# Climate Change and the Nobel Prize in Economics

Economists are not your friends

## 1. The Age of Rebellion

Rebellion is in the air. On November 17 of last year, the "Gilets Jaunes" movement spontaneously erupted in France, in reaction to a planned tax on diesel fuel. Over 300,000 people took part in demonstrations across the country, with actions ranging from blocking roundabouts to vandalizing banks, shops and luxury vehicles. As I write these words, the movement is still holding demonstrations across France every Saturday.

Almost as spontaneously, a youth movement calling itself *Extinction Rebellion* came into being in the UK, and held its first "Rebellion Day" on the same day that the Gilets Jaunes first shook France. This initial action, which blocked London's five main bridges, was much smaller and lower key than the Gilets Jaunes protests, but by April 2019, non-violent civil disobedience protests brought large sections of London to a halt, and resulted in the arrest of over 1,000 demonstrators.

These movements are superficially diametrically opposed: one was provoked by measures to address climate change, the other is demanding action on climate change. However, they are united by one key detail. The policy action that the Gilets Jaunes oppose, and the policy inaction that Extinction Rebellion deride, are both the products of economists—and most specifically, the economist who was awarded the Nobel Prize in Economics for his work on Climate Change, William Nordhaus.

The Gilets Jaunes rebellion was sparked by the proposed introduction of a carbon tax on diesel fuel—and this is precisely the method that Nordhaus and most economists recommend to use to combat Climate Change.

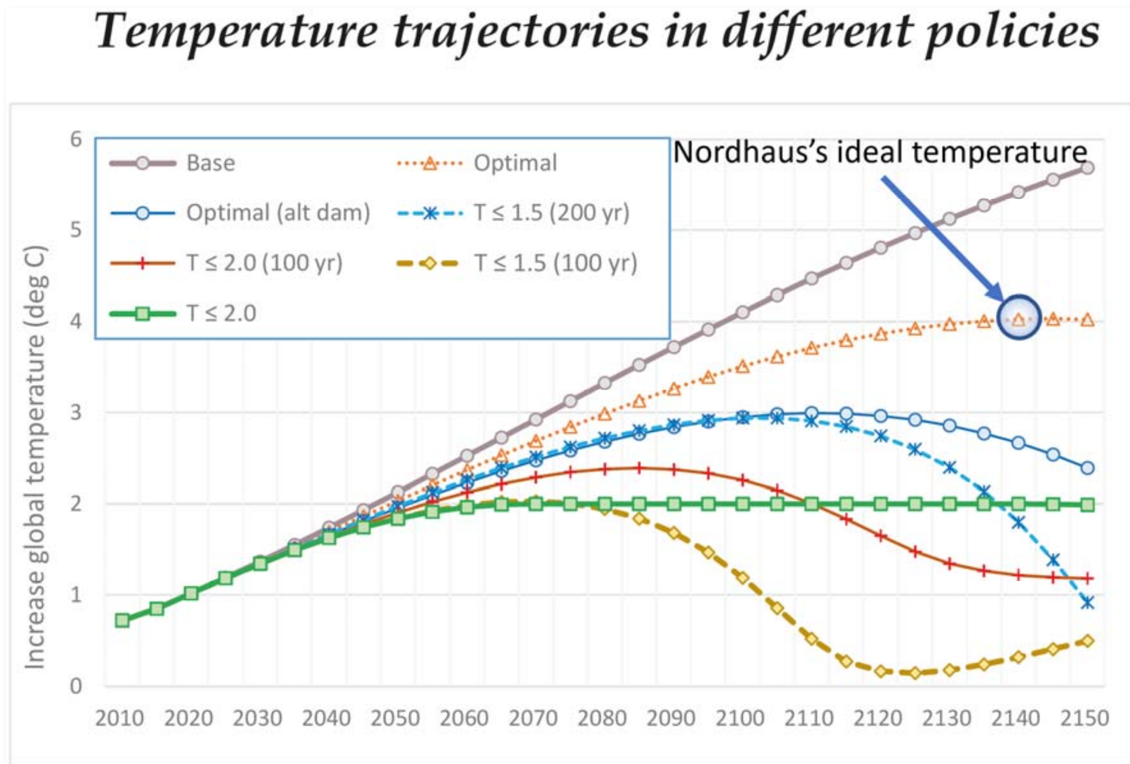
Extinction Rebellion was sparked by the failure of policymakers to do anything substantive to prevent Climate Change, and they are demanding policies that would cause net CO2 emissions to fall to zero by 2025:

> Government must act now to halt biodiversity loss and reduce greenhouse gas emissions to net zero by 2025…
>
> The truth is that the climate and ecological emergency poses an unprecedented existential threat to humanity and all life on Earth.
>
> Rapid, unprecedented changes to many aspects of human life – energy use and supply, transport, farming and food supply, and so on – are now needed to avert global climate and ecological catastrophe.
>
> Globally governments have been unwilling to tackle a problem of this magnitude. In 2015, the UN Paris Agreement on Climate Change was signed by world leaders to limit global warming to 2°C above pre-industrial levels. However, scientific evidence now tells us that our leaders have not taken enough action and we are still on a path to reach 3-4°C, which will be

> catastrophic to all life on Earth. (https://rebellion.earth/the-truth/demands/, May 3rd 2019)

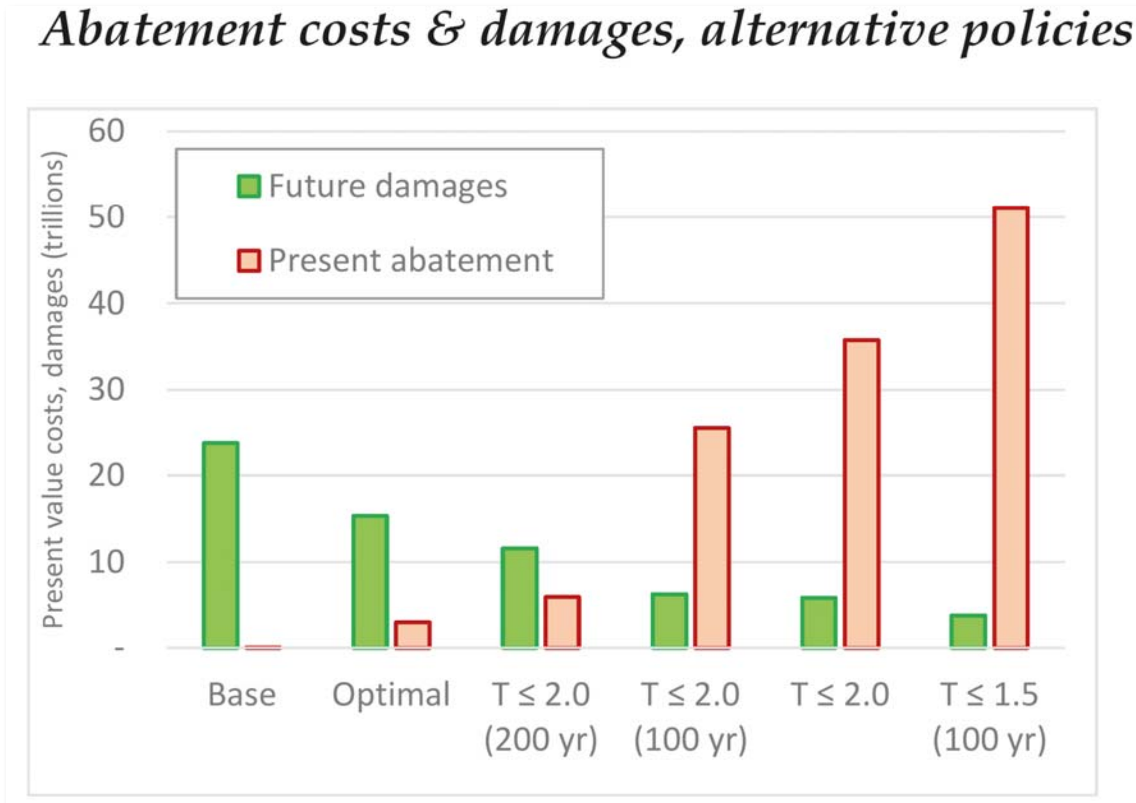
Nordhaus agrees that man-made Climate Change is happening—he is not a “Climate Change Denier” (henceforth, *CCD*). However, his research actually encourages policymakers ***not*** to take the action that Extinction Rebellion demands, or anything like it. He instead recommends moderating Global Warming so that the Earth’s temperature will stabilize at 4 degrees above pre-industrial levels in the mid-22nd century.

*Figure 1: Slide 6 in Nordhaus's 2018 Nobel Prize Lecture, annotated*




Nordhaus also argued that the policy Extinction Rebellion recommends, of restrict Global Warming to 1.5 degrees—even if it is done over the next century, rather than the next five years as Extinction Rebellion demands—would cost the global economy more than 50 trillion US dollars, while yielding benefits of well under US$5 trillion.

*Figure 2:Slide 7 in [Nordhaus's 2018 Nobel Prize Lecture]*




How is it possible that the optimal temperature for the planet is 4 degrees above pre-industrial levels—and that damages from that level of warming would amount to under 10% of global GDP—when it would also be "catastrophic to all life on Earth"? How is it possible that Global Warming of 1.5 degrees would reduce global GDP by only a few trillion US dollars—less than 5% of what GDP would have been in the absence of Global Warming—while the policies to achieve that limit, even if executed over a century rather than just five years, would cost over ten times as much?

It isn't. Instead, either Extinction Rebellion's claims are vastly overblown, or Nordhaus's estimates of the economic damages from Global Warming drastically understate the dangers.

Both are possible, of course. But categorically, Nordhaus's estimates of the potential economic damage from Global Warming are nonsense. They are also one of the key reasons why policymakers have not taken the threat seriously: why act with urgency if the damages are going to be so slight, and the costs of immediate action so high?

In reality, Nordhaus's work is even more misleading about the dangers of Climate Change, and the costs of abatement, than mainstream macroeconomic models were about the likelihood of a serious economic crisis in 2008.

Universally, these models predicted that 2008 was going to be a great year, and effectively advised policymakers to take the credit for it. Then the Global Financial Crisis happened. Before the crisis, apart from a small band of dissenting economists (of whom I am one), most of the world treated economic modelling as scientific. Then, as the biggest economic crisis since the Great Depression erupted, public confidence that economists knew what they were doing plummeted: even the

Queen of England asked economists at the London School of Economics “if these things were so large how come everyone missed it?” (Pierce 2008).

As disastrous as that error by macroeconomists was, it has nothing on the disaster that will befall humanity if policymakers continue to treat Nordhaus’s soothing “expert” advice on the economic consequences of Climate Change seriously. For Extinction Rebellion to succeed, one of its first targets must be Nordhaus, his DICE model, and the Nobel Prize that gave his work the false air of scientific legitimacy.

## 2. Playing DICE with Life on Earth: Nordhaus’s Damage Function

DICE stands for “Dynamic Integrated model of Climate and the Economy”. It’s the mathematical model from which Nordhaus derives the results noted in the previous figures.

DICE is based on the Neoclassical long term growth model devised by the mathematical prodigy Frank Ramsey in 1928 (Ramsey 1928). This is the same foundation as the mainstream RBC (“Real Business Cycle”) and DSGE (“Dynamic Stochastic General Equilibrium”) macroeconomic models that completely failed to anticipate the 2008 Global Financial Crisis.

