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The Economic Impact of Greenhouse Gas Emissions

By Ken Gregory

Energy Balance Climate Sensitivity

The most important parameter in determining the economic impact of climate change is the sensitivity of the climate to greenhouse gas emissions. Climatologist Nicholas Lewis used an energy balance method to estimate the Equilibrium Climate Sensitivity (ECS) best estimate at 1.45 °C from a doubling of CO_2 in the atmosphere with a likely range [17 - 83% confidence] of 1.2 to 1.8 °C. ECS is the global temperature change resulting from a doubling of CO_2 after allowing the oceans to reach temperature equilibrium, which takes about 2500 years.

A more policy-relevant parameter is the Transient Climate Response (TCR) which is the global temperature change at the time of the CO_2 doubling. A doubling of CO_2 at the current growth rate of 0.55%/year would take 126 years. The analysis gives the TCR best estimate at 1.21 °C with a likely range [17 - 83%] of 1.05 to 1.45 °C.

The two periods used for the analysis were 1859-1882 and 1995-2011. They were chosen to give the longest early and late periods free of significant volcanic activity, which provide the largest change in forcing and hence the narrowest uncertainty ranges. The long time between these periods has the effect of averaging out the effect of short-term ocean oscillations such as the Atlantic Multi-decadal Oscillation (AMO) and the Pacific Decadal Oscillation (PDO), but it does not account for millennium scale ocean oscillations or indirect solar influences.

Aerosols are the dominant contribution to uncertainty in climate sensitivity estimates. Nicholas Lewis writes, "In this context, what is IMO a compelling new **paper** by Bjorn Stevens estimating aerosol forcing using multiple physically-based, observationally-constrained approaches is a game changer." Stevens is an expert on cloud-aerosol processes. He derived a new lower estimate of aerosol forcing. Lewis used the new estimate for aerosol forcing and used estimate of other forcings given in the fifth assessment report by the IPCC.

Adjustment for Millennium Cyclic Warming and Urban Warming

This analysis by Lewis does not account for the long-term natural warming from the Little Ice Age (LIA), likely driven by indirect solar activity. The temperature history shows an obvious millennium scale temperature oscillation, indicating that natural climate change accounts for a significant portion of the temperature recovery since the LIA.

