Growth Constant Fingerprints of Economically Driven Climate Change:

From 1780 origin to post-WWII great acceleration

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Abstract

The growth constants seen in long-term world climate and economy data show long periods of constant coupling, and other fingerprints of causation by human action and choices. It clarifies root causes and the critical need for whole system steering as a mitigation strategy. The recent 40 year smooth and steady 2 %/yr compound growth of Atmospheric CO2 should alarm anyone who sees it, showing clearly that our major sustainability interventions have had *zero* effect, evidently due to misunderstanding of the system we are responding to.

It all began with a relatively abrupt ~1780 burst of CO2 to begin the greenhouse effect immediately following the commercialization of Watt's rotary steam engine. The trend then stabilized for 160 years of maximizing long-term economic growth producing atmospheric CO2 growing at a steady 1.48%/yr, interrupted only by WWII. After 1960 a new 2.0%/yr growth constant for atmospheric CO2 PPM developed an effect of the globalization effort to accelerate growth even faster, a fact interestingly confirmed by converging log plots of Post WWII economic impact indicators.

Approximate linear correlation between atmospheric CO2 PPM and the rate if energy capture by the greenhouse effect allows simple linear fitting the CO2 PPM curve to Earth 's surface ºC temperature curves. With almost no pause for the COVID recession the 2.0% CO2 growth constant has continued, which projected implies that the 1.5 ºC threshold may be reached by 2031, nine years earlier than the IPCC's 2018 prediction of 2040. Discussion follows on how - without recessions - the pace of growth can decline to reduce the rate of CO2 accumulation and provide funding for technical mitigations; a combined effect quite essential to steering the global system to safety.

Supplementary references:

Figures deck:
http://synapse9.com/_pub/GrowthConstPrintsOfEconDrivCC-figs.pdf (Pending)

Preliminary Studies and Figures:
http://synapse9.com/_pub/GrowthConstPrintsOfEconDrivCC-refstudies.pdf (Draft)

Keywords:

natural systems physics, climate, human fingerprints, economic drivers, self-organization, growth constant states, coupling CO2 & warming; whole system steering to safety

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I. Introduction

The needed reorganization of the world economy to avert the worst of climate change will be better understood by closely studying the long history of climate change. That starts here with a close examination of the long record of accumulating atmospheric CO2 and the recognizable signs of familiar historical human intentions and events it exposes. That will provide a better basis for anticipating what the effect of other actions might have now. The main interest is making the whole story of climate change easier to tell, with data showing how starting in 1780, we began to build our whole future around endlessly growing environmental impacts, leading to a sharp acceleration of climate and other impacts after WWII. The data even suggests the reason may be our abiding fear of recessions, inadvertently leading us to sacrifice the Earth .

Among the significant findings are that climate change began somewhat abruptly in 1780, with the rapid spread of coal and wood-fired steam engine use, and proceeded at a growth constant of 1.48 %/yr for 160 years, ending with WWII. The evidence then shows that the CO2 PPM growth rate sharply increased to a steady rate of 2.0 %/yr with globalization. That gave us our recent decades of rapid climate change acceleration, and other impacts as ever-faster economic expansion ran into numerous disruptive societal and environmental limits. The relatively smooth CO2 PPM data and its approximately linear correlation with the greenhouse effect combine to make a simple analog proxy for climate change, helping expose, explain, and predict underlying trends in Earth temperatures. Principal among them is how the proxy projection of climate change and its sharp post-WWII exponential acceleration. Assuming the COVID recession is temporary, the established 2 %/yr growth constant is the climate change trend that will resume. The strong coupling of various other economic impact growth constants and the common origin of their coupling in the 1930s shows the same thing and point to a need to revise all our post-WWII economic thinking to succeed in slowing climate change.

1.1. Main Scientific Questions

Human fingerprints seen in long-term economic growth constants show that we organized human society to maximize the rate of economic growth for centuries. The detailed data in the 1970s shows the long-term fixed coupling between various growth constants such as GDP fossil fuel use, climate change, economic energy efficiency, and other global indicators. The global integration of the growth process with historical events and trends connects the economy's whole system behavior with the concurrent rapid growth of modern global societal distress and profound harm to nature's integrity, beauty, and value. The implication is that climate change is just one part of that whole system problem, not a technology problem, and solving it calls for a global change of heart.

There is evidence of growth constants being amenable to change, but as they reflect the world economy's behavior as a whole, it is unclear what determines that. What is also not evident, then, is what humanity could do to quickly change our highly integrated but unsustainable plan for the future. The paper leads to suggestions for starting the plausible hope that the economy could emulate the natural maturation process that brings the growth of individual lives to a climax (Henshaw 2020a). We might also recognize the pattern of growth to maturity in the difference between starting and completing useful work (Henshaw 2018). Fig 1 shows three outcomes of starting a compound growth process to illustrate the basic science of living system growth. Alternative #3 in Fig 1 shows a growth system making a "turn forward" rather than continuing ever-upward. If followed by the world economy, it would smoothly stretch its final doubling in size over perhaps the next hundred years rather than the next 25. That pattern of gradual climax to growth is how living systems reach their peak of vitality. While it does not say how to do it, it does help by showing us a gaping hole in our knowledge of how so many kinds of growth systems survive their growth.

The main gaps in knowledge that should be resolved by the data presented are:

1. finding the burst of development starting anthropic climate change
2. finding the real trend behind very erratic Earth surface temperatures
3. finding the primary human choices responsible for rapid temperature acceleration
4. finding that the system behaves as a whole and needs a whole system response.

The scientific opportunity to show these results comes primarily from:

5. the very smooth shape of the atmospheric CO2 PPM data over time (Fig 2)
6. the near-linear relation between greenhouse heating and atmospheric CO2 PPM (Fig 4).

1.2. Methods

The primary scientific method is analog data curve fitting and pattern recognition of system change in growth systems. It first originated with a series of micro-climate field studies in the late 1970s. As the sun moves in an arc from east to west, stable convection networks repeatedly formed and reformed as the direction of sunshine moved (Henshaw 1978). Closely observing the dynamics of indoor and outdoor convection currents offered useful clues to the shifting positive and negative feedback system periods of their development. That work expanded to studies in several fields in the 80s and 90s (Henshaw 1995). The broad useful finding is that it is useful to study the non-linear beginning and ending periods of self-organizing system dynamics as "learning curves" to understand what forms of organization are developing.

The *S*-shaped curves of non-linear development throughout nature often correspond to alternating positive and negative feedback loops in developmental processes is confirmed by further investigation. That applies to developing complex energy systems of all observable scales and kinds (Henshaw 1978, 1979, 1985, 1995, 1999, 2008, 2010a, 2010b, 2011, 2015, 2018). The recognizable non-linear shapes of alternating feedback processes in time-series data are markers t for identifying their reciprocating processes and other causal relations, with degrees of confidence established in each case. Standard linear scaling, curve-fitting, and conversion to log and derivative rate of change trends are also used. The primary difference is that the research uses a diagnostic pattern recognition method for the systemic behavior of natural processes. That is in place of the usual scientific method, which substitutes models for naturally occurring and often autonomously behaving systems.

