Growth-constant Fingerprints of Economically Driven Climate Change:
From 1780 origin to post-WWII great acceleration

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Abstract

The data curves linking growing rates of climate change and the world economy show many fingerprints of human action and intent, clarifying root causes and exposing a need for whole system steering as a mitigation strategy. A rather abrupt ~1780 start of the CO_2 greenhouse effect coincides with the invention of rotary steam power. That starts rapid atmospheric CO_2 pollution growth with a 160-year long growth-constant of 1.48 %/yr, interrupted only by WWII. After 1958 the growth-constant of atmospheric CO_2 jumps to 2.0 %/yr, an effect of globalization, confirmed by converging log plots of Post-WWII economic impact indicators. Approximate linear correlation between CO_2 PPM and the greenhouse effect allows fitting the CO_2 PPM curve to earth's surface ºC data. Assuming the COVID recession is temporary, the 2.0 % growth-constant in CO_2 implies that the 1.5 ºC threshold would be reached by 2030, ten years earlier than the IPCC's 2018 prediction of 2040. Discussed is how, without recessions, the pace of growth can decline to relieve the high cost of its growing impacts and fund climate change mitigation.

Supplementary references:

Figures deck:
http://synapse9.com/pub/2020GroConstPrintsOfEconDrivCC-figs.pdf (Draft)

Preliminary Studies and Figures:
http://synapse9.com/pub/2020GroConstPrintsOfEconDrivCC-refstudies.pdf (Draft)

Keywords:

climate change, human fingerprints, economic drivers, self-organization, growth-constants, systemic coupling, natural growth, managed growth, whole-system steering

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 corrective actions might have. Telling the whole story of climate change will also make it easier to tell. The data shows the greenhouse effect appearing to start abruptly in 1780 and growing exponentially at a steady rate, then sharply accelerating after WWII. The data even suggests the reason for that acceleration may lie in be our abiding fear of recessions, preventing us from using foresight, and so letting all our impacts hugely disrupt the earth.

Among the significant findings are that climate change began rather abruptly in 1780, with the rapid spread of coal and wood-fired steam engine use, settling at a growth-constant of 1.48 %/yr for 160 years until WWII. The evidence then shows that the CO2 PPM growth rate sharply increased to a constant of 2.0 %/yr with globalization in the 1950s and 60s. That is what gave us our recent decades of rapid climate change acceleration and other impacts, as ever-greater use of fossil fuels and the release of carbon from biomass hit 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 °C temperatures, revealing and helping explain and predict an accurate long term trend in earth temperatures and its recent acceleration. Assuming the COVID recession is temporary, the CO2 growth constant post-1958 of 2.0 %/yr is the temperature change trend that will resume. An array of other coupled economic growth constants reveals more human fingerprints, pointing to the origin of their coupling in the 1930s. That shows how the world economic system behaves as a whole system, not a jumble of parts, and points to a need to revise all our post-WWII economic thinking to succeed in slowing climate change and the growth of the economy's other punishing earth impacts.

1.1. Main Scientific Questions

Long-term economic growth constants of the economy show both human behavior and intention to maximize economic growth for centuries. More detailed data available since the 1970s shows the long term fixed coupling of GDP and its components, such as meat and food consumption, energy and fuel use, climate change, and growing energy efficiency (Fig 7). The connection of that global integration of the growth process with historical events tells the whole story. The economy's whole system behavior links directly with the modern growing global societal distress and profound harms caused to nature's integrity, beauty, and value. The implication is that climate change is just one part of that whole system problem, a problem that technology alone will not solve, and calls for a global heart change.

What is not evident is what humanity could do to quickly change our highly integrated but also highly unsustainable economic plan for the future, but to study and follow nature's examples. The paper leads to suggestions for how the economy could emulate the natural maturation process that brings the growth of individual lives to a climax (Henshaw 2020a). We might also recognize and build on the pattern of growth to maturity we all use for beginning and completing any sort of useful work (Henshaw 2018).

Fig 1 shows three outcomes of starting a compound growth process to illustrate the natural science of living system growth. Alternative #3 in Fig 1 shows a growth system making a "turn forward" (event B) rather than continuing ever-upward. If followed by the world economy as shown, it would smoothly stretch its final doubling in size over perhaps the next hundred years, rather than the next 22 past average rate. That pattern of gradual climax to growth is how living systems reach their peak of vitality. That does not say how to do it, but it does help show us a gaping hole in our knowledge of how so many kinds of growth systems thrive long after 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 used is analog data curve fitting and pattern recognition of system change. This practice 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 following the sun's direction (Henshaw 1978). Closely observing those dynamics offered useful clues to the shifting positive and negative feedback periods of each stable state's development. That work expanded to studies in several fields in the 80s and 90s (Henshaw 1995). The broad useful finding is it helps expose what forms of organization are developing to study as "learning curves," the non-linear beginnings and endings of self-organizing system change.

Those *S*-shaped curves of non-linear development often correspond to alternating positive and negative feedback loops of organizational processes possible to confirm by further investigation. That applies to studying complex energy systems of all observable scales and kinds (Henshaw 1978, 1979, 1985, 1995, 1999, 2008, 2010a, 2010b, 2011, 2015, 2018, 2020a). The recognizable non-linear shapes of alternating feedback processes in time-series data -- their integrals and derivatives -- are then markers for identifying the reciprocating processes involved and other causal relations, with degrees of confidence needed in each case. Standard linear scaling and curve-fitting, and conversion to log and derivative rate of change trend displays are also used. The primary difference in the approach is its use of a diagnostic rather than a representational scientific method to study environmentally embedded complex systems.