That its macroeconomic cousins fared so badly at their chosen task is cause enough for concern. These models were intended to forecast short-term economic growth, and were completely wrong about the immediate economic future, to disastrous effect. Was this failure just because the underlying technology was never meant to handle short-term economic dynamics? Or is the underlying Neoclassical growth model itself simply a poor model of reality?

This is a serious issue that I’ll take up in later chapters. However, the features that Nordhaus has added to model Climate Change are far worse than the inadequate foundation on which it was built.

DICE’s major additions to the standard model are:

- A “damage function” that relates the increase in average global temperature to a decline in GDP. This is the source of the “Future damages” estimates shown in Figure 2;
- An “abatement function” that calculates the cost of reducing global temperature rise over what would happen if nothing were done to tackle Climate Change. This is the source of “Present abatement” estimates shown in Figure 2; and
- Equations to relate GDP growth to the increase in CO2 levels in the atmosphere, along with the impact of that increased CO2 on the average global temperature.

By far the most egregious fallacy in Nordhaus’s model is its Damage Function. This function is the first substantive graphic in the DICE manual, and one look at it (see Figure 17) should give anyone—even Climate Change Deniers (CCDs)—cause for concern. Even if Anthropogenic Global Warming were a myth, even if the temperature rise was being caused by the Sun, would it really be true that a 5 degree increase in the average temperature of the globe would only reduce global GDP by 5 percent?

*Figure 3: Nordhaus's Damage Function, showing the estimated reduction in GDP for an increase in global mean temperature*

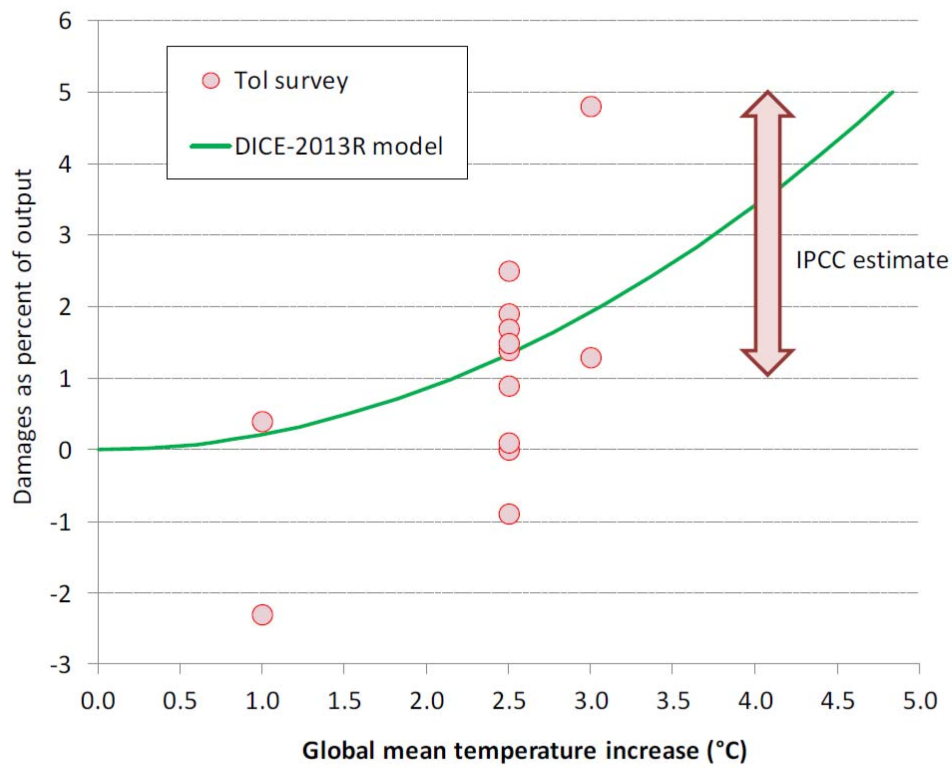



**Figure 2. Estimates of the Impact of Climate Change on the Global Economy**
This figure shows a compilation of studies of the aggregate impacts or damages of global warming for each level of temperature increase (dots are from Tol 2009). The solid line is the estimate from the DICE-2013R model. The arrow is from the IPCC (2007a). [impacts_survey.xlsx]

This is *not*, as is sometimes believed, the result of Nordhaus applying a high discount rate to the impact of climate change in the distant future. This instead is his estimate of how much lower global GDP would be in the future—say, 130 years from now—compared to what it would have been, if temperatures had instead remained at pre-industrial levels. Given the urgency that characterises the Global Warming debate, this is, on the face of it, an extremely benign view of the impact of an increase in the global average temperature on GDP.

Nordhaus has commented on the trivial significance his model's estimate of the damage from climate change, noting that "that the difference between a climate-change and a no-climate-change scenario would be thinner than the line drawn by a number 2 pencil used to draw the curves"—see Figure 4 and the quote in full:

*Figure 4: Figure 9 from Nordhaus 1993*

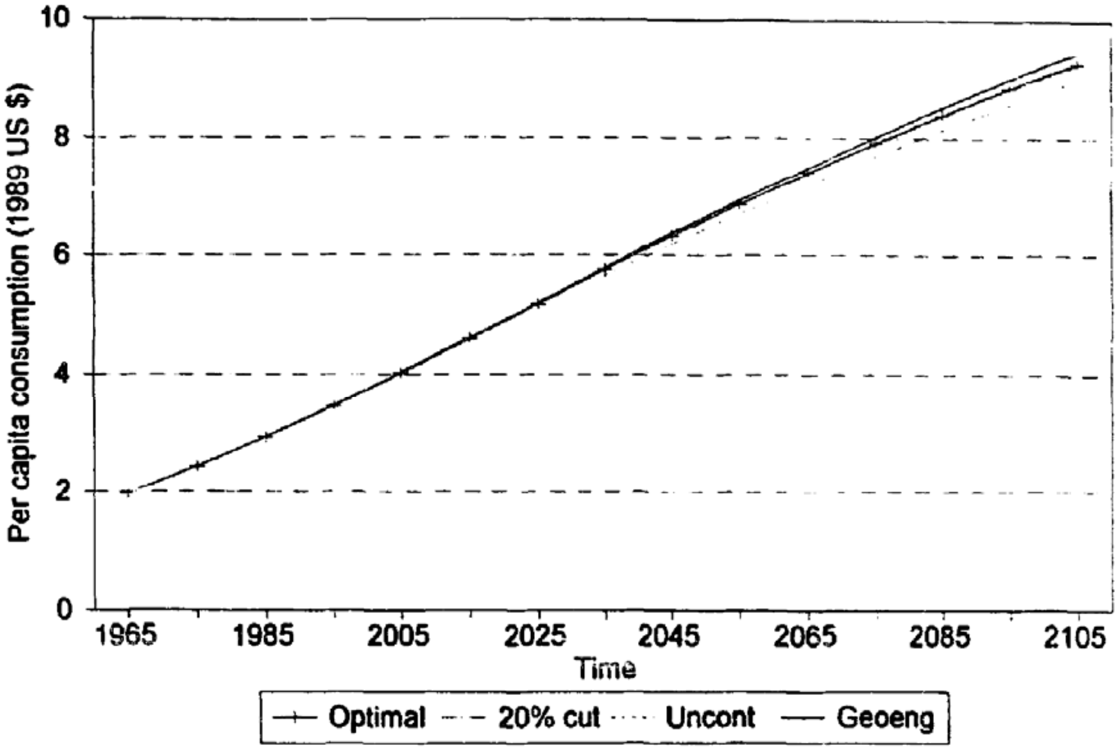



Fig. 9. Per capita consumption (1989 US $).

> Finally, fig. 9 shows the trajectory of real consumption per capita in the four cases. The striking feature of this figure is that, even though there are differences among the cases studied here, the overall economic growth projected over the coming years swamps the projected impacts of climate change or of the policies to offset climate change. In these scenarios, future generations may be worse off as a result of climate change, but they are still likely to be much better off than current generations. In looking at this graph, I was reminded of Tom Schelling's remark a few years ago that the difference between a climate-change and a no-climate-change scenario would be thinner than the line drawn by a number 2 pencil used to draw the curves. Thanks to the improved resolution of computerized graphics, we can now barely spot the difference! (Nordhaus 1993, pp. 47-48)

He reiterated this benign view in a 2017 paper, "Revisiting the social cost of carbon" (Nordhaus 2017):

> Including all factors, the final estimate is that the damages are 2.1% of global income at a 3 °C warming, and 8.5% of income at a 6 °C warming. (Nordhaus 2017, p. 1519)

If the predictions of Nordhaus's Damage Function were true, then everyone—including Climate Change Believers (CCBs)—should just relax. An 8.5 percent fall in GDP is twice as bad as the "Great Recession", as Americans call the 2008 crisis, which reduced real GDP by 4.2% peak to trough. But that happened in just under two years, so the annual decline in GDP was a very noticeable 2%. The

8.5% decline that Nordhaus predicts from a 6 degree increase in average global temperature (here CCDs will have to pretend that AGW is real) would take 130 years if nothing were done to attenuate Climate Change, according to Nordhaus's model (see Figure 1). Spread over more than a century, that 8.5% fall would mean a decline in GDP growth of less than 0.1% per year. At the accuracy with which change in GDP is measured, that's little better than rounding error. We should all just sit back and enjoy the extra warmth.

Except those in New York, London, Sydney, Cape Town, Los Angeles, San Francisco, and numerous other coastal cities of course, because they be too busy moving to higher ground: 6 degrees is well above the threshold at which all of Greenland and the Antarctic will melt completely (even if it's the Sun's fault, rather than AGW) (Steffen, Rockström et al. 2018, Figure 3, p. 8255). That will take much more than a century of course, but a planetary temperature rise of 6 degrees will doom any city less than 70 metres above sea level. They will all have to be relocated and rebuilt.

Human settlements closer to the Equator that are well above sea level will be safe from rising sea waters, but they will also be on the move: a 6 degree increase in temperature will make many of them unliveable. The obvious suspects—the Middle East and Northern Africa—would see average summer temperatures of over 40 degrees in their major cities, and much of their countryside. Moving them, or emigrating from them, would be essential for survival (see Figure 5 and Figure 6).

So all this human movement, and all this city rebuilding, plus everything else that a 6 degree rise in temperature (however it was caused) would trigger, will only reduce global GDP by 8.5%? This claim fails what Robert Solow appropriately christened "the smell test" (Solow 2010, p. 12):[1] if an economic model returns a prediction like this, it has to be … fill in your favourite expletive here.