As a convention, we call all kinds of systems that exhibit organizational growth "living systems," though their independent lives may be quite temporary (Fig 1, #1 & #2). Of most interest are the living systems that will eventually stabilize and develop roles in their new environments and, in that way, have lives after their growth (Fig 1 #3). Curve #3 looks like the usual sigmoid or '*S*' curve but has three organizational development periods, each starting with a system change event. The first is the divergent *start-up* or *takeoff* period, then a convergent *finish-up or maturation* period, followed by the *life* or *fulfillment* period. Each period begins with a system change. The first (A) is the *spark* or *seed*, and the system change from *start-up* to *finish-up* periods (B) is the *turn forward*. At the end of the *finish-up* period and the beginning of the *fulfillment is* (C), is *joining* or *arrival.* Following that nomenclature, we can call the problem with our current economic system that it has no plan to *turn forward* toward *arrival* and *fulfillment.* See also (Henshaw 2020a) for a more detailed view of the same model.

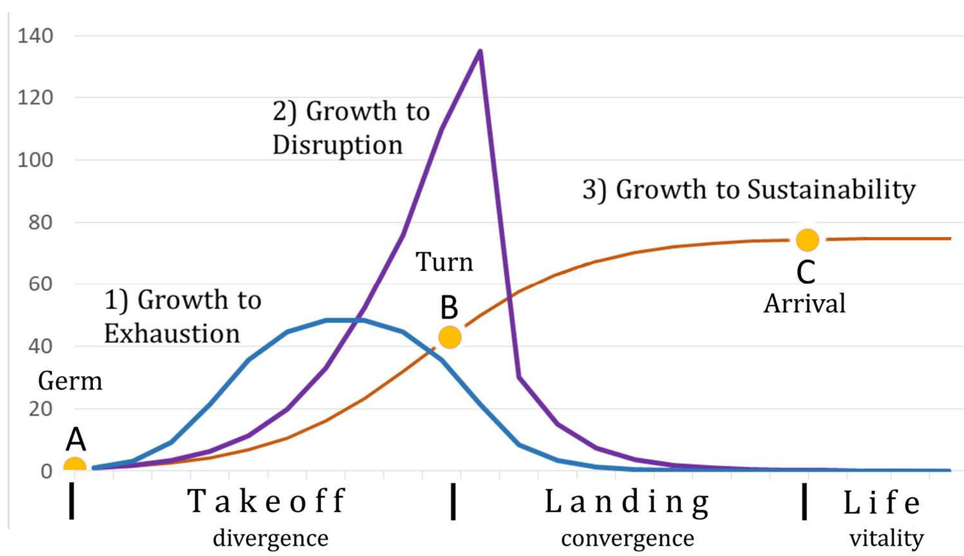

Fig 1. Three degrees of "living-system" sustainability - All start with *Takeoff* event A of an organizational seed pattern, like a crystal, spark, or germ cell connecting with resources to feed it. Only type #3 has events B and C, though the organizational turn forward to Landing in the new environment and the mature system's arrival to its new *Life*.

The main differences between the living-system growth paths shown in Fig 1 come from how systems variably respond to environmental change once their growth process starts and whether their design can change to become sustainable in response to natural internal and external limits.

1. Growth to Exhaustion – for systems like a campfire that flare up and burn out, having event A but not B. Some conversations are like that, too, not getting past a greeting or stalling after the first subject is touched on, also seedlings or businesses that get started but are unable to renew their first resource.

2. Growth to Disruption – for systems that grow until it disrupts their functions without using up their resources, having event A but not B. Explosions that blow out their own flame are like that, new businesses that break up over arguments about money, or others that misjudge their market and spend so much on growing they ignore other challenges, perhaps collapse during growth.

3. Growth to Sustainability – for systems that germinate and grow steadily but then sense the approach of limits and change by turning forward to seek new relationships in their surroundings, rather than turn ever upward, having events A, B, and C. Event C is the living system's point of maturity and arrival when its relationships in the new environment solidify

A related depiction of the 'S' curve as the story of life is in the book by Jonas Salk, recently republished by his son Jonathan (Salk & Salk 2018). Salk depicts the *takeoff* and *landing* periods as Epic A and Epic B. The book is very nicely illustrated as a story and gives many suggestions for distinguishing the qualitative differences between the divergent and convergent phases. From an ecologist's view, H. T. Odum (2007, p.283) similarly illustrated the same issues, showing six alternatives, including the three in Fig 1. The current history of economic growth, as depicted in Fig 2, from around 1780 to 2020, is like curve #2 of Fig 1, racing upward as if even the sky has no limit, raising the question if it will ever turn forward.

Identifying the feedback and feedforward loops at work that build, adapt, and connect the system's parts with its environment is what associates a particular growth curve with its working growth processes. For example, the growth indicators associated with divergent GDP (Fig 7), Food consumption, Energy Use, CO2 Emissions, Atmospheric PPM, and Economic Energy Efficiency reflect the production, demand, and investment feedback loops driving our system of more driving more.

II. Results

1.3. The Origin of Global Warming

Associating climate change with human decisions starts with finding the seed event that initiates the growth process. The IPCC (2014) marks the beginning of climate change with a long-term average temperature baseline from 1850-1900 to define the Earth 's pre-industrial temperature, a 50-year period. Tree ring studies by Mann et al. (1998) also roughly correspond. In addition, scientists use various other baseline used for climate change, such as the 1961-1990 average Earth surface temperature. Abram et al. (2016) found climate change to have probably begun by ~1835. Hansen (2018) offers an excellent summary of the climate science behind those views for those interested in the standard models.

One's first impression of the nominally 500-year history of atmospheric CO2 (Fig 2) is how smooth the curve is, primarily due to how local events are so widely diluted by the whole atmosphere. Up to 1958, the measurements of CO2 PPM are from sampling air bubbles from deep ice cores. That method does introduce some local irregularity, visually eliminated by integrating the data with a spline curve. However, that would be unethical not to show what variation is meaningful[1]. Therefore, the data from 1959 to 2019 shows the values for unaltered atmospheric sample data displaying the natural smoothness of change in the atmosphere's composition.

Growth systems generally start very small and develop slowly, consistent with originating from small events amplified by positive developmental feedback of a system's working parts. As a result, their stages of development are at first small and often not noticed. Fig 2 shows the start of a long-term growth constant for CO2 PPM as a shift from lazy ripples that abruptly shift to systematic acceleration in about 1780. After 1780 the variation in the curve is centered on the constructed growth constant. So the big question is, did something big happen in 1780?