As a convention, any system exhibiting organizational growth is in the category of "living systems." However, their independent lives may be quite temporary, such as for curves #1 & #2 in Fig 1. Of most interest are the living systems that stabilize and develop roles in their new environments growth takes them to have independent lives after growth (Fig 1 #3). Curve #3 looks a bit 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 *takeoff (or start-up)* period, then a convergent *landing (or maturation)* period, followed by the peak *life* (or *fulfillment)* period. Each life period begins with a system change event. The first (A) is the *germ, spark,* or *seed*. The second (B) is the *turn forward (from Takeoff* to *Landing)*. The last (C) is the *arrival (or affirmation)* event. 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 more detailed views of much the same model.

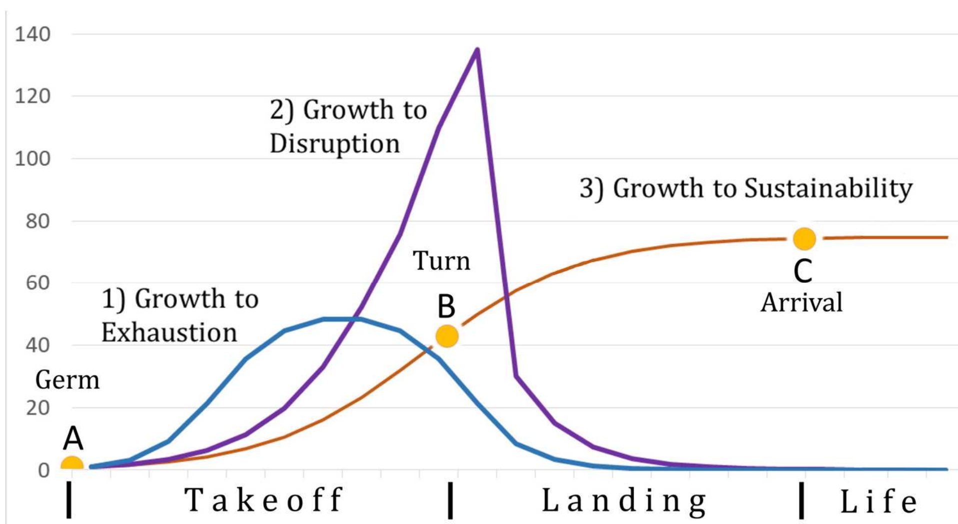

Fig 1. Three degrees of "living-system" sustainability - All start with *Takeoff* event A of an organizational seed pattern, like a crystal, spark, or germ cell connecting with resources to feed it. Only curve #3 has events B and C, the turn forward to Landing in the new environment, and the mature system's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

The main differences between the growth paths shown in Fig 1 depend on whether a growth system develops a new organization for tapping new resources and adapting to natural 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 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 they disrupt their functions without using up its resources, having event A but not B. Explosions that blow out their own flames are like that. Thriving startup businesses that break up over arguments about money, misjudge their markets, or ignore other challenges also display collapse during growth.

3. Growth to Sustainability – for systems that germinate and thrive in growth but then respond limits by turning forward to seek new relationships in their surroundings, having events A, B, and C. Event C is the living system's point of maturity and arrival at fulfillment when its relationships in the new environment take hold.

A related depiction of the 'S' curve as a story of life is in the book "New Reality" 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 of organizational development. From an ecologist's view, H. T. Odum (2007 p.283) similarly illustrated many of the same issues but draws six alternative curve sequences that include the three in Fig 1. Note that the anthropic history of atmospheric CO2, Fig 2 from 1780 to 2020, is like curve #2 of Fig 1, racing ever upward as if even the sky has no limit, raising the question of whether it will ever turn forward.

What associates a particular growth curve with its working growth processes is identifying the feedback and feedforward loops at work that build, adapt, and connect the system's parts with its environment. 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.

2. Results

2.1. 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, using that as the earth's pre-industrial temperature, a 50-year average. Tree ring studies by Mann et al. (1998) also roughly correspond. Climate scientists use various other baselines for climate change, such as the British use of the 1961-1990 average. Abram et al. (2016) found that climate change had probably begun by ~1835. Hansen (2018) offers an excellent summary of the climate science behind these 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. That is primarily due to how fluid the atmosphere is in distributing local changes through the whole atmosphere. It is also due to the measurements of CO2 PPM up to 1957 being from sampling air bubbles from ice-cores. The local irregularity that introduces is then eliminated by integrating the data with a spline curve. That makes it smooth again, but would be dishonest if not intended to show what is meaningful[1]. From 1958 to 2019, yearly average atmospheric values display the natural smoothness of change in the atmosphere's composition.

Growth systems generally start very small and first develop slowly, consistent with originating from small innovations amplified by positive developmental feedback of working parts. As a result, their stages of development are at first often not noticed. Fig 2 shows the start of a long-term growth-constant for CO2 PPM as a shift from lazy ripples before 1780 that abruptly shift to systematic after. Note the 160 year period when variation in the data varies around the constructed 1,48 %/yr growth-constant. So the big question is, did something big happened in 1780?

