical use. Central to this present work is the use of general patterns to aid the discovery of how the parts of some particular case fit.

Boulding also developed several general principles of structural growth restated here:

1) <u>Nucleation principle</u>: Three useful examples of how a nucleus is needed to initiate growth are first how a dust spec is needed to initiate the condensation of raindrops. The second and third are how students are unable to retain information on new subjects until some insight nucleates in their minds and how student ability to improvise transforms when they realize that language has grammar.
2) <u>Non-proportional scales principle</u>: Changes of different properties of a whole tend to have different scales, as for differences in length, surface area, weight and volume.
3) <u>D'Arcy Thompson principle</u>: The form of a natural system results from its patterns of growth (what grows is what becomes), resulting in various emergent laws of proportionality.

4) The Carpenter Principle: that growth exhibits unexplained coordination of the whole as if a carpenter is in charge of making the parts fit, requiring the parts to be individually designed.
5) Principle of Equal Advantage: Hypothesizing that systems have parts that fit together by all seeking their role in an organization with the highest potential. (corollary to the carpenter principle)
6) Principle of natural pace: Natural equilibrium rates of growth in an organism or system such that higher (or lower) growth rates may disturb the functioning of the system even to the point of its collapse.

Alan Turing's paper on morphogenesis (1952), offers theoretical equations for the spontaneous emergence of new forms of organization, using a biosystem model. Relatively recent efforts demonstrate Turing's model for the patterning of animal markings and other organic geometries, such as the leopard's spots and sand ripples on dunes (Ball 2015) but not the general case advocated by Turing. Observable conditions seen to illustrate better what Turing was trying to explain. Growth appears to spontaneously emerge from in a protected location, where delicate parts can develop undisturbed. Examples are a state of calm "before the storm," or how species develop by punctuated equilibrium (Gould 2009). Not only do new species and storms arise from quiet places, but also new life emerges from the protected conditions of the womb, and fresh ideas generally occur in a calm mind. These examples also seem to suggest that growth develops more from delicate patterns than random external disturbances.

Walter Elsasser was a noted physicist who then studied biosystems, and Stuart Kauffman, a noted theoretical systems biologist. Both were suspicious of the random theory of evolution. Elsasser (1987) found that if there were only random variations, the chance of persistent order anywhere in the universe would be smaller than one chance is the estimated total number of particles in the universe. Kauffman (1993) struggled with the same problem; only he saw it as a need for evolution to have a way of restraining mutation. In either case, they concluded that the statistical laws of physics, however useful for engineering, could not have been how the complex designs of nature developed. The answer may be in plain sight. Life and nature are processes of accumulative change, with past developments the necessary foundation for following ones. The rings of a tree trunk are added one at a time, for example. Though other cases differ in design, all growth seems to follow the same general rule of building on the pattern before.

Theoretical biologist Robert Rosen (1993) seems to have started his critique of the standard scientific model of nature by observing that natural change is open-ended and accumulative, unlike how science defines equations to have predetermined answers. That growth processes are also adaptive makes them seem opportunistic as well, further reducing the applicability of deterministic models. Modern complexity science has responded with accumulative and adaptive computer models; however, still using deterministic statistical rules. That has generated lots of applications for complex deterministic problems, robotics, and artificial intelligence without seeming to explain the emergent properties of natural system organization or to replicate them (Pines 2014).

Rosen may have made his most significant contribution by turning the light of biological reasoning on the process of science itself, depicting the accumulating adaptive design process by which science itself works (Fig 2). The figure shows science as a loop of knowledge formation and testing, a rising spiral if one likes. The systematic process we see in science today starts with observations of nature and "encoding" them in the formal language of science and studied for their implications. That is followed by "decoding" the implications to test their application in nature, to see if natural causation matches, then using those observations to repeat the cycle.

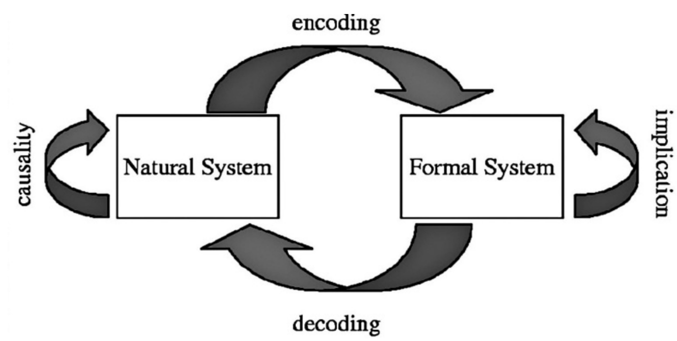


Fig 1. Robert Rosen's Heuristic Model of Scientific Learning: A cycle of first *observing causality* in nature for *encoding* into the scientific language of *implications,* to be used for *decoding* into test applications, and repeated with further *observation and testing.*

Similar alternating cycles of exploratory adaptation are central to most human endeavors. Almost all work involves an alternating cycle of progress and evaluation, taken from start to finish. A standard model for it calls the process "action research" (Henshaw 2018). One can observe the same general kind of exploratory adaptation in animal behavior of all kinds, as repeated exploration and adaptation. Animals are not applying human values, of course, but do display similar opportunistic exploration that gives the impression of intelligence and results in accumulative learning (Henshaw 2008). The same pattern seems evident in economic cycles, as alternating periods dominated by one paradigm of production followed by a period of retooling to create the next paradigm, organically changing the direction of history. So, taking some care, of course, it seems one can use the Rosen model as a general guide to the exploratory learning process of natural growth systems of all kinds too.

Interest in this kind of granular detail of natural systems may have been on the minds of scientific thinkers for a long time, of course, but limited by the scientific vocabulary of determinism. The occasional poetry and wisdom of many scientists suggest it. To curious observers, it would also seem hard not to be struck by how coordinated the interactions of most natural systems seem to be. The subject seems even traceable to the ancient Greek word that eventually became 'physics,' the Greek word 'Φύσς,' pronounced "phúsis" (Wikipedia), [2] initially referring to the productivity of nature in giving birth to new things. How the ancient Greek term for the creativity of nature came to refer to a study of invariable laws of nature (Merriam Webster:

[2] (Wiktionary: Φύσς) Translated "gro.sis" and pronounced "fi.sis. https://en.wiktionary.org/wiki/%CF%86%CF%8D%CF%83%CE%B9%CF%82

physics)[3] is a puzzle. Boulding's "principle of advantage" would suggest that scientific studies bringing economic success might have grown fastest, changing the meaning of the craft as it followed its paths of success. A singular focus on deterministic rules did emerge, and not on the creative processes of nature.