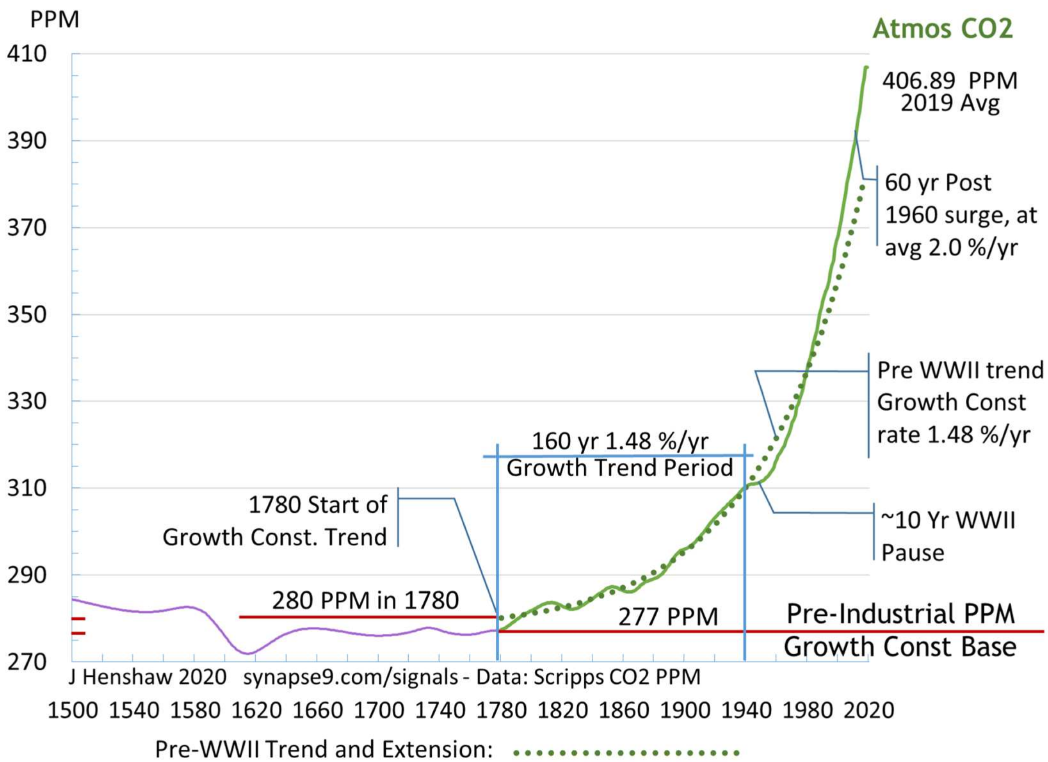

Fig 2. Atmospheric CO2 PPM from 1500 to 2019 showing pre and post-WWII systemic growth constants of 1.48 %/yr (Eqn 1) and 2.0 %/yr (per Fig 3), respectively.

[1] See Fig 10 in Suplementary Electronic files for Reference studies or Figures deck,

- Format for visual fit growth constant $Y = A * e^{X*r} + B$ (1)
  A = amplitude, B = baseline, r = exponent
- 160 yr Pre-WWII visual fit growth constant $\int_{1780}^{1940} \text{PPM} = 2 * e^{X*0.0148} + 277$ (2)

The year 1780 was just four years after the US declaration of independence and eight years before the US constitution's ratification. Globally it was a time of revolutionary scientific, economic, and governmental change; in the US and Europe, global shipping and water-powered industry played a large role in fulfilling the great promise of the century-long cultural revolution known as the Enlightenment[2]. A clue to the answer is the odd way the growth curve fits the Pre-WWII data, starts seeming to begin in mid-air.

The dotted curve, representing the 160-year pre-WWII CO2 growth constant, seems to begin 3 PPM above the green line of CO2 data, labeled "Pre-Industrial PPM." To Fit the data mathematically (Eqn 1 & 2) requires adjusting three variables, an amplitude (scale factor), a baseline, and an exponent. The implied baseline (277 PPM) for the growth constant gives the whole curve the appearance of having a 1780 jump start. The 277 PPM baseline was determined entirely by the shape of the growth curve that fit pre-WWII data. So it seems something in the environment would have had to give the CO2 PPM growth constant curve a 3 PPM jump-start. The details of industrial history seem to confirm it as a real event.

The sudden jump in the trend seems to represent real pent-up demand from *prior* industrial development, converting to fossil fuel use after 1780, followed by the first wave of fossil fuel pollution shown from 1780 to 1820. Some question remains about that first 40-year wave, as we will see in Fig 3, but if there was a big kick-off event, it is quite logical there would have been a starting wave. That kick-off event seems to be a period from 1776 to 1781 that ended with James Watt perfecting the steam engine. In 1781, he perfected the *rotating power shaft option* for the steam piston power he had been selling. That new rotary power was revolutionary and would have produced a long surge of applications for upgrading earlier water-powered industries in England, Europe, America, and for ships at sea.[3]

Exposing the 40-year start-up surge of CO2 pollution also shows why it can be worth looking at this level of detail to find seemingly small misalignments and bumps on data curves. They only look random to us until we understand them. To nature, they usually represent something happening that a little extra curiosity might reveal. This case also demonstrates why telling a story from the beginning helps set the stage and identify the forces that will later drive the narrative. Here it exposes the world economy's driven nature as businesses aggressively invest in advantages, using their money and technology to make more money.

We can also glean from the historic rise of atmospheric CO2 that up to WWII, the green data curve wanders back and forth across the 160-year dotted growth constant curve *but does not depart from it* until abruptly ending as WWII breaks out. That is evidence of homeostatic fluctuation about a systemic norm. It is a sign

[2] Wikipedia https://en.wikipedia.org/wiki/Age_of_Enlightenment

[3] Watt steam engine https://en.wikipedia.org/wiki/Watt_steam_engine

of self-correcting whole system organization, evidence that the whole tends to correct diverging parts. We will see signs of that in many other global economic indicators, as seen in Fig 7 and 8. So, it makes economic sense that the development of the world economy, driven to maximize profit, would sometimes increase its growth rate and fall back from rates that cannot be sustained, showing dynamic self-correcting behavior. That the world economy's dynamics produce such long-duration growth constants is still a surprise, as a lasting "groove" to operate in, but a system that produces them is something we cannot ignore.

In Fig 2, the WWII pause in rising CO2 pollution seems to be over by about 1960. Then, as if with a vengeance, the curve accelerates to a constant growth rate of 2.0 %/yr. That persists almost 60 years to 2019 before the COVID pause. Maximizing growth is, of course, not just an apparent natural property of ambitious entrepreneurs. It is also a familiar world economic policy and concentrated scientific, technological, and industrial collective effort to maximize growth on a steady course between dangerous overheating and painful recession. So finding evidence of two long growth constant periods, the second faster than the first, is a remarkable display of the world economy working just as it is supposed to, except, of course, for not limiting its also dramatically growing external costs.

So what happened in the 1960s to raise the growth constant of CO2 PPM? The most transformative changes seem to have been the computerization of business, science, and communications. Strings of major scientific advances greatly increased the efficiency, precision, and imagination of new technologies while giving businesses powerful tools for fabricating industries, cutting costs, and inventing new products. The creation of the modern network of global growth-promoting international government, financial institutions, and treaties that we call globalization also greatly benefited from advanced computers and communications. One of the profound ironies the increasing growth rate curve exposes is that the period since 1960 includes many of the most dramatic increases in industrial energy efficiency.