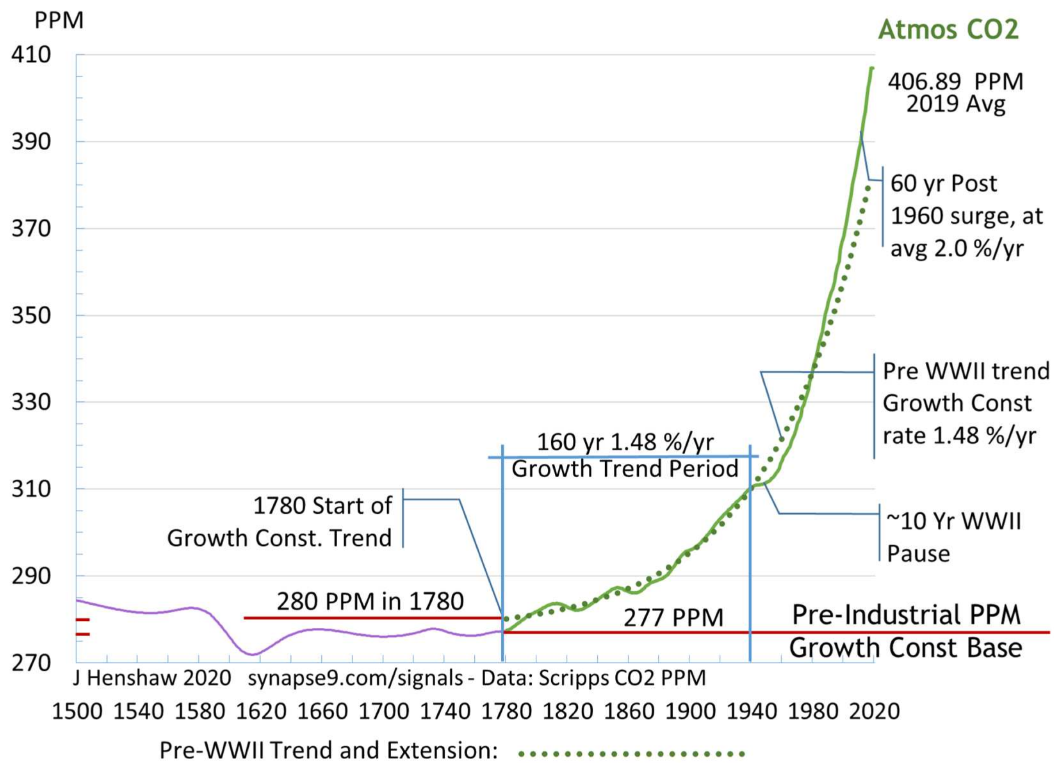

Fig 2. <u>Atmospheric CO2 PPM from 1500 to 2019</u> showing pre and post-WWII systemic growth-constants of 1.48 %/yr (Eqn 1) and 2.0 %/yr (per Fig 3), respectively.

- Format for visual fit growth-constant $Y = A * e^{X*r} + B$ (1)
  A = amplitude, B = baseline, r = exponent

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

- 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. Global trade of the growing US and European economies played a large role in fulfilling the great promise of the prior century-long cultural revolution known as the Enlightenment[2]. A clue to what happened in 1780 is the odd way the CO2 growth curve fits the Pre-WWII data, seeming to have a jump start.

The dotted 160-year pre-WWII CO2 growth-constant starts from 280 PPM, 3 PPM above the green line of CO2 data labeled "277 PPM" "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) was determined entirely by the shape of the growth curve found to fit the pre-WWII CO2 data, giving the curve the appearance of having a 1780 jump start. So it seems something in the environment would have had to give the CO2 PPM growth-constant curve a 3 PPM start. Industrial history seems 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. We see it as the first big wave of fossil fuel pollution going above the trend, 1780 to 1820. Questions remain about that first 40-year wave, as we will see in Fig 3, but if there was a big kick-off event, it is likely to have had a starting wave. That real kick-off event seems to be from 1776 to 1781, during which James Watt perfected the steam engine. In 1781, he perfected the *rotating power shaft option* so that steam pistons could power drive shafts. 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 converting ships at sea.[3]

Success in exposing the apparent jump-start of growing human-caused 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 often 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

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

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

norm, i.e., systemic organization. It is a sign of self-correcting system behavior, evidence that the whole tends to correct diverging parts. We will see signs of that in many other global economic indicators in Fig 7 and 8. It makes economic sense that the development of the world economy, driven by people maximizing 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 displays a persistence 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 turns steeply upward to a growth-constant rate of 2.0 %/yr (see Fig 3). That persists almost 60 years through 2019 and until the COVID recession. Maximizing growth is, of course, not just an apparent natural property of ambitious entrepreneurs. It is also a very familiar world economic policy and concentrated scientific, technological, and industrial collective effort to maximize growth steer a steady course between dangerous overheating and painful recession. So finding evidence of two long growth-constant periods, the second much faster than the first, is a remarkable display of the world economy working just as it is supposed to, except, of course, for persisting so dramatically toward environmental disaster.

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 advances in science greatly increased the efficiency, precision, and imagination of new technologies while giving business powerful tools for fabricating industries, cutting costs, and inventing new products. The advances in computer communication in the 1960s also transformed the policymaking tools creating the modern network of global growth-promoting international government and financial institutions. It is those global institutions and business cooperation treaties that we call globalization.

2.2. Fine details of CO2 growth rate movements

Fig 3 presents the detailed annual growth rates of CO2 (upper curve) (dy/Y - % change) aligning with the raw data curve below for reference. It helps raise new questions and give new answers. The two growth-constants are the horizontal dashed red lines. Some sharp observers might ask is if it is just a coincidence that 1958 is both when the data switches from ice core to mountain top CO2 measures and is also nominally when the elevated 2.0 %/yr growth-constant period begins? What may not be coincidental is that the technology available to do automated remote mountain top measurements would coincide with world industrial revival following WWII. The raw data curve (green line) is so much steeper than the extension of the 1.48%/yr growth-constant (dotted green line), it confirms the 2% growth-constant seen in the growth rate data above is real. After 1958 the growth rate curve is rough, reflecting the switch to unsmoothed annual measures, but over the years still stabilizes around the 2.0 %/yr line, indicating damped oscillation. That is another strong indicator of the homeostatic behavior of the growth rates of CO2 in the 61 yr 1958 to 2019 period. Also of interest is the absence of any sign of the great recession in 2008-2009.

