Growth Constant Fingerprints of Economically Driven Climate Change: 1780 origin and major post-WWII acceleration

Electronic Supplementary Material – prelim draft

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Preliminary Studies, Methods, Economic Coupling

A. Fine detail of Historic CO2 PPM data

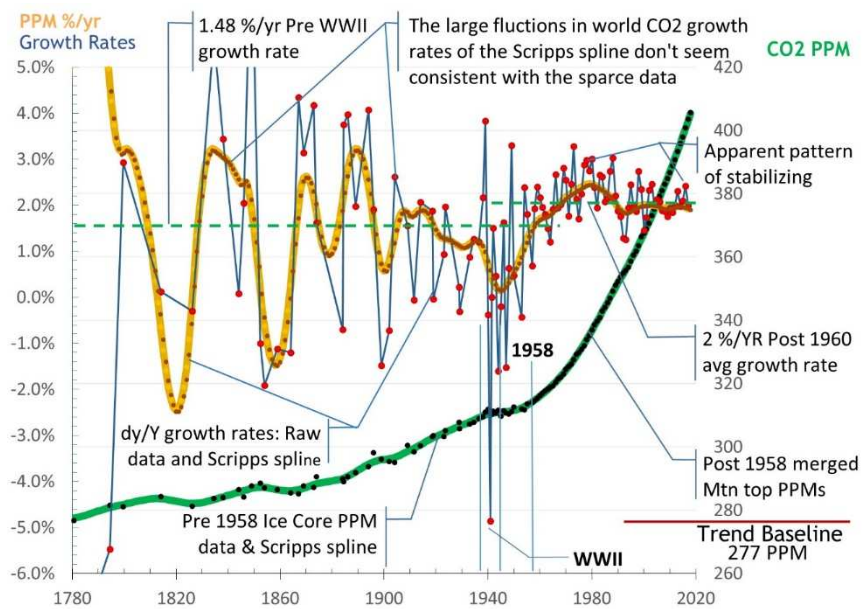

Fig 7. Unrealistically large fluctuations of CO2 PPM growth rates; The sparse and irregular ice core data prior to 1958, was only made to look regular by the Scripps spline, misrepresenting the much more regular trend found in the study (Fig 3). Note the useful way the more dense data in the WWII period and beyond seem to validate the trends of that period, showing decreasing fluctuation as a sign of damped oscillation from the 1970s on. - Data: From Scripps source: (Scripps, 1958 to present) (Macfarling Meur 2006). "ice core data before 1958, and yearly averages of direct observations from Mauna Loa and the South Pole after and including 1958."[1]

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[1] http://scrippsco2.ucsd.edu/data/atmospheric_co2/icecore_merged_products

B. Defects of automatic PPM growth trend

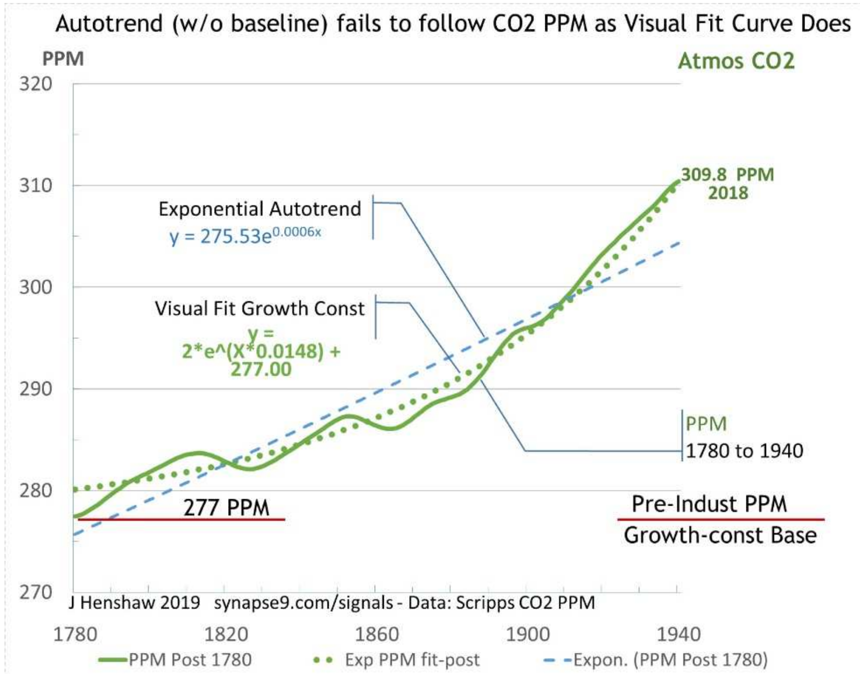


Fig 8. Relative heating rates for CO2 PPM: Taken from Figure 6 in Mitchell (1989) "Greenhouse heating due to trace gases, showing [top scale] concentration of CO 2. […] The triangles denote 1985 concentrations".

Fig 8 gives an enlarged view of the 160 yr since 1780, showing the CO2 data and visually fit growth constant plus an exponential trend line made by Excel. Why the Excel's automatic trend line approximates the growth curve as straight line is that its formula does not prompt the user for the baseline. All growth curves are finite "events" with distinct beginnings and ends marking periods of systemic change. Here you can also see clearly how the 160 year trend seems to start 3 PPM above the data at the 1780 beginning of the trend. It suggests the industrial development that began our addictive use of fossil fuels had an earlier formative period, and that the 1780 "big bang" was not the development of new industry, but the conversion of old industry to a new power source.