1.4. Detailed CO2 growth rate movements

To raise new questions about the early and current CO2 growth rate constants, Fig 3 shows 1780 to 2019 CO2 PPM data again (lower curve) with its annual growth rates above (dy/Y - % change). The two growth constants are the horizontal dashed red lines, the early 160-year 1.48 %/yr rate, and the current 59-year 2 %/yr rate. The first question some sharp observers would ask is whether it is coincidental that 1958 is both the start of the switch from ice core to mountain top CO2 measurements and the approximate start of the elevated growth constant period. What may not be coincidental is that the technology available to do automated remote mountain top measurements would coincide with world industrial recovery following WWII. The post-1960 data curve (green line) is steeper than the extension of the 1.48%/yr growth constant (dotted green line), which confirms the 2% growth constant. The fluctuation of post-1960 annual growth rates about the 2 %/yr line also suggests damped oscillation, an even stronger indicator of homeostatic behavior in the 1960 to 2019 period.

The post-1960 period seen here is another fingerprint of human choices, reflecting the period of worldwide economic integration we call "globalization," during which the world's scientific, business, financial, institutional, and government communities modernized and reorganized the world for maximum growth. Worldwide government policy still relies on increasing efficiency to reduce energy use and environmental impacts. However, the data has long shown that business does not use efficiency for that purpose, but quite the opposite (Jevons 1885). Businesses, however, use efficiency to reduce unit costs to help multiply units sold, causing efficiency gains to accompany growing, not shrinking, energy use rates and CO2 pollution. That is the real product of globally marshaling our best minds to accelerate growth and create our modern, highly unsustainable world. The dramatically accelerating increases in consumption and inequality come with ever more disruptive societal distress and environmental destruction, with human fingerprints in the data showing what we have done.

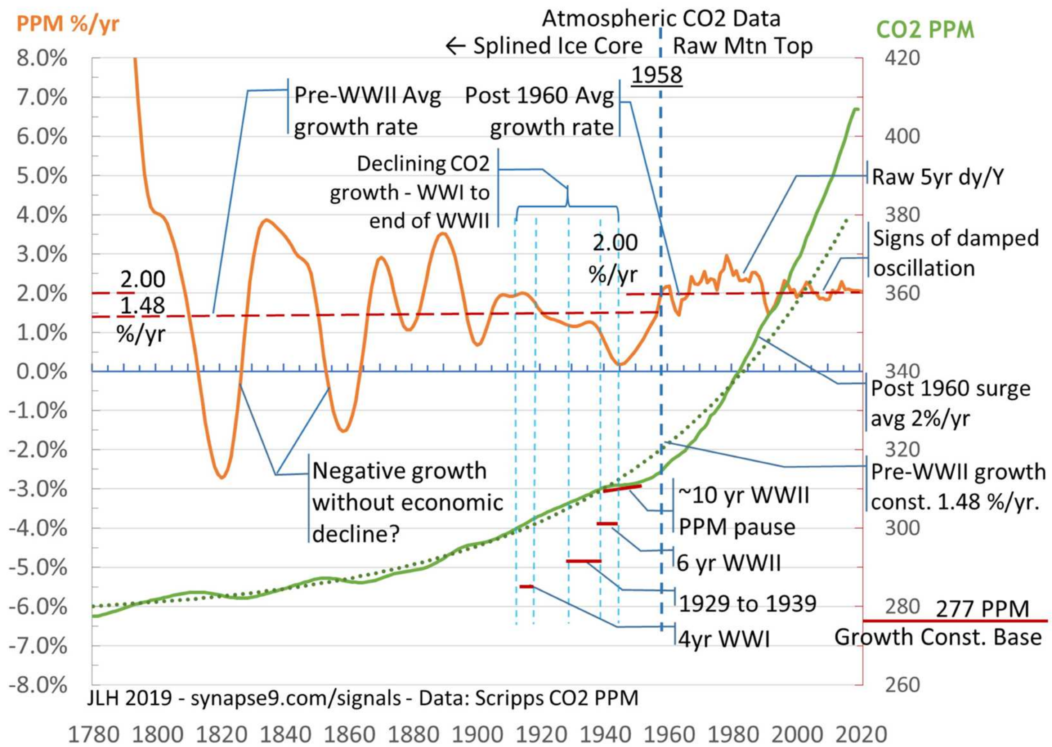

Fig 3. The Scripps CO2 data on the Rt axis (lower curve) is smoothed with a spline of the raw data to 1958 and merging Atmospheric sources after that. Annual dy/Y growth rates (upper curve, Lt axis) using a 5yr average (Eqn 2). The dashed lines show the growth constants found, shifting from 1.48 %/yr before to 1.90 %yr after WWII.

- Eqn: Five-point smoothing for dy/Y annual growth rates for splined Scripps CO2 data.

$$f(Y_n) = (Y_{n+2} - Y_{n-2})/(4 \cdot N_{n-2}) \quad (3)$$

Of some concern in Fig 3 are the large fluctuations in the annual growth rates of CO2 PPM in the first 100 years. If we are confident of the data, they might be presumed to represent instability in the world economy's self-organization. The raw data[4] shows a few places where a single data point could influence the shapes of the spline. The question is whether the spline curves show as waves, centered around 1810

[4] See Supplementary Reference – Figures or RefStudies figure 10

and 1850. Each wave has a long period with both up and downward sides, showing real declines in atmospheric CO2. There seem not to have been dramatic long-term recessions, and CO2 pollution is supposed to be long-term. The other possibility seems to be that there were other fluctuating sources and sinks for CO2, but none were found.

1.5. Fitting Climate Change & Atmospheric CO2

The full economic meaning of the growth constant fingerprints of human choices seen in the CO2 PPM record requires directly connecting them to the recent global warming records and showing that both are direct consequences of long-term post-WWII economic policy. To be sure that others can understand the analytical challenges requiring creative solutions, they need discussion in some detail. As a result, the next few pages will have more than usual descriptions of the analog curve fitting methods.

Fig 4 shows theoretical physics curves for the intensity of the greenhouse effect, showing the near-linear shape for various GHGs, in Watts/m^2, for the range of concentrations of interest for this study. That dramatically simplifies using the CO2 PPM data as a proxy indicator for the greenhouse effect and Earth temperature. That means linear scaling of the CO2 PPM data is a valid proxy for the Earth temperature if successfully calibrated using the HadCRUT4 °C data used by IPCC as a reference. That will compare the CO2 climate forcing trend with the IPCC's statistical averaging of the highly irregular HadCRUT4 Earth temperature data (Fig 6 jagged curve).

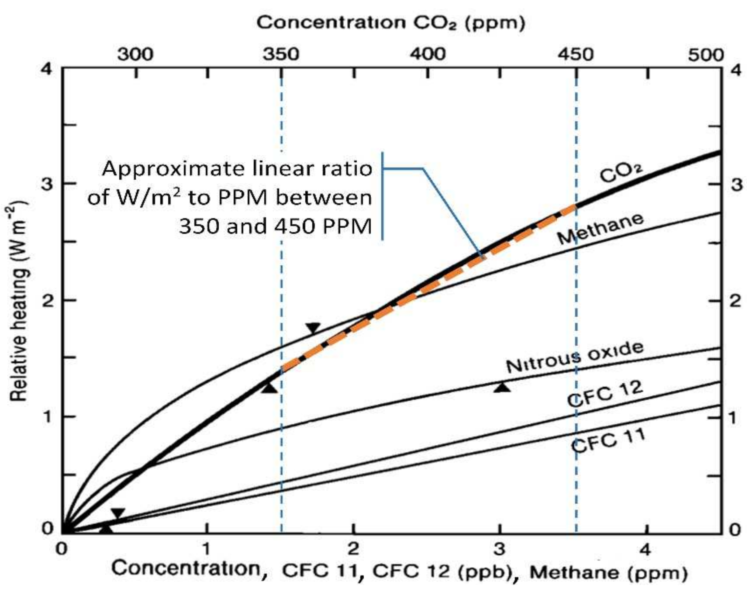

Fig 4. Relative heating rates for atmospheric CO2 PPM and other GHGs: From Figure 6 in Mitchell (1989): "Greenhouse heating due to trace gases, showing [top scale] concentration of CO 2. [ ] The triangles denote 1985 concentrations." A text label with a leader and dashed blue and orange lines are additions for clarity.