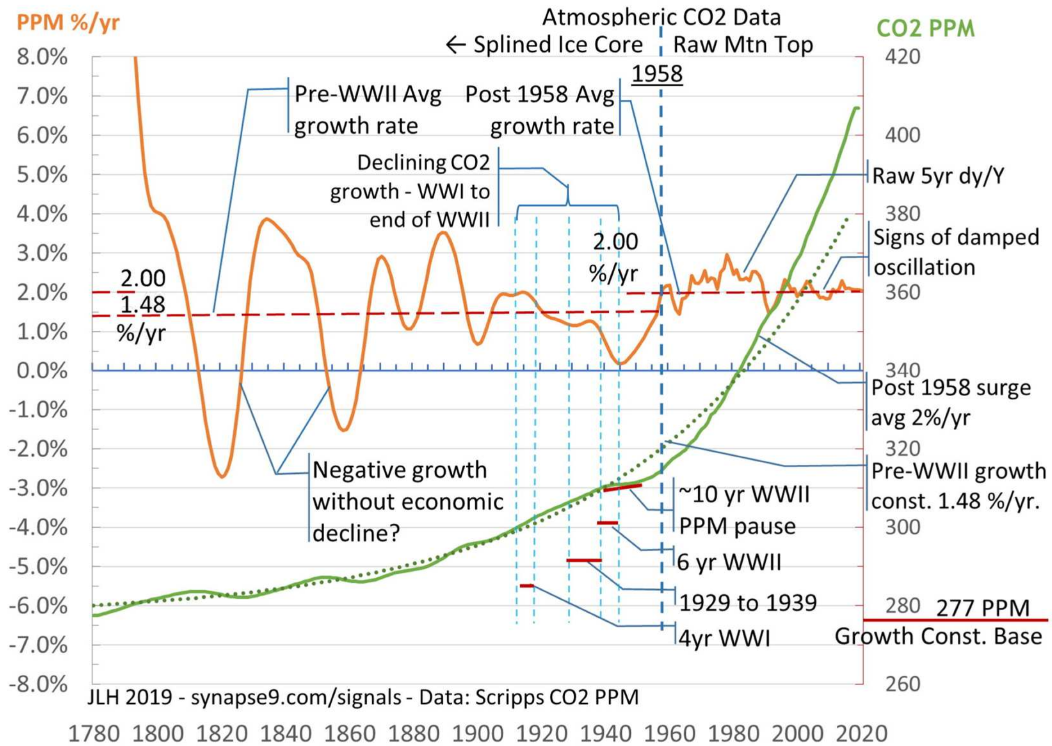

Fig 3. The Scripps CO2 data and its annual dy/Y growth rates - Annual dy/Y growth rates (upper curve & Lt axis) shows 5yr average rates (Eqn 3). The dashed lines show the growth-constants, shifting from 1.48 %/yr before to 2. 0 %yr after 1958.

- Five-point smoothing for dy/Y annual growth rates for CO2 data.

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

Of some concern in Fig 3 are the two largest CO2 PPM growth rate fluctuations, from 1780 to 1880. They line up with the first two waves in the data curves below, and we have reason to think the first corresponds to the startup period of steam engine use, absorbing pent-up demand. However, why would there be a second, and why would they show periods of declining CO2? A close look at the un-splined raw data[4] shows a few places where a single data points might influence bends in the curve. There seem not to have been deep recessions in this period, though, and CO2 pollution is supposed to be long term. Perhaps at first, large capacity CO2 sinks drew down atmospheric CO2 concentrations for a hundred years until they were exhausted, and pollution rates grew.

The post-1958 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

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

maximum growth. An irony is that government policy worldwide still relies on increasing efficiency for reducing energy use and environmental impacts. The data has long shown that business does not use efficiency for that purpose, but quite the opposite (Jevons 1885). What businesses do is use efficiency to reduce unit costs to help multiply units sold, causing efficiency gains to accompany growing, not shrinking, energy use rates, CO2 pollution, and all the other systemic impacts of the economy as a whole. That is the hidden real product of globally marshaling our best minds to accelerate growth to create our very modern but highly unsustainable world. The dramatically accelerating increases in both consumption and inequality come with ever more societal distress and environmental destruction, with human fingerprints in the data showing who is responsible.

2.3. Fitting Climate Change & Atmospheric CO2

The full meaning of our economic growth-constant fingerprints requires directly connecting these growth rate studies of CO2 with the trends in rising earth temperature, showing both to be direct consequences of post-WWII economic expansion. We will keep the discussion of analysis details as short as possible but include enough so technical readers can follow the story.

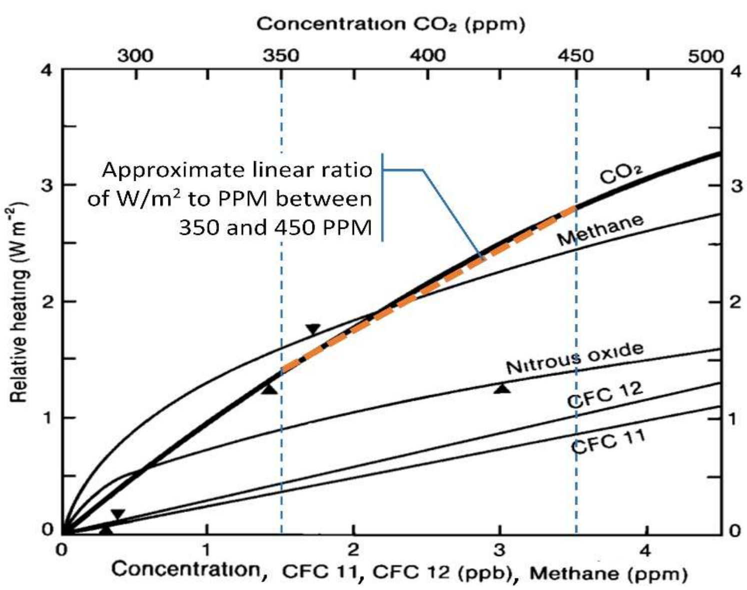

Fig 4. Relative heating rates for atmospheric CO2 PPM and other GHGs: From Figure 6 in Mitchell (1989): "Greenhouse heating due to trace gases, showing [top scale] concentration of CO 2. [ ] The triangles denote 1985 concentrations." A text label with a leader and dashed blue and orange lines are additions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

Fig 4 shows theoretical physics curves for the intensity of the greenhouse effect. The essential feature is how GHG intensity measures, in Watts/m^2, are approximately linear for the range of concentrations of interest for this study. That dramatically simplifies scaling the CO2 PPM data to serve as a proxy indicator for the HadCRUT4 °C temperature anomaly data used by IPCC. HadCRUT4 earth temperature data (Fig 6 jagged curve) is highly irregular. That has limited the IPCC studying it statistically, and the CO2 proxy curve (called PPM°C) is as smooth as the CO2 data, shows the earth temperature as following growth curves as the physics says it should.

