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HOW MANY PEOPLE CAN THE EARTH SUPPORT?

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The title of this paper is the same as the title of Cohen's 1995 book[1] because I am trying to deal with the same question, "How many people can the earth support?". Cohen did a very thorough job – in 532 pages – of reviewing the literature and dealing with the question. This paper will be much shorter.

I am trying to deal with the relationship between climate change and the world's people wanting to live as the developed world lives which requires the use of a great deal of energy, much of it carbon dioxide producing, in hopes our politicians can make intelligent choices and not condemn too many people to poverty .

Many people tell us that the climate is always changing -- which is true. However, one thing that has not happened before is the huge human population and that population's dependence on energy.

In this paper I fit three equations modeling population growth to recent United Nations population data and project that growth for 100 years in hopes that politicians trying to deal with climate change think about how many people there are now and how many there may be in the future whose lives depend upon being able to use energy. Revising the title question a bit: "How many people can the earth support living the way the developed world lives?".

The sections of this paper are, in order: summary and conclusions, discussion of the models, the data used, the methods employed, and two appendices.

SUMMARY AND CONCLUSIONS

The only thing we know for "sure" are the UN data, which are estimates, not a census. The population modeling that I, and others[2], have done are summaries of data and attempts at forecasting, subject to sets of assumptions. They all have to be taken with a grain of salt; at best they make one think about the situation and what may happen.

Given what I read in the scientific literature and popular press, and my modeling, I think we are approaching a limit on the number of people that the earth can support living the way the developed world lives. I expect that the developing world will keep developing as fast as possible because people do not want to live in poverty. I expect the world will slowly shift to non-carbon based energy where possible but will continue using carbon based energy as needed no matter what that does to the climate. And, I expect the changing climate will result in marginal developing countries failing economically, if not being physically destroyed.

I have not discussed pollution and solid waste, including plastics. However, the problems with pollution and solid waste will surely affect the ability of the earth to support an expanding human population.

The best politicians can do is slowly raise the price of carbon, raising it so slowly that it does not force their constituents into poverty. There are many people, whose livelihood depends upon their using large quantities of carbon based fuels,

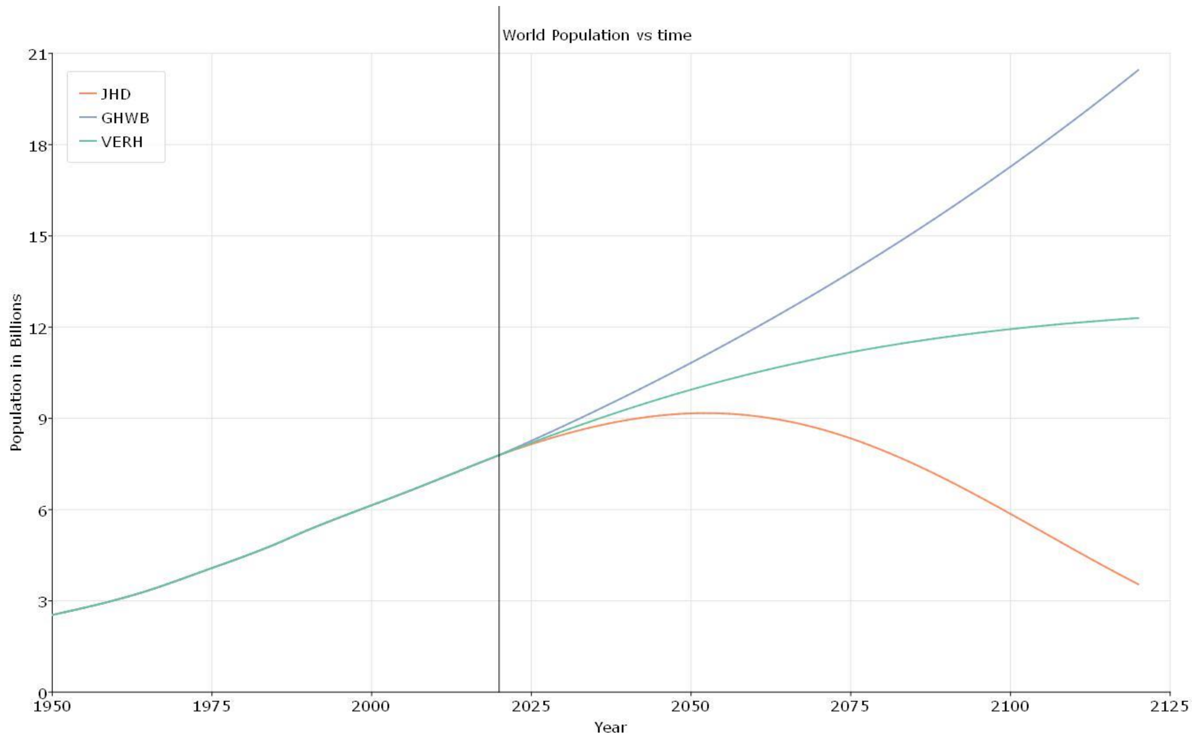
[1] Joel E. Cohen, How Many People Can the Earth Support, W.W. Norton & Company, 1995, 532pp.