C. Defects of historical emissions data

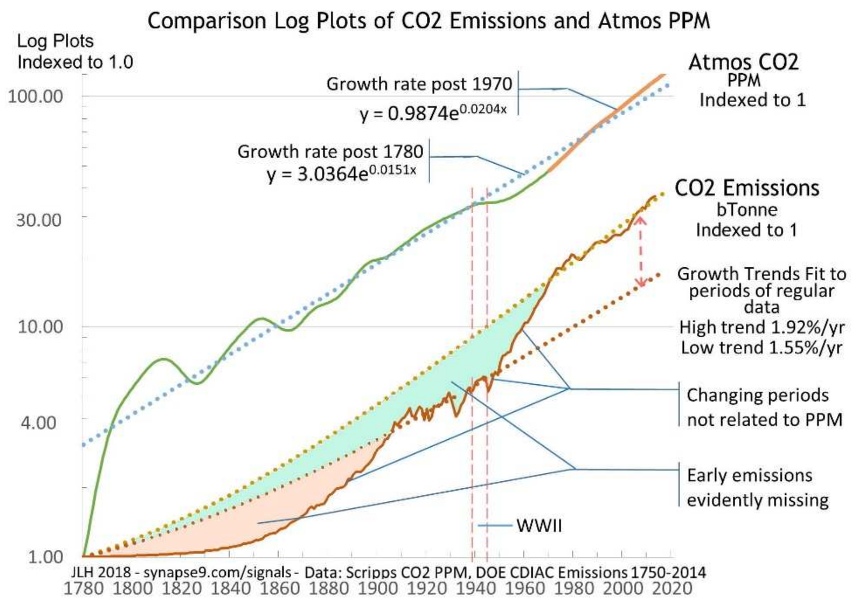


Fig 9. Incompleteness of historic CO2 Emissions data shown by comparing Log plots: 1) Atmospheric CO2 PPM and 2) CO2 Emissions, both indexed to 1.0. Unlike the continuous accumulation seen in CO2 PPM the long term the trend for CO2 Emissions shows four inconsistent trends, the last one similar to the most recent period..

CO2 *Emissions* High & LowTrend:	Y=0.4*^(0.0192X) + 0.0 or... (X*0.0155)	(5)
PPM Trend Post 1780 Avg:	Y = 2e^(0.0151 X) + 277.00	(6)
PPM Trend Post 1970	Y = 0.9874e^(0.0204 X)	(7)

This study did not use the available long terms emissions data due to the following evidence that it was, as one might expect, highly incomplete. Fig 8 shows a log plot of the Scripps CO2 PPM data (relative to the 277 baseline) indexed to 1.0. The historical CO2 Emissions data below is also indexed to 1 for side by side comparison. Due to what seem to be four largely unexplained trends chained together, apparently variation in data collection, I decided not to use this data. . DOE CDIAC data: https://cdiac.ess-dive.lbl.gov/ftp/ndp030/global.1751_2014

D. Composition of GHGs

The following charts of increasing GHG emission by source are from the IPCC 2014 "Climate Change 2014 Synthesis Report, Summary for Policymakers."[2]

[2] https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_SYR_FINAL_SPM.pdf

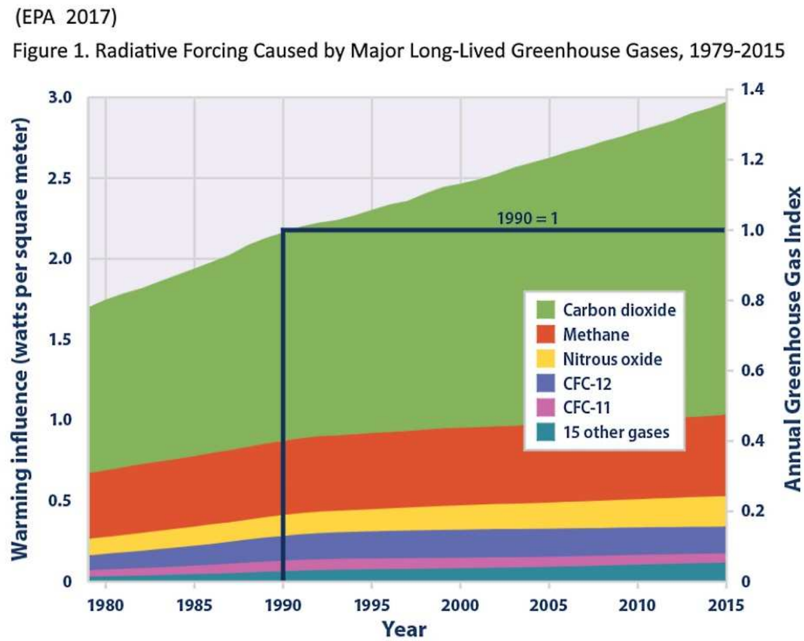


Fig 10. The proportion of CO2 in total GHG concentration. Increasing from 55 to 65 % between 1970 and 2010. That trend goes back to 1950 as shown on Fig 9, with CH4 and NO2 being the majority before then. (EPA 2017)