Growth Models for Case Studies

Simple growth models used for diagnostic study give a hands-on feel for the research method.

Three Growth Models to use for Studying Growth System Designs

In Fig 2, the first and second degrees of sustainability show development curves for types of system-building that fail to go to completion and drop away. The first, 1) "Growth to Exhaustion," depicts a growth system that consumes its starting resource without building access to additional resources. Examples are a seedling that fails to put down roots, a match that flairs its phosphorus head and goes out, or a business that just consumes its seed capital without attracting a market. The second, 2) "Growth to Disruption," represents a system that succeeds in building ever-expanding access to resources, but makes itself unstable, expanding ever faster until its rate of acceleration disrupts its operation. Examples are, a) a common gardening problem of seedlings that shoot up till they fall over, b) businesses that grow too fast and collapse in confusion[4], and c) growth driven economies that keep growing despite signs of diminishing rates of return.

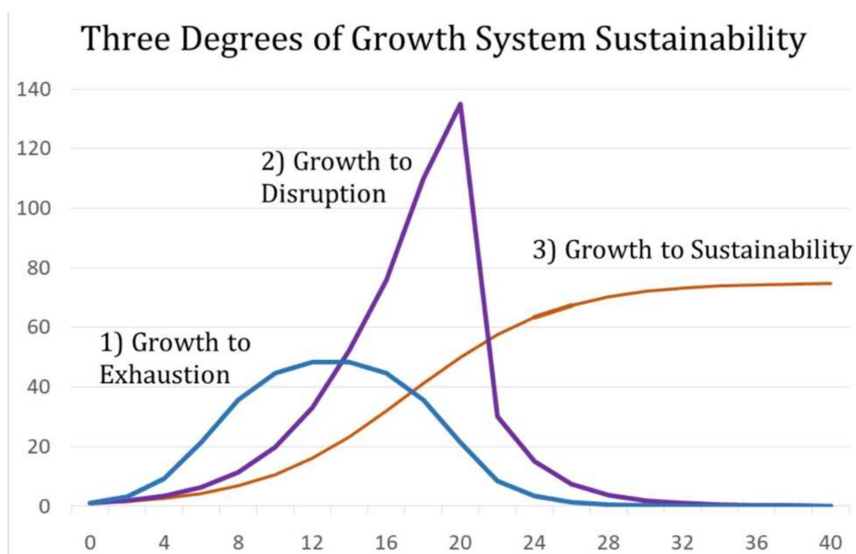


Fig 2. Three degrees of endurance: 1) Consuming available resources without a system for finding more. 2) Building a system while ignoring its limits of internal coordination. 3) Using the start-up period to build a system to then stabilize for long life.

3 (Merriam Webster: physics; History and Etymology) https://www.merriam-webster.com/dictionary/physics

4 8 Dangers of Growing Your Business Too Fast https://www.inc.com/cox-business/eight-dangers-of-growing-your-business-too-fast.html

The third growth pattern, 3) "Growth to sustainability," is for growth systems that are responsive to internal or external strains. As strains first emerge, instead of continuing to use its surplus resources just for growing its scale and power, growth instead shifts surplus resources for building system resilience. That change of purpose is what causes Type 3 growth to stabilize, repurposing its surpluses to climax its growth at a peak of vitality rather than a peak of exhaustion or disruption. Fig 3 shows a more detailed view of the strategy.

With lots of easy mistakes for growth systems to make, as for entrepreneurs, success may come as a result of multiple failures. Every attempt is a trial by fire, perhaps calling for a strategy of "try, try again" for systems that mature while also surviving multiple failures.

Life Stages of Growth Timeline

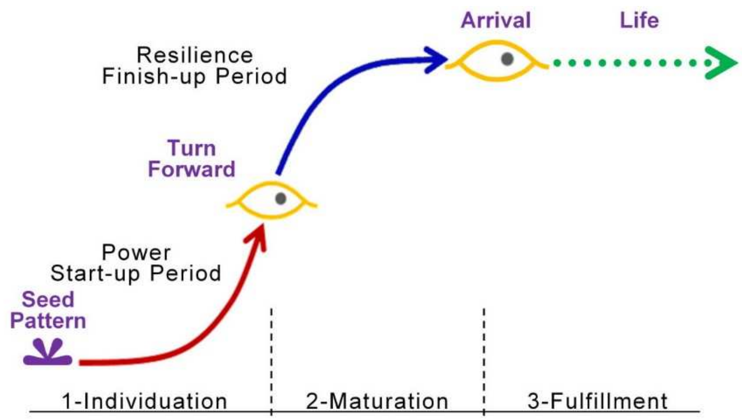


Fig 3. The six stages of natural growth alternate between events of reorganization and periods of development with the new organization.[5]

1) the **seed event,** , followed by 2) **start-up growth period** (red)]─***Individuation***

2) the **turn forward event,** , and **finish-up growth period** (blue)]─***Maturation***

3) the **arrival event,** , and **Climax life period** (green)]─***Fulfillment***

[5] For alternate terminology see Supplemental Topics Appendix I. and Henshaw (2018 Sec IV)

Simple Organization Plan for an Ecological Economy

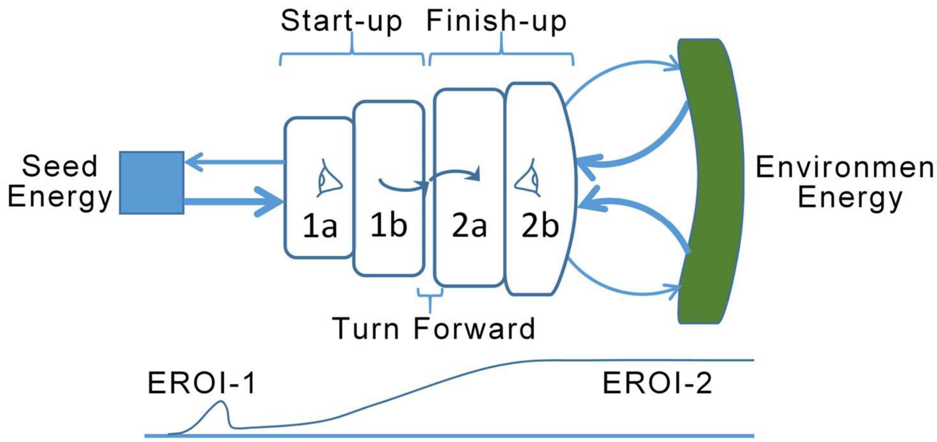


Fig 4. An economic system needs energy supplies greater than its operating energy costs to balance its energy budget. Its first energy source, EROI-1, is usually consumed as the system develops more lasting energy resources, EROI-2.

