Critique of "Comprehensive evidence implies a higher social cost of CO_2"

A recent *Nature* article, Rennert et al. 2022, estimates the social cost of CO_2 summed through 2300. The authors find a total cost of $185 per ton of CO_2, more than three times the value of $51 used in current U.S. regulatory decisions. $90 of that is due to increased mortality from higher temperatures, $84 to reduced agricultural output, $2 to sea level rise and $9 to energy costs for residential and commercial buildings.

The claim of this article is that the numbers for mortality and reduced agricultural output are substantial exaggerations due to multiple unrealistic assumptions.

Mortality

The mortality calculation in Rennert is based on regional figures for increased mortality per degree of temperature rise from Cromar et al. 2022. Temperature-related mortality depends, among other things, on income, since richer people can afford air conditioning and better insulated homes and have less need to go out in unfavorable weather. The economic model in Rennert implies per capita GNP roughly tripling by 2100, increasing about eleven-fold by 2300,[1] but since Cromar does not include income in the relation between temperature and mortality Rennert ignores the effect of that increase on temperature-related mortality. Socioeconomic conditions are mentioned in Cromar as a factor to be considered in future work but the implicit assumption of the two articles taken together is that, despite the large projected increase of income, the relation between temperature and mortality will remain at the level of the recent past.

Temperature Distribution Over the Year

The article estimates the effect of increases in average temperature without specifying the distribution over the year. An increase of 2°C in winter and 0°C in summer would have a very different effect on mortality than an increase of 0°C in winter and 2°C in summer. Increases in temperature due to anthropogenic climate change, as projected in the IPCC reports, are greater in winter than in summer, so reduce mortality from cold more and increase mortality from heat less than a uniform increase with the same average. The data in the articles used by Cromar to deduce temperature-related mortality are from temperature variation little of which is due to climate change so have no reason to reproduce that pattern.

Carleton et al. 2022, a more recent and more sophisticated calculation of the contribution to the SCC from temperature-related mortality, uses the same time period and discount rate as Rennert but takes account of the effect on mortality of both income and the temperature distribution. It found a value of $36.6 for a high emissions scenario (RCP 8.5) and $17.1 for a moderate emissions scenario (RCP 4.5). The latter is much closer than the former to the assumptions in Rennert.

Technology

Temperature-related mortality depends on medical, heating, cooling, and insulating technologies. We do not know how much those technologies will improve over the next three centuries but that there will be no change is not a plausible assumption. Yet that is the assumption implicit in

[1] Calculated from Figure 2b in Rennert. Even an eleven-fold increase in income would still leave countries such as India, Nigeria, and Indonesia with incomes substantially lower than current U.S. incomes.

Rennert, which applies the increase in temperature-related mortality per degree of warming calculated in Cromar from past data to project the increase from now to 2300. Changes in mortality over recent history suggest that the effect they are ignoring would be large.

Thus, for example, Sidney et al. find an annual decline in cardiovascular mortality in the United States from 2000 to 2011 of 3.79%. If that rate were to continue for the rest of the century it would reduce cardiovascular disease, one of the sources of temperature-related mortality, about twenty-fold by 2100.

Lay et al., calculating temperature-related mortality rates first with 1973-82 data and then with 2003-13 data, found that the predicted increase in temperature-related mortality in the U.S. for a 2°C increase fell by more than 97%, for a 6°C increase by 84%, due to changes in mortality rates over thirty years. Yet Rennert projects mortality rates on the assumption that the relation between temperature and mortality will remain constant for almost three hundred years.

Migration

A fourth factor ignored in Cromar is adaptation by migration. Currently, 280,000,000 people, about 3.5% of the world population, live in a different country than they were born in. If some parts of the world become less attractive due to climate change and some more, populations can be expected to shift in response, reducing temperature-related mortality.

In summary, I found four problems with the mortality calculation from Cromar as used in Rennert:[2] neglecting the effect of income on temperature-related mortality, ignoring the pattern of temperature change implied by greenhouse warming, neglecting the effect of technological change, ignoring adaptation by migration. The first two can be corrected by substituting the result in Carleton for that in Cromar, reducing the SCC due to temperature-related mortality from $90/ton to something between $17.1/ton and $36.6/ton. Correcting the third and fourth should further reduce it by a large but unknown amount.

Effect of Climate Change on Agriculture

Rennert bases its estimate of the effect of climate change on agriculture on Moore et al. 2017. I find two problems with its calculations.

Technological Change

One way of adapting to a changed environment is by modifying crop varieties. Biotech is a rapidly progressing field so we can expect our ability to modify crop varieties to improve over time. A more primitive form of biotech, selective breeding, adapted maize to the cooler climate of North America with the result that a once tropical crop is now grown in both tropical and temperate regions. As our biotechnology improves we should be able to do it with other crops in the other direction a little faster, in decades instead of millennia. Research in adapting wheat to hotter temperatures is currently ongoing.[3]

CO_2 Fertilization

[2] These are not errors in Cromar et al. viewed as an estimate of current effects of temperature change but become errors when incorporated into Rennert et al. and used to project effects into the far future.

[3] At the John Innes Centre in Norwich.