*Figure 5: [Cities in Africa whose average summer temperatures today exceed 34 degrees]() for at least one month*

**Average temperatures for selected cities in Africa**
**°C (°F)**

| Country | City | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Algeria | Reggane | 16.0 (60.8) | 18.2 (64.8) | 23.1 (73.6) | 27.9 (82.2) | 32.2 (90.0) | 36.4 (97.5) | 39.8 (103.6) | 38.4 (101.1) | 35.5 (95.9) | 29.2 (84.6) | 22.0 (71.6) | 17.8 (64.0) | 28.3 (82.9) |
| Somalia | Bosaso | 25.0 (77.0) | 25.0 (77.0) | 26.7 (80.1) | 28.8 (83.8) | 31.1 (88.0) | 35.6 (96.1) | 35.6 (96.1) | 36.1 (97.0) | 33.3 (91.9) | 27.8 (82.0) | 25.6 (78.1) | 25.6 (78.1) | 30.0 (86.0) |
| Djibouti | Djibouti | 25.1 (77.2) | 25.7 (78.3) | 27.0 (80.6) | 28.7 (83.7) | 31.0 (87.8) | 34.2 (93.6) | 36.4 (97.5) | 36.0 (96.8) | 33.1 (91.6) | 29.3 (84.7) | 26.9 (80.4) | 25.4 (77.7) | 29.9 (85.8) |
| Sudan | Port Sudan | 23.3 (73.9) | 23.0 (73.4) | 24.3 (75.7) | 26.5 (79.7) | 29.3 (84.7) | 32.2 (90.0) | 34.1 (93.4) | 34.5 (94.1) | 32.1 (89.8) | 29.3 (84.7) | 27.3 (81.1) | 24.7 (76.5) | 28.4 (83.1) |
| Sudan | Khartoum | 23.2 (73.8) | 25.0 (77.0) | 28.7 (83.7) | 31.9 (89.4) | 34.5 (94.1) | 34.3 (93.7) | 32.1 (89.8) | 31.5 (88.7) | 32.5 (90.5) | 32.4 (90.3) | 28.1 (82.6) | 24.5 (76.1) | 29.9 (85.8) |
| Mali | Timbuktu | 21 (70) | 23 (73) | 27 (81) | 31 (88) | 33 (91) | 34 (93) | 32 (90) | 31 (88) | 31 (88) | 30 (86) | 26 (79) | 21 (70) | 28 (82) |

[1] "When it comes to things as important as macroeconomics, I think that every proposition has to pass a smell test: Does it really make sense?" [Robert Solow talking to the *House of Representatives Subcommittee On Investigations And Oversight Committee On Science And Technology*]() about why mainstream macroeconomic models failed to anticipate the 2008 crisis.

*Figure 6: Cities in Asia/Middle East whose average summer temperatures today exceed 34 degrees for at least one month*

**Average temperatures for selected cities in Asia**
**°C (°F)**

| Country | City | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kuwait | Kuwait City | 12.5 (54.5) | 14.8 (58.6) | 19.3 (66.7) | 24.9 (76.8) | 31.5 (88.7) | 36.0 (96.8) | 37.7 (99.9) | 36.8 (98.2) | 33.3 (91.9) | 27.3 (81.1) | 19.9 (67.8) | 14.1 (57.4) | 25.7 (78.3) |
| Iran | Ahvaz | 12.3 (54.1) | 14.7 (58.5) | 19.0 (66.2) | 24.9 (76.8) | 31.1 (88.0) | 35.2 (95.4) | 37.3 (99.1) | 36.7 (98.1) | 33.0 (91.4) | 27.3 (81.1) | 19.8 (67.6) | 14.0 (57.2) | 25.4 (77.7) |
| Saudi Arabia | Riyadh | 14 (57) | 16 (61) | 21 (70) | 26 (79) | 32 (90) | 34 (93) | 36 (97) | 35 (95) | 32 (90) | 27 (81) | 21 (70) | 16 (61) | 26 (79) |
| United Arab Emirates | Dubai | 18.7 (65.7) | 19.3 (66.7) | 22.3 (72.1) | 26.1 (79.0) | 29.9 (85.8) | 32.2 (90.0) | 34.4 (93.9) | 34.4 (93.9) | 32.1 (89.8) | 28.7 (83.7) | 24.3 (75.7) | 20.6 (69.1) | 26.9 (80.4) |
| Bahrain | Manama | 17.2 (63.0) | 18.0 (64.4) | 21.2 (70.2) | 25.3 (77.5) | 30.0 (86.0) | 32.6 (90.7) | 34.1 (93.4) | 34.2 (93.6) | 32.5 (90.5) | 29.3 (84.7) | 24.5 (76.1) | 19.3 (66.7) | 26.5 (79.7) |
| Iraq | Baghdad | 9.7 (49.5) | 12 (54) | 16.6 (61.9) | 22.6 (72.7) | 28.3 (82.9) | 32.3 (90.1) | 34.8 (94.6) | 34 (93) | 30.5 (86.9) | 24.7 (76.5) | 16.5 (61.7) | 11.2 (52.2) | 22.77 (72.99) |
| Iraq | Erbil | 6.2 (43.2) | 8.1 (46.6) | 12.2 (54.0) | 17.4 (63.3) | 23.6 (74.5) | 28.9 (84.0) | 32.9 (91.2) | 32.1 (89.8) | 28.2 (82.8) | 21.4 (70.5) | 14.1 (57.4) | 8.3 (46.9) | 19.5 (67.1) |
| Oman | Muscat | 21 (70) | 22 (72) | 25 (77) | 30 (86) | 34 (93) | 35 (95) | 34 (93) | 32 (90) | 31 (88) | 30 (86) | 25 (77) | 22 (72) | 28 (82) |
| Yemen | Aden | 25.7 (78.3) | 26.0 (78.8) | 27.2 (81.0) | 28.9 (84.0) | 31.0 (87.8) | 32.7 (90.9) | 32.7 (90.9) | 31.5 (88.7) | 31.6 (88.9) | 28.9 (84.0) | 27.1 (80.8) | 26.0 (78.8) | 29.1 (84.4) |
| Pakistan | Lahore | 12.8 (55.0) | 15.4 (59.7) | 20.5 (68.9) | 26.8 (80.2) | 31.2 (88.2) | 33.9 (93.0) | 31.5 (88.7) | 30.7 (87.3) | 29.7 (85.5) | 25.6 (78.1) | 19.5 (67.1) | 14.2 (57.6) | 24.3 (75.7) |
| Myanmar | Mandalay | 21.9 (71.4) | 24.4 (75.9) | 28.8 (83.8) | 31.9 (89.4) | 31.3 (88.3) | 30.8 (87.4) | 30.8 (87.4) | 30.2 (86.4) | 29.7 (85.5) | 28.8 (83.8) | 25.7 (78.3) | 22.2 (72.0) | 28.0 (82.4) |
| India | New Delhi | 13.8 (56.8) | 16.5 (61.7) | 22.1 (71.8) | 28.7 (83.7) | 32.8 (91.0) | 34 (93) | 30.9 (87.6) | 29.7 (85.5) | 29 (84) | 26.1 (79.0) | 20.5 (68.9) | 15.3 (59.5) | 25 (77) |

It doesn't take long to find the sources of [expletive deleted] in Nordhaus's model. There are several, but the most egregious of all is the mathematical form of his "Damage Function".

## Mostly Harmless

With all the obvious complexities and uncertainties in the whole issue of how climate interacts with the economy and vice versa, Nordhaus chose to use the second-simplest relationship possible between two variables: a quadratic.[2] He simply assumes that the relationship between change in global temperature (relative to the level in 1900) and reduction in GDP is a function of the temperature difference squared:

> "The current version assumes that damages are a quadratic function of temperature change" (Nordhaus and Sztorc 2013, p. 11)

His estimate of the damages to GDP from an increase in temperature over pre-industrial levels is shown in Equation (1.1) and Figure 7.

$$D_{NH}\left(temp_{diff}\right) = 0.00267 \cdot temp_{diff}^{\ 2} \tag{1.1}$$

[2] The simplest relationship is a linear one.

*Figure 7: The parameters for Nordhaus's estimate of damage from temperature change in the code for his DICE model*[3]