For an ecologist's view of the same issues, H. T. Odum (2007 p.283) similarly illustrates growth paths that reflect different types of growth systems, showing six alternatives that include the three in Fig 2. He also represents each with diagrams and equations for computer models. His depiction does reflect systems as being adaptive or not, but treats the systemic differences as resulting from external environmental pressures, not responsive internal design, as would be needed to navigate an economy or ecology.

A more detailed view of growth to longevity is shown in Fig 3 as an "S" curve with the names for six organizational stages of growth, three developmental events followed by associate developmental periods. Not all "S" curves that trace change over time show patterns of organizational development, so to interpret it that way it has to be verified. The converse is generally true, though, that developing organization, such as for the growth of industries, communities, and ecologies and cultures and personal relationships of all kinds have to build up in an "S" curve fashion.

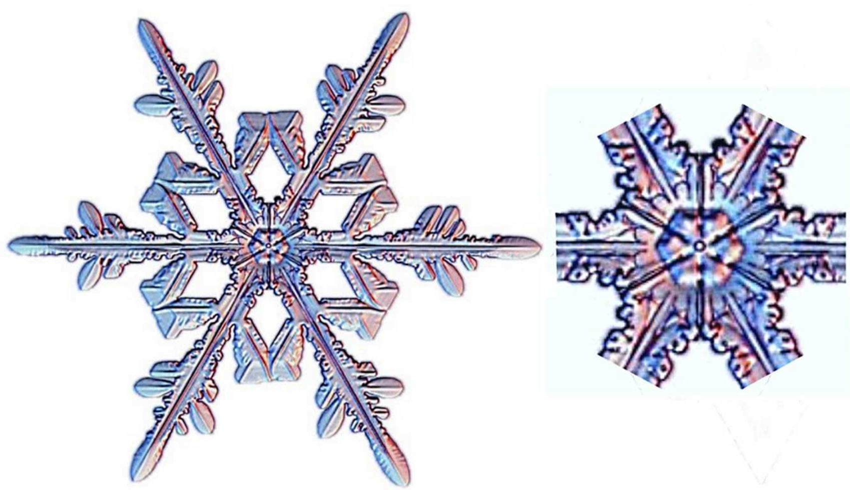
Perhaps the example we can learn the most from, though, is the personally familiar creative work of a home or office project. That might be just for throwing a party, for reorganizing the living room or the office, or producing a deliverable for a client, even starting a business or doing a renovation. The accumulative effort invested in any of them will first build-up and then level-off with the energy invested tracing an "S" curve. Any such project starts with some inspiration, a fresh idea "catching on," serving as the "nucleation" of combined interests that get the work started. What follows are stages of clarifying the whole idea, identifying its requirements, and then organizing the team and their tasks. Once the framework of the project set, the team can turn to filling in the details and then preparing for its delivery.

Our personal experiences with that creative cycle let us learn things from any one case to apply to others, as all cases involve much the same process taking something creative to its release as a finished product. It is part of nearly everything we do, like even making lunch or dinner, making friends, gardening and building design, and organizing neighborhood groups. So what one learns on one may have application to others. They all start with a fresh idea that catches on, starting with small, then the more energetic steps of organizing and doing the work, followed by the smaller steps of adding details and finishing touches for delivery.

Fig 4 also depicts the start-up and growth periods of an emerging system but represented as an abstract organism adding to its body size, section by section, 1a, to 1b then 2a, to 2b, also like adding sections to an expanding business operation. The first building section, 1a, is developed using the finite seed energy resource at the left. Subsequent building sections are parts 1b, 2a, and 2b, each using increasing amounts of the lasting environmental energy source at the right. The first two sections correspond to the beginning and end of the start-up period, the last two sections, the beginning, and the end of the finish-up period.

To use Fig 3 and 4 as guides, one studies features of a growth system that might correspond to the typical stages of sections of development. As illustrated in the three Case Studies below, one tries to arrange the evidence available to fit the two models, Fig 3 or Fig 4 as a way to generate perspective. Once the life cycle of the subject is identified, one looks for information to fill the gaps and to locate past turning points and how they occurred, to then extend the model to consider future changes in direction that will occur. For example, often not visible in the commotion of a working business is the handshake that marks the new business partners settling on a plan of action. That "seed" contains a general idea of the business will be organized, that gets passed on as the business develops, always building onto its original ideas and values. If one is looking for ways to change a business, understanding the seed understanding from which it grew might help, suggesting ways changes could either better harmonize or depart from it.

Whether called it a "seed," "spark," "germ," or "nucleation," the growth process that builds on it can often cover over all evidence of where it started, so an observer might not find direct evidence of it. For the snowflake shown in Fig 5, we can see a tiny dot in the center where the crystallization began. What we cannot see is the molecular pattern that propagates its uniquely complex six-pointed geometry. What we have to rely on is our ability to trace the pattern back toward its origin.



Snowflake details   Central kernel

Fig 5. A Snowflake and its Central Kernel: The crystal design builds up from a tiny central dot. The smallest visible hexagonal shape is still quite simple, and the next rings increasingly complex as if the filigree design was “entangled” within the tiny crystal core.

Being able to see a bit of what one cannot see makes the pattern that originates the growth process partly a presumption and partly an accumulation of observations that reifies the science, still relying on verification if used for an application. The same is true for that moment when two people suddenly take an interest in each other. That fleeting ‘spark’ seems big and is the start of everything that follows but relies on validation from what comes later to make it true.