Increases in CO_2 concentration in the atmosphere increase the yield of C3 crops and reduce water requirements for both C3 and C4 crops. Moore uses a figure of 11.5% increase in C3 yield with a doubling of CO_2 concentration, writing “This is very close to estimates from experimental field studies for C3 crops” and footnoting the claim to Long et al. 2006. Long, however, found increases of 12%, 13%, and 14% (rice, wheat, and soybeans) from an increase to 550 ppm *from the ambient concentration*, which implies an increase of about 17.5% for a doubling.[4] Kimball 2016, a survey of FACE (Free-air CO_2 Enrichment) studies of which Long is one, found that “Yields of C_3 grain crops were increased on average about 19%” by increasing CO2 from 353 ppm to 550, which implies a 23% increase for a doubling.

Taylor and Schlenker 2022 used random variation in CO_2 concentration observed by NASA’s Orbiting Carbon Observatory-2 satellite, combined with county level crop yield data, to directly observe the effect of varying CO_2 concentration on crop yields in actual agricultural practice. They found that a 1 ppm increase in CO_2 equates to a 0.4%, 0.6%, 1% yield increase for corn, soybeans, and wheat, respectively. Their article includes a discussion of reasons why the FACE studies may have substantially underestimated the effect.[5]

Moore uses an anomalously low value for CO2 fertilization of C3 crops — 2/3 the value in the source they cite, half the value found in the most recent survey of FACE results, lower still relative to the results in Taylor and Schlenker 2022. That is at least part of the reason that they get a much more negative result for the social cost of carbon than earlier studies that used earlier and higher estimates from enclosed rather than free air studies — FUND, which found a net benefit, or AgMIP, which found a cost but a substantially smaller one.[6] Replacing Moore’s 11.5% by Kimball’s 23% would substantially reduce the contribution of the effect of climate change on agriculture to the cost of carbon.

Conclusion

Correcting the neglect of technological change and using a more realistic value for CO_2 fertilization would reduce Moore’s estimate substantially, might make the net effect of climate change on agriculture positive.

Effect of Climate Change on Usable Land Area

Human land use is currently limited, almost entirely, by cold, not heat — the polar regions are empty, some of the hottest regions densely inhabited. Warming due to anthropogenic climate change will push temperature contours towards the poles, producing a large increase in the amount of land in the northern hemisphere warm enough for human use. A rough estimate (unpublished) finds an increase of 10.8 million km^2 from an increase in global temperature of 3°C. Zabel et al. 2014 estimate an increase of suitable cropland by 5.6 million km^2 by the end of this century,

[4] “Such an adjustment is justified because to a first approximation growth responses by plants to elevated CO_2 are generally linear between 300 and 900 ppm” (Kimball). Ambient CO_2 in 2000 was about 370 ppm. I am using that figure, starting with 13%, the average of the three values reported.

[5] Observed variation was only over a range of about 15 ppm so their results do not tell us how large the effect would be for much greater increases in CO_2 concentration but they suggest that the FACE results seriously underestimate the yield increases from CO_2 fertilization. According to the authors, “recent work has pointed out potential measurement error, arguing that FACE estimates should be adjusted upward by 50% to account for the effect of air turbulence and CO2 fluctuations (Allen et al. 2020)”

[6] Moore et al. Fig. 4.

Ramankutty et al. 2002 an increase of 6.6 million km^2.[7] A less optimistic calculation by Xhang et al. finds a change in agricultural land availability ranging from -.8 million km^2 to +1.2 million km^2. Xhang and Zabel do not, but Ramankutty does, take account of the increased area of cropland from the reduction in water requirements due to increased CO_2.

The benefit from increased cropland should be included as a subtraction from the cost of carbon. Moore spends two paragraphs discussing reasons why the social cost of carbon might more than they calculate, devotes no attention to reasons why it might be less.

A General Problem

Over the past two centuries, technological change has replaced sailing ships with jet planes for long distance transportation. Over the past century, medicine has progressed from a point where almost no contagious diseases were curable to one where almost all are. Over the past fifty years, computer technology has progressed to the point where the typical member of a developed society carries in his pocket a computer more powerful than any that existed fifty years ago. There is no reason to believe that the process has stopped and no way of predicting its effects on the world beyond the very short term. As I wrote in a book published fifteen years ago:

> … with a few exceptions, I have limited my discussion of the future to the next thirty years or so. That is roughly the point at which both AI and nanotech begin to matter. It is also long enough to permit technologies that have not yet attracted my attention to start to play an important role. Beyond that my crystal ball, badly blurred at best, becomes useless; the further future dissolves into mist. (Friedman 2008)

Rennert sums costs over the next three centuries, with about two-thirds of the total coming after 2100.[8] Their solution to the problem of predicting technological change over that period is, with the exception of their estimates of CO_2 production and energy costs, to ignore it, implicitly assume technological stasis. That is the wrong solution, but any projection of technological change that far into the future would be science fiction not science.

What they claim to do cannot be done.

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[7] A less optimistic calculation by Xhang et al. finds a change in agricultural land availability ranging from -.8 million km^2 to +1.2 million km^2(“Climate change impacts on global agricultural land availability” by Xiao Zhang and Ximing Cai, 2011 *Environ. Res. Lett.* 6 014014.). Xhang and Zabel do not, but Ramankutty does, take account of the reduction in water requirements due to increased CO_2.

[8] As estimated from Extended Data Fig. 2 in Rennert et al.

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