The article "*Critique of 'Lotka's wheel and the long arm of history': Best available historical data shows major differences pre-1970, raising new questions.*" terms the original paper by Garrett et al. (2022) "flawed" (hereafter GGK22). It misrepresents both the data and methods in GGK22 and presents alternatives that do not reflect the analysis techniques that were performed in GGK22, justify alternatives, perform an uncertainty analysis, or even seem plausible. The critique includes personal asides, the mathematics is impossible to understand, it is left unstated in the figures what units are used for quantities, and when units in the analyses are presented, they are used inconsistently for the same quantities. There are frequent uses of very large numbers of significant digits for imprecise quantities, up to nine for an exponential growth rate in one case. Otherwise, I discuss the main methodological concerns below.

A primary conclusion of GGK22 as stated in the abstract is that "In each of the 50 years following 1970 for which reliable data are available, 1 exajoule of world energy was required to sustain each 5.50±0.21 trillion year 2019 US dollars of a global wealth quantity defined as the cumulative inflation-adjusted economic production summed over all history." That is the ratio W for cumulative inflation-adjusted production Y (or $W(t) = \int_0^t Y(t)\,dt' = \sum_i Y_i$), to the rate of energy consumption E, is effectively observed to be a constant for a 50-year period since 1970, that is $w = W/E = \int_0^t Y(t)\,dt' =$ constant. As is argued in the GGK22 article, this constancy, were it to hold, it would imply that inertia, i.e. deep history, plays a guiding role in the evolution of future consumptive needs by civilization, one far higher than has generally presumed.

The result that $w = W/E$ is a constant was originally anticipated based on thermodynamic reasoning as first described in Garrett (2011) and it was also elaborated upon in GGK22. As with any hypothesis, it's validity rests on a statistical evaluation, as well as the accuracy of the statistics used. In GGK22, a half century period between 1970 and 2019 was used to evaluate w. That the statistic holds for any period before or after can really only be speculation, but for that period covering two-thirds of the total historical growth in civilization energy demands w was observed to be nearly constant. It was speculated that this constancy is a fundamental feature of the global economy: energy consumption sustains flows along the civilization networks that have previously been built through prior economic production, allowing for fraying of those networks by way of the downward correction from the nominal to the real GDP, as is commonly ascribed to economic inflation.

However, as a time integral of inflation adjusted economic production, the accuracy of the calculation of W – and hence $w = W/E$ – relies on a reconstruction of historical economic data. Any reexamination of the statistics and the methods is important because any reconstruction necessarily requires some subjective choices. It is also challenging. An independent reexamination of the methods used in GGK22 could shed light on better approaches. B. Hanley provides revised reanalysis datasets from which he makes arguments that w is not in fact a constant, in any time period.

To address the Hanley critique, I compare the reanalysis dataset in GGK22 to that proposed as alternative of Hanley, what he terms a replicate dataset. Statistics for world primary energy consumption since 1970 are stated clearly enough by both sources. Specifically as stated in the Methods of GGK22 *Yearly statistics for world primary energy E_i are available for both consumption and production from the Energy Information Administration (EIA) of the US Department of Energy (DOE) for the period 1980 through 2018 and for consumption from British Petroleum (BP) for the years 1965 through 2019 (DOE, 2020; BP, 2020). A yearly composite of E_i in units of EJ yr^{-1} for the years 1970 to 2019 is created from the average of the three datasets while using single* *sources when only one is available. The difference between the values in the BP and EIA datasets is significant at 8.5 ± 1.5 %, but it is steady and small relative to the 180 % increase in energy consumption over the 50-year time period considered here.* In the Hanley critique, no argument is presented why the energy data used in GGK22 is problematic. The data set Hanley used was obtained from Our World in Data (Ritchie and Rosado, 2020) which refers to the Statistical Review of World Energy. No averaging is made of consumption and production as in GGK22 but this is a small consideration. Based on that dataset, consumption in 2019 was 588 ExaJoules compared to 595 ExaJoules in the GGK22 dataset. Because this difference is small, it is presumed that the two analyses are in sufficient alignment even if the GGK22 datasets is more comprehensive.

However, Hanley shows a reconstruction of energy demands in 1 CE that is *three orders of magnitude* smaller than that which may be inferred from GGK22 assuming w is a constant. Where such large discrepancies exist it should be possible to perform a simple test to determine if one result or the other is unreasonable. The Hanley critique presents the global consumption rate of energy in 1 CE as 0.0623 ExaJoules, which split among the estimated 225 million people in the world at that time would correspond to a civilization consumption rate averaging to about 9 Watts per person. Human metabolic needs are approximately 100 Watts. To feed those needs using modern agriculture, the efficiency is about 10% implying order 1000 Watts of consumption. Presumably ancient agriculture was less efficient, and then of course not all primary energy at that time or any time went into feeding people in a subsistence lifestyle. Militaries, buildings, roads, and sailing networks were also needed. Whatever the source of the calculation, the 9 Watts per person presented by Hanley as part of a superior dataset reconstruction is simply far to small to be plausible, to enable any form of civilization sustenance, and by two to three orders of magnitude.