3 Case Studies

The three case studies below demonstrate the use of the natural growth models (Fig 3 and 4) for interpreting recorded growth process timelines. The exercise teaches a kind of guided exploratory guesswork, like stepping stones, for illuminating the natural behaviors behind the data, suggesting new hypotheses to test, and some insight into what at first is unseen. The life stories of natural systems are more varied, of course, so starting to ask whether the models fit at all is a needed first step.

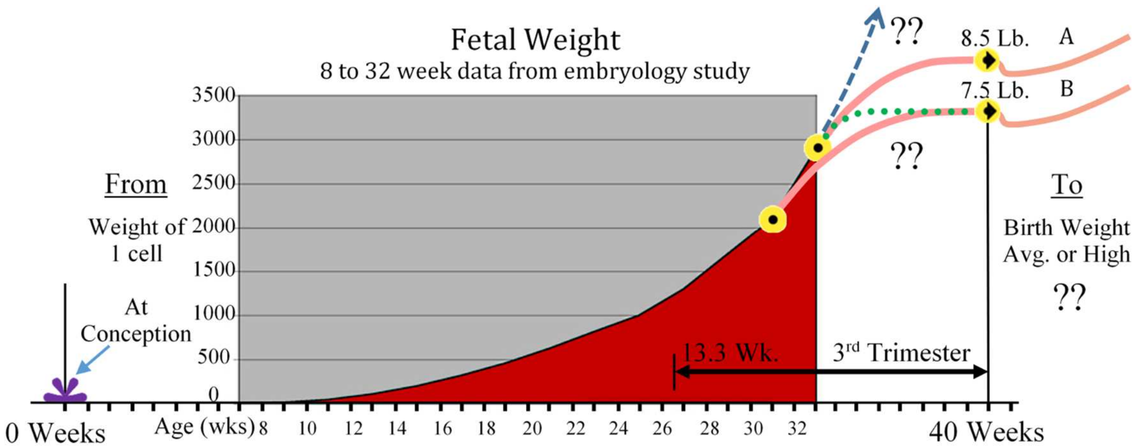


Fig 6. Case Study I. Human Gestation based on partial data on fetal weight.

Case Study I Human Gestation

Stage	Observations
0 Context	The data shows only 26 weeks, on an expanded 40-week scale. The maternal environment is a protected and nourishing place for the descending unfertilized egg.
1 Seed	Fertilization marks "Week 0," the blastocyst (~200 cells) implanted in about ~5 days.
2 Start-up	The growing embryo's weight does not register until "Week 8" but has been doubling in size about every 5 ½ days, some 42 times, by week 33 [6]
3 Turn Forward	To locate the Turn Forward; we first try Week 31 ( ) then Week 33 ( ). *Do you see why? Is there a better guess?* Placed at Week 31 assumes the last data point is a little high. That choice allows a smooth curve to the 7.5 lb average birth weight at 40 weeks.
4 Finish-up	There are four choices. The **dashed blue line** extends the data trend to a 40 week birth weight of ~1000 lbs? (NO). The **dotted green line** levels off suddenly to hit the avg birth weight of 7.5 lb? (NO). Is either lower and upper **pink curve** ( ) best, both showing weight gain curving smoothly toward either 7.5 or 8.5 lb? (OK) *Which 3rd Trimester growth curve seems most natural,* A or B? *Which is more likely birth weight 7.5 or 8.5 lb*
5 Arrival	Birth at 40 weeks ( ) leaves a newborn stressed and needing to recover, a dip in the curve.
6 Life	*How does weight gain during infancy and childhood proceed? In big spurts? Might physical growth be slowing the whole time, explaining why it takes 20 years?*[7]
7 New Context	Leaving home for a bustling world and further developing skills for Life.

- The study shows expanding the interpretation beyond the limited data as a guide to asking new questions, here trying to determine the final shape of the growth curve at birth. The primary constraint for all the options is maintaining the smooth natural shape of the growth curves seen in the data (the continuity).

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[6] Data source- Univ of New South Wales Embryology Study - https://embryology.med.unsw.edu.au/embryology/index.php/2009_Lecture_22

[7] Mayo Clinic "Pregnancy week by week" https://www.mayoclinic.org/healthy-lifestyle/pregnancy-week-by-week/in-depth/fetal-development/art-20045997

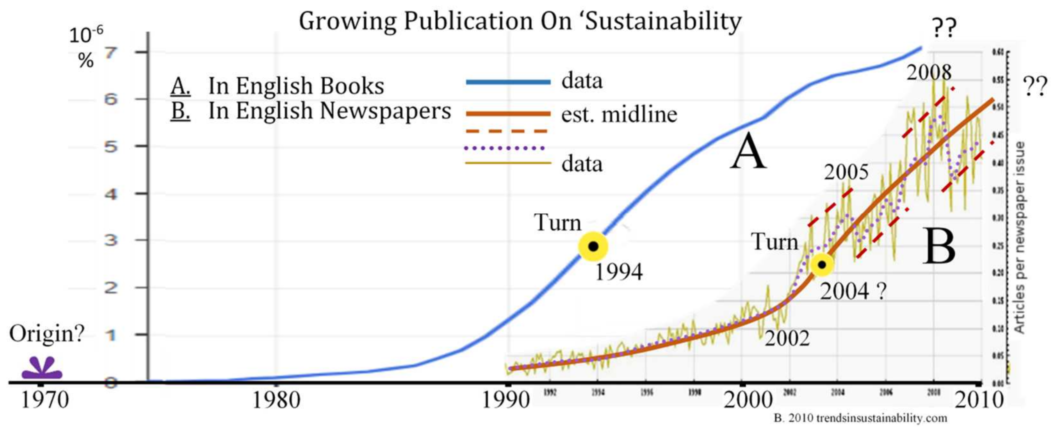

Fig 7. Case Study II. Data on book and newspaper publishing on 'sustainability.'

Case Study II The Growth of Publishing on Sustainability [8, 9]

0 Context — Concern with growing environmental harm began centuries ago. A great modern wave of concern is evident in the publication of books and newspaper articles on "sustainability" in the 1980s and 90s.