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** Climate damage parameters
     a1     Damage intercept              /0     /
     a2     Damage quadratic term           /0.00267 /
     a3     Damage exponent                /2.00   /
```

In his most recent, but as yet undocumented, version of his model (DICE-2016R2), he has revised this ***down*** to 0.00227 (Nordhaus 2018, p. 345).[4]

One property of a quadratic is that there are no discontinuities, and therefore no points at which the relationship implied by the function simply breaks down. In the context of modelling climate change, using a quadratic for the relationship between an increase in global temperature and the economy implies that there are no temperature levels that set off catastrophic breakdown in the economy by triggering fundamental qualitative shifts in the climate—such as melting the icecaps, stopping the Gulf Stream, or turning El Nino from a temporary phenomenon into a permanent one. Nordhaus acknowledges this in the same sentence, *and justifies the absence of such a feature in his Damage Function by an appeal to a survey of actual climate scientists about whether there are tipping points in the climate:*

> The current version assumes that damages are a quadratic function of temperature change *and does not include sharp thresholds or tipping points, but this is consistent with the survey by Lenton et al. (2008)*." (Nordhaus and Sztorc 2013, p. 11. Emphasis added.)

So climate scientists concurred that there are no "sharp thresholds or tipping points" in the climate—or at least, in the relationship between temperature increase and the economy? I wanted to see evidence of that! I expected Nordhaus to provide a detailed exposition of this research, since this assertion is crucial to Nordhaus's choice of a simple quadratic—and a trivial coefficient for it—to model the economic damages from climate change.

I was disappointed. *Not only was there no further explanation, there was no reference for Lenton in his bibliography either*.[5] Fortunately, the paper (Lenton, T. M., H. Held, et al. (2008). "Tipping

[3] Page 97 of Nordhaus (2013).

[4] "The parameter used in the model was an equation with a parameter of 0.227 percent loss in global income per degrees Celsius squared with no linear term. This leads to a damage of 2.0 percent of income at 3°C, and 7.9 percent of global income at a global temperature rise of 6°C. This coefficient is slightly smaller than the parameter in the DICE-2013R model (which was 0.267 percent of income per degrees Celsius squared). The change from the earlier estimate is due to corrections in the estimates from the Tol numbers, inclusion of several studies that had been omitted from that study, greater care in the selection of studies to be included, and the use of weighted regressions. Note also that the revised damage coefficient is the only change from the 2016R model used in Nordhaus (2017)."

[5] There is a pattern here: he acknowledges Lenton's work again in another paper in 2018 (Nordhaus, W. D. (2018). "Global Melting? The Economics of Disintegration Of The Greenland Ice Sheet." Cowles Foundation Discussion Paper, No. 2130), and quotes it. But again, his bibliography lacks the reference, and he persists with a quadratic damage function:

> Concerns about the impact of climate change on large-scale and unmanageable earth systems have taken center stage in the scientific and economic analysis of

elements in the Earth's climate system." Proceedings of the National Academy of Sciences **105**(6): 1786-1793) can be found online (Lenton, Held et al. 2008). Since this paper played a key role in Nordhaus's justification of his simple damage equation, I decided to check it very carefully—something Nordhaus himself quite obviously did not do.[6]

There is one sentence in this paper, and only one sentence, which could in any way be construed to support Nordhaus's contention that a damage function without "sharp thresholds or tipping points" is "consistent with the survey by Lenton". This is the first sentence In the paper's third paragraph:

> Many of the systems we consider do not yet have convincingly established tipping points. (Lenton, Held et al. 2008, p. 1786)

However, the point of the paper was *to try to quantify those tipping points*—not to argue that they don't exist! The very next sentence makes this obvious:

> Nevertheless, increasing political demand to define and justify binding temperature targets, as well as wider societal interest in nonlinear climate changes, makes it timely to review potential tipping elements in the climate system under anthropogenic forcing. (Lenton, Held et al. 2008, p. 1786)

The remainder of the paragraph confirms that the purpose of the survey was to provide what was currently missing ("convincingly established tipping points"), *not to decide whether tipping points exist or not, and to conclude in the negative*:

> To this end, we organized a workshop entitled ''Tipping Points in the Earth System'' at the British Embassy, Berlin, which brought together 36 leading experts, and we conducted an expert elicitation that involved 52 members of the international scientific community. Here we combine a critical review of the literature with the results of the workshop to compile a short list of potential policy-relevant future tipping elements in the climate system. *Results from the*

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> climate change. Continued warming threatens to push large-scale earth systems beyond tipping points. This issue was highlighted in an influential paper on key "tipping points" of the earth system (Lenton et al. 2008). They write:
>
> "Human activities may have the potential to push components of the Earth system past critical states into qualitatively different modes of operation, implying large-scale impacts on human and ecological systems. Examples that have received recent attention include the potential collapse of the Atlantic thermohaline circulation (THC), dieback of the Amazon rainforest, and decay of the Greenland ice sheet (GIS). Such phenomena have been described as ''tipping points'' following the popular notion that, at a particular moment in time, a small change can have large, long-term consequences for a system…"

[6] I wish I could say that I was surprised by this, but it's what I've come to expect from Neoclassical economists—though I know few examples as bad and as blatant as Nordhaus's here. Neoclassical economists are more interested in maintaining their world view than they are in assessing information that might challenge it. My guess is that Nordhaus simply looked for a survey of climate scientists, read this one until he found an appropriate sentence (three paragraphs in), and didn't read the rest of the paper.

> *expert elicitation are used to rank a subset of these tipping elements in terms of their sensitivity to global warming and the associated uncertainty*. (Lenton, Held et al. 2008, p. 1786. Emphasis added)

The survey restricted itself to large components of the Earth's biosphere, with tipping points that could occur in this century, and whose effects would be felt within this millennium:

> We consider ''components'' of the Earth system that are associated with a specific region (or collection of regions) of the globe and are at least subcontinental in scale (length scale of order ≈1,000 km)… we focus on the consequences of decisions enacted within this century that trigger a qualitative change within this millennium, and we exclude tipping elements whose fate is decided after 2100 (Lenton, Held et al. 2008, pp. 1786-87).

*Figure 8: The systems with tipping points considered in Lenton's survey*

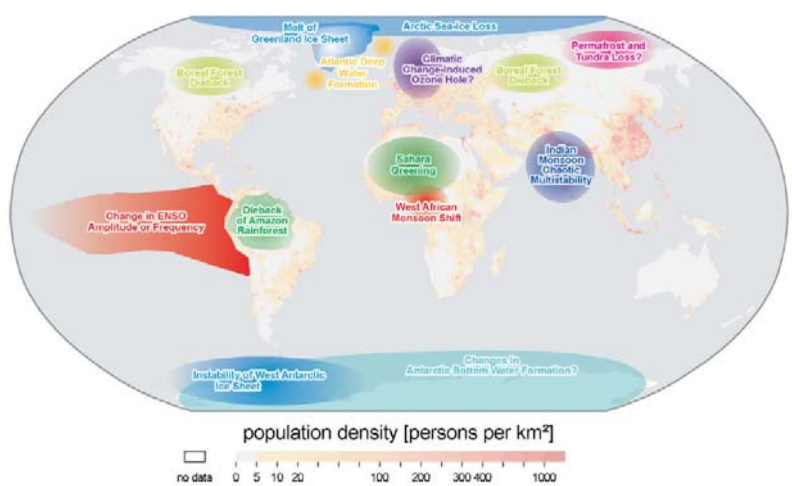


**Fig. 1.** Map of potential policy-relevant tipping elements in the climate system, updated from ref. 5 and overlain on global population density. Subsystems indicated could exhibit threshold-type behavior in response to anthropogenic climate forcing, where a small perturbation at a critical point qualitatively alters the future fate of the system. They could be triggered this century and would undergo a qualitative change within this millennium. We exclude from the map systems in which any threshold appears inaccessible this century (e.g., East Antarctic Ice Sheet) or the qualitative change would appear beyond this millennium (e.g., marine methane hydrates). Question marks indicate systems whose status as tipping elements is particularly uncertain.

Far from justifying the absence of "tipping points" in any model of the relationship between the economy and global warming, the paper asserts that tipping points exist, and pretending that they don't exist, via "smooth projections of global change", could, rather than providing a sensible guide to policy, lull society "into a false sense of security":

> Society may be lulled into a false sense of security by smooth projections of global change. *Our synthesis of present knowledge suggests that a variety of tipping elements could reach their critical point within this century under anthropogenic climate change*. The greatest threats are tipping the Arctic sea-ice and the Greenland ice sheet, and at least five other elements could surprise us by exhibiting a nearby tipping point. This knowledge should influence climate policy… (Lenton, Held et al. 2008, p. 1792. Emphasis added)

So the very reference that Nordhaus uses to justify **not** having a tipping point in his Damage Function establishes that **his Damage Function should have a tipping point**.

There is a simple way to describe Nordhaus's statement that his smooth damage function is "*consistent with the survey by Lenton*". It is a lie. The exact opposite is the truth: Nordhaus's smooth damage function without tipping points is ***inconsistent*** with the survey by Lenton. In any other discipline, what Nordhaus has done here, rather than leading to a Nobel Prize, would result in accusations of fraud.