[2] See Cohen (1995).

who are more concerned about paying monthly bills than preventing future deleterious changes in the climate. The negative reaction to Oregon's bill HR2020 in 2019 was rural Oregon's resistance to being driven into poverty.

DISCUSSION

The graph below shows the UN data from 1950 to 2020 and a plot of the three equations from 2021 to 2120. The details and logic supporting the equations are discussed in the methods section.



The plot to the left of the vertical line is the plot of the UN data; in 1950 the world population is 2.5Billion people, in 2020 it is 7.8B, over three times as many people. The plots to the right of the vertical line are plots of the three equations. The data plotted is shown in appendix I.

The plot starting at 2020, 7.8B and ending at 2120, 20.5B is the plot of the GHWB equation. If allowed to go on forever, it will go higher forever. Given the problems with climate change, I find it hard to believe that human population can grow without bounds and live the way the developed world now lives. However, reading the popular press, others think this will happen and are acting accordingly.

The plot starting at 2020, 7.8B and ending at 2120, 12.3B is the plot of the VERH equation. If allowed to go on forever, it will asymptotically approach a ceiling of 12.9B. That is easier to believe than the GHWB equation but, again, given the problems with climate change, I wonder if the earth can support 4.5B more people in the fashion the developed world lives.

The plot starting at 2020, 7.8B, rising to a maximum at 2052 of 9.2B and ending at 2120, 3.5B is the plot of the JHD equation. In my opinion, given the problems with climate change, this is a more reasonable forecast than the first two. However, the implication is that we may be coming to the population limit in the near future.

DATA

The data[3] are File POP/1-1; Total annual populations (both sexes combined) by region, sub-region and country, estimated for the years 1950 – 2020. A description of the data used and the methods applied in estimating past population estimates and demographic changes (fertility, child, adult and overall mortality, international migration) are provided for each country or area. The estimates for each country and area are summed to make the estimate for the world for the period in thousands of people. I used the estimates for the world assuming that there will be no significant migration to or from the world within the next 100 years.

METHODS

All computations were done with Gauss 19.1[4]; using the Gauss language and application Curve Fit Version 3.1.15 which fits an hypothesized curve to the data minimizing the residual variance with numerical techniques. The three curves I used are described below. The computer printout is shown in appendix II.

In 1991, President George H. W. Bush issued a proclamation recognizing World Population Week stating: "Population growth in itself is a neutral Phenomenon…every human being represents hands to work, not just another mouth to feed."[5] I interpret this to mean that population can grow without bounds coming up with equation 1, the first equation, which I call the GHWB curve.

$$\frac{DP}{dt} = Pr + A \qquad (1)$$

Where: P = population,

r = increase rate,

t= time,

A is a constant[6],

and $\frac{DP}{dt}$ is the rate of change, or first derivative[7], of population with respect to time.

