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Commentary

Reply to Anthoff and Tol

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We would like to comment on two issues: the message of our article and the remedies to the division-by-zero problem.

What we found

The FUND model, as used by the U.S. government's Interagency Working Group, produces a very low estimate of the social cost of carbon, in part because it projects a large net benefit of climate change in agriculture.

We identified two defects in the FUND equation for crop yields as a function of temperature. First, the yield-maximizing temperature for each region is a Monte Carlo parameter that varies over implausibly wide ranges: the 95% confidence intervals stretch from well below the temperatures of the last ice age, up to temperatures that human beings cannot survive. Second, the crop yield equation includes fractions with denominators that would be equal to zero for a particular value of the Monte Carlo parameter.

Both defects would be expected to produce an excessively wide range of results on successive iterations of the Monte Carlo analysis — some with extremely large net benefits, others with extremely large net damages. (As the key parameter approaches the divide-by-zero point from one side, the fraction tends toward positive infinity; on the other side, it tends toward negative infinity.) FUND has a built-in limit on the size of agricultural damages but no corresponding limit on the size of agricultural benefits, as explained in a footnote in our article. This asymmetric limitation screens out the excessive damages but leaves the excessive benefits intact, making the average outcome artificially positive. That is, the defects we identified both tend to exaggerate the benefits of climate change for agriculture.

We then made two simple changes in the structure of the crop yield equation, leaving everything else unchanged. Each of these changes more than doubled the estimate of the social cost of carbon. As we said in the article,

> These changes are introduced solely to explore the sensitivity of FUND outputs to the structure of [the crop yield equation], not as recommendations for a corrected model structure; the authors of FUND have, quite reasonably, responded that this simple tinkering with one equation is not an appropriate way to revise the model.

Anthoff and Tol's response

When we first drafted our analysis, we sent it to David Anthoff for comment before releasing it to anyone else. His thoughtful response is acknowledged in several places in our article, although we continue to disagree about a number of issues.

To date we have received no response on the question of FUND's use of implausible temperature ranges. On the divide-by-zero problem, David Anthoff and Richard Tol have responded that the results of their Monte Carlo runs are always screened after the fact, and compared to the "trimmed" results with extreme values removed; in their unpublished sensitivity analyses on the runs used by the Interagency Working Group, removal of an unspecified number of runs that came closest to the divide-by-zero point reportedly had little effect on the results.

It is possible to run a model with a known algebraic defect, and then manually screen the results to determine whether any distortions were caused by the defect — but it does not seem to us like an ideal modeling methodology. Since the appearance of our critique of FUND version 3.5, software (but no documentation) for FUND version 3.6 has been released. In version 3.6, the crop yield equation has been rewritten to remove the risk of division by zero.

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