The problematic extreme irregularity in the best available temperature data is due to the earth having such complicated ways of moving around the sun's energy. The heat moves around by ocean currents of varying depths, is absorbed in surface soils and forests, and circulates as weather in the different domes of the atmosphere. Atmospheric heat-trapping by CO2 would be independent of the surface temperature and the ways it 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 at 1880 and 1945 that match the ones in the HadCRUT4 data (Fig 6). These waves do not appear in the historical CO2 record, so the greenhouse effect does not cause them. So they seem to reflect departures from rather than trends of global warming. The puzzle is how to fit the smooth PPM°C curve to the temperature data showing multiple great waves, the last as recent as 1945. The solution found gives a plausible explanation for why the linearly scaled PPM°C curve should skirt rather than pass through the large waves in the HadCRUT4 data, unlike standard curve fitting. Fig 6 shows the scaling of the PPM°C curve to pass just below the two 1880 and 1945 "great waves" in the HadCRUT4 temperature data at the nominal centerline of the fluctuations.

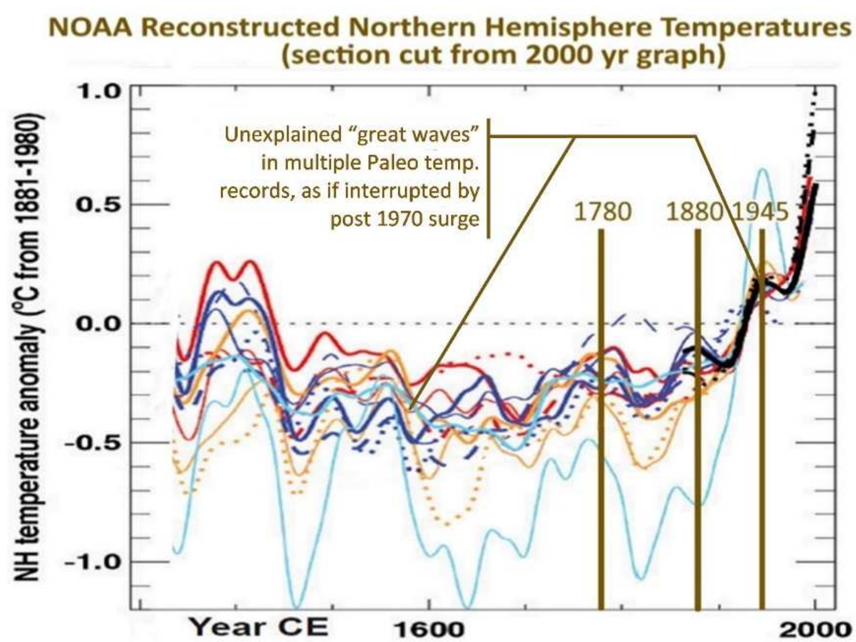

Fig 5. A 900 yr portion of a 2000 yr Northern Hemisphere paleotemperature record combining all methods, NOAA (2007): The title and marks in brown) are added (and an extraneous red line removed). Note how the recent great wave pattern seems affected by the great acceleration in climate forcing.

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 CO2 warming. One useful observation (Fig 6) is that the long series of multi-decade great waves in the paleoclimate data (Fig 5) 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.

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

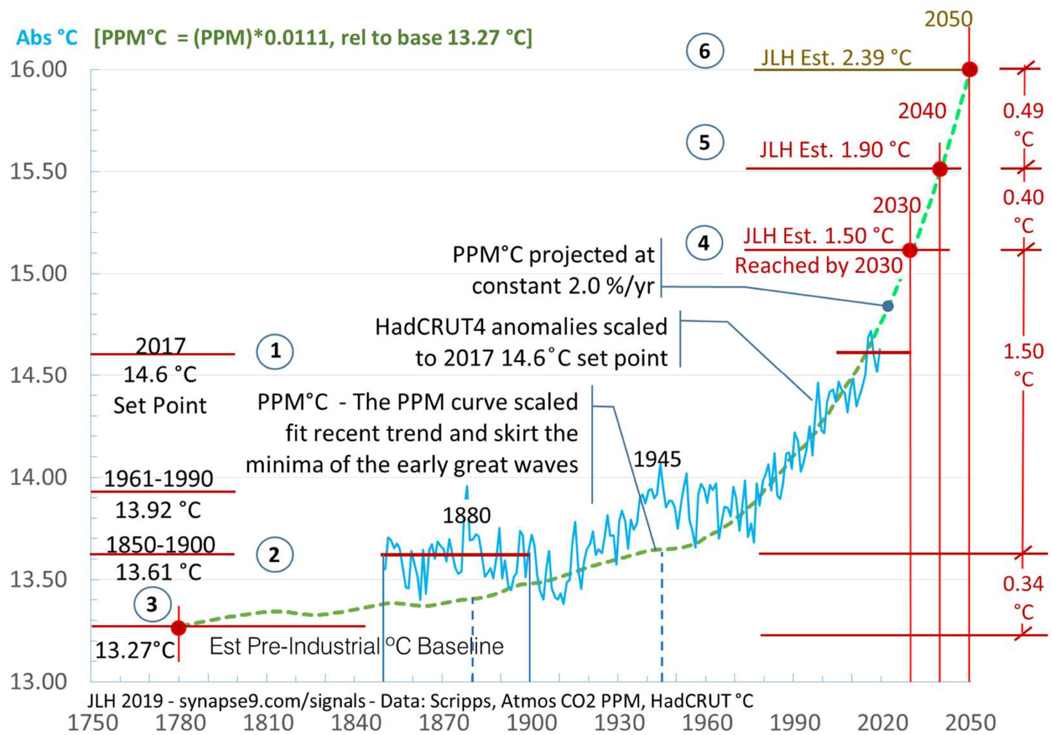

Fig 6. <u>The fitting of the PPM°C proxy curve to the abs °C HadCRUT4 anomalies</u>. Using a linear scale factor of 0.0111 and Pre-Industrial base point of 13.27 °C PPM data is converted to PPM°C (Eqn 4), picked to follow the midline of the °C values and skirt the minima of the two great waves, and projecting at 2.0 % (Eqn 5) [5]