1 Seed — Curve A (in books) traces of the rise of "sustainability" in books from the 1940s, growing steadily from 1970. Curve B (in papers) might have had a long gestation too.

2 Start-up — Growth of Curve A is about ten years ahead of Curve B. Why? *Did sustainability start as a matter of private debate before becoming a matter or public debate? Was it that reporters were not reading books? Why else would covering it as news be delayed?*

3 Turn Forward — Curve A turns from curving upward to forward in 1994, seeming to mark the maturation of the book audience. For curve B it is less clear, marked as 2004? The newspaper audience shifts from smooth growth to wild fluctuation. *What might have caused the large swings of newspaper interest? If not signaling the resolution of the issue, what else might the turning points indicate?*

4 Finish-up — Curve A after 1994 shows steady slower growth. Curve B after 2004 was very hard to estimate. First midpoints of the data's largest fluctuations (••••) were traced. Then the extremes of the data's largest fluctuations (– – –). Finally, the smooth curve (▬▬) threading the first two. Neither data source is available after 2010. *Where might the trends have gone since 2010? Are the issues headed for resolution yet? Interest seems still strong. Was there a peak or a plateau? Is its promise fulfilled or the opposite?*

5 Arrival — The resolution of the sustainability issues would mark our arrival at a model for living in the future. *When might that occur? If not directly ahead, what is in the way? Is the discussion still searching for direction? What has become clear?*

6 Life — As in life, maturity is still a very eventful kind of steady-state. *In that sense, what is needed for the discussions of sustainability to fulfill its promise?*

- The study shows how departures from the model can start a useful narrative. All that is needed is some evidence hints of beginning middle and end.

[8] Google "Ngram" for Sustainability - https://books.google.com/ngrams/graph?content=sustainability

[9] Global Sherpa.org http://globalsherpa.org/news-trends-sustainability-development-issues/ publishing research by trendsinsustainability.com

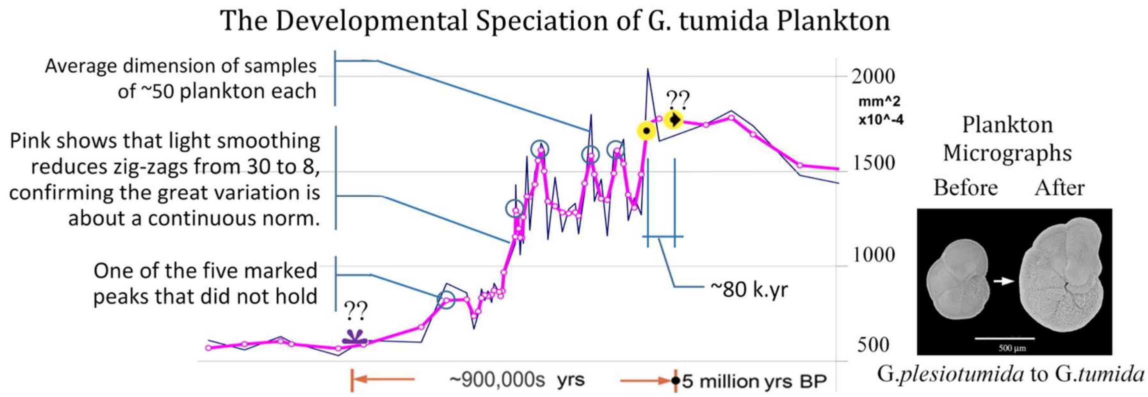

Fig 8. Punctuated evolution over 900 k.yrs of the G.tumida plankton, showing repeated bursts of increase in shell size, that then fall back until finally, one holds ().

Case Study III An evolutionary case of "try, try, again."[10]

0 Context	The jittery data line (blue) and more regular running average line (pink) trace a 900 k.yr evolutionary transition from one species of open ocean plankton to another (Henshaw 2007). Statistical tests show that the noise in the data is variation about a continuous norm. Light smoothing then approximates that trend, revealing several periods of rare continuity in evolutionary change.
1 Seed	The initiating seed event (??) for the G.*tumida* transition is placed at the estimated earliest point when the instability in the species genome might have developed.
2 Start-up	Five spurts of growth then collapse () establishing a "try, try again" development path. *Why might the evolutionary spurts have collapsed? Might study of similar patterns of repeated failure help?*
3 Turn Forward	After the highest of all growth peaks, the trend Turns Forward () after some ~820,000 years. *What are examples of "try, try again" efforts that that finally succeed? In personal or business relations. In cultural struggles?*
4 Finish-up	In the end the resolution is unclear, except that it came relatively quickly, within only an estimated 80,000 yr from the Turn Forward to the estimated point of Arrival.
5 Arrival	After the estimated point of Arrival (), the trend line returns to the kind of lazy drifting as before the long wild transformation struggle began.
6 Life	*What is life for a new species?* Here it is hard to say without a lot more understanding of how tripling the size of this common open ocean plankton changes its ecology.

- Think about "try, try, again" patterns, and what drives them in personal, business, and political struggles. Natural systems do not have human motives, of course; however, they might have fixations with similar effects. A self-organizing system might be disrupted repeatedly by some innovation that persists, like a handicap, only resolved by some future innovation. During such a period, the system would have struggles between its own old and new orders. *Are **all** great struggles perhaps like that, facing issues that come back again and again until finally resolved? Can the resolution of today's human fixations be informed by other very long struggles, like the evolution of G.tumida appears to display?*

[10] Ocean core data collected by Bjorn Malmgren (1983), Further analysis by Henshaw (2007)

Eco-Economics of Growth

"Try, try again" is also a way to describe the growth model of our world economy, continually trying to double in size and complexity as fast as possible, until large parts fail, producing another moderate to severe slide. To better understand that pattern, where it comes from and what to do about it, it will help to look at the world economy as being an ecology too, focusing on the following four characteristics both have in common:

1. Ecologies and economies both need energy for all their parts, each part balancing its energy budget with energy to spare similar to balancing financial budgets with positive rates of return.
2. Both need to rely on combining different specializations into individual productive units that adapt and work as wholes.
3. Those working units of both have living parts and rely on their exploratory learning to establish environmental niches and to make homes for their ways of living and their connections with others.
4. Both also thrive on moderately disruptive innovation, causing "creative destruction" as new kinds of organization disrupt the old, triggering system turnover, adaptation, and a reshuffling of relationships.