The second equation – equation 2, which I call the VERHULST (abbreviated VERH) curve[8], was hypothesized by Pierre Verhulst, a professor of mathematics in Belgium in 1836. The notion being that a population could only grow so big, it could not grow without bounds.

$$\frac{DP}{dt} = \mathrm{Pr}(1 - \frac{P}{K}) \qquad (2)$$

Where K = is an asymptotic constant.

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[3] United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019, Online Edition. POP/DB/WPP/Rev.2019/POP/F01-1.

[4] Copyright Aptech Systems, Inc. Chandler, AZ USA. 1984-2018. All Rights Reserved Worldwide.

[5] Cohen (1995).

[6] I originally tried this equation with no constant but it did not fit the data at all.

[7] This derivative is a numerical derivative computed from the population data.

[8] Both Cohen (1995) and Murray, J.D. Mathematical Biology, Springer-Verlag, 1989, 767pp. The equation is slightly different in each reference. I used the equation in Murray.

And the other terms are as in equation 1.

The third equation – equation 3, I call the JHD curve because I it made up. The notion being that the world population is larger than it has ever been and starting to bump into limits. The equation models population increasing at a decreasing rate, going to zero and then going negative resulting in a shrinking world population.

$$\frac{DP}{dt} = \Pr(at^2 + bt + c) \qquad (3)$$

Where: a, b, and c are constants.

And the other terms are as in equations 1 and 2.

All three differential equations can be solved for population as a function of time. The solution to equation (2) is the classic logistics equation. I chose to estimate the parameters with the differential equations, because I had less numerical problems estimating the parameters compared to using the population as a function of time. I estimated future populations with the following recursive equation: $P_{t+1} = P_t + DP_t$ Where the terms are as in the above three equations and $dt = 1$.

In equations (1) and (2), the derivative of population is a function of population. In equation (3) it is a function of both population and time.

POP-2019-07-02 OUT 11/25/19 14:43:28
Data in 10^3.

YEAR	JHD	GHWB	VERH
1950.0000	2536431.1	2536431.1	2536431.1
1951.0000	2584034.3	2584034.3	2584034.3
1952.0000	2630861.6	2630861.6	2630861.6
1953.0000	2677609.0	2677609.0	2677609.0
1954.0000	2724846.7	2724846.7	2724846.7
1955.0000	2773019.9	2773019.9	2773019.9
1956.0000	2822443.3	2822443.3	2822443.3
1957.0000	2873306.1	2873306.1	2873306.1
1958.0000	2925686.7	2925686.7	2925686.7
1959.0000	2979576.2	2979576.2	2979576.2
1960.0000	3034949.7	3034949.7	3034949.7
1961.0000	3091843.5	3091843.5	3091843.5
1962.0000	3150420.8	3150420.8	3150420.8
1963.0000	3211001.0	3211001.0	3211001.0
1964.0000	3273978.3	3273978.3	3273978.3
1965.0000	3339583.6	3339583.6	3339583.6
1966.0000	3407922.6	3407922.6	3407922.6
1967.0000	3478770.0	3478770.0	3478770.0
1968.0000	3551599.1	3551599.1	3551599.1
1969.0000	3625680.6	3625680.6	3625680.6
1970.0000	3700437.0	3700437.0	3700437.0
1971.0000	3775759.6	3775759.6	3775759.6
1972.0000	3851650.2	3851650.2	3851650.2
1973.0000	3927780.2	3927780.2	3927780.2
1974.0000	4003794.2	4003794.2	4003794.2
1975.0000	4079480.6	4079480.6	4079480.6
1976.0000	4154666.9	4154666.9	4154666.9
1977.0000	4229506.1	4229506.1	4229506.1
1978.0000	4304533.5	4304533.5	4304533.5
1979.0000	4380506.1	4380506.1	4380506.1
1980.0000	4458003.5	4458003.5	4458003.5
1981.0000	4536996.8	4536996.8	4536996.8
1982.0000	4617386.5	4617386.5	4617386.5
1983.0000	4699569.3	4699569.3	4699569.3
1984.0000	4784011.6	4784011.6	4784011.6
1985.0000	4870921.7	4870921.7	4870921.7
1986.0000	4960567.9	4960567.9	4960567.9
1987.0000	5052522.1	5052522.1	5052522.1
1988.0000	5145426.0	5145426.0	5145426.0
1989.0000	5237441.6	5237441.6	5237441.6
1990.0000	5327231.1	5327231.1	5327231.1
1991.0000	5414289.4	5414289.4	5414289.4
1992.0000	5498919.8	5498919.8	5498919.8
1993.0000	5581597.5	5581597.5	5581597.5
1994.0000	5663150.4	5663150.4	5663150.4
1995.0000	5744213.0	5744213.0	5744213.0
1996.0000	5824892.0	5824892.0	5824892.0
1997.0000	5905045.8	5905045.8	5905045.8
1998.0000	5984793.9	5984793.9	5984793.9
1999.0000	6064239.1	6064239.1	6064239.1