Since that paper, Lenton has worked with other climate scientists to estimate what the tipping point temperature might be—where a tipping point is defined as "a planetary threshold in the trajectory of the Earth System that, if crossed, could prevent stabilization in a range of intermediate temperature rises" (Steffen, Rockström et al. 2018, p. 8252).[7] They describe the Earth as having had a natural glacial-interglacial limit cycle, of about 100,000 years' duration, for the last 1.2 million years (the period during which modern humans evolved), and assert that industrially-induced temperature change has already put us on a cycle towards a "Hothouse Earth" limit cycle (see Figure 9).

[7] Lenton is the 4th-listed co-author on this paper, which has 16 authors in total.

*Figure 9: The glacial-interglacial cycle plus the Hothouse Earth cycle we are now on (Steffen, Rockström et al. 2018, p. 8253)*

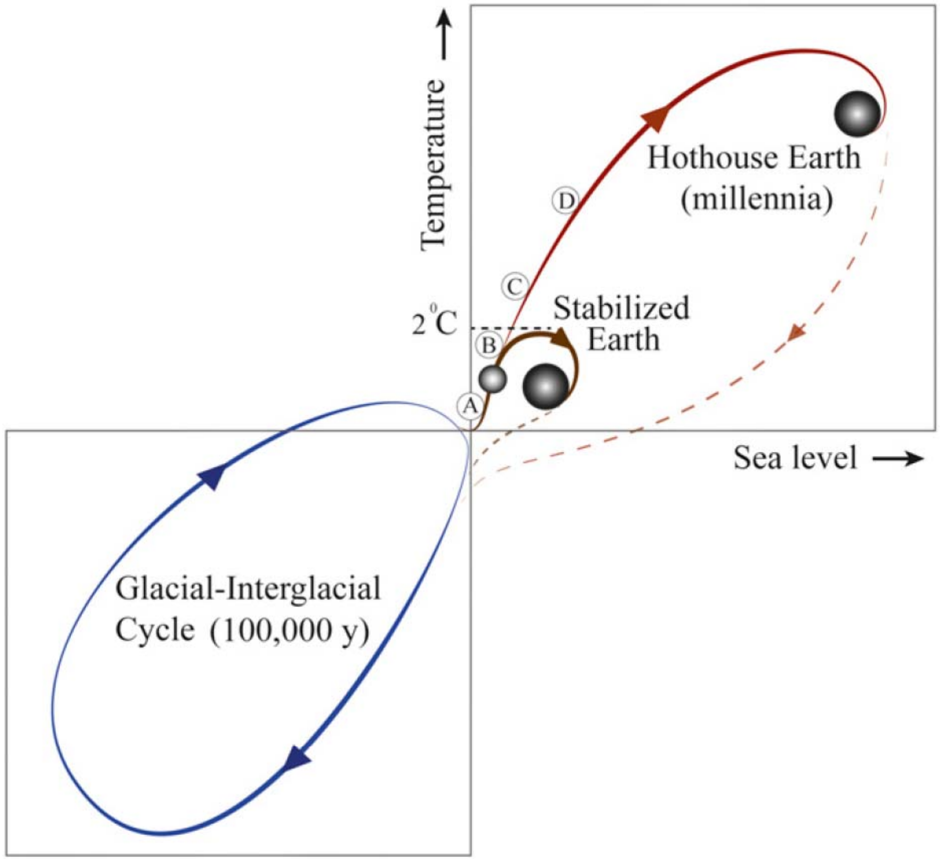


**Fig. 1.** A schematic illustration of possible future pathways of the climate against the background of the typical glacial–interglacial cycles (*Lower Left*). The interglacial state of the Earth System is at the top of the glacial–interglacial cycle, while the glacial state is at the bottom. Sea level follows temperature change relatively slowly through thermal expansion and the melting of glaciers and ice caps. The horizontal line in the middle of the figure represents the preindustrial temperature level, and the current position of the Earth System is shown by the small sphere on the red line close to the divergence between the Stabilized Earth and Hothouse Earth pathways. The proposed planetary threshold at ∼2 °C above the preindustrial level is also shown. The letters along the Stabilized Earth/ Hothouse Earth pathways represent four time periods in Earth's recent past that may give insights into positions along these pathways (*SI Appendix*): A, Mid-Holocene; B, Eemian; C, Mid-Pliocene; and D, Mid-Miocene. Their positions on the pathway are approximate only. Their temperature ranges relative to preindustrial are given in *SI Appendix*, Table S1.

The danger they see in crossing a temperature threshold is that, once it is crossed, a cascade caused by feedbacks from other elements of the planetary climate will propel the Earth to far higher temperatures that are incompatible, not only with industrial society, but potentially with human life. It is analogous to stepping over a cliff: once you have stepped over it, you don't remain at that height, but fall to a far lower level. Here, if we pass a tipping point (say, 2 degrees of warming), the ecosphere doesn't stay there but rises far higher by a series of feedback effects (see Figure 10).

*Figure 10: Into the valley of heat*

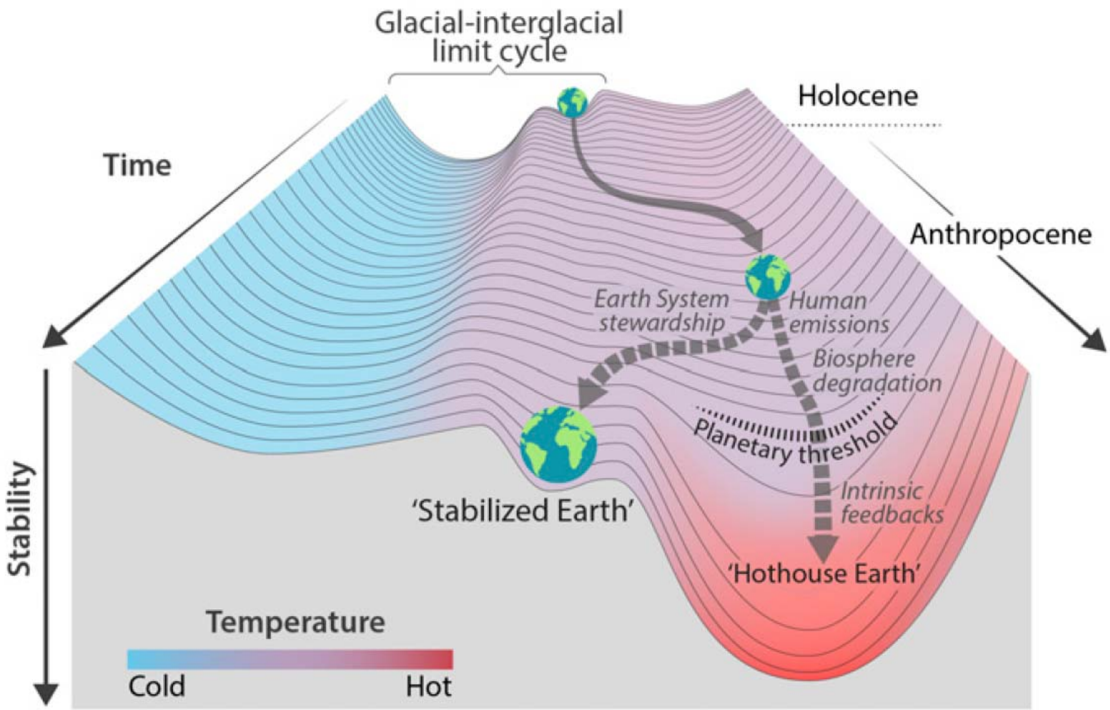


**Fig. 2.** Stability landscape showing the pathway of the Earth System out of the Holocene and thus, out of the glacial–interglacial limit cycle to its present position in the hotter Anthropocene. The fork in the road in Fig. 1 is shown here as the two divergent pathways of the Earth System in the future (broken arrows). Currently, the Earth System is on a Hothouse Earth pathway driven by human emissions of greenhouse gases and biosphere degradation toward a planetary threshold at ~2 °C (horizontal broken line at 2 °C in Fig. 1), beyond which the system follows an essentially irreversible pathway driven by intrinsic biogeophysical feedbacks. The other pathway leads to Stabilized Earth, a pathway of Earth System stewardship guided by human-created feedbacks to a quasistable, human-maintained basin of attraction. "Stability" (vertical axis) is defined here as the inverse of the potential energy of the system. Systems in a highly stable state (deep valley) have low potential energy, and considerable energy is required to move them out of this stable state. Systems in an unstable state (top of a hill) have high potential energy, and they require only a little additional energy to push them off the hill and down toward a valley of lower potential energy.

This paper, published in August 2018 (a few months before Nordhaus received the Nobel Prize), provides more detail on the planetary subsystems that could both be triggered by higher temperatures, and which could then cause a cascade effect on other subsystems (see Figure 11). Notice that several of them are triggered at between 1 degree (which we are already at) and 3 degrees of warming, while all of them are triggered by a level of warming (5 degrees) that Nordhaus blithely assumes will only reduce GDP by 8.5%.

[Nordhaus and economists in general as “Climate Change Trivializers” (*CCTs*)]

*Figure 11: The planetary subsystems considered in (Steffen, Rockström et al. 2018) and the trigger temperatures for them*

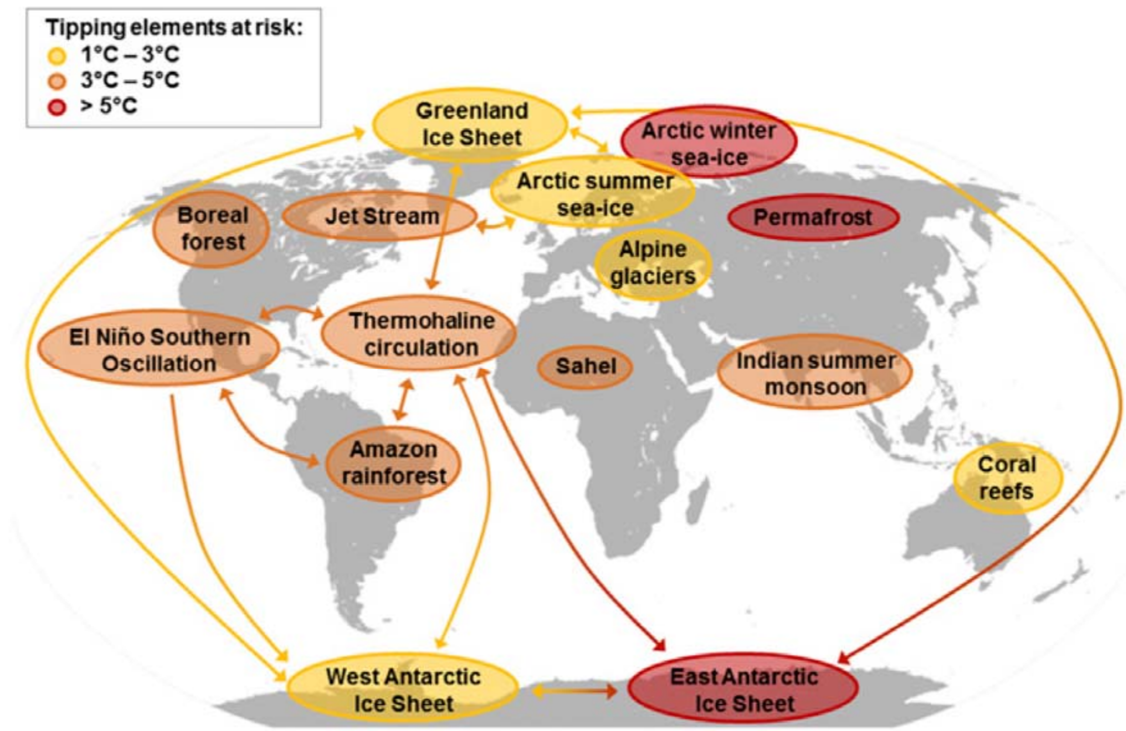


**Fig. 3. Global map of potential tipping cascades. The individual tipping elements are color- coded according to estimated thresholds in global average surface temperature (tipping points) (12, 34). Arrows show the potential interactions among the tipping elements based on expert elicitation that could generate cascades. Note that, although the risk for tipping (loss of) the East Antarctic Ice Sheet is proposed at >5 °C, some marine-based sectors in East Antarctica may be vulnerable at lower temperatures (35–38).**

They ultimately suggest 2 degrees as the trigger temperature above which a “Hothouse Earth” outcome may be inevitable:

> We suggest 2 °C because of the risk that a 2 °C warming could activate important tipping elements (12, 17), raising the temperature further to activate other tipping elements in a domino-like cascade that could take the Earth system to even higher temperatures (Tipping Cascades) (Steffen, Rockström et al. 2018, p. 8254)

> While this may seem to be an extreme scenario, it illustrates that *a warming into the range of even the lower-temperature cluster (i.e., the Paris targets) could lead to tipping in the mid- and higher-temperature clusters via cascade effects*. Based on this analysis of tipping cascades and taking a risk-averse approach, we suggest that *a potential planetary threshold could occur at a temperature rise as low as ~2.0 °C above preindustrial* (Fig. 1). (Steffen, Rockström et al. 2018, p. 8255. Emphasis added.)

Far from supporting the smooth, continuous, "no tipping points" approach pushed by Nordhaus, Lenton and his colleagues disparage (as forcefully as is feasible in refereed academic publications) the entire Neoclassical approach:

> With these trends likely to continue for the next several decades at least*, the contemporary way of guiding development founded on theories, tools, and beliefs of gradual or incremental change, with a focus on economy efficiency, will likely not be adequate to cope with this trajectory*. Thus, in addition to adaptation, increasing resilience will become a key strategy for navigating the future. (Steffen, Rockström et al. 2018, p. 8257. Emphasis added.)

Nordhaus does at least express a caveat or three about the simplistic, and clearly unjustified function he uses to estimate damage from global warming:

> I would note an important warning about the functional form in equation (5) when using for large temperature increases. The damage function has been calibrated for damage estimates in the range of 0 to 3 °C. In reality, estimates of damage functions are virtually non-existent for temperature increases above 3 °C. Note also that the functional form in (5), which puts the damage ratio in the denominator, is designed to ensure that damages do not exceed 100% of output, and this limits the usefulness of this approach for catastrophic climate change. The damage function needs to be examined carefully or re-specified in cases of higher warming or catastrophic damages. (Nordhaus and Sztorc 2013, p. 11)

Paraphrasing this, "if there aren't tipping points in the global climate, then you can use my model to guide policy; but if there are, you're on your own". That's about as useful as a car without a steering wheel. It will work fine if you're on a straight road, but if the road bends, you're dead. And Climate Change is the ultimate "long and windy road".

That might sound harsh—and it is. But justifiably so. We use models to guide us in situations that we have not yet encountered, or in which we have made policy mistakes in the past. It is no defence of a model to say—after the catastrophe that it said couldn't happen did happen—that it was only designed for situations in which catastrophes didn't occur. Ironically, that is precisely the defence that Ben Bernanke made of mainstream macroeconomic models after the 2008 financial crisis:

> Although economists have much to learn from this crisis, as I will discuss, I think that calls for a radical reworking of the field go too far… Economic models are useful only in the context for which they are designed. Most of the time, including during recessions, serious financial instability is not an issue. The

> standard models were designed for these non-crisis periods, and they have proven quite useful in that context. (Bernanke 2010)

That is a fob-off, not a justification for models that only work during "non-crisis periods". A model that only applies in conditions where it is not needed, when you don't have an alternative when it is needed, is worse than useless. It, as Lenton's paper stated, lulls you "into a false sense of security", which evaporates catastrophically when the actual catastrophe strikes.

With macroeconomics itself, such useless models let the world walk blindfolded into the biggest economic crisis since the Great Depression. However painful that crisis was, it will be nothing on the ecological and economy calamities that will occur if any of the tipping points noted by the "the survey by Lenton" are actually triggered.

This can easily be illustrated by replacing Nordhaus's quadratic with a very similar one that does have tipping points: a "rational function". This is a fraction with one polynomial divided by another. Since Nordhaus's function is just a square of the (difference in) temperature, the required function has a constant times temperature to the third power on the numerator, and the tipping point minus temperature on the denominator.