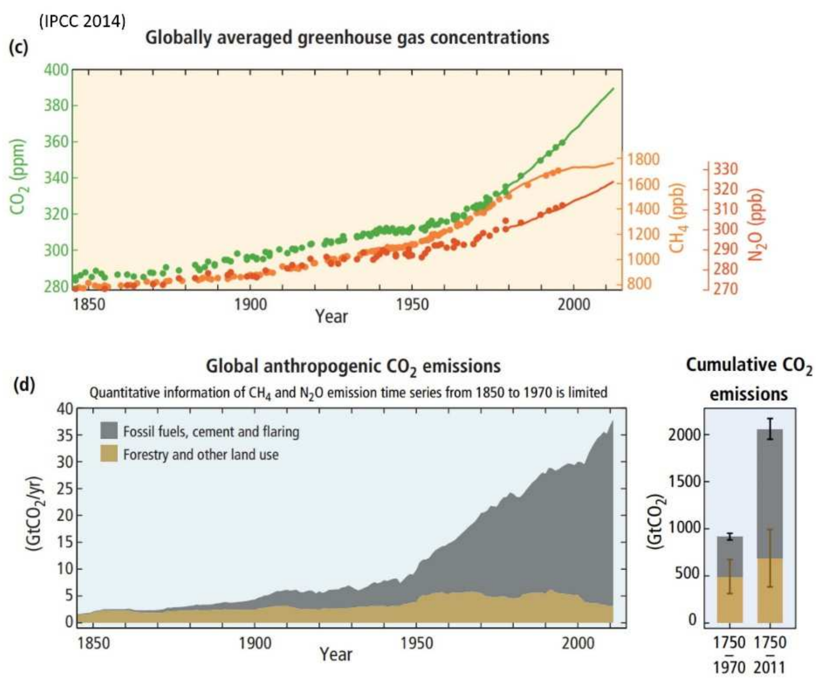


Fig 11. The proportion of CO2 in total GHG concentration. Increasing from 55 to 65 % between 1970 and 2010. That trend goes back to 1950 as shown on Fig 9, with CH4 and NO2 being the majority before then. (IPCC 2014) There does seem to be a CO2 growth pause between 1910 and 1945, followed by a major acceleration corresponding to globalization, but growth of CO2 emissions began around 1870 could be due to the incompleteness of the data, as shown in Fig 10 (IPCC 2014)

E. Upper atmosphere cooling

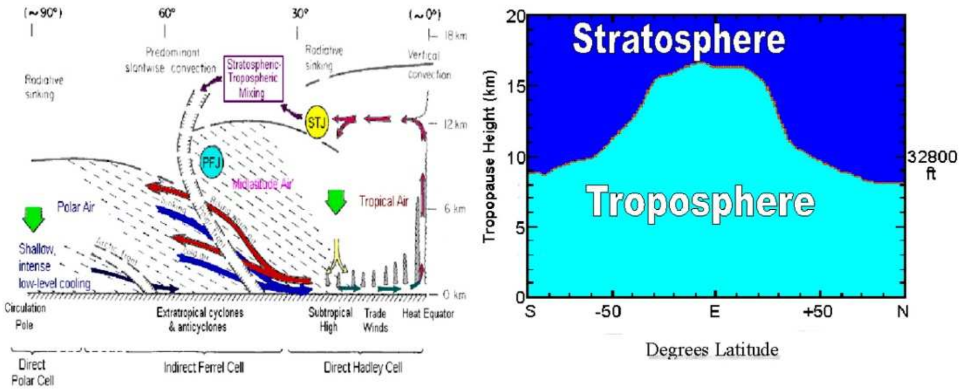


Fig 12. Troposphere-Stratosphere mixing (Gerts & Linacre 1997)

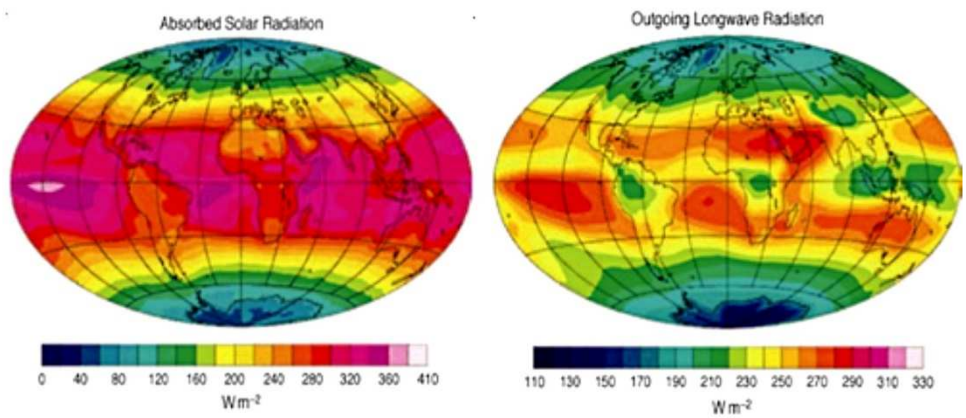


Fig 13. World Heat Maps, probably NASA. Showing equatorial heat and upper atmosphere hotspots of concentrated radiative cooling

F. Coupling of warming constants to economic growth constants

Mathematical coupling between two variables is defined as a known relation between them. Coupling between two environmental systems or between two parts of the same system also implies some organizational tie between the two. It can be strict or loose, as for a dancing couple, who sometimes move in very different ways but still in relation to each other, a coupling usually easy to recognize but could be hard to define.