The extreme irregularity in the best available temperature data is due to the Earth having such complicated ways of moving around the sun's energy by ocean currents of varying depths, surface soils and forests, and the weather in the different domes of the atmosphere. Atmospheric CO_2 would trap heat in the atmosphere independent of the surface temperature and not be affected much by how the heat moves around.

A second analytical challenge concerns the remnant of multi-decade temperature waves in the paleoclimate data (Fig 5). The paleoclimate ºC data does show two great waves in 1880 and 1945 that match the ones in the HadCRUT4 data. However, these waves do not appear in the historical CO_2 record, so they seem to reflect departures rather than trends that the CO_2 PPM curve might be scaled to fit. The solution found was a plausible explanation for why the linearly scaled PPM°C curve (°C proxy) should skirt rather than pass through the large waves in the HadCRUT4 data. The fit found is shown in Fig 6. The solution was to scale the PPM°C curve to pass below the two "great waves" in the HadCRUT4 data at the nominal centerline of the high-frequency variation of that data.

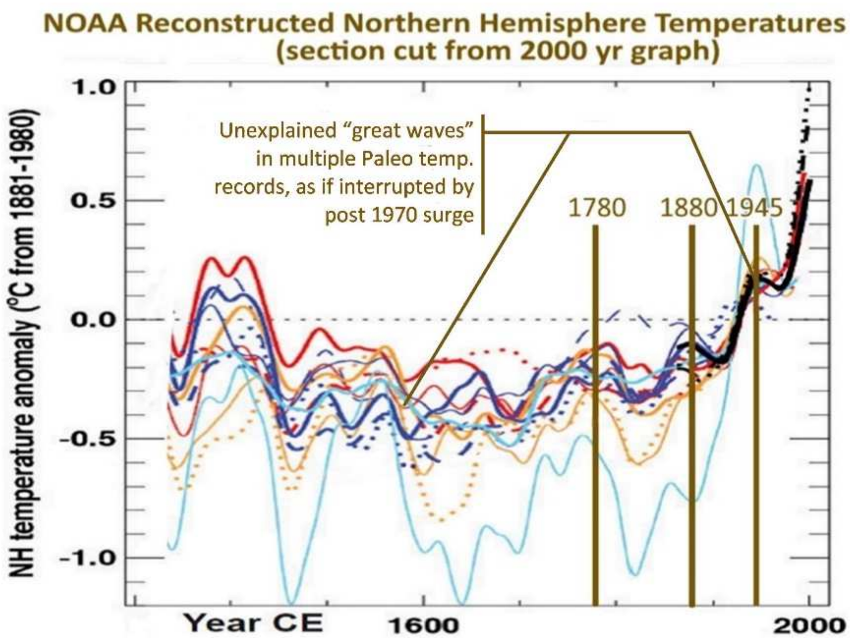

Fig 5. A 900 yr portion of a 2000 yr Northern Hemisphere paleotemperature record combining all methods, NOAA (2007): The title and marks in brown) are added (and an extraneous red line removed). Note how the recent great wave pattern seems affected by the great acceleration in climate forcing.

To make that curve fitting choice required finding a plausible cause for those great waves in the paleoclimate data, to know if they are part of or incidental to the greenhouse effect's accumulative CO_2 warming. One useful observation (Fig 6) is that the long series of multi-decade great waves in the paleoclimate data seems to end after 1945. That suggested the post-WWII acceleration of greenhouse heating somehow interfered with whatever cycle drove the long history of multi-decade waves. It also helps to notice the diminished "little-wave" in 2005, perhaps a diminished echo of the preceding multi-decade wave pattern.

It took a year of study to settle on a satisfying educated guess about what that interrupted paleoclimate cycle might be. For this writing, it only needs to be plausible that the great waves are some climate cycle that stops working as warming intensifies. That phrase was the productive clue, "a cycle that stops working as warming intensifies." The affirmation is partly from how much it improves the greenhouse effect data fit to the recent Earth temperature trends (the PPMºC curve to the HadCRUT ºC data).

What seems plausible is that the great paleoclimate temperature waves could represent multi-decade variation in upper atmosphere convection, high altitude troposphere convection cells penetrating the stratosphere or above. Previously thought to be rare, satellite images of outgoing longwave radiation from the Earth now show numerous standing radiative hotspots. That seems clear evidence that outgoing radiation from the upper stratosphere is variable and localized[5]. While it is probably different from the familiar kind of storm, they look like they ebb and flow. When upward warm air travel is blocked, the Earth heats up, and when openings for it develop, it cools. That cycle appears to end when greenhouse heating became so intense the openings in the stratosphere never closed, and the periodic cooling cycle stopped[6].