2000.0000		6143493.8	6143493.8	6143493.8
2001.0000		6222626.6	6222626.6	6222626.6
2002.0000		6301773.2	6301773.2	6301773.2
2003.0000		6381185.1	6381185.1	6381185.1
2004.0000		6461159.4	6461159.4	6461159.4
2005.0000		6541907.0	6541907.0	6541907.0
2006.0000		6623517.8	6623517.8	6623517.8
2007.0000		6705946.6	6705946.6	6705946.6
2008.0000		6789088.7	6789088.7	6789088.7
2009.0000		6872767.1	6872767.1	6872767.1
2010.0000		6956823.6	6956823.6	6956823.6
2011.0000		7041194.3	7041194.3	7041194.3
2012.0000		7125828.1	7125828.1	7125828.1
2013.0000		7210582.0	7210582.0	7210582.0
2014.0000		7295290.8	7295290.8	7295290.8
2015.0000		7379797.1	7379797.1	7379797.1
2016.0000		7464022.0	7464022.0	7464022.0
2017.0000		7547858.9	7547858.9	7547858.9
2018.0000		7631091.0	7631091.0	7631091.0
2019.0000		7713468.1	7713468.1	7713468.1
2020.0000	****	7794798.7	7794798.7	7794798.7
2021.0000		7868739.1	7887242.1	7875847.1
2022.0000		7941384.3	7980245.7	7956426.4
2023.0000		8012662.0	8073812.8	8036512.6
2024.0000		8082499.6	8167947.0	8116082.3
2025.0000		8150824.6	8262651.7	8195112.8
2026.0000		8217564.2	8357930.2	8273581.9
2027.0000		8282645.7	8453786.1	8351468.2
2028.0000		8345996.5	8550222.9	8428751.1
2029.0000		8407544.2	8647244.1	8505410.5
2030.0000		8467216.9	8744853.3	8581427.2
2031.0000		8524943.2	8843053.9	8656782.8
2032.0000		8580651.9	8941849.7	8731459.6
2033.0000		8634273.1	9041244.1	8805440.6
2034.0000		8685737.2	9141240.9	8878709.8
2035.0000		8734975.9	9241843.6	8951251.8
2036.0000		8781921.7	9343056.0	9023052.2
2037.0000		8826508.5	9444881.7	9094097.1
2038.0000		8868671.4	9547324.5	9164373.7
2039.0000		8908347.1	9650388.1	9233870.0
2040.0000		8945473.7	9754076.3	9302574.5
2041.0000		8979991.0	9858392.8	9370476.8
2042.0000		9011840.7	9963341.4	9437567.2
2043.0000		9040966.5	10068926.	9503836.8
2044.0000		9067314.1	10175151.	9569277.5
2045.0000		9090831.5	10282019.	9633882.0
2046.0000		9111468.7	10389534.	9697643.6
2047.0000		9129178.7	10497702.	9760556.5
2048.0000		9143916.5	10606525.	9822615.7
2049.0000		9155640.1	10716007.	9883816.8
2050.0000		9164310.3	10826153.	9944156.2
2051.0000		9169890.6	10936966.	10003631.
2052.0000	MAX	9172347.8***	11048451.	10062239.
2053.0000		9171651.6	11160611.	10119978.
2054.0000		9167774.9	11273451.	10176848.
2055.0000		9160694.0	11386975.	10232848.
2056.0000		9150388.6	11501187.	10287978.