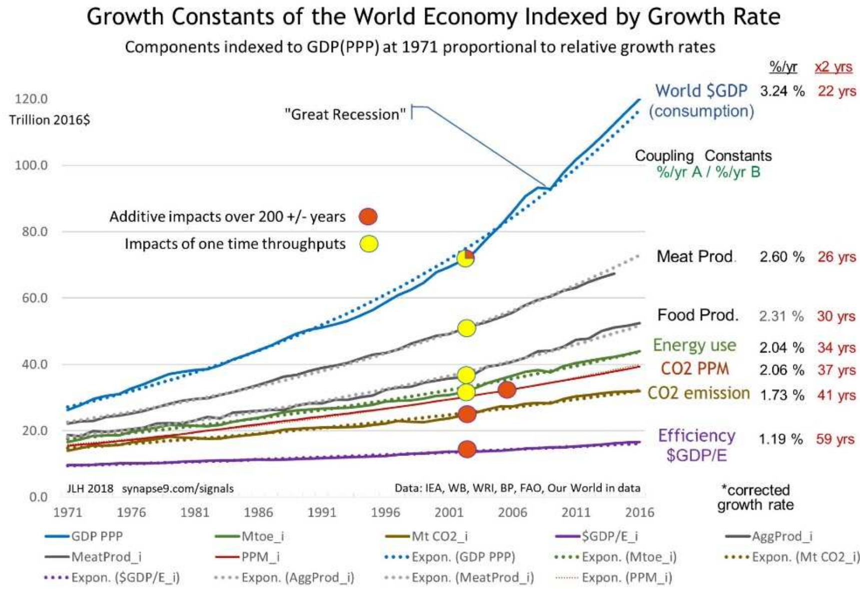


Fig 14. Coupled Growth Constants of the World Economy; Trends and growth constants calculated by automatic curve fitting, presented as a family by indexing each to GDP (PPP) proportional to the ratio of their growth rates. See Table 2 for average growth equations and coupling to GDP. See Appendix VI. equations 19, 20 & 21 for more details. See Appendix I. for data sources.

Fig 12 shows the raw data from seven growth indicators of the global economy, all moving together as if all part of the same system, displaying a pattern of separation that also keeps them together. How the graph was made did not change any data, but indexed the data units of each variable to the units of GDP and proportional to the ratio of their growth rates. So, for example, the growth constant for GDP is 3.24% and for Energy use is 2.04%/yr, so Energy use was indexed to a value in 1971 of 2.04/3.24 times the value of GDP in 1971. That each curve has a growth constant, they may also be in a constant ratio to one another at other times than just the point of being indexed to GDP in proportional to their growth rates. The test for that is whether the growth constants all extend to some common origin, as seen to be the case in Fig 14.

That makes the self-organization of the economy itself a new force to contend with, inhibiting the "decoupling" (UNEP 2011) of global economic growth from its growing global environmental impacts, calling for a new kind of strategy (Henshaw 2015).

The growth rates are not changed. Only how the curves are displaying in relation to their growth rates, all have average growth rates throughout the period that are constant, with one exception.

That exception is the CO2 PPM growth rate which stabilized on 1.90%/yr during the beginning of the period as seen in Fig 3. The great question is whether these coupled growth rates can be "decoupled." Certainly, some industries can be enter or leave an economy as others make room or exclude them, just as in an ecology where individual species can create or lose their niches.

The question is, are these indicators separable or all parts of one thing. If they were separable and economic decoupling underway, what we'd see is a steady drift in some of these curves away from their early growth constants. The CO2 PPM, CO2 emissions, and Energy use curves would be steadily dropping below their average growth rates, and the energy efficiency curve (GDP/E) would be rising faster its earlier average. We see none of that.

Tbl 1. Equations and Growth Coupling Rates for Fig 12, 13 & 14 Growth Constants

Title	Growth Constant Equations	GDP Coupling rate		Eqn#
GDP (PPP)	Y = 26.307*e^(0.0324*x)	.0324/.0324 =	1	(8)
Meat production	Y = 22.006*e^(0.0260*x)	.0260/.0324 =	.802	(9)
Food production	Y = 17.83*e^(0.0231*x)	.0231/.0324 =	.713	(10)
Econ Energy Use *	Y = 17.118*e^(0.0204*x)	.0204/.0324 =	.630	(11)
CO2 Atmos. PPM **	Y = 15.554*e^(0.0206*x) **	.0206/.0324 =	.635	(12)
CO2 Emissions	Y = 14.514*e^(0.0173*x)	.0173/.0324 =	.534	(13)
Energy Efficiency (GDP/E)	Y = 9.337*e^(0.0119*x)	.0119/.0324 =	.367	(14)
* Note sum of energy and efficiency coupling rates: .630+.367 = ~1 because Eff defined as = GDP/E				

This largely completes the presentation of the data, and suggestions for how to interpret it. The next seven figure raise side issues and perspectives. Fig 13 & 14 are log plots of the Fig 12 data. Fig 13 uses the same time period as Fig 12 and Fig 14 shows the same data but expanding the period to 1780, offering perhaps the strongest direct evidence of the organizational coupling between these dimensions of the world economy. Fig 15, 16, 17, and 18 show detailed views of the smoothed annual growth rates of the economic data of Fig 12.