1.6. Projecting Climate Change to 2030, 2040, and 2050

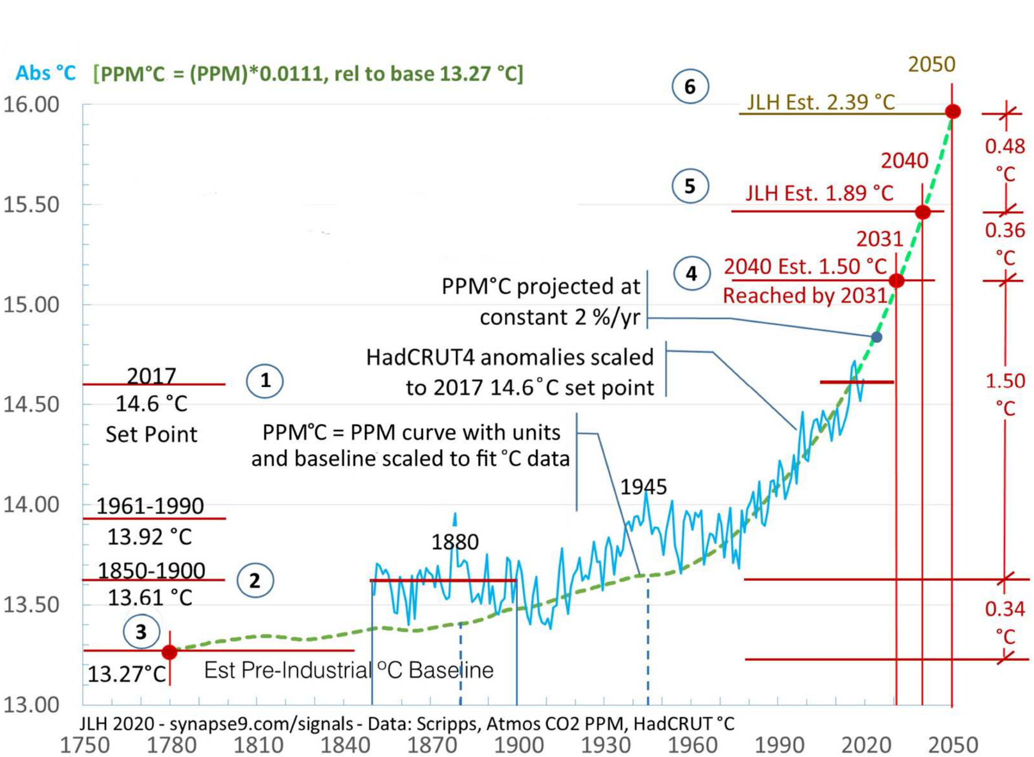

Fig 6. <u>The fitting of the PPM°C proxy curve to the abs °C HadCRUT4 anomalies</u>. Using a linear scale factor of 0.0111 and a Pre-Industrial base point of 13.27 °C to convert PPM to PPM°C (Eqn 4). Picked to follow the midline of the °C_values and the minima of the

[5] See Supplemental References – Sections I.H&I for figures and periodic heat waves in the stratosphere

[6] See Supplemental References Section I.B for a more detailed comparison of the CO_2 and °C data

two great waves. From 2019 to 2050, the current stable growth state of 0.2 %/yr is used (Eqn 5) [7]

- PPM converted to PPM°C PPM°C = PPM*0.0111, relative to 13.27 ºC base (4)
- PPM°C projection PPMCproj(1) = (PPM°C(0)*(1+.02), relative to 13.27 ºC base] (5)

The steps in generating Fig 6, circled 1 through 6, also included determining absolute °C values for the HadCRUT4 temperature anomalies, the IPCC 1850-1900 baseline, and the British 1961-1990 baseline.

(1) The 14.6 ºC set point for the 2017 HadCRUT4 Earth temperature is based on Hawkins's suggestion (2018). It is a test value easily updated if determined.
(2) Calculating the average HadCRUT4 temperatures between a) 1961 to 1990 and b) 1850 to 1900 are commonly used baselines used by British Meteorology and the IPCC.
(3) Adjusting the PPMºC curve (Eqn 4) variables to fit the HadCRUT4 data and determine the Pre-Industrial baseline temperature of 13.27 ºC.
(4) Project the PPMºC curve at its terminal growth constant rate of 2 %/yr from its end in 2018 to 2031, and record the ºC values on the results table.
(5) Extend the projection to 2040 and record the ºC values on the results.
(6) Extend the projection to 2040 and record the ºC values on the results.

It was exciting to discover the last small change in assumptions that allowed scaling the CO2 PPM curve to thread right up the middle of the HadCRUT4 temperature anomalies, particularly from about 1970. That makes it easy to project the proxy curve beyond 2020 at 2 %/yr and testable in the near term. The economic implication is that with "business as usual," the 1.5 °C threshold is crossed by 2031, not 2040. The IPCC business-as-usual projection of 1.5 °C in 2040 (2018) projects local statistical trends, not long-term whole system growth constants[8]. The finding also explains why climate change and other economic impacts seem to be accelerating (Dunlop & Spratt, 2018). Climate impacts are at the 2 %/yr growth rate and double the greenhouse effect every 28 years. That difference cuts in about half the time for mitigation measures to avoid some of the worst climate change effects. Even worse, it shows that the real solutions require transforming the world economy, not just changing technologies. Perhaps it would ultimately be easier to make our first step to stop ever worsening our problem.

Of course, the scaling of the PPM°C curve to fit the data is a matter of careful judgment that mathematical methods could do as well. It is not subjective, though, as a simple scaling of raw data to best fit another causally connected form of raw data. There is no change in the *shape* other than its baseline and vertical scale. Other factors reduce the subjectivity of visual curve fitting too. Successively smaller changes are needed to fit rigidly controlled shapes to multiple determining features of the data. Because of the above,

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[7] See Supplementary References include Section II on Types of Trend lines and Plots that describes each graphing and plotting method in some detail

[8] See Supplemental Referneces – Figure 19

an educated curve fitting by eye can often be more accurate than statistical averages and projections. The data's close visual fit might also mean that other factors such as cloud cover, humidity, and other GHGs are insignificant or linearly related to CO2. Most importantly, it assumes environmental science can organize around interpreting data as a dynamic life story, based on a familiar history and help validate the conclusions.

III. The Coupling of CO2 with GDP

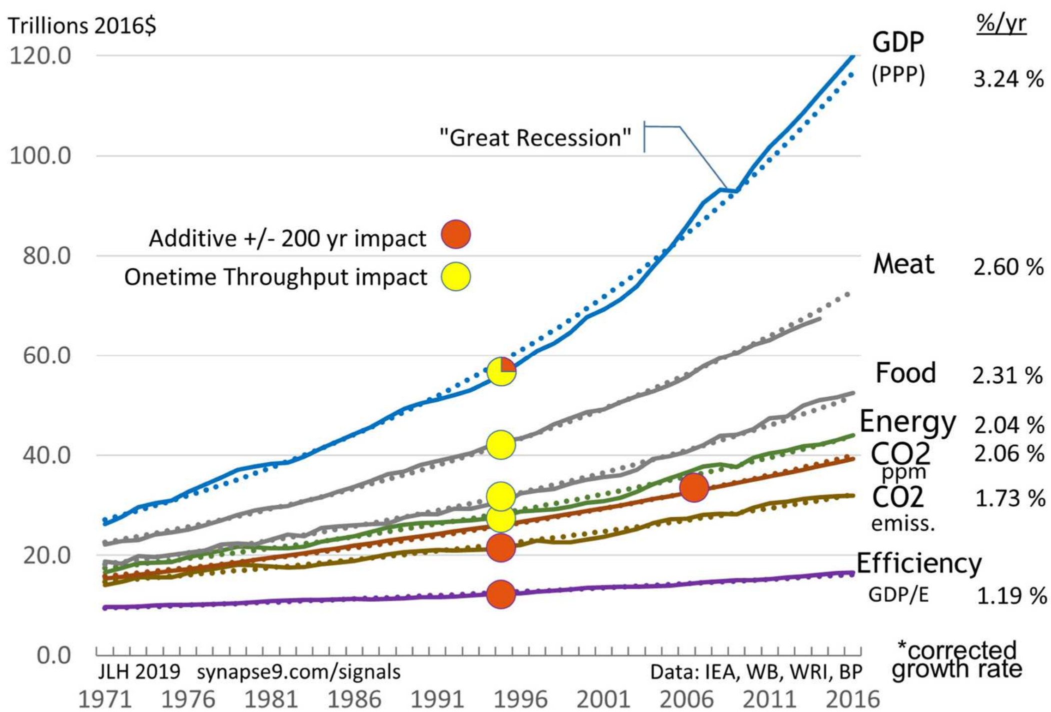

Fig 7. Growth constants of World GDP and Economic Factors – Each component is indexed to World GDP in 1971, in proportion to its relative growth constant.[9] How the parts move together illustrates how the system behaves as a whole and is responsible for the growth of its ALL IMPORTANT systemic externalities[10] too.