If, for the moment, we take the coefficient on Nordhaus's function seriously, this asserts that the 1 degree increase in temperature over pre-Industrial levels that has already occurred has reduced global GDP by a mere 0.236% of what it would have been in the absence of global warming.[8] A rational function with a tipping point will coincide with Nordhaus's 1-degree-damage estimate if the coefficient on its numerator is equal to Nordhaus's coefficient multiplied by the tipping point level minus one.[9]

For the denominator, since the survey work Nordhaus used to justify not having tipping points actually reached the conclusion that the tipping point was probably about 2 degrees, it's reasonable to use that as the tipping point temperature. To illustrate how the dangers still exist even if the tipping point is much higher, I also use a 4 degree tipping—since that's the level Nordhaus's model predicts we'll reach this century under the BAU (Business As Usual) scenario that his damage function actually encourages.

A Tipping Point makes an enormous difference to the implied damage to GDP from rising temperature levels. Contrary to Nordhaus's assertion that caution is needed "when using [his model] for large temperature increases", his model is unreliable for temperatures that are well within the levels on which he has made pronouncements about what global warming will do to GDP.

Even at just a 1.5 degree increase—the level that Extinction Rebellion wants politicians to set as a maximum—the estimate of damages are 1.5% of GDP (three times Nordhaus's estimate) with a 2 degree tipping point, and 0.9% of GDP (1.8 times Nordhaus's estimate) with a 4 degree tipping point (see **Error! Reference source not found.**).

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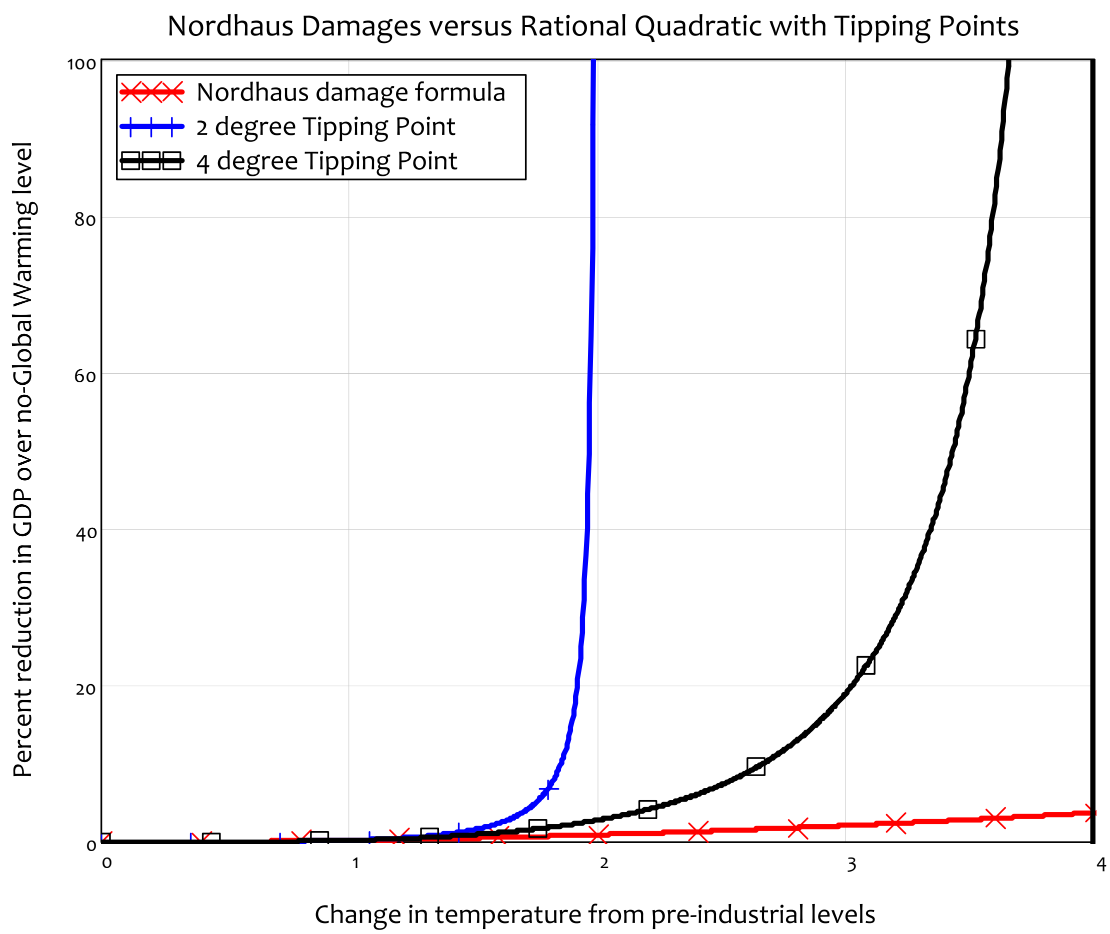
[8] This is the latest value of his coefficient, as given in Nordhaus 2018, "Projections and Uncertainties about Climate Change in an Era of Minimal Climate Policies." American Economic Journal: Economic Policy Volume 10, page 345.

[9] For a 2 degree tipping point, the rational function's coefficient is 0.00236; for a 4 degree tipping point, it's 0.00708.




At higher temperatures, but ones which are still well within the range over which Nordhaus deigns to make predictions, the disparity is even more marked. As we approach a 2 degree warming level, a 2-degree tipping point function implies the total destruction of the economy—not because it will happen immediately at that level, but because feedback effects will be set in train that drive the global temperature far higher, potentially to levels that are incompatible with the continued existence of human society. Steffen et al. contrast this outcome with their preferred trajectory towards what they call "Stabilized Earth" in which humans actively manage the planet's temperature to maintain it below the 2-degree threshold:

> A critical issue is that, if a planetary threshold is crossed toward the Hothouse Earth pathway, accessing the Stabilized Earth pathway would become very difficult no matter what actions human societies might take. Beyond the threshold, positive (reinforcing) feedbacks within the Earth System—outside of human influence or control—could become the dominant driver of the system's pathway, as individual tipping elements create linked cascades through time and with rising temperature (Fig. 3). In other words, after the Earth System is committed to the Hothouse Earth pathway, the alternative Stabilized Earth pathway would very likely become inaccessible. (Steffen, Rockström et al. 2018, p. 8256)

*Table 1: Nordhaus' Damage Function versus those based on 2 and 4-degree tipping points[10]*

| | | Tipping Point | | Ratio to Nordhaus | |
|---|---|---|---|---|---|
| GDP reduction at ... | Nordhaus | 2 degree | 4 degree | 2 degree | 4 degree |
| 1 degree | 0.2% | 0.2% | 0.2% | 1.0 | 1.0 |
| 1.5 degrees | 0.5% | 1.5% | 0.9% | 3.0 | 1.8 |
| 1.999 degrees | 0.9% | 94.8% | 2.6% | 105.3 | 2.9 |
| 2.5 degrees | 1.4% | ∞ | 6.6% | ∞ | 4.7 |
| 3 degrees | 2.0% | | 15.5% | | 7.8 |
| 3.5 degrees | 2.7% | | 36.9% | | 13.6 |
| 3.999 degrees | 3.5% | | 99.8% | | 28.5 |

This alone is enough to reject outright Nordhaus's assurances about the manageability of climate change. Nordhaus has put the world into a Dirty Harry movie gone bad: having advised policymakers that a simple and low tax on carbon is a Magnum 44 for shooting climate change, they scoff at the danger, telling climate change "'Do you feel lucky, punk?". In reality, climate change is armed with a howitzer, and the policy Nordhaus recommends—letting the global temperature reach levels 4 degrees above pre-industrial levels—would unleash that howitzer well before we saw that temperature.

But what about the data to which Nordhaus fitted his inappropriate function? Don't the data points to which he fitted his function (see Figure 3) imply that 4 degrees isn't so dangerous? And also, where did Nordhaus get the data about the reduction in GDP *from temperature levels we haven't yet experienced*?

## The Data You Fit When You Don't Have Data

Nordhaus made his name with a no-holds-barred attack on the model that was the precursor to the 1972 Limits to Growth study (Meadows, Randers et al. 1972). In a paper subtitled "Measurement without Data" (Nordhaus 1973), he lambasted the model and the data to which it was fitted—or rather, in his opinion, *the absence of data*:

> The treatment of empirical relations in *World Dynamics* can be summarised as *measurement without data*. The model contains 43 variables connected by 22 non-linear (and several linear) relationships. *Not a single relationship or variable is drawn from actual data or empirical studies*. (Nordhaus 1973, p. 1157. Emphasis in original)

You would expect that, given this attack on the absence of data in models developed using a rival methodology—"system dynamics"—that Nordhaus would be scrupulous in fitting his model to real data.

You would be wrong.

Take another look at Nordhaus's damage function graph again—reproduced here as Figure 12 for convenience—this time focusing on the data points rather than the function. Notice firstly that there

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[10] Nordhaus notes that his formula "is designed to ensure that damages do not exceed 100% of output" (Nordhaus 2013, p. 11). The formula is $DamageFunction = \frac{Damage}{1+Damage}$. The temperature rise used for the 4-degree rise is actually 3.99999, since the tipping point function's value is not defined at 4-degrees (colloquially, it is "infinite" at that point).

is no way these can be regarded as “data” in the conventional meaning of that term, since there are only 4 input values (global mean temperature increases over pre-industrial levels of 1, 2.5, 3 and 4 degrees), and there are multiple and very different output points (estimates of the damage to global GDP at that level of warming) for every input—not the range of inputs and outputs one normally sees when a function is being fitted to the scatter diagram of relationship between two empirical data series. These are not data, they are estimates.

Secondly, these estimates are derived from a very limited number of studies: there are just 14 data points in total—one from each of 12 studies plus two from one study by Mendelsohn et al. (Mendelsohn, Schlesinger et al. 2000), plus a large range taken from the IPCC report. Any self-respecting scientist would baulk at fitting a function to such a limited range of observations.

Thirdly, these “data” points involve temperature levels that have not been experienced in human history—how then were they derived?

*Figure 12: Nordhaus's damage function and the "Data" to which it is fitted (Nordhaus and Sztorc 2013, p. 12)*

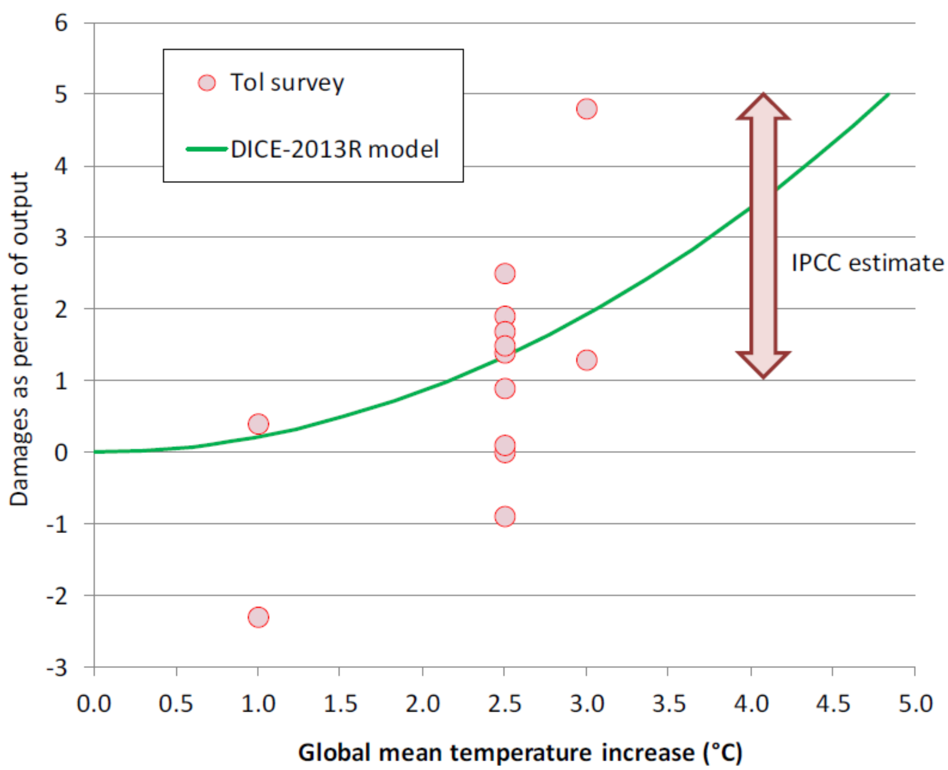


**Figure 2. Estimates of the Impact of Climate Change on the Global Economy**
This figure shows a compilation of studies of the aggregate impacts or damages of global warming for each level of temperature increase (dots are from Tol 2009). The solid line is the estimate from the DICE-2013R model. The arrow is from the IPCC (2007a). [impacts_survey.xlsx]

To know that, we have to turn to “the Tol (2009) survey” that Nordhaus notes was the source of these numbers: all Nordhaus himself did was increase the scale of damages by an arbitrary 25% to account for “non-monetized impacts” not considered by these studies:

> *DICE-2013R uses estimates of monetized damages from the Tol (2009) survey as the starting point*. However, current studies generally omit several important factors (the economic value of losses from biodiversity, ocean acidification, and political reactions), extreme events (sea-level rise, changes in ocean circulation, and accelerated climate change), impacts that are inherently difficult to model (catastrophic events and very long term warming), and uncertainty (of virtually all components from economic growth to damages). I have added an adjustment of 25 percent of the monetized damages to reflect these non-monetized impacts. (Nordhaus and Sztorc 2013, p. 11)

Tol conveniently lists the sources of all his data points in his Table 1—reproduced here as Figure 13.

*Figure 13: The studies surveyed in Tol 2009*

*Richard S. J. Tol* 31

*Table 1*

**Estimates of the Welfare Impact of Climate Change**

*(expressed as an equivalent income gain or loss in percent GDP)*

| | | | *Worst-off region* | | *Best-off region* | |
|---|---|---|---|---|---|---|
| *Study* | *Warming (°C)* | *Impact (% of GDP)* | *(% of GDP)* | *(Name)* | *(% of GDP)* | *(Name)* |
| Nordhaus (1994a) | 3.0 | −1.3 | | | | |
| Nordhaus (1994b) | 3.0 | −4.8 (−30.0 to 0.0) | | | | |
| Fankhauser (1995) | 2.5 | −1.4 | −4.7 | China | −0.7 | Eastern Europe and the former Soviet Union |
| Tol (1995) | 2.5 | −1.9 | −8.7 | Africa | −0.3 | Eastern Europe and the former Soviet Union |
| Nordhaus and Yang (1996)[a] | 2.5 | −1.7 | −2.1 | Developing countries | 0.9 | Former Soviet Union |
| Plambeck and Hope (1996)[a] | 2.5 | 2.5 (−0.5 to −11.4) | −8.6 (−0.6 to −39.5) | Asia (w/o China) | 0.0 (−0.2 to 1.5) | Eastern Europe and the former Soviet Union |
| Mendelsohn, Schlesinger, and Williams (2000)[a,b,c] | 2.5 | 0.0[b]<br>0.1[b] | −3.6[b]<br>−0.5[b] | Africa | 4.0[b]<br>1.7[b] | Eastern Europe and the former Soviet Union |
| Nordhaus and Boyer (2000) | 2.5 | −1.5 | −3.9 | Africa | 0.7 | Russia |
| Tol (2002) | 1.0 | 2.3 (1.0) | −4.1 (2.2) | Africa | 3.7 (2.2) | Western Europe |