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

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 of that curve fitting choice also comes partly from

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

how much it improved the proxy curve's fit to the recent earth temperature trend, allowing confident projection of the PPM°C curve.

The plausible interpretation of the great paleoclimate temperature waves is that they represent multi-decade variation in how heat gets to the outer atmosphere for radiation into space. Storms in the troposphere do not reach the stratosphere, but some other kinds of high-altitude convection seem to. Satellite images of outgoing longwave radiation from the earth show numerous slow-changing radiative hotspots that appear to gradually ebb and flow.[6] When openings in the stratosphere for upward warm air travel are blocked, the earth heats up, and when they open, the earth cools faster. That cycle appears to end when greenhouse heating became so intense that the openings in the stratosphere never closed, and the periodic cooling cycle stopped.[7] Some other cycles might conceivably begin, of course, conceivably even accelerated cooling to help slow climate change.

The steps taken 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) Choosing the 14.6 ºC set point for the 2017 HadCRUT4 earth temperature was based on Hawkins's suggestion (2018). A test value easily updated if determined.
(2) Calculating the average HadCRUT4 temperatures between 1961 to 1990 and 1850 to 1900 commonly used baselines -- used respectively by British Meteorology and the IPCC.
(3) Adjusting the PPMºC vertical scale and baseline (Eqn 4) to fit the HadCRUT4 data and determine the pre-industrial baseline temperature of 13.27 ºC.
(4) Projecting the PPMºC curve at its terminal growth-constant rate of 2.0 %/yr from the data's end in 2019 to 2030 and record the ºC values.
(5) Extend the projection to 2040 and record the ºC values on the results.
(6) Extend the projection to 2050 and record the ºC values on the results.

It was quite 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 after about 1970. That makes it easy to project the proxy curve beyond 2020 at 2.0 %/yr to test against future data. The economic implication is that with "business as usual," the 1.5 °C threshold is crossed by 2030, not 2040. The IPCC (2018) business-as-usual projection of 1.5 °C in 2040 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 have been growing at the 2.0 %/yr growth rate, which projects a doubling of greenhouse warming in 28

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

[7] See Supplemental References Section I.B for a more detailed comparison of the CO2 and °C data

[8] See Supplemental Referneces – Figure 19

years. That difference cuts in half the time for mitigation measures to take effect and avoid some of the worst of climate change. The good news sounds a lot like bad news, however. This analysis shows that the real solutions require transforming the world economy as a whole, not just changing technologies. That is why it seems we have spent 30 years on climate change and have not yet bent the curves. Perhaps it would ultimately make things easier if our first step is to stop making our problem ever worse.

Of course, the way the PPM°C curve was vertically scaled to fit the data is also somewhat subjective, as the boundary points for the baseline and midline of the resent period were judgmental. There is no change in the shape other than its vertical start and scale, however. 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, 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 shows that environmental science can organize around interpreting data as a dynamic life story based on data and familiar history to validate the conclusions.

2.5. The Coupling of CO2 with GDP

To clearly show how the world economy works as a whole, Figs 7 and 8 show the constant coupling of growth constants for GDP, Meat, Food, Energy, CO2 PPM, CO2 Emissions, and Economic Energy Efficiency. The growth trends were not manually adjusted to fit the data but calculated by Excel. The graphing method for Fig 7 is to index each data series to 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 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 growth maximizing 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 back to 1780. What one sees in Fig 8 is that all five current growth trends intersect at their projected value for 1935, something that cannot be a coincidence.

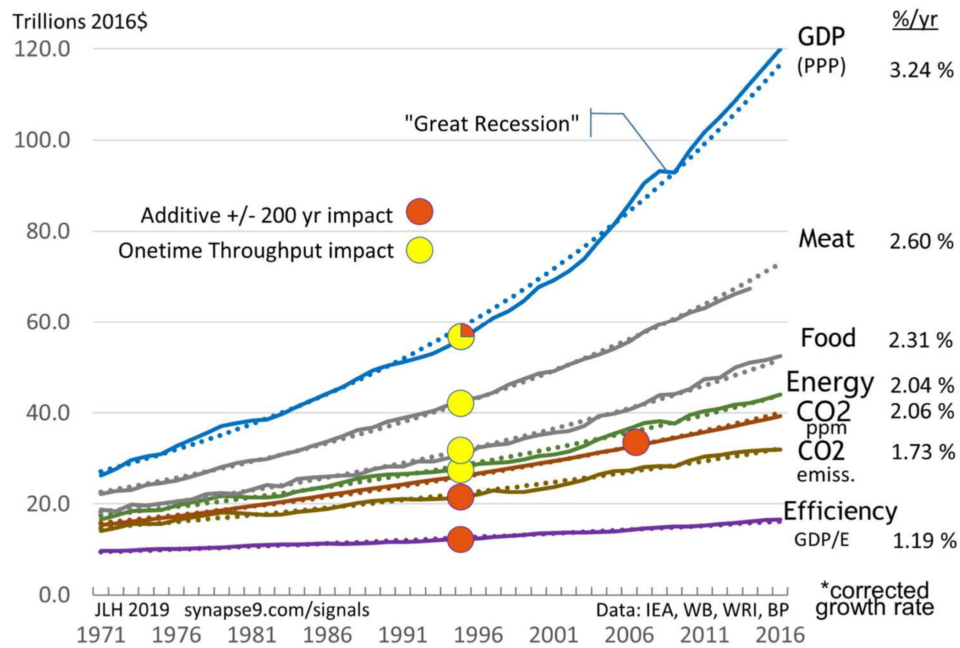

Fig 7. Growth-constants of World GDP and Economic Factors – Components are indexed to World GDP of 1971, in proportion to each relative growth-constant. 9 How the parts move as a whole illustrates how the system behaves as a whole, making the whole responsible for the growth of its systemic externalities.