- Proportional indexing $EF_{1971} = GDP_{1971}*(R\%_{EF} / R\%_{GDP})$ (6)

Figs 7 and 8 show the constant coupling of growth constants for GDP, Meat, Food, Energy, CO2 PPM, CO2 Emissions, and Economic Energy Efficiency to show how the world economy works as a whole. Excel automatically generated the growth trends. The graphing method for Fig 7 is to index each data series to

[9] See Supplemental References, Section I Figs 20, 21 and 22 repeat Figs 7 & 8 with more detail, and in Sections II & III describe graphing methods and data sources.

[10] An experimental catalog of exponentially increasing externalities that producing societal crises around the world. https://synapse9.com/_r3ref/100CrisesTable.pdf

1971 GDP, scaled in proportion to their relative growth rates (Eqn 6). There is some variation in the data curves, but they all seem to fluctuate consistently about their exponential trendline. Some indicators tested did not display long-term coupling of growth constants, such as for concrete and inequality, and so were not shown.

The economic message is that many parts of the system steadily move together, behaving as a whole as ideal rules of self-regulating free-market behavior suggest it should. Behaving as a whole means many things, like that the parts stick together. As a maximizing growth system, each part and its connections would become optimized for working together to maximize growth. Changing one of the coupled parts would change them all without changing the system, up to the point of crisis or inflection when new design principles emerge.

Another remarkable feature of the current steady coupling of the parts is that, in theory, if the parts are changing in constant proportion to one another, this property of the system should extend back in time to the origin of the system. Fig 8 shows the result of a log plot of the five direct economic indicators in Fig 7 (without the CO2 PPM and GDP/E) from 2020 to 1780. What one sees is that all five current growth trends intersect at their projected value for 1935. The series for

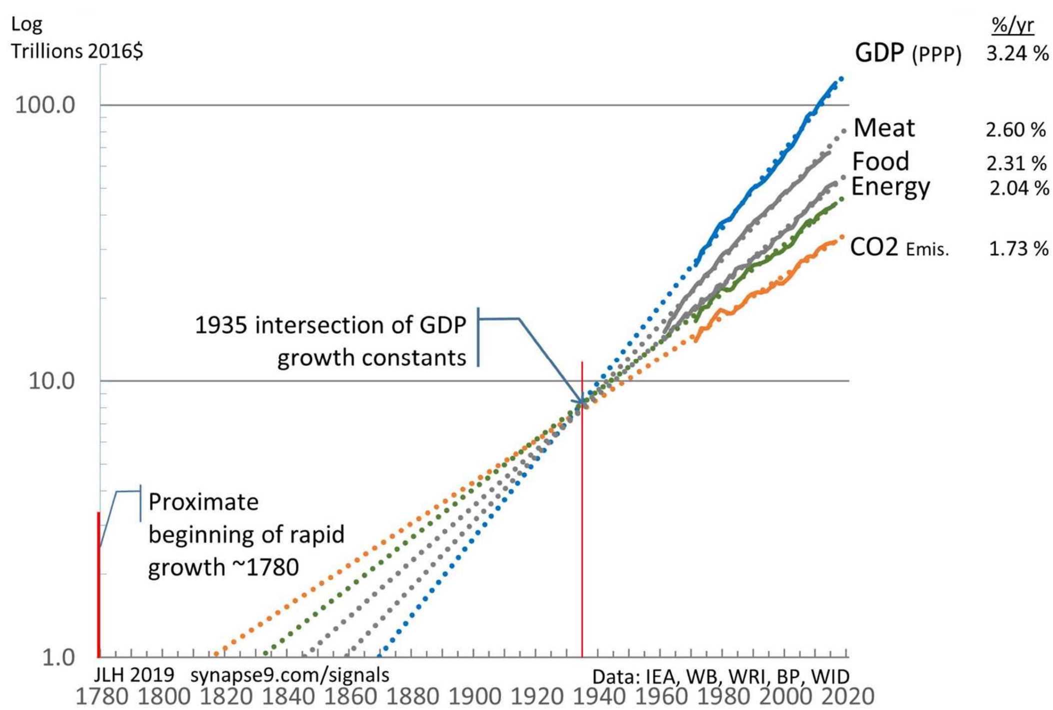

Fig 8. Log Plot of GDP and indexed EFs growth rates from Fig 7, back to 1780 - The remarkable convergence of post-1970 growth constants at 1935 suggests that Post-WWII globalization was a design for perpetual recovery from the great depression.

A simple explanation for Fig 8 is that the coordinated globalization of growth after 1960 may have originated with the economic thinking of 1935. The Post-WWII recovery, the Marshall Plan, and the economic globalization of the 50s, 60s, and 70s may have been a direct extension of the policies for recovering from the depression. Perhaps not coincidentally, 1935 was the publication date of the General

Theory of JM Keynes (1935), a way of thinking about economies that guided much economic policy for years. It might also have been that post-war economic policy was rooted in fear of recurring depressions. It led to economic, political, financial, and social forces all fixated on escaping from the great depression as a new world order. Another speculation is that it had deeper cultural roots in how political and financial interests concentrated their power by promoting individual self-interests to sell themselves and means of profiting, rather than selling the common interest, among the many ways of looking at it.

IV. Discussion

If nothing else, it seems quite clear that the current economic system developed a very stable organization for maximizing its growth, independent of the directly coupled rising threats of its many kinds of local and global externalities (Meadows et al. 1972, 2007,)(Steffen et al. 2015, 2018). Whatever the motivations, backward thinking, perhaps based on a fear of the past, also seems to have produced our equal failure to look to the future. The strenuous efforts to raise these issues in the 1960s and 70s were pushed aside by decades of government and institutional greenwashing, replacing real sustainability with promises of "decoupling." One only needs to see the long-term coupling of GDP growth constants (Fig 2, 3, 6, 7, & 8) to see that decoupling the economy from its central sources of environmental impacts is illusory. It is as fundamental as the difficulty of driving a car without its wheels.

The main question is, are we locked into taking growth to destruction? Or is there a system design principle that might let us steer our highly organized and resilient but dangerously unsustainable economic growth system to avoid breaking down first as in the 1930s? To understand the system design principle that appears to promise, one needs only to look at the numerous examples of how organisms, ecologies, and cultures of all sorts develop. They generally start from some small seed pattern that multiplies and then vigorously expands but gracefully turn toward their peak of vitality and longevity (Henshaw 2015, 2018, 2020a). The same system design principle is evident in how people manage home, societal, and business projects. Organizational projects of all kinds follow the same sequence of diverging and converging learning curves, switching from one to the next, as seen in Fig 1, curve #3. Managed growth processes generally begin with casting about for the design pattern with which to start. The start-up first leads to an accumulation of expanding efforts, and the usually graceful turn forward to converge on completing and coordinating details for producing a serviceable result.