For a frequent reminder of these and other granular details of the ecological design of economies, it is useful to call them eco-economies for short.

That eco-economies evolve and grow by adapting to innovation helps explain how growth can be a smooth process, at a pace at which the parts can adapt. When those learning parts are people, it is easy to imagine how the innovation and adaptation of the working parts take place, exploiting opportunities, and overcoming challenges. It also appears to imply the converse, too, that wherever one sees smoothly progressing organizational growth, it is the innovation and adaptation of the parts that are bringing it about. That helps covey the picture of eco-economies as multi-level living systems. We can even directly observe it in the observed activity of all animal species, including people, almost always searching their environments as a way of living, in search of food, safety, and to sustain community as well (Henshaw 2008). Think of the complex world of a freshwater pond, as a thriving center for the interwoven niches of numerous species created by how their active members arrange the economy of their niches. In a healthy pond, the small fish can dart into the reeds and shallows when big fish come around, both learning to survive, with each community making a niche for itself while serving each other (Forbes 1887).

As growth initially progresses smoothly along its exponential path, the parts need to adapt to successively bigger and faster changes in their environment. That could explain why growth involves the shedding of large outmoded parts, unable to follow the fastest moving parts. It is the granular details of how eco-economies first smoothly, but then disruptively, adapt to continual growth that becomes the systemic limits to growth and recurring risks of collapse. So it appears that the decision-making behind the endless pursuit of growth, pushing the parts to increase productivity ever faster, is at least an important piece of the world eco-economy's "try, try again" problem. A good example is the financial crisis of 2008, which came partly from excessive speculation that stretched the obligations of insecure homeowners until their cascading failure triggered a global collapse. Fig 9 shows how the main eco-economy decision-makers are connected to help identify their roles and relations, and where their responsibility lies.

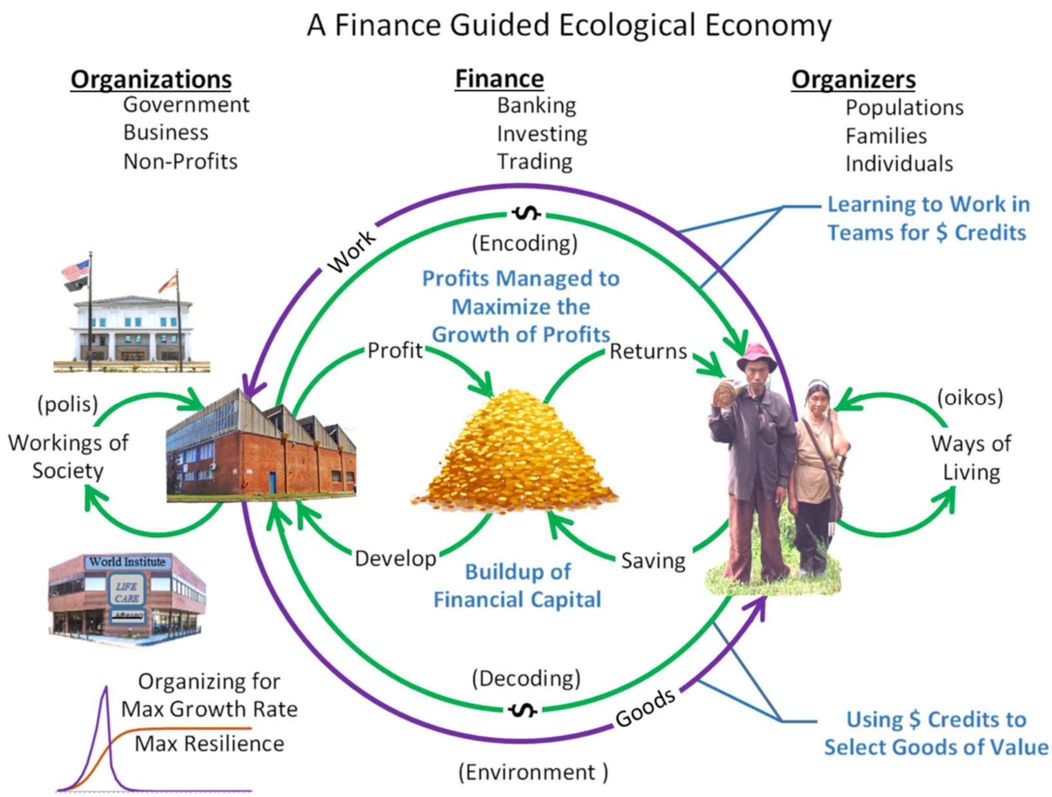

Fig 9. Decision-Making in a Finance Guided Eco-Economy: Business and Investor choices set future directions, usually to maximize their growing profits. Consumer choices reward attractive products. Government and Non-Profit choices respond to societal values and needs. Until there is a crisis, the rising cost of growth "externalities" is not counted.

In the center of the world eco-economy model, Fig 9, is the pool of accumulated investment funds, represented as a pile of gold. Usually, those investment funds and their profits go to whatever purposes promise to make them grow the fastest, not counting the costs of "externalities," such as driving climate change and making the parts of the eco-economy produce and change ever faster. Government policy also usually aims to maximize growth, overlooking how that maximizes the growing costs of the externalities for which the government will also be expected to pay. Here we are assuming a well-regulated money supply that expands and contracts only with the material value of the economy. In normal conditions, fiat currency expands and contracts with the creditworthiness of borrowers. The value of currency also varies with central bank efforts to stabilize low inflation and government economic policy.

Technically, the business or financial profits from investments can go to any purpose its recipients desire, as it is a surplus. So, in addition to owner self-interests, profits could be invested in balancing the rising costs of externalities or to selectively invest in other purposes such as the interests of the eco-economy as a whole or its various investor, business, government, societal, or private parts. The profits come from the organization of the parts, creating greater value together than the costs of their separate parts, producing a surplus as a whole. System resilience importantly comes from the ability of the parts of a system to share resources as needed, including profits that could be converted to any resource.