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

A simple explanation for Fig 8 is that the coordinated globalization of growth after 1958 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-WWII economic policy was rooted in fears of recurring depressions and led to economic, political, financial, and social forces designing a future modeled on escaping from the great depression. It may also be rooted in political and financial interests concentrating their power and promoting individual self-interests over the common interest. It might be most productive to ask, "*what* were we thinking" when we organized modern societies around using science and technology to take us on the shortest path to infinity?

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[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.

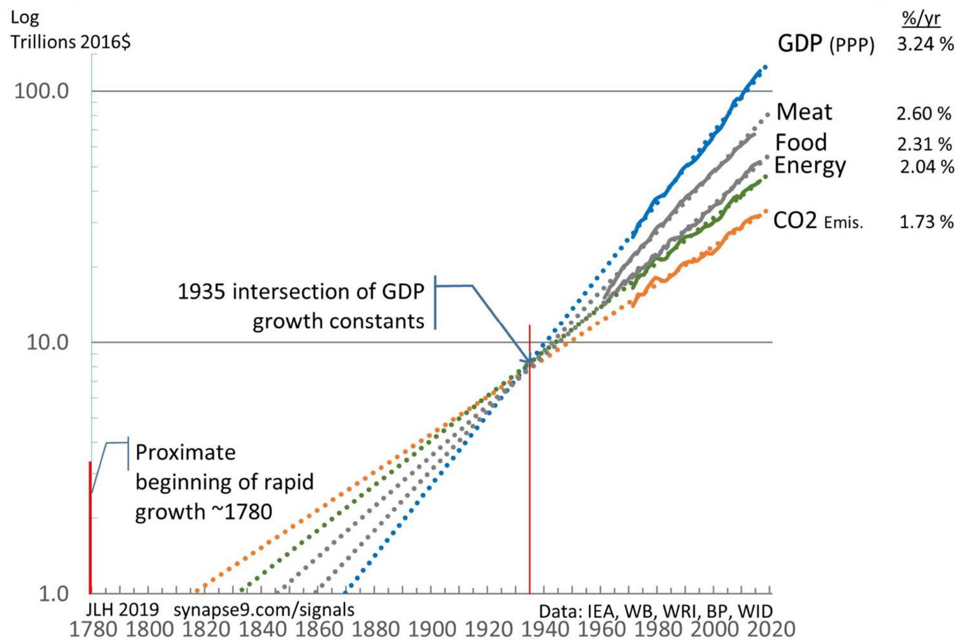

Fig 8. Log Plot of GDP and indexed EFs growth rates from Fig 7, back to 1780 - The remarkable convergence of post-1970 growth-constants at 1935 appears to suggest that Post-WWII globalization was a design for perpetual recovery from the great depression.

3. Discussion

If nothing else, it is clear that the world economy developed a very stable organization for maximizing growth while ignoring the directly coupled threats of growth's many kinds of local and global externalities (Carson, R. 1962; Meadows et al. 1972, 2007; Macfarling et al. 2015, 2018). Whatever the motivations, based on fear of the past, greed, or anything else, it also produced an enormous failure to look to the future. The many efforts to raise these issues in the 1960s and 70s were simply pushed aside by decades of government and institutional greenwashing. Examples include claims that "green growth" could reduce impacts with "decoupling" (UNEP 2014) and the continuing belief in the use of efficiency for reducing economic impacts (UN 10 YFP 2016; Wikipedia 2020). One only needs to look at the long-term coupling of GDP growth constants and impacts (Fig 2, 3, 6, 7, & 8) to see that growth efficiency does not decouple the economy from any of its primary sources of environmental impacts.

The main question is, are we locked into taking growth to our destruction? Could there be a system design principle for letting us steer our highly organized and resilient growth system to safety without a general collapse, as in the 1930s? The design principle that appears to promise that is the turn forward depicted in Fig 1, curve #3. We could learn to apply it from studying the many examples of how organisms, ecologies, and cultures of all sorts develop, to see how successful growth matches the strategy people use to manage home, societal, and business projects. Successful organizational projects all tend to follow first diverging then converging learning curves, shifting from one to the other. To start work projects, we generally begin with casting about for the design pattern with which to start. If successful, the accumulation of expanding efforts leads to a graceful turn forward for completing and coordinating the details, fulfilling the design as a 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 rapidly lead to whole system failure. The formula for Fig 9 (Eqn 7) starts each curve with the same rate of increase and when it starts to respond to limits (1, 2, 3, 4, 5), shifts to using the same rate but for approaching the limit; departing from its origin to converging on its destination. Responding early has little consequence but responding late does. Slow response to systemic limits leads to an increasingly disruptive response. The general principle is to gauge the best time to respond, as the first response to noticing limits. Humanity's response to natural limits has been just the opposite, putting off response for as long as possible, leading to what is already a major catastrophe.