2057.0000	9136841.9	11616091.	10342241.
2058.0000	9120040.5	11731691.	10395636.
2059.0000	9099974.9	11847992.	10448166.
2060.0000	9076639.0	11964997.	10499833.
2061.0000	9050030.7	12082712.	10550642.
2062.0000	9020151.5	12201140.	10600594.
2063.0000	8987007.0	12320285.	10649695.
2064.0000	8950606.6	12440153.	10697949.
2065.0000	8910963.5	12560747.	10745361.
2066.0000	8868094.9	12682071.	10791936.
2067.0000	8822022.2	12804132.	10837679.
2068.0000	8772770.6	12926931.	10882598.
2069.0000	8720369.1	13050475.	10926699.
2070.0000	8664850.9	13174768.	10969988.
2071.0000	8606253.2	13299813.	11012473.
2072.0000	8544617.0	13425617.	11054161.
2073.0000	8479987.1	13552183.	11095059.
2074.0000	8412412.4	13679515.	11135177.
2075.0000	8341945.3	13807620.	11174521.
2076.0000	8268642.1	13936501.	11213101.
2077.0000	8192562.8	14066162.	11250925.
2078.0000	8113770.9	14196610.	11288003.
2079.0000	8032333.4	14327848.	11324342.
2080.0000	7948320.7	14459881.	11359953.
2081.0000	7861806.4	14592715.	11394844.
2082.0000	7772867.6	14726353.	11429026.
2083.0000	7681584.2	14860802.	11462507.
2084.0000	7588039.0	14996065.	11495298.
2085.0000	7492317.7	15132147.	11527408.
2086.0000	7394508.7	15269055.	11558847.
2087.0000	7294703.0	15406792.	11589625.
2088.0000	7192993.6	15545363.	11619752.
2089.0000	7089476.1	15684775.	11649238.
2090.0000	6984247.9	15825031.	11678093.
2091.0000	6877408.3	15966137.	11706326.
2092.0000	6769058.3	16108098.	11733949.
2093.0000	6659300.5	16250920.	11760971.
2094.0000	6548238.6	16394607.	11787402.
2095.0000	6435977.7	16539165.	11813253.
2096.0000	6322623.7	16684599.	11838532.
2097.0000	6208283.1	16830914.	11863251.
2098.0000	6093063.3	16978116.	11887418.
2099.0000	5977071.7	17126209.	11911045.
2100.0000	5860416.2	17275201.	11934140.
2101.0000	5743204.5	17425095.	11956713.
2102.0000	5625543.9	17575897.	11978775.
2103.0000	5507541.7	17727614.	12000334.
2104.0000	5389304.2	17880249.	12021400.
2105.0000	5270937.1	18033810.	12041983.
2106.0000	5152545.1	18188301.	12062092.
2107.0000	5034231.5	18343729.	12081736.
2108.0000	4916098.6	18500098.	12100924.
2109.0000	4798247.0	18657415.	12119665.
2110.0000	4680775.4	18815686.	12137969.
2111.0000	4563780.9	18974915.	12155844.
2112.0000	4447358.5	19135109.	12173299.
2113.0000	4331600.9	19296274.	12190342.