The problems are more of a basic scientific nature when it comes to calculation of cumulative inflation-adjusted world economic production summed over all history W. The approach outlined in the Methods section of GGK22 is that *Economic production is tallied and averaged using World Bank (WB) and United Nations (UN) statistics for the years 1970 to 2019 (The World Bank, 2019; United Nations, 2010) and expressed here in units of trillions of market exchange rate, inflation-adjusted "real"-year 2019 dollars.* So there are two key points here, which are that the production statistics must be adjusted for inflation and expressed in Market Exchange Rate (MER) values. The reason to do so was described in greater detail in a prior article referenced in the methods by Garrett et al. (2020) and in the paper the critique references by Garrett (2011). In the Hanley et al. critique, no criticism is made of statistics used or the choice to focus on real, MER dollars so presumably that is not an aspect in contention.

However, Hanley mixes and matches datasets to reconstruct a long time series for economic production that is inconsistent in its choice of units for each year, and so cannot be used for the purpose of addition to calculate W. The economic production statistics they use since 1990 appear to have as their original source the Penn World Tables, although details are not given. If this is the case, the both key points of MER, inflation-adjusted dollars are satisfied.

For data between 1960 and 1990, the Hanley critique states use of data from the Federal Reserve (NYGDPMKTPCDWLD). These are expressed in MER dollars but they do *not* account for inflation to convert from current-year nominal to fixed-year real dollars. This is explicitly stated in the Federal Reserve dataset but not acknowledged by Hanley. The description in Hanley is difficult to follow but it appears a scaling multiplier is applied to the Penn World Table datasets to match the two economic production datasets post-1990, and that the Federal Reserve data set is used as the basis for a longer time series. Not surprisingly, by not adhering to the requirement of using real

MER dollars for all years the result is an average 44% difference between the GGK22 and Hanley datasets. The difference is washed away by Hanley with "*The discrepancy is due to a change in how OWID GWP and its data sources are calculated versus other datasets, and the difference is consistent enough.*" This is misleading. For the purpose of calculating W, and error will be cumulative, in this case introduced by not considering the growing devaluation of purchasing power through inflation. Most importantly, for the purpose of calculating W, it makes no sense to sum dollars from one year to the next where they are expressed in the different units of current dollars from different years. The error is like adding 1 pint to 1 quart and saying there are two quarts.

For the reconstruction of GDP for earlier years, Eq. 5 is difficult to understand and highly contrived given $e^{\ln x} = x$. The reconstruction refers to Our World in Data datasets for GDP statistics pre-1960, which in turn appear to use the same Maddison database used by GGK22. This database appears to have been adjusted for inflation, which is good. However, what is not considered is the second necessary adjustment to convert from purchasing power parity dollars used in the Maddison database to market exchange rate dollars. Specifically, as stated by GGK22: *The dataset is adjusted for inflation and to convert from currency expressed in purchasing power parity dollars to market exchange units using as a basis for adjustment the time period between 1970 and 1992 for which concurrent market exchange rate (MER) and purchasing power parity (PPP) statistics are available.* An argument might be made that PPP dollars are preferable to MER dollars. I don't believe this would be appropriate for physical reasons. Whatever the choice, there must be consistency when creating a continuous time series of economic production. The final dataset for Y Hanley uses is a mix of real, inflation-adjusted, MER, and PPP data. Without *consistent* careful adjustment for inflation and to MER dollars across the full 2000 year time series, the numbers in each year cannot be added to create the central quantity W. Any summation must use numbers with the same units. Not all dollars are the same.

As a note, the value of W obtained by GGK22 for year 1CE was not a summation of a much longer dataset as stated in Section 1.5.2 of the critique. The method was stated in the Methods section of GGK22 to be something quite different, an inference from the GDP at that time assuming that W and population were growing equally fast. Note too the discussion of uncertainties that might accompany this assumption. *The value for cumulative production in 1 CE. W(1) is obtained by assuming that W was growing as fast as population at that time at rate and that* $Y(1) = R_W W(1)$. *Population data from 1 CE and 1 century before and after suggest that global population was 170 million and growing at 0.059 %* yr^{-1} *(United States Census Bureau, 2018). While there are inevitable uncertainties in the reconstruction of W as with any other, the yearly values of W since 1970 that are emphasized here cover two-thirds of total growth, so the calculations are more strongly weighted by recent data that are presumably most accurate. Thus, calculation of W, most particularly the conclusion that w is nearly a constant, can be shown to be relatively insensitive to uncertainty in the older statistics (Garrett et al., 2020).*

Even the datasets provided in the supplement of GGK22 are misrepresented, although it is unclear how or why. Figure 1E pretends to reproduce the GGK22 data. However, it shows a distinct positive trend in the time series between 1970 and 2019 for $w = W/E$. This is false. Figure 2c for w in GGK22 shows a different time series with no clear trend. The value presented by Hanley for w in 1970 is about 5 (although no units are given). In the GGK22 dataset provided in the supplement it is 6.1 inflation-adjusted year-2019 MER USD per ExaJoule per year. The difference may seem small but it is significant where constancy is claimed.

The mathematics in section 2.2 makes no sense. How is economic production Y equal to a growth rate g? How can a dimensioned rate r be added to a dimensionless number unity? It also appears to refer to calculus but not in any way that is familiar or that leads to results that are comprehensible.

While I completely applaud taking a closer look at the reconstruction in GGK22, the critique by Hanley is far too idiosyncratic in its analysis to be of a standard I believe suitable for publication in an EGU journal. As a suggested path forward, I suspect that a reconstruction of the timeline of civilization energy consumption in the distant past might be made using a combination of ice-core carbon dioxide concentrations, a carbon cycle model, and an assumption of a mean fuel makeup that does not minimize the widespread reliance on wind, water, and sunlight. People built where they could sail, navigate rivers, and grow crops because they offered forms of primary energy that could be efficiently accessed.

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