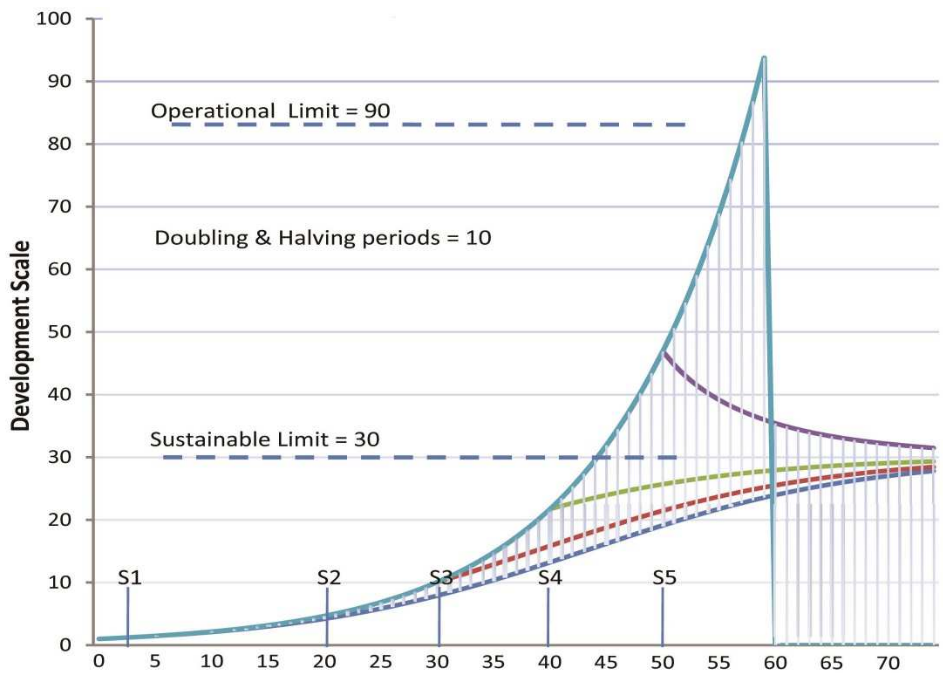

Fig 9. <u>Early and late starting times in responding to growth limits (S1-5).</u> - Making the turn forward <u>*well before*</u> crossing the sustainable limit avoids drastic change. Growing past the sustainable limit leads to disruptive change. Starting time S6 is not shown because collapse occurs without a decision. (figure 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)

Everyone knows about this principle from personal experience. Pushing some limits brings rapidly escalating threats. We saw this with COVID, that delayed responses led to catastrophic results. We could have rewarded rather than ridiculed the needed social discipline and saved hundreds of thousands of lives. For the economic growth crisis, it is the same, only many times larger. We face the same looming existential threat from ignoring our still rapidly accelerating destruction of the earth. The system design discipline of making a turn forward when adapting to limits would also present challenges, but certainly not hurt so much as being negligent and hoping the challenge we face just goes away like Trump hoped COVID would do.

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 because then they can move in. An owner may make last-minute changes, but they are sure to be smaller and smaller, as both owner and builder see the natural limits of money running out and winter coming. Both those draconian threats and the desire to finally 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 future of growing inequities and disasters? Could we pause and tell the builders it is time to turn forward to making the earth a good place to live? Perhaps the key is in asking why we chose in the 1950s and 60s to dramatically accelerate our growing impacts just as we were discovering how destructive it had become, and just as the social culture was turning toward making the earth a better home.

Culture-change can be full of twists and turns, but did we perhaps let our gift for enslaving the earth turn on us to enslave ourselves too? It could be a combination of things, such as being at a loss for what to do, not seeing a practical strategy. The carrot-and-stick pressures that drive endless growth are what we need to break away from as we set a new destination. For both natural and managed growth plans, making a turn forward strategy works similarly. It is to repurpose resources previously used for driving divergent growth to support the forward needs of refining, coordinating, and maturing a new system to complete its design. The design to complete is that of the economy as a system designed for continual reinvention. That need not stop and is vital for people's lives. The plan is then to keep its creativity but stop letting it multiply unmanageable problems.

That transfer of resources from one kind of investment fund to another needs to be part of it, acting as a relief valve to slow-growing crises while funding long-lasting solutions. Investors can freely do that with their assets, as we see as global philanthropy and impact investment movements. The most basic financial rule would be to have investors continuing free-market principles and make profits much the same ways, but spend rather than compound them. The latter, compounding, is a primary driver of the growth imperative, boundless wealth concentrations, and our ever-growing wave of environmental disasters (Henshaw 2020a). Because that one action would change a lot, people would follow their own rules until it is clear what the general rules should be, to level the playing field, and protect the global commons the way that seems most acceptable.

With disaster straight ahead, there are strong motivations for avoiding another enormous catastrophe. Whether we avoid it depends on the earth's financial owners realizing that not destroying their property is a natural fiduciary duty of ownership. Of course, a thriving, sustainable and finite economic world would be far more profitable than a blind and failing one. So we need to do this with open eyes and hearts. However, can the wealthy of the world recognize their duty and see it as an opportunity? We do see critical movement in that direction. Is it the right goal? Is it in time? The choice is like standing on the shore and wondering what to do. Will we take the plunge?

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 CO2 and rising temperatures to allow linear scaling of the smooth CO2 data curve, making a proxy PPM°C curve, showing the history of climate change more accurately. We also found the proxy curve implying a pre-industrial temperature of 13.27°C and likely 1.5 °C in 2030, not 2040.

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 regarding the global coupling of growth and its myriad growing impacts.

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

4. Bullet Points

- Growth constants in CO2 data tell fascinating real story of climate change.

- Fingerprints of human actions clarify root causes and suggest new strategies.

- The 1780 invention of rotary steam power kick-starts the greenhouse effect.

- 1935 crossing of growth-constants shows escape from depression a fatal design

5. Acknowledgments

This work has been self-funded for many years, so I am grateful for having had the time and resources. My greatest debt is to my numerous correspondents over the years, to my editors for high standards, and reviewers for making excellent suggestions.

6. 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.
   (Keeling & Keeling 2017; Macfarling 2006).

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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