2114.0000	4216598.7	19458416.	12206982.
2115.0000	4102439.7	19621540.	12223227.
2116.0000	3989209.3	19785653.	12239086.
2117.0000	3876990.1	19950761.	12254566.
2118.0000	3765861.8	20116869.	12269677.
2119.0000	3655901.4	20283983.	12284425.
2120.0000	3547182.4	20452110.	12298818.

APPENDIX II

```
POP-2019-07-01 OUT        11/24/19        16:41:10

GHWB CURVE

dp/dt = p*r+A
starting parameters

     0.020000000
       100000.00

================================================================================
 CurveFit Version 3.1.15                                  11/24/2019   4:41 pm
================================================================================

return code =    0
normal convergence

Number of cases      69

estimated residual variance     6.44366E+07

The covariance matrix of the coefficients is not available

Parameters   Estimates      Gradient
----------------------------------------------
Inc Rate     0.006060  29367.773041
Alfa     45207.261657     -0.007697

Number of iterations    7
Minutes to convergence     0.00000
parameters =
    0.0060599520
       45207.262
Parameter covariance matrix =
   3.8447123e-07       -1.9075673
      -1.9075673        10398325.
Std error =
   0.00062005744
       3224.6433
data variance =    1.5176738e+08
resid variance =        64436563.
'r^2' =       0.57542548




VERHULST CURVE

dp/dt = r*p*(1-p/K)
starting parameters
```

```
     0.020000000
       12000000.

===============================================================================
 CurveFit Version 3.1.15                                 11/24/2019   4:41 pm
===============================================================================

return code =    0
normal convergence

Number of cases      69

estimated residual variance     2.58886E+07

The covariance matrix of the coefficients is not available

Parameters   Estimates      Gradient
----------------------------------------------
Inc Rate     0.026416    397.163703
Constant 12854590.715059     -0.001193

Number of iterations    11
Minutes to convergence     0.00000
parameters =
     0.026415859
       12854591.
Parameter covariance matrix =
   2.6093493e-07       -136.30510
      -136.30510    8.6118395e+10
Std error =
   0.00051081790
       293459.36
data variance =    1.5176738e+08
resid variance =        25888620.
'r^2' =       0.82941908




JHD CURVE
 dp/dt = r*p*(a*t^2+b*t+c)
starting parameters

     0.020000000
      -2.0000000
      -3000.0000
       12000.000

===============================================================================
 CurveFit Version 3.1.15                                 11/24/2019   4:41 pm
===============================================================================

return code =    0
normal convergence

Number of cases      69
```

```
estimated residual variance     2.57510E+07

Parameters     Estimates     Std. err.   Est./s.e.  Prob.    Gradient
----------------------------------------------------------------------
Inc Rate        0.000000             .          .        .  184.500000
Alfa           -5.054581             .          .        .    0.000001
Bravo        -867.137873             .          .        .   -0.000000
Charlie     33856.049032             .          .        .    0.000000

Covariance matrix of parameters computed from
cross-product of first derivatives

Number of iterations    13
Minutes to convergence     0.00017
parameters =
   2.8759108e-07
      -5.0545807
      -867.13787
       33856.049
Parameter covariance matrix =
    -0.012854374       -225923.11       -38758208.    1.5132539e+09
      -225923.11   -3.9707302e+12   -6.8119807e+14    2.6596319e+16
      -38758208.   -6.8119807e+14   -1.1686284e+17    4.5627277e+18
   1.5132539e+09    2.6596319e+16    4.5627277e+18   -1.7814460e+20
Std error =
      0.11337713
       1992669.1
   3.4185207e+08
   1.3347082e+10
data variance =    1.5176738e+08
resid variance =        25750987.
'r^2' =       0.83032594
```