The implication of Fig 9 is that responding to natural limits sooner than necessary has little effect on the path or the limit of growth, but responding late can be highly disruptive or cause a whole system failure. The formula (Eqn 7) switches each curve's steering at its response time (1, 2, 3, 4, 5), which starts with diverging from the past and switches to converging on the future limit. There is very little overall difference between responding early and enormous consequences of responding too late. A slow response to systemic limits leads to an increasingly disruptive response. The general principle is to gauge the best time to respond as the very first response to noticing limits. Humanity's response to natural limits has been just the opposite, putting off response for as long as possible.

Everyone knows about this principle from personal experience that pushing some limits risks rapidly escalating threats. It was the same with COVID, that early and repeated denial led to catastrophic results. We could have managed the discipline if it had been rewarded rather than ridiculed and saved hundreds of thousands of lives. We face the same looming existential threat from ignoring our accelerating destruction of the Earth by maximizing our exponential growth rates. The discipline of adapting to limits would not hurt so much and would bring about smooth change, in contrast to the long-lasting depression likely to come from ignoring it.

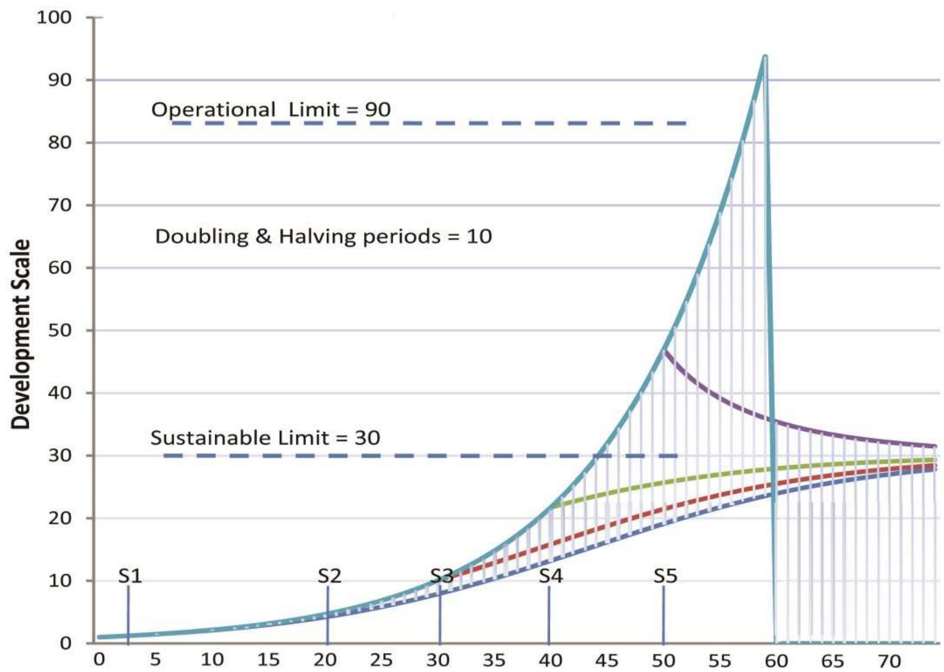

Fig 9. Starting times in responding to growth limits (S1-5) only matters if too late. - Making the turn forward *well before* crossing the eventual sustainable limit avoids the need for radical change. Going past the limit before turning leads to increasingly disruptive change. Starting time S6 is not shown because collapse occurs without a decision. (reprinted from Henshaw 2010b)

- Excel formula for each starting time in Fig 9: If Y_0 < OpLim,
  Y1=Y0*(1+RateConst*(1-Y0*(If Before = 0, else = 1/SustLim))) (7)

We do not precisely know the sustainable or disruptive limits, just that we seem locked into exponentially degrading our natural and societal capital assets. That itself is a signal of fast-rising threats directly ahead. Other signs also suggest we are well past sustainable limits too. That roughly puts us at Fig 9's response time S5, needing immediate dramatic change, and headed next to complete system failure otherwise. Lots of efforts also indicate efforts to climax are underway, too but hindered by our fixation on endless growth

What often lets a growth system make a smooth turn forward is anticipating the desired end. When building a home, the owner looks forward to finishing it so they can move in. An owner may make last-minute changes, but they are sure to be smaller and smaller, as both they and the builder see the natural limits of money running out and winter coming. Those draconian threats and the clamor to settle in turn the focus to the move-in date rather than making more changes. What are the equivalent choices for helping our present world tear away from its path of growing inequities and disasters as a future, to pause and turn toward making a good home instead? Perhaps the key is in asking why we chose to dramatically accelerate economic growth just as we were discovering how destructive it would become, in the 1950s and 60s, and just as the social culture was turning toward seeking to better our natural home. Culture change can be full of twists and turns, but did we let our gift for enslaving the Earth turn on us and enslave ourselves too?

A real possibility may be that having visions of peace on Earth did not come with a practical strategy for achieving it, a strategy to replace the carrot-and-stick pressures that drive endless growth with new energy for a smooth turn forward. It works similarly for both natural growth and managed development plans. The pattern is to repurpose resources used for the mostly completed divergent growth period to serve the new work of refining, coordinating, and maturing to complete the design. Think of an economy as a system designed for continual self-reinvention. The present need would then be to refine it to last and serve us well rather than keep multiplying its unmanageable problems.

That transfer from one kind of investment fund to another would be like a relief valve, shifting resources from where they cause growing problems to where they can serve lasting solutions. The trick is how to free them up; with disaster straight ahead, looking for the more profitable seems like a good bet. In this case, it would depend on the Earth's financial owners realizing that part of their natural duty of ownership, to both nature and humanity, is not destroying their property. Shifting to a sustainable model of economic creativity would, of course, be far more profitable than the alternative. Would the wealthy of the world recognize their duty and see it as an opportunity? We do see considerable movement in that direction. However, is it the right goal, and is it in time?

The main gaps in knowledge filled by the data are:

1. We found evidence of pent-up industrial demand for efficient steam engine rotary power that kick-started climate change in about 1780

2. We found the linear relation between CO_2 and rising temperatures to imply that a linear scaling of the smooth CO_2 trend would more accurately represent the real trend of climate change. We also found the smooth trend underlying the irregular surface temperature data to also indicate a more accurate pre-industrial average temperature at 13.27°C

3. We identified Post-WWII globalization in the 1950s and 60s as the primary human choice responsible for the recent rapid acceleration of climate change, coincident with the scientific and cultural alarm due to the global coupling of growth and its myriad growing impacts.

4. We showed how the world economy behaves as a whole and needs a whole system response, best described by the many examples of how both natural and managed growth systems make the turn forward to reach a climax of peak performance and longevity.

The scientific opportunity to show these results comes primarily from:

5. the very smooth shape of the atmospheric CO2 PPM data over time (Fig 2)
6. the near-linear relation between greenhouse heating and atmospheric CO2 PPM (Fig 4).

JLH

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VI. Data Sources

1. Atmospheric CO2 PPM 1501-2019 Figs 2, 3, 5, 7, 8,
   http://scrippsco2.ucsd.edu/data/atmospheric_co2/icecore_merged_products
   Atmospheric CO_2 record from splined ice core data before 1958, and yearly average measurements from of Mauna Loa and Antarctica after and including 1958.

2. HadCRUT4 Earth temperatures 1850-2017 – Fit 5, 7
   Rosner - OurWorldInData.org: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

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