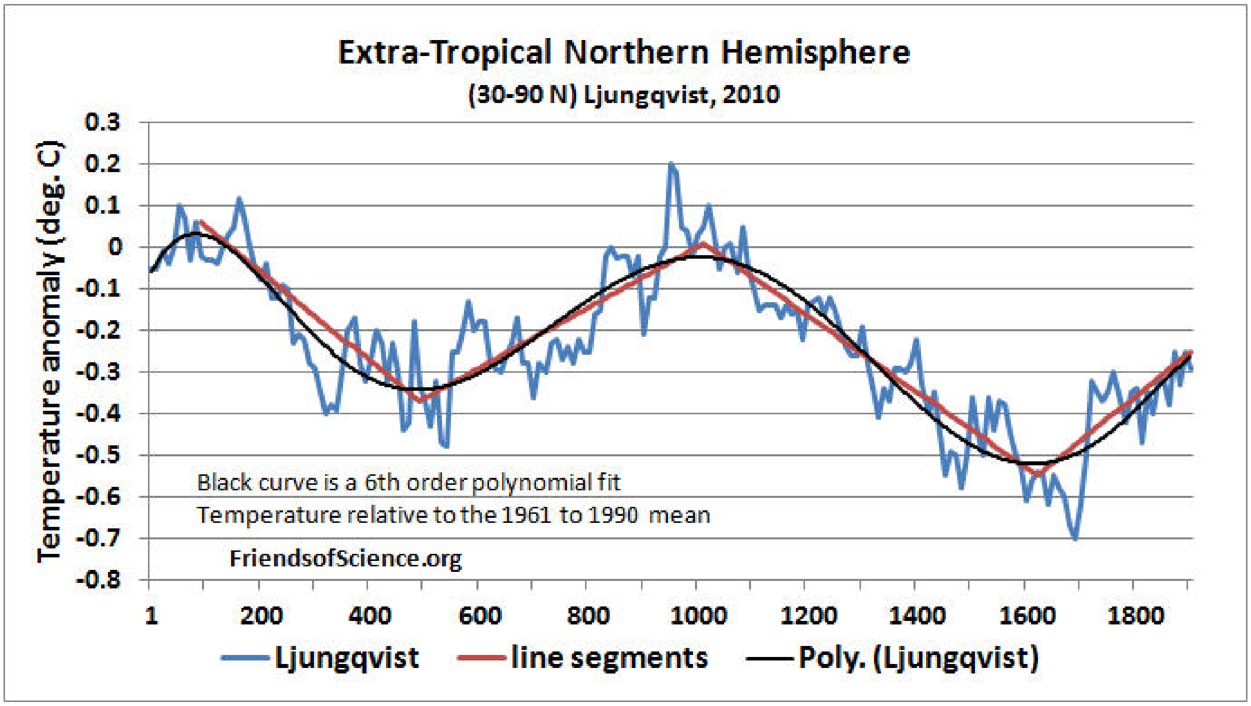

Figure 1. Extra-tropical Northern Hemisphere temperature change adapted from Ljungqvist 2010 with a 6th order polynomial fit and line segments. Roman Warm Period AD 1-300; Dark Age Cold Period 300-900; Medieval Warm Period 800-1300; Little Ice Age 1300-1900; Current Warm Period 1900-now.

Fredrik Ljungqvist prepared a temperature reconstruction of the Extra-Tropical Northern Hemisphere (ETNH) during the last two millennia with decadal resolution using 30 temperature proxies. Human-caused greenhouse gas emissions did not cause significant temperature change to the year 1900 because cumulative CO_2 emissions to 1900 were insignificant. The average of the absolute natural temperature change over the four periods as shown in Figure 1 was 0.095 °C/century.

The Ljungqvist 2010 paper gives several reasons why the reconstruction likely "seriously underestimates" the temperature variability but does not make any corrections to his reconstruction. The tree-ring proxies are biased toward the summer growing season. If the Little Ice Age (LIA) cooling was more pronounced during winter months the annual estimate would be biased too warm. The large dating uncertainties of the sediment proxies has the effect of "flattening out" the temperatures so the true magnitude of the warm and cold periods are underestimated.

The proxy temperature did not rise as sharply during the 20th century as the thermometer record did, indicating the instrument temperature record is biased high due to the uncorrected urban heat island effect (UHIE) and/or underestimated reconstructed temperature variations from the proxies.

The annual temperatures show 23% more variability than the tree growing season temperature variability weighted by tree growth rates, indicating that the tree-ring proxies underestimate the temperature variability. Eight of the 30 proxies have this tree-ring seasonal bias. Assuming the dating uncertainty of the 12 sediment proxies spreads the resolution over 100 years it was estimated that these proxies underestimated the temperature variability by 12%. The weighted average bias of the 30 proxies was estimated at 11%.

The southern hemisphere and tropics temperature variability is less than the northern extra-tropics due to the larger ocean area. Considering the coolest and warmest two-decade periods of the instrument record, the global temperatures vary by only 80% of the ETNH. The global natural recovery from the LIA is estimated at 0.084 °C/century, which account for the proxy bias and the global adjustment.

Numerous papers have shown that the UHIE contaminates the instrument temperature record. A study by McKitrick and Michaels 2007 showed that almost half of the warming over land since 1980 in instrument data sets is due to the UHIE. The UHIE over land is about 0.14 °C/decade, or 0.042 °C/decade on a global basis since 1979.

The millennium warming and UHIE corrections reduce the temperature change between the two periods of the analysis due to greenhouse gases from 0.72 °C to 0.51 °C The best estimate of ECS considering the millennium warming cycle and the UHIE is 1.02 °C and the best estimate of TCR is 0.85 °C.

Summary of Climate Sensitivity Estimates

Table 1 summarizes the ECS and the TCR best estimate, likely and extremely likely confidence intervals for 5 cases. All forcing-based estimates use initial and final periods of 1859-1882 and 1995-2011, respectively. Ranges are to the nearest 0.05°C.

Table 1 - Estimates of Equilibrium Climate Sensitivity and Transient Climate Response with Uncertainty Ranges.