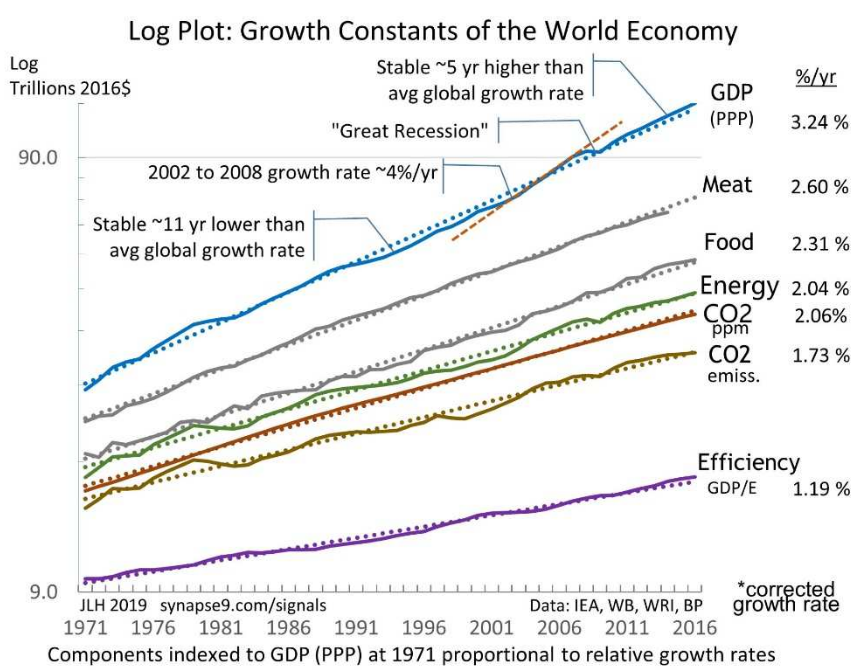


Fig 15. Log Plot of the data series and growth constants of Fig 10, as indexed in scale to GDP proportional to their growth rates, for comparison.

Fig 13 lets one closely examine how well the average growth rate trend lines fit the data, showing clearly how the GDP PPP and CO2 PPM data depart from the average. For GDP PPP there is a curious sustained periods of growth rate "drop, hold, surge, and hold" pattern, with the "great recession" at the end of the surge. It was temporary, though, and led to a long stable period of slightly higher than the usual global growth rate. These do not seem like "fluctuations" but "sticky swings" that set a short term new course for the whole. That seems to make them very unpredictable.

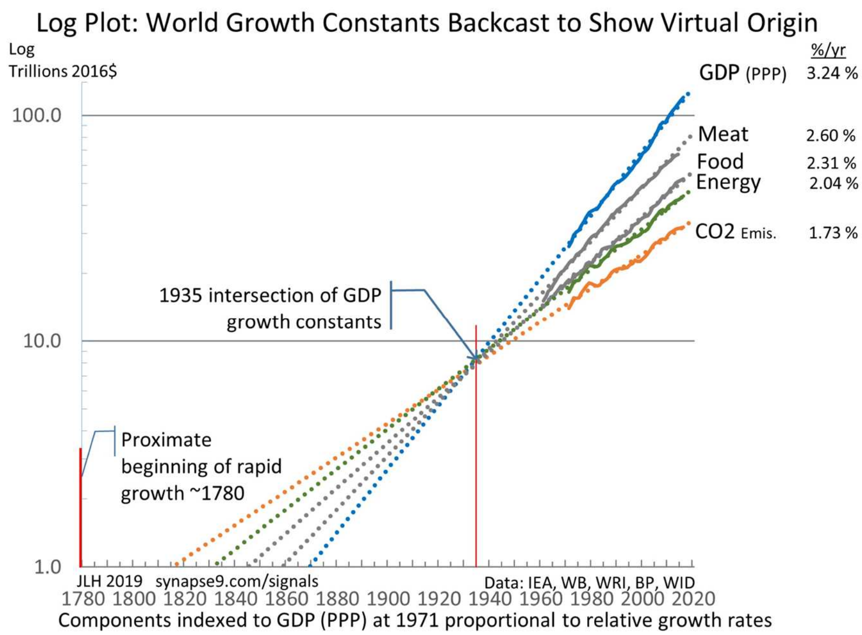


Fig 16. Displaying the implied origins of the global growth system by back-casting its growth constants.

Expanding the period of the log plot to 1780 (Fig 14), and "backcasting" the trend lines, lets one see whether the separate growth constants for each data set are really in constant proportion to one another throughout. Those that have a common point of intersection, as shown in Fig 14 are GDP, Meat, Food, Energy use, and CO2 emissions. The other two, CO2 PPM and economic Efficiency (GDP/E) both intersect with GDP at ~1920.

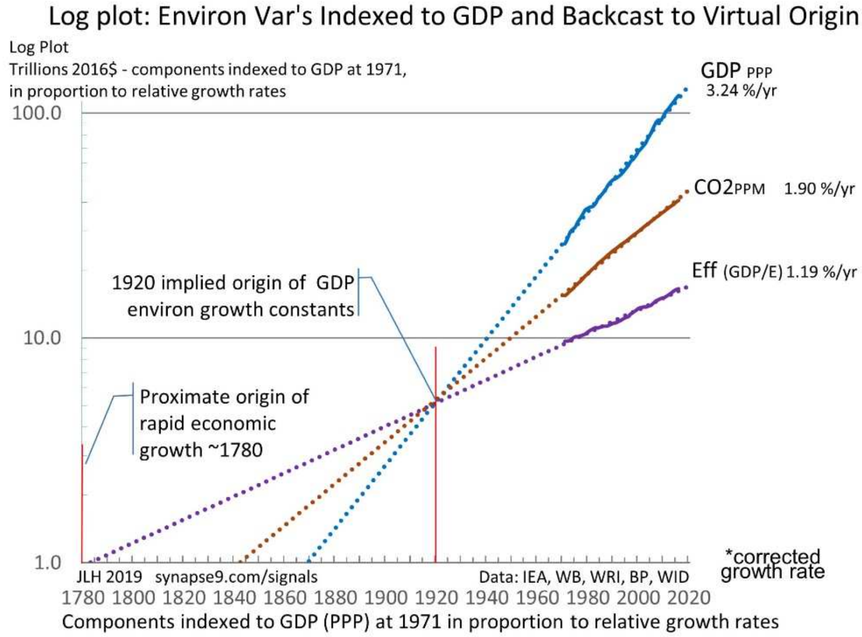


Fig 17. Displaying the implied origins of the global growth system by back-casting its growth constants.