All sectors combine differing specializations to create emergent productivities that work together to make profits from creative organization. During growth, the system as a whole can be steered toward two general outcomes, illustrated in Fig 9 in the lower-left corner, one maximizing the growth rate to collapse, the other turning forward in time to maximize long term resilience. Given the increasingly hazardous directions the world is now taking,[11,12,13] the need to make the post-COVID-19 economy devote its spare resources to higher purposes. The cultures of all six decision-making sectors: 1) society, 2) government, 3) non-profits, 4) business, 5) finance, 6) family and individuals, would all need to reassess their choices and work together, each playing its part, rather than force our world on an ever more dangerous path.

Steering the Eco-Economy

Family and Individuals: Many individual and family financial choices are hidden from view. The most hidden it perhaps the most obvious, how one chooses to live one's life. There are also hidden choices people make about their savings. More people with substantial assets have been spending on targeted societal needs in recent times, but they usually still grow their unearned incomes by reinvesting financial profits. Those hidden choices have lasting impacts, as much or more than their roles in family, work, and society. It is good to save and have reserves, of course, but perhaps not to save more in unearned financial income than earned income from labor. Also hidden is how little direct environmental impact individual consumer choices have. Research shows that the environmental impacts of individual spending depend much more on our total income than on what we buy (Henshaw 2011), so what helps make one's life meaningful is quite likely to be the most rewarding as well as the most impactful choice.

Government and Non-Profit Sectors: The role of each level of government in steering society includes conveying a vision to inspire constituents and delivering essential services; including courts, defending voter,

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[11] 2019 WEF Global Risks Report http://www3.weforum.org/docs/WEF_Global_Risks_Report_2019.pdf
"Global Risks out of Control - Is the world sleepwalking into a crisis? Global risks are intensifying but the collective will to tackle them appears to be lacking. Instead, divisions are hardening. The world's move into a new phase of state-centred politics, noted in last year's Global Risks Report, continued throughout 2018. The idea of "taking back control"—whether domestically from political rivals or externally from multilateral or supranational organizations—resonates across many countries and many issues. The energy now being expended on consolidating or recovering national control risks weakening collective responses to emerging global challenges. We are drifting deeper into global problems from which we will struggle to extricate ourselves".

[12] 2019 UN Global Assessment Report on Disaster Risk - https://gar.unisdr.org/ Conclusion: - "Disaster risks emanate from development pathways, manifesting from the trade-offs inherent in development processes. In some ways, this has always been well recognized. What is new in today's increasingly interconnected society is the diversity and complexity of threats and hazards, and the complex interaction among them, which result in "an unprecedented global creation of risks, often due to previous socioeconomic development trends interacting with existing and new development dynamics and emerging global threats." P 418

[13] Experimental list of The Top 100 Disruptive World Crises Growing with Growth (Henshaw 2020): https://www.synapse9.com/_r3ref/100CrisesTable.pdf

civil and legal rights, maintaining infrastructure, public services of all kinds, protecting the environment, regulating business and finance, supporting scientific research, providing for the common defense, and national and international relations. Non-Profits, like service organizations and schools of all kinds, guide society with their more specialized societal inspirations and services. Both help enable the eco-economy's ability to make good collective choices. Given the increasing global risks the world faces, perhaps the most critical role for government and non-profits is advancing a genuinely sustainable "new normal." Change is always difficult, but that does not make it safe to forge ahead with our consumptive and disruptive habits of old, repeating Hardin's Tragedy of the Commons (1968).

Business and Development: The most direct way business and development determine the eco-economy's future is by investing in new business and infrastructure, physically building its new directions. Product development and advertising can either support or redirect new societal development choices too, often creating needs where none exists, such as to make consumption more glamorous. Where it becomes unethical is when growth-driven businesses pollute or disrupt society and the environment, maximizing growing paper profits and ignoring growing material side effects. Lots of small businesses limit their growth to just optimizing their services, to become anchors of their neighborhoods and communities. They only need to grow to a point they can pay off their debts and then devote their profits to family and community.

Finance, and Investing: The primary steering role of finance is moving money to wherever it can reliably make the most profit or serve other needs of investors. That shifts financial support from less to more desired uses. At a healthy level, it produces continuous healthy turnover in the economy. If the profits produced are regularly reinvested, that "compounding" of profits drives system-wide compound growth and ever-faster increasing and so disruptive turnover. That start-up kind of growth is essential in a new eco-economy's early stages. It becomes self-destructive if carried too far, destabilizing society or its environment.

Because whatever grows the fastest in an eco-economy naturally takes over, that rewards those investing their profits in whatever is growing fastest, giving the greatest reward to people hoarding their wealth and ignoring the side-effects. In a maturing eco-economy, facing complications of growing environmental resistance to growth, compounding adds to its conflicts with ever more 1) stimulus, 2) competitive pressure and struggle, 3) disruptive turnover, 4) financial and social inequities, 5) concentrations of wealth, 6) and deteriorating societal and environmental conditions; all the worst effects of capitalism in crisis. What gets overlooked is that investors might also choose, or be persuaded, to invest in their own and the common interest, distributing wealth when that is what allows the whole eco-economy to thrive, rather than foolishly trying to extract it all (Keynes 1932 Ch16-III).

There are quite numerous alternative economic proposals for how the world economy can achieve a thriving steady-state. The ones that seem most compatible with the natural systems view voiced here seem to be Kate Raworth's "Doughnut Economics" (2017) and Bill Baue and Ralph Thrum's 'r3.0'[14]. Both models propose a

[14] https://www.r3-0.org/about-us/ r3.0 promotes Redesign for Resilience and Regeneration. As a global common good not-for-profit platform, crowdsourcing recommendations for transformations across diverse fields and sectors.

transformation to an eco-economy of sufficiency that is equitable and distributive while respecting the whole spectrum of now threatened planetary boundaries. What we propose here differs strategically, focusing on the steering role, and natural fiduciary duty, of business and financial investment decision-makers, as they make decisions about everyone's future. It seems they are both the people most responsible and in the best position to assess good lasting value as we all move on from just maximizing our shares. Financial decision-makers are also the ones most caught in the trap of perpetual self-inflation and may need a little firm persuasion to try something new. That is, of course, only one sector of the natural steering of the world eco-economy. The roles of all the parts are critical for achieving a soft climax for our growth-driven world eco-economy. Perhaps it is reasonable to hope we could all rise to the occasion, and the result would retain much of the prior eco-economy's creativity and profitability while leaving behind its dependence on its ever-growing disruption of the earth and piling up unearned income.