	ECS Best Estimate	ECS 17-83% range °C	ECS 5-95% range °C	TCR Best Estimate	TCR 17-83% range °C	TCR 5-95% range °C
IPCC AR5	*3.0*	1.5-4.5	1-*6.5*	*1.75*	1-2.5	*0.5*-3.0
Using AR5 Forcings	1.64	1.25-2.45	1.05-4.05	1.33	1.05-1.80	0.90-2.50
As above but with Stevens' Aerosol Forcing	1.45	1.20-1.80	1.05-2.20	1.21	1.05-1.45	0.90-1.65
As above but with Natural Millennium Warming	1.22	0.95-1.55	0.80-1.95	1.02	0.85-1.25	0.70-1.45
As above but with UHIE Correction	**1.02**	**0.75-1.35**	**0.60-1.75**	**0.85**	**0.70-1.10**	**0.55-1.30**

The best estimate TCR of 0.85 °C implies that the global temperature will increase from 2016 to 2100 due to anthropogenic CO_2 emissions by only 0.57 °C if atmospheric CO_2 continues to increase at the current rate of 0.55%/year. Actual temperatures may rise or fall depending on natural climate change.

Social Cost of Carbon

The US Government's Interagency Working Group (IWG) on Social Cost of Carbon (SCC) uses three Integrated Assessment Models (IAM) to determine the social costs and benefits of greenhouse gas emissions. Two of these models, DICE and PAGE, do not include the benefits of CO_2 fertilization and other benefits of warming, and fail to account for adaptation.

The FUND model does include these benefits, but arguably underestimates the benefits of CO_2 fertilization. Idso (2013) found that the increase in the atmospheric concentration of carbon dioxide that took place during the period 1961-2011 was responsible for increasing global agricultural output by $3.2 trillion (in constant 2005 US$).

The FUND model shows that Canada benefits from emissions by 1.9% of gross domestic product by 2100, equivalent to a benefit of $109 Billion annually in 2015 dollars when assuming an ECS of 3 °C. Anthropogenic climate change will have only positive impacts in Canada which increase throughout the 21st century..