| Maddison (2003)[a,d,e] | 2.5 | −0.1 | −14.6 | South America | 2.5 | Western Europe |
| Rehdanz and Maddison (2005)[a,c] | 1.0 | −0.4 | −23.5 | Sub-Saharan Africa | 12.9 | South Asia |
| Hope (2006)[a,f] | 2.5 | 0.9 (−0.2 to 2.7) | −2.6 (−0.4 to 10.0) | Asia (w/o China) | 0.3 (−2.5 to 0.5) | Eastern Europe and the former Soviet Union |
| Nordhaus (2006) | 2.5 | −0.9 (0.1) | | | | |

*Note:* Where available, estimates of the uncertainty are given in parentheses, either as standard deviations or as 95 percent confidence intervals.

[a] The global results were aggregated by the current author.

[b] The top estimate is for the "experimental" model, the bottom estimate for the "cross-sectional" model.

[c] Mendelsohn et al. only include market impacts.

[d] The national results were aggregated to regions by the current author for reasons of comparability.

[e] Maddison only considers market impacts on households.

[f] The numbers used by Hope (2006) are averages of previous estimates by Fankhauser and Tol; Stern et al. (2006) adopt the work of Hope (2006).

This table alone should be enough for you to realise that there is something very fishy about this so-called data. Firstly, five of the 13 studies cited are by Nordhaus himself! Perhaps he's a prolific experimentalist or field researcher as well as a modeller, but it is strange that almost half of the studies to which his damage function is fitted are studies by himself.

Tol is the source of two further estimates—one of which finds a *positive* impact from the 1-degree warming we have already experienced: he estimates that GDP today is 2.3% *higher* than it would have been in the absence of global warming. Another researcher (Maddison) turns up in two of the other studies.

Just three people are the sources of fully 9 of the 14 data points Nordhaus used. We are talking about an extremely limited and interconnected group here—and as Tol does acknowledge, the researchers are even more incestuous than this table implies:

> The studies can be roughly divided into two groups: Nordhaus and Mendelsohn are colleagues and collaborators at Yale University; at University College of London, Fankhauser, Maddison, and I all worked with David Pearce and one another, while Rehdanz was a student of Maddison and mine. (Tol 2009, p. 30)

Furthermore, Tol notes in footnote f to his Table 1 (see Figure 13) that "the numbers used by Hope (2006) are averages of previous estimates by Fankhauser and Tol" (Tol 2009, p. 31).

For good measure, Nicholas Stern—who, note, is not a source of any of these data points—is also caught up in this web of intellectual incest since "Stern et al (2006) adopt the work of Hope" (Tol 2009, p. 31, note f to Table 1). Thus, the numbers to which Stern fitted the damage function in his "Integrated Assessment Model" (the generic term used to describe the models of Nordhaus, Tol and Stern) are the same numbers to which Tol and Nordhaus also fitted the models.

This makes Tol's assessment (of even the larger number of researchers who did marginal cost estimates using these studies) as "a reasonably small and close-knit community who may be subject to group-think, peer pressure, and self-censoring" (Tol 2009, p. 43) something of an understatement. What superficially are 14 independent data points on estimates on Nordhaus's graph (see Figure 12) collapse to estimates from three slightly distinguished groups in the one clan: Nordhaus and co-authors Boyer and Yang, plus Mendelsohn and co-authors Schlesinger and Williams, plus Hope, who relies on estimates from Nordhaus and Fankhauser; Tol, Fankhauser, Maddison and Rehdanz, with Fankhauser being the overlap with Nordhaus's group; and Plambeck and Hope, with Hope being the overlap with Tol's group via using its "data".

Given the obvious potential for group-think that Tol himself acknowledges, one has to hope that the individual studies themselves are differentiated in nature, and robust.

Abandon hope once more: Tol classifies these studies into just three methodologies: interviews of experts; the "enumerative" approach; and the "statistical approach". Though all of these are suspect, by far the worst is the so-called "statistical approach".

When I first read Tol's description of the "statistical approach", I was speechless. Despite having made a career out of critiquing Neoclassical economics (Keen 2001; Keen 2011), and despite this exposing me to all manner of absurd assumptions used to reach desired outcomes, nothing had prepared me for how bad this methodology was. *It assumes that the impact of climate change on the economy over time can be assessed by measuring the impact on income of differences in temperature on different regions of a country today*. In Tol's words:

> Mendelsohn's work (Mendelsohn, Morrison, Schlesinger, and Andronova, 2000; Mendelsohn, Schlesinger, and Williams, 2000) can be called the statistical approach. *It is based on direct estimates of the welfare impacts, using observed variations (across space within a single country) in prices and expenditures to*

> *discern the effect of climate.* ***Mendelsohn assumes that the observed variation of economic activity with climate over space holds over time as well***; and uses climate models to estimate the future effect of climate change. (Tol 2009, p. 32)

This was so stupid, on so many levels, that I had to ask myself whether I was reading the work of scholars, or a speech by Donald Trump.

The most critical stupidity in this assumption is that it ignores the fundamental cause of Global Warming itself: the increase in the temperature of the entire biosphere, caused by additional greenhouse gases retaining energy that would otherwise be harmlessly radiated into outer space.

A region of one country—say, Baltimore in the USA, with an average maximum temperature of 18 degrees—differs in temperature from another—say Boston, average maximum temperature 15 degrees—because of variations in geography (Boston is about 600km northeast of Baltimore).[11] A comparison of income and temperature today in Boston to income and temperature today in Baltimore involves *no* variation in the energy retained by the biosphere thanks to global warming, and therefore no variation in global temperature itself. The comparison of relative welfare due to 2.5 degree temperature variations between different parts of one country at one point in time therefore tells you *absolutely nothing* about the impact of raising the temperature of the entire atmosphere by another 1.5 degrees over the amount we have already increased it.

If we are to compare Boston today with a future Boston in which temperature levels are globally 1.5 degrees higher than today (2.5 degrees higher than pre-industrial times, the temperature variation considered by Mendelsohn), then we have to take into account a stupendous increase in the amount of energy in the atmosphere.

It takes just over a kilojoule of energy (1,000 joules) to raise the temperature of a kilogram of air by one degree.[12] The mass of the atmosphere is estimated at 513,000,000,000,000,000,000 kilograms. To increase the average temperature of the atmosphere by another 1.5 degrees requires $7.7 \times 10^{14}$ gigajoules of energy. To put that in context, that is equivalent to exploding *12 billion* Hiroshima-size atomic bombs (the bomb dropped on Hiroshima unleashed a force equivalent to exploding 20,000 tons of TNT). That is roughly 2 atomic bombs for every person alive today—or setting off 40,000 tons of TNT per person.

When you factor in that the atmosphere absorbs only 3% of the increased energy retained by additional greenhouse gases (the ocean takes 90% and land mass the remaining 7%), the amount of additional energy needed to emulate the impact of raising global temperatures by another 1.5 degrees via increased $CO_2$ is closer to 60 atomic bombs per person—or exploding about 1 million tons of TNT per person alive today.

This detail is entirely missed by Mendelsohn. His study simply asks if the world's population would be happier if the temperature of the place where they live rose by 2.5 degrees, *with no increase in the energy level of the atmosphere*. That, in itself, is an impossible question: the temperature of the atmosphere can only rise if more energy is injected into it, or retained by it. It is also an irrelevant question to the impact of global warming.

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[11] I'm using US examples partly because that was the basis for Mendelsohn's numbers: "the climate-response functions in this paper have been calibrated only for the United States" (Mendelsohn et al. 2000, p. 38).

[12] The definition of a Joule is the amount of energy needed to increase the temperature of a gram of water by one degree. It takes slightly more energy to heat a gram of the atmosphere: 1.004 Joules.

Mendelsohn's musings also ignore the extent to which regions of the world are dependent on each other today. Temperature on Earth ranges from a low of around minus 90 degrees in the Antarctic to 70 degrees in Iran. People live in almost all of those habitats because of the relationships those regions have with the rest of the planet: food can't be grown in Antarctica, but it is imported by research groups there so that they can survive. When you compare temperature and welfare in one location to temperature and welfare in another, you are assuming that the temperatures of locations on the rest of the planet don't change.

But when you consider global warming of 2.5 degrees, even if you assume that the temperature increase is evenly distributed, places that are colder than minus 87.5 degrees will no longer exist, while places that are 72.5 degrees will come into existence, and everywhere else will be 2.5 degrees warmer. All this is ignored by assuming "that the observed variation of economic activity with climate over space holds over time as well".

Not amazingly, Mendelsohn concluded that global GDP would actually rise from a 2.5 degree increase in temperature over pre-industrial levels, by $145 billion in US 2009 dollar terms—see Figure 14.

*Figure 14: Mendeksohn shows net benefits from a 2.5 degrees warming over pre-industrial levels,* ***assuming no increase in global temperature***