Let us say some of these intersections are coincidental. That would make Fig 10 evidence that the modern growth system emerged as a unified system behaving as a whole in the 1920s and early '30s. It implies that to change the behavior of the economy to come to a prosperous climax without CO2; we would need to change its 100-year-old growth system when it is in a fluid state too.

G. Annual Growth Rate Variation

Fig 3 & 7 give examples how looking closely at the smoothed annual growth rates can expose systemic designs, in that case exposing apparent damped oscillation revealing the global economy settling on a new fixed CO2 PPM growth rate in the post 1960 period. Fig 12, below offers a similar insight from studying the irregular fluctuations in world GDP PPP, energy use and CO2 emissions, using center-weighted 5 point smoothing. The strong pattern of coupled swings in the growth rates of energy use and CO2 emission shows a regular pattern of "CO2 recessions" (red lines) when many people have though signaled the beginning of CO2 emission decline, declaring "decoupling" of growth from fossil fuel use had arrived, such as in the IEA news item (2017) saying the most recent slowing of CO2 emissions was "signaling a continuing decoupling of emissions and economic activity." Even the raw data in the article show similar flattening in the four previous cycles of the fluctuation 1980. So scientific bodies seem susceptible to inventing trends that are not there as economists, social media and climate change deniers.

Five point center weighted average smoothing

$$f(Y_n) = ((Y_n+Y_{n+1}+Y_{n+2})/3 - (Y_{n-2}+Y_{n-1}+Y_n)/3) / 2*Y_n \qquad (15)$$

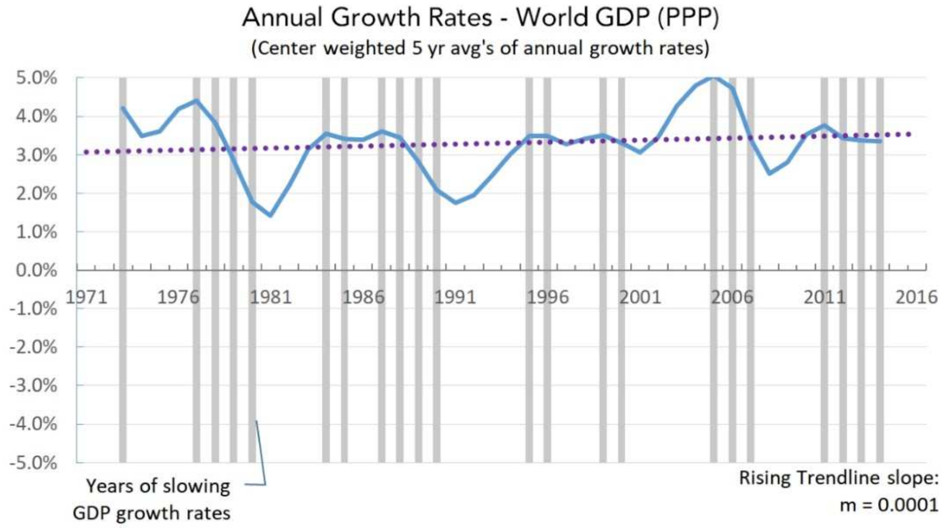
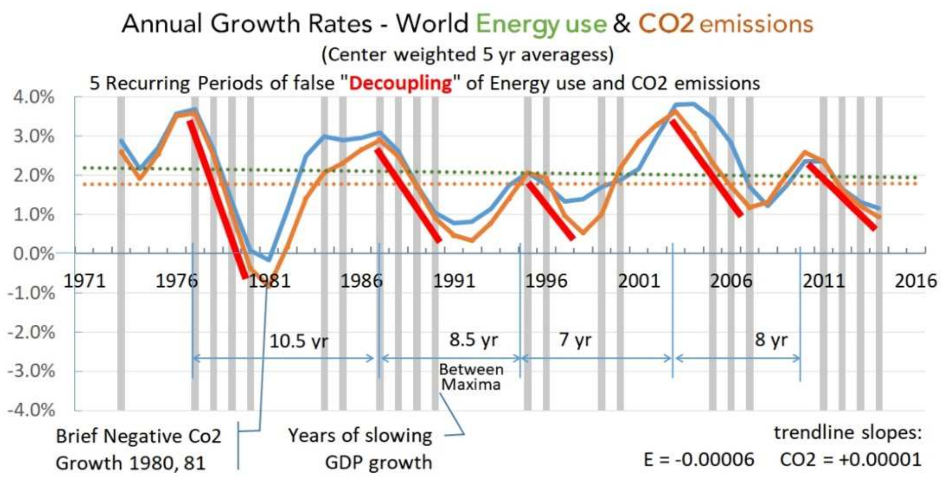


Fig 18. Recent History of Annual World GDP PPP growth rates



B

Fig 19. Recent History of Annual World growth rates of World Energy Use and CO_2 emissions. Three of the five major fluctuations seem synchronized, with energy use and CO_2 emissions having more exaggerated declines than GDP PPP starting around 1996 and 2011, of course always rebounding. The 5 pt smoothing trims two points on either end of the series.