When to Turn?

It is quite natural to be caught off guard by emerging systems that develop exponentially. That makes it very surprising that we do not study how to notice of their invasive behaviors. Fear helps but is a blunt instrument. Let us hope the 55% of the COVID-19 deaths in the US that could have been avoided if social distancing had been in place only one week earlier, and 83%, if two weeks earlier,[15] will have been sacrificed for a genuinely great purpose. However, we are making the very same tragic error wasting decades in responding to the exponential threat of climate change, only to have COVID-19 force our first small step in reducing our CO2. Would taking the hint now be enough? The severity of the climate crisis will still be much greater for our delayed response so far, even if also much less if we respond to the COVID-19 loss of life to take action.

The best examples of runaway exponentials to learn from are the most familiar ones, things that could become crises, but we have learned enough to respond to in time. Skirting the edge of going too far is both fun and a little dangerous in many situations, such as judging how to steer a perfect curve as when surfing, skiing, sailing, canoeing, or flying. There is pure art and pleasure in those steering challenges and little danger except in extreme conditions. Part of the challenge to steering growth systems is that 1) they have lives of their own, and 2) they can rapidly produce extreme conditions that may not be overcome. That is due to their pattern of "regular doubling," to which one must quickly gauge a response.

We are very practiced at timing the turn forward with lots of things, such as in taking creative tasks from beginning to end. Most creative tasks for work or home require managing an exponential start-up period and timing a turn forward to achieve a satisfying completion. Whether it is a large or small project, the start-up period always involves exploring different strategies that expand on the seed idea and when ready, selecting what ones to finish. That period expanding creativity needs go far enough to produce something practical *and*

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[15] J. Glanz and C. Robertson, NY Times, 5/21/20, *Lockdown Delays Cost at Least 36,000 Lives, Data Show*https://www.nytimes.com/2020/05/20/us/coronavirus-distancing-deaths.html

come to an end soon enough to leave time and resources to produce a successful product. That "turn forward" is often a bit gut-wrenching, as the stakes can be quite high. One also experiences the same urgency in simple things like leaving time to finish homework, to finish preparations for dinner, or to bring in a harvest.

Even smart project managers can get caught off guard, spend too much time messing with complicated plans, and use up time needed for finishing a practical one. Knowing when turn forward is also a common urgent task when developing a new personal relationship, growing a business, or as for us, steering a whole growing world eco-economy. The reorientation of the process, from starting up something to completing it, is much the same, however, a matter of choosing what experiments to take to completion. For an eco-economy that needs to respond to sustainable limits, Fig 10 illustrates five degrees of "sinking feeling" that it is time to turn forward: early, prompt, slow, delayed, and "none." The most general rule for "when to turn" is then "once it is ready" AND "before it is too late." Going by Fig 10, that balance point seems to be the last point without an abrupt bend in the curve, scale S1! Scale S1 is just over two doublings away from the limit.

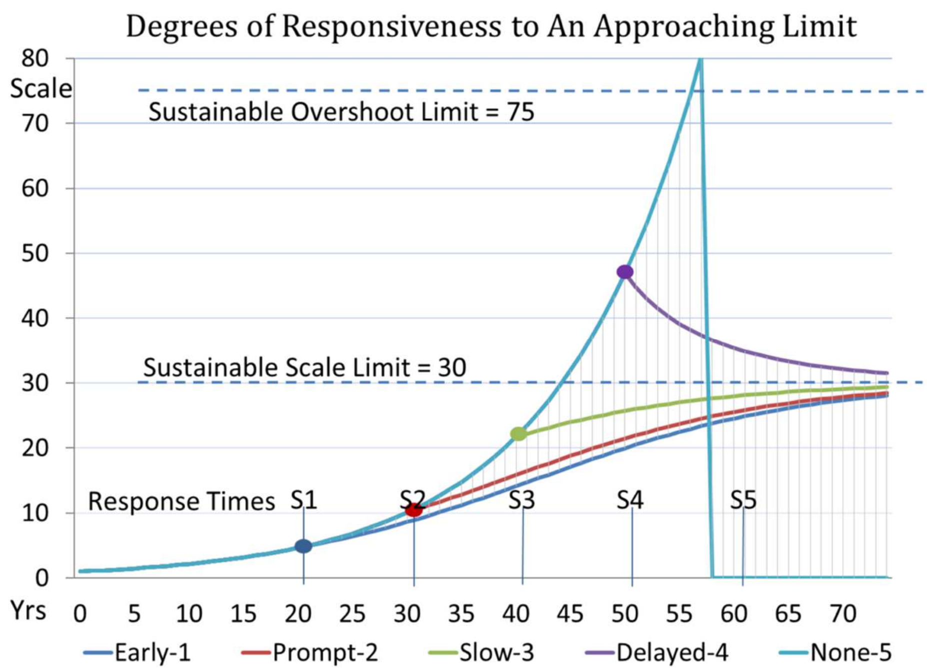

Fig 10. Scale of Urgency for Turns Forward, Delayed Response to Sustainable Limits: Increasing delays in response require an increasingly disruptive response. Each curve grows and approaches the sustainable limit at the same +7 %/yr, the assumed natural rate of development. Delay #5 does not make the turn. (Henshaw 2008)

To help guide a turn forward for the world eco-economy, lists of guiding values and principles of good planetary design, such as the UN developed for the SDGs, would help the various economic steering sectors develop their agendas. The SDGs focus mainly on desired economic benefits but ignore most of the tasks of sustainability, so among other things, guiding principles for real sustainability, respecting planetary boundaries, and responding to our many growing crises would be needed too. Three systemic health factors others might leave out are:

1) sustaining the system's healthy investment in creativity, especially as growth slows,

2) combining shared and direct externality costs in accounting for investment responsibilities
3) containing societal overhead costs and learning to live more simply
4) to reverse declines in net available energy, reducing demand to balance supply.

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