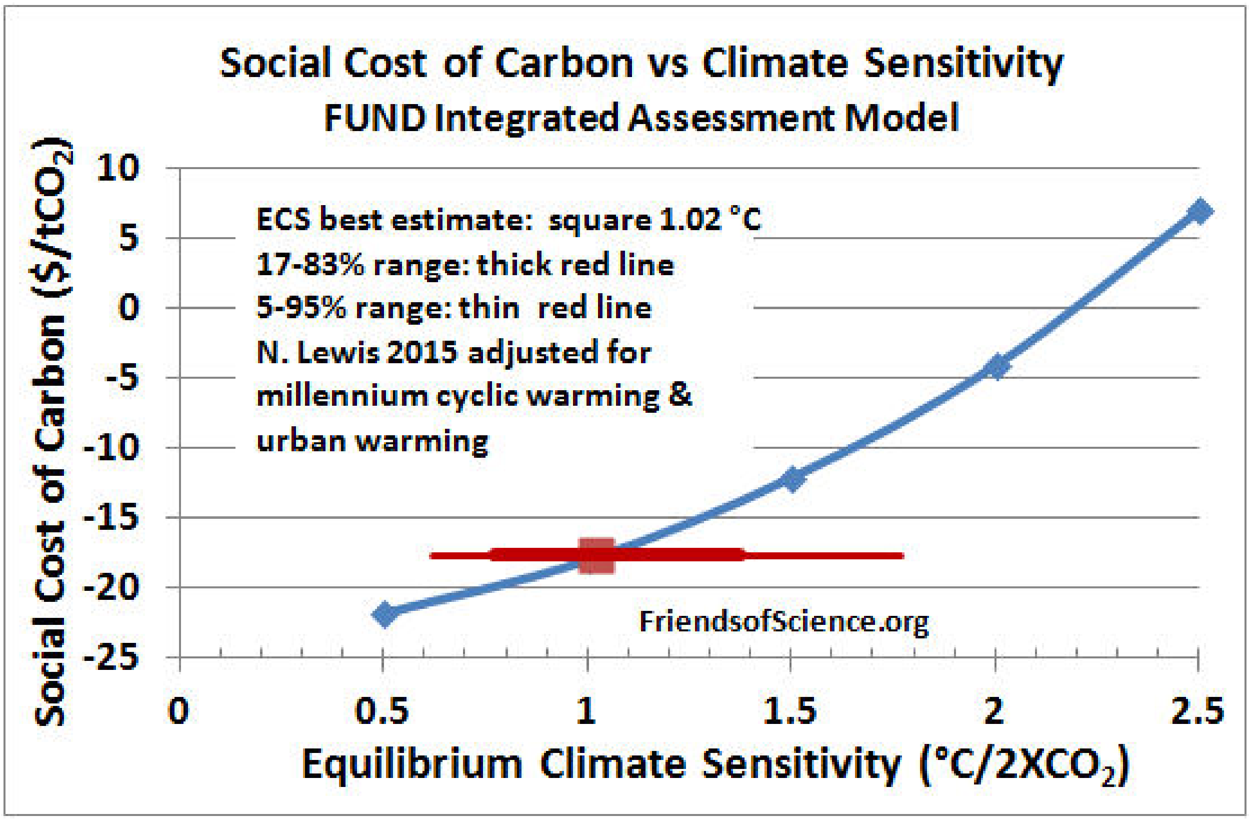

Figure 2. The equilibrium climate sensitivity (ECS) as calculated by N. Lewis using aerosol forcing by Stevens, other forcings and heat uptake by IPCC AR5 and global surface temperatures adjusted to account for natural millennium cyclic warming and urban warming from 1980. The ECS best estimate is shown by the red square, uncertainty ranges by the red lines. Social cost of carbon as determined by the FUND integrated assessment model is shown by the blue line, for emissions in 2010 in constant US$2007.

Figure 2 shows the SCC (blue line) as a function of ECS. The ECS best estimate is indicated by the red square. The thick red line shows the 17-83% probability range, and the thin red line shows the 5-95% probability range of the ECS estimate. The SCC values assume emissions in 2020, a real discount rate of 3%, in constant US$2007.

Social cost of carbon values were calculated for all values of ECS and weighted by the probability of the ECS values to determine the probability ranges of the SCC values as indicated in Figure 3. The analysis shows that on a global basis, the best estimate of the SCC of -16.6 US$/t$CO_2$, which is very beneficial. The likely range is -19.3 to -11.5 US$/t$CO_2$, and it is extremely likely to be less than -4.3 US$/t$CO_2$. These results show that instead of imposing a carbon tax on fossil fuels, there should be a subsidy equal to about 17 US$/t$CO_2$.

The benefits of CO_2 fertilization, reduced cold weather related mortality, lower outdoor industry costs such as construction costs, increased arable land area and reduced heating costs greatly exceed harmful effects of warming on a global basis.

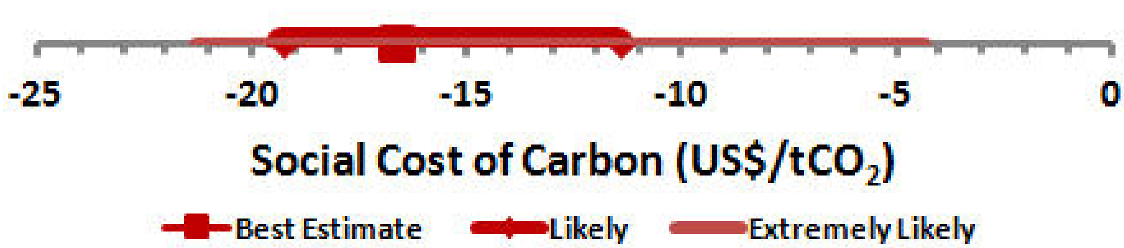

Figure 3. Social Cost of Carbon in US$/t$CO_2$ indicating best estimate, likely 17-83%, and extremely likely 5-95% uncertainty ranges. The uncertainty ranges do not include uncertainty associated with the millennium warming cycle or the urban warming effect. Emissions in 2020, 3% discount rate, in constant US$2007.

A longer, technical version of this article, with a section on Alberta's climate plan, and references is available in PDF format at http://www.friendsofscience.org/index.php?id=2205

The data and calculations are at http://www.friendsofscience.org/assets/files/SCC_Lewis_CS_2.xls Excel spreadsheet.