*R. Mendelsohn et al. / Comparing impacts across climate models*

Table 3
Aggregate impacts in 2100 by GCM model Cross-sectional responses (billions of 1990 $/year).

| GCM | Continent[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Total | Africa | Asia | LatAm | WEur | Comm | NAm | Ocean |
| BMRC | 150 | −10 | 32 | −3 | 2 | 100 | 29 | −1 |
| CCC | 152 | −18 | 31 | −6 | 5 | 108 | 33 | −2 |
| GF30 | 185 | −5 | 35 | 3 | 6 | 106 | 41 | −2 |
| GFDL | 184 | −9 | 31 | 2 | 5 | 114 | 42 | −1 |
| GFQF | 165 | −12 | 35 | 0 | 6 | 98 | 41 | −3 |
| GISS | 131 | −15 | 17 | −7 | 7 | 94 | 38 | −2 |
| HEND | 97 | −28 | 8 | −10 | 5 | 95 | 32 | −4 |
| OSU | 116 | −15 | 0 | −3 | 6 | 93 | 37 | −1 |
| POLS | 173 | −16 | 39 | −7 | 6 | 101 | 53 | −4 |
| POLD | 175 | −10 | 21 | −2 | 8 | 112 | 48 | −2 |
| UIUC | 98 | −31 | −1 | −14 | 5 | 99 | 42 | −2 |
| UKMO | 136 | −21 | 16 | −5 | 6 | 104 | 39 | −3 |
| WANG | 119 | −22 | 1 | −9 | 7 | 102 | 43 | −3 |
| WASH | 143 | −13 | 22 | −2 | 5 | 96 | 38 | −3 |
| **AVERAGE** | **145** | **−16** | **21** | **−5** | **6** | **102** | **40** | **−2** |

[a] The continents above are Africa, Asia, Latin America, Western Europe, the former Soviet Union and Eastern bloc, North America, and Oceania.

He finally reached a conclusion that 2.5 degree of warming would have simply *increased* global GDP by 0.1% in 2100—compared to what GDP would be with no global warming—by weighting his regional effects by population. More people live in regions where GDP would fall (Africa [minus 16 billion US dollars in 1990 prices] and Latin America [-5]) than where it would rise (primarily the ex-Soviet Union states, abbreviated as "Comm[unist]" in his Table 3 [+102] and Northern America [++40]), but the rise in GDP in the countries that gain ($21 billion for Asia, $6 billion for Europe, $102 billion for the former Soviet bloc, and $40 billion for North America) was far larger than the fall for continents (Africa minus $16 billion, Latin America minus $5 billion, and Oceania minus $2 billion).

Given that this is an estimate of what global GDP will be in 2100, over 80 years from now, this is effectively arguing that global warming has zero impact upon the economy.

"Zero" is also the weight that should be applied to Mendelsohn's data point. This study about the relationship between temperature and income today in the absence of global warming tells us absolutely nothing about what the impact of global warming will be.

The same weight can be applied to the data points from Nordhaus (2006) and Maddison (2003) as well, since as Tol notes, they both use the same approach as Mendelsohn:

> Studies by Nordhaus (2006) and Maddison (2003) use versions of the statistical approach as well… assuming that "climate" is reflected in incomes and expenditures—and that the spatial pattern holds over time. (Tol 2009, p. 32)

So three of the estimates of the damages from climate change that Nordhaus uses to justify his quadratic damage function should simply be thrown out: Mendelsohn's 0.1% rise, Nordhaus's 0.9% fall, and Maddison's 0.1% fall.

That leaves 11 other data points—one of which, of zero impact on GDP, was also provided by Mendelsohn using what he calls "Experimental approach":

> The Experimental approach constructs process-based simulation models from carefully conducted scientific experiments. Using laboratory-controlled settings, experiments are run on crops, trees, and other subjects to determine their sensitivity to temperature, precipitation, and carbon dioxide. Simulation models are constructed from the experimental evidence to predict what will happen in the aggregate. (Mendelsohn, Schlesinger et al. 2000, p. 38)

Tol describes the same procedure as the "enumerative method" (Tol 2009, p. 31), and notes that four other data points in his paper use the same approach: Fankhauser (1.4% fall in global GDP from a 2.5 degree rise in temperature; Nordhaus 1994a (1.3% fall for a 3 degree rise); Toll 1995 (1.9% fall for a 2.5 degree rise) and Toll 2002 (2.3% ***rise*** in GDP for a 1 degree rise in temperature):

> Fankhauser (1994, 1995), Nordhaus (1994a), and me (Tol, 1995, 2002a, b) use the enumerative method. In this approach, estimates of the "physical effects" of climate change are obtained one by one from natural science papers, which in turn may be based on some combination of climate models, impact models, and laboratory experiments. The physical impacts must then each be given a price and added up. For agricultural products, an example of a traded good or service, agronomy papers are used to predict the effect of climate on crop yield, and then market prices or economic models are used to value the change in output. (Tol 2009, pp. 31-32)

At first glance, this approach appears scientific: with respect to the impact of global warming on agriculture, it takes data from scientific experiments on the impact of changes in "temperature, precipitation, and carbon dioxide" on different crops, and then works out the monetary value of those impacts. However, there is one fundamental failing that Tol himself acknowledges: it only measures the direct effects of climate change, ignoring the feedback effects. But it is precisely the feedback effects that determine the overall impact of climate change.

For example, using the Canadian Climate Centre model, Mendelsohn estimates that a doubling of $CO_2$ levels will cause an increase in temperature of 3.5 degrees and a 4% increase in precipitation levels (row three in Figure 15).

*Figure 15: Mendelsohn's experimental approach data sources and estimates (Mendelsohn, Schlesinger et al. 2000, p. 40)*

*R. Mendelsohn et al. / Comparing impacts across climate models*

Table 1
GCM model simulations: global annual averages for doubling the pre-industrial carbon dioxide concentration.

| Acronym | Institution | $\Delta T$ (°C) | $\Delta P$ (%) | Reference |
|---|---|---|---|---|
| BMRC | Bureau of Meteorology Research Center | 2.11 | 2.38 | [10] |
| CCC | Canadian Climate Centre | 3.50 | 4.00 | [2,3,17] |
| GF30 | Geophysical Fluid Dynamics Laboratory (R30 run) | 4.00 | 8.3 | [35,36] |
| GFDL | Geophysical Fluid Dynamics Laboratory (first run) | 4.00 | 8.3 | [35,36] |
| GFQF | Geophysical Fluid Dynamics Laboratory (Q-flux run) | 4.00 | 8.30 | [35,36] |
| GISS | Goddard Institute for Space Studies | 4.20 | 11.00 | [7–9] |
| HEND | Henderson-Sellers using CCM1 at NCAR | 2.50 | 5.60 | [11] |
| OSU | Schlesinger and Zhao at Oregon State University | 2.40 | 7.80 | [26] |
| POLD | Pollard and Thompson-GENESIS with dynamic sea-ice | 2.27 | 3.13 | [31] |
| POLS | Pollard and Thompson-GENESIS with static sea-ice | 2.27 | 3.13 | [31] |
| UIUC | Schlesinger at University of Illinois at Urbana-Champaign | 3.37 | 5.53 | [28] |
| UKMO | United Kingdom Meteorological Office | 5.20 | 15.00 | [38] |
| WANG | Wang et al. at State University of New York at Albany and NCAR[a] | 3.90 | 6.90 | [33] |
| WASH | Washington and Meehl using CCM1 at NCAR | 4.82 | 4.75 | [34] |

[a] NCAR is the National Center for Atmospheric Research.

This information is combined with experimental predictions about what will happen to agricultural output given these changes: if CO2 levels double, temperature rises by 3.5 degrees, and rainfall rises by 4%. Not surprisingly, for much of the world, the results are positive: colder, drier regions get more warmth and rainfall. When these effects are applied to different regions based on their current growing conditions, overall output rises: see Figure 16, which shows Mendelsohn's results for the impact of a 2.5 degree increase in GDP using his "experimental approach": they imply a $55 billion increase in GDP from a doubling of $CO_2$ levels (and the consequential increases in temperature and precipitation):

*Figure 16: Mendelsohn's experimental approach results (Mendelsohn, Schlesinger et al. 2000, p. 40)*

Table 2
Aggregate impacts in 2100 by GCM model experimental responses (billions of 1990 $/year).

| GCM | Continent[a] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Total | Africa | Asia | LatAm | WEur | Comm | NAm | Ocean |
| BMRC 54 | −112 | −31 | −67 | 1 | 224 | 48 | −9 | |
| CCC | 28 | −139 | −52 | −87 | 9 | 250 | 62 | −13 |
| GF30 | 210 | −79 | −9 | −30 | 14 | 245 | 83 | −16 |
| GFDL | 203 | −100 | −8 | −37 | 12 | 267 | 81 | −12 |
| GFQF | 134 | −113 | −1 | −49 | 13 | 224 | 78 | −17 |
| GISS | 45 | −103 | −86 | −59 | 15 | 217 | 73 | −13 |
| HEND | −69 | −163 | −103 | −73 | 9 | 216 | 66 | −21 |
| OSU | −33 | −111 | −157 | −45 | 13 | 209 | 68 | −10 |
| POLS | 147 | −134 | 40 | −92 | 10 | 230 | 114 | −22 |
| POLD | 163 | −103 | −77 | −44 | 20 | 270 | 112 | −14 |
| UIUC | −139 | −186 | −161 | −97 | 10 | 223 | 85 | −12 |
| UKMO | 27 | −139 | −97 | −62 | 14 | 245 | 82 | −17 |
| WANG | −29 | −143 | −145 | −72 | 18 | 239 | 90 | −17 |
| WASH | 25 | −123 | −90 | −55 | 12 | 219 | 79 | −18 |
| **AVERAGE** | **55** | **−125** | **−70** | **−62** | **12** | **234** | **80** | **−15** |

[a] The continents above are Africa, Asia, Latin America, Western Europe, the former Soviet Union and Eastern bloc, North America, and Oceania.

However, if temperature did rise by 3.5 degrees, the land on which agriculture occurs will change (even if we ignore the tipping point issue). Effects that are not reproduced in laboratories will occur in the real world—for example, locust populations may explode, undermining production; bees might

## 3. Edits and cites from Nordhaus and Others

in Measurement without Data

> “The current version assumes that damages are a quadratic function of temperature change and does not include sharp thresholds or tipping points, but this is consistent with the survey by Lenton et al. (2008).”

Nordhaus gives the following overview of DICE:

> The DICE model views the economics of climate change from the perspective of neoclassical economic growth theory (see particularly Solow 1970). In this approach, economies make investments in capital, education, and technologies, thereby reducing consumption today, in order to increase consumption in the future. The DICE model extends this approach by including the “natural capital” of the climate system. In other words, it views concentrations of GHGs as negative natural capital, and emissions reductions as investments that raise the