Fig 17 shows a fascinating historical pattern of great overshoot in food production after periods of slowing world GDP growth, lessening over time, suggesting world food supplies have become more regulated or producers better informed and less prone to create peaks of oversupply. Fig 18 shows another fascinating pattern of gradually declining rates of growth driving increased energy efficiency, with sharp peaks or their absence that seem to reflect historical social conditions.

Behaviors to study in Food and Economic Efficiency growth rates include the strong irregular and independent fluctuation in food and meat production, the steady trend of rising annual energy efficiency growth rates, not noticed in the exponential trend lines of Fig 17 and 18

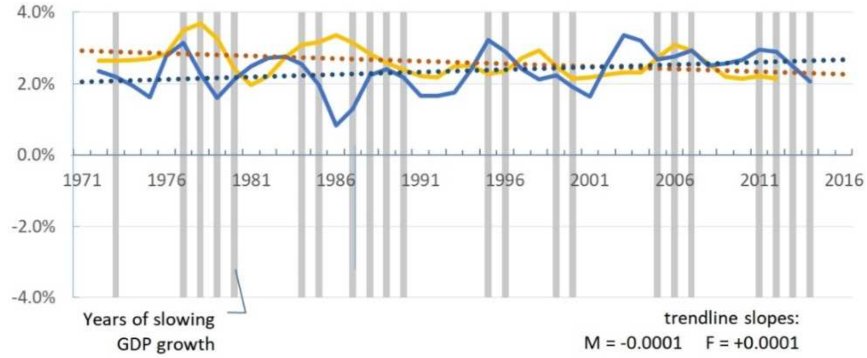
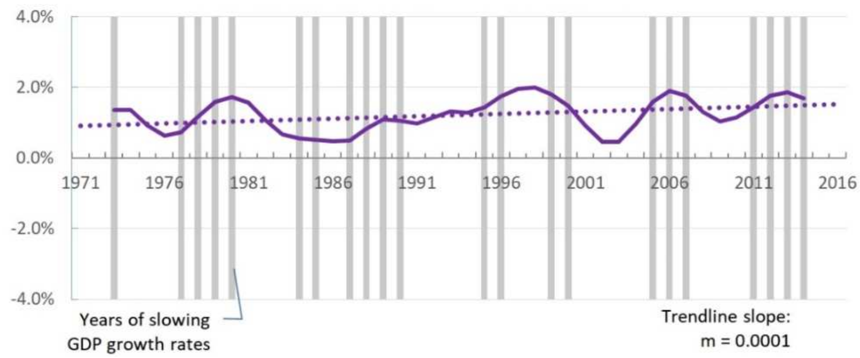


Fig 20. Annual Growth Rates of World Food and Meat Production, 5 pt center weighted averages.



B

Fig 21. Annual Growth Rates of World Economic Energy Efficiency, 5 pt center weighted averages. Distinct long term decline in the ratio of the growth rates of economic energy efficiency (GDP/E) and GDP, showing the center-weighted 5 point average dy/Y growth rates for each series.

H. Data Splicing for Long term GDP PPP

Continuous current data sources going back to ~1971 were not found. As shown in Fig 13, the GDP PPM curve was spliced. Discontinued IEA data sets from preceding studies were used and spliced to series from WRI and World Bank sources that did not go back as far. The earlier IEA data indexed and spliced to the WRI and WB data at 1990. There is some visible departure of new and old GDP PPP data, more or less expected, as a result of how Purchasing Power Parity calculations are made, with the more out of date data being discarded. Due to the WRI CO2 data being updated two years slower than any other, two years of projection at the current global CO2 PPM linear rates, seeming not to effect the interpretation.

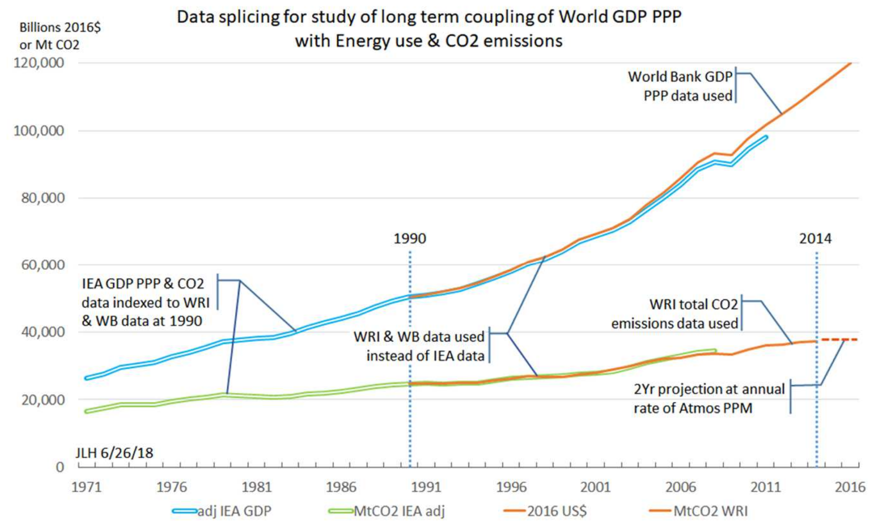


Fig 22. Splicing of old and new data sources showing the long overlap portion of earlier data discarded, and two yr projection of CO2 emissions data at rates proportional to current atmospheric accumulation https://www.co2.earth/annual-co2

I. Types of trend lines and plots

The main data curves are shown along with trend lines to help the reader distinguish systemic processes from the departures.

<u>*Hand drawn trends*</u> – Interpretations of the probable midline trend of irregular data, leaving open the question of what is causing the departures and noise, but considered informed intuition of the probable driving forces.

<u>*Calculated Growth Constants*</u> – Using Excel there is an option to calculate exponential trend lines, and show the formula on the figure. Here the formulas are left off the figures but written in an equation below the relevant figure, such as:

Excel Exp. Trends $$Y = s*e^\wedge(X*r) \tag{15}$$

<u>*Manually fit calculated growth curves*</u> - Fig's 3, 4, 6, 8, and 9, Excel also allows one to draw exponential curves to represent the centrality of a data set where automatic curve fitting is impractical or to highlight a particular trend, for which I used the following generic equation.

Manually fit growth curves $$Y = s*e^\wedge(X*r) + b \tag{16}$$

The manually fit growth trend might start from an automated exponential trend as for the data (Fig's 1, 3, 5), or from plotting the annualized growth rates (dy/Y). Then the constants of the manually fit curve **s**, **r**, and **b** values are adjusted until it looks like a convincing central thread, which you then test to see if it helps expose verifiable patterns of fluctuation. It is a bit like threading a necklace and then looking to see what the jewels are. It can also help to switch to a log plot view, continuing to make adjustments until it both fits and helps you explain what else is happening.

In any case, diagnostic curve fitting is for both highlighting the trend and highlighting the departures. Being able to confidently identify the departures is often needed to feel confident that an accurate systemic trend has been identified. The object is to find a combination of midlines and departures that prove to raise useful new questions, as a sign of progress in understanding the complex systems involved.

Manual fit scaled series – Fig 6

Manual fit scaled series curve $$Y = s*F(x) + b \tag{17}$$

Used for scaling the CO2 PPM curve to make the PPM°C curve to represent the centerline of the trend of Climate change.

Standard plots – All the original plots were done on Excel. Labeled data values taken from the data series and located on the charts or pointed to visually.

Five-point center weighed smoothing – Fig 2, 3, 7, 9, 15, 16, 17, 18 : For studying the fine scale trends and variations of growth rates. This simple formula is for smoothing time series data assumed to reflect an underlying continuity. It is similar to the "derivative reconstruction" algorithm (Henshaw 1999), in having a smoothing kernel with a hole in the middle to more accurately reflect the sequence as a shape flowing from before to after, to make it easier to recognize changes in flow. For centered-weighted 5 pt smoothing equation 11 is used.

Five pt center weighted $$dy/Yf(Y) = ((Y1+Y2+Y3)/3 - (Y3+Y4+y5)/3) / (2*Y3) \tag{18}$$

Log Plots – Fig 9, 13, 14: Log plots were used to test the accuracy and display the common origin of the coupled growth trends of GDP components. As mentioned above log plots were also helpful for fine adjustment of manually fit growth curves. Linear plots were used for most of the growth curves to better display the true dynamics. Log plots

Applied to sequence $$Y_n.f(Y_n) = ((Y_n+Y_{n+1}+Y_{n+2})/3 - (Y_{n-2}+Y_{n-1}+Y_n)/3) / (2*Y_n) \tag{19}$$

Growth Rate Indexed Curves – Figs 12, 13, 14: Indexing various dimensions of a whole system to one of its primary dimensions is done to show them as a family of curves and study their statistical or functional coupling. When the dimensions all have constant growth rates their behavior as a family can be clearly shown by scaling each dimension to the primary in proportion to their growth rates. For example, a dimension with half the growth rate of GDP would be scaled to be indexed to half the value of GDP. You might think of it as having a way to show the height, weight and food consumption of a person on the same graph.

GDP and the factors related to it shown in Figs 12, 13, 14 all have nominally constant growth rates. The units of the latter are indexed to GDP at 1971 in proportion to their relative growth rates so that if a factor has half the growth rate of GDP it is scaled to half the value of GDP at 1971.

Indexing condition for Ai(n) $$(GDP(n)/Ai(n)) = rGDP)/rA \tag{20}$$

Indexing	Ai(n) = A(n)*I	(21)
Scaling factor	I = (GDP(1971)/ A(1971))* rA/rGDP	(22)

Economic Data Sources

4. Historical Co2 Emissions 1751-2013 Fig 8
   US DOE DOE CDIAC data: https://cdiac.ess-dive.lbl.gov/trends/emis/overview_2014.html

5. Modern CO2 Emissions – 1971-2016, Fig 9, 10, 11, 12
   Archived IEA CO2 data extended with WRI CO2 emissions: https://www.wri.org/resources/data-sets/cait-historical-emissions-data-countries-us-states-unfccc

6. GDP (PPP) 1971 – 2016* Fig 9, 10, 11, 12
   Archived IEA PPP data extended with recent World Bank data, see Fig 13 for illustration
   WB: https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.CD?end=2016&start=1990

7. World economic energy use 1965-2017 – Fig 9, 10, 11, 12
   BP: https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html

8. World Meat Production – 1961-2016 Fig 9, 10, 11, 13
   Rosner - OurWorldInData: https://ourworldindata.org/meat-and-seafood-production-consumption

9. World Food Production – 1961-2016 Fig 9, 10, 11, 13
   FAO: http://www.fao.org/faostat/en/#data/QI

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