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VALUING CLIMATE CHANGE CATASTROPHES[‡]

Shutting Down the Thermohaline Circulation[†]

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Past climatic changes in the Earth's history have been associated with a shutdown or slowdown of the thermohaline circulation as vast amounts of freshwater were introduced into the Atlantic Ocean (Bond et al. 1997). We use data on future climate from hosing experiments with three climate models with and without a slowdown of the thermohaline circulation. These experiments show that the expected cooling in Western Europe due to a slowdown of the thermohaline circulation is less in magnitude than the expected warming due to increasing greenhouse gas concentrations. As ocean currents redistribute rather than create heat, a slowdown of the thermohaline circulation would also lead to slightly accelerated warming elsewhere. The integrated assessment model FUND and a meta-analysis of climate impacts are used to evaluate the change in human welfare associated with a slowdown of the thermohaline circulation. We find modest, but by and large, positive effects on human welfare. Compared to earlier papers (Link and Tol 2011, 2004), we use more realistic climate scenarios and more detailed and up-to-date impact estimates.

I. The Thermohaline Circulation

The Thermohaline Circulation (THC) is a vast system of currents across all four oceans, with deep water formation off the Antarctic Peninsula and Greenland and upwelling in the northern parts of the Pacific and Indian Ocean. The Gulf Stream and North Atlantic Current, part of the THC, transport water from the tropics north and east—keeping Europe warm—where evaporation increases salinity and density so that the water sinks. This mechanism can be disrupted, and it has been in the past, most recently by meltwater of the Laurentide Ice Sheet (Barber et al. 1999). Melting of the Greenland Ice Sheet and an increase in rainfall over the North Atlantic due to the increase in the atmospheric concentrations of greenhouse gases could have a similar effect (Broecker 1997).

Early papers suggested that the THC was rather fragile to anthropogenic climate change (Rahmstorf 1995), but later research finds a more robust THC. For instance, a model intercomparison finds a reduction in THC strength of 18 to 25 percent for moderate climate change, and 36 to 44 percent for more pronounced warming (Weaver et al. 2012). One expert elicitation finds that the chance that the THC weakens by 50 percent or more by 2100 is 0 to 40 percent, with an average across experts of 22 percent (Zickfeld et al. 2007). Another expert elicitation puts the probability of a halving of the THC by 2100 at 4 to 74 percent, with an average of 24 percent

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(Arnell, Tompkins, and Adger 2005). In a Bayesian study, the THC is expected to weaken by 17 percent between 2000 and 2100, with a 10 percent probability of a total collapse (Urban and Keller 2010). We do not contribute to that debate. Indeed, we do not even assign a probability to a THC shutdown or explore the implications for climate policy. Instead, we focus on the impacts of a THC shutdown. In order to do so, we use the results of so-called hosing experiments with three General Circulation Models. In this set-up, the THC shutdown is not caused by internally consistent physical processes in the model. Instead, additional fresh water is added to the North Atlantic, like a Death Star suddenly appearing in the sky and hosing down water.

Figure 1 shows the effect on temperature at the country level. As is common, we use the change in the average annual temperature as an indicator of the severity of climate change. Three of the models consider a freshwater input of 0.1 Sv[1] near Greenland, not inconsistent with the amount of meltwater that could be expected from that ice-sheet (Vizcaíno et al. 2010). This implies a slowdown of the THC of 27 ± 14 percent (Swingedouw et al. 2013), and a cooling of less than 1°C for most countries. The impacts are more pronounced if the THC slows down by two-thirds, as it is in the fourth scenario (Vellinga and Wood 2008), but cooling is still less than 2°C in most countries; some countries see a small warming. Note that the models agree on the sign of the temperature change for only 70 out of 155 countries.

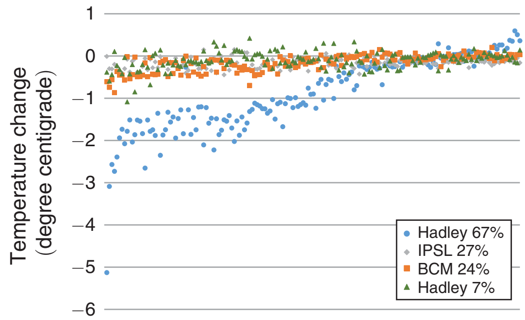

FIGURE 1. TEMPERATURE CHANGE BY COUNTRY IF THE THERMOHALINE CIRCULATION SHUTS DOWN

Notes: Each mark represents a scenario-country pair. Results are ranked, from low to high, on the average over the four scenarios. Results are for hosing experiments from three climate models. Temperature anomalies represent the difference between a scenario with greenhouse warming and a scenario with greenhouse warming and the effects of changes in the thermohaline circulation. Results were aggregated from the grid to the country using area-weights by the current authors. The temperature change is the difference in the annual mean surface air temperature, averaged over the last 30 years of the model run. The percentages in the legend refer to the extent of the slowdown of the thermohaline circulation.

II. Impacts of Climate Change

A. *Meta-Analysis*

Tol (2015) surveys the literature on the total welfare impacts of climate change. He finds that a piecewise linear function best describes the relationship between global impacts and climate change. The impacts are static, that is, the change in equilibrium welfare due to a change in the equilibrium climate. We here use the same function for national impacts imputed from regional and global impact estimates reported in the literature. See online Appendix A.

B. *FUND*

The Climate Framework for Uncertainty, Negotiation and Distribution (FUND) is an integrated assessment model. We here only use it to estimate the impacts of climate change. FUND's impact module differs in three ways from other integrated assessment models and indeed the meta-analysis above. First, FUND has separate representations of all major impacts. This allows for richer dynamics and more realistic nonlinearities. Second, impacts do not just depend on climate change, but also on sea level rise and the atmospheric concentration of carbon dioxide. This mutes the effect of a THC slowdown. Third, in FUND, vulnerability to climate change changes with development. We use the impact module of FUND version 4.0; see online Appendix B. The impacts in FUND, and indeed other integrated assessment models, are level effects on welfare, assuming both smooth economic development and climate change (Tol 2009).

Dell, Jones, and Olken (2014) discuss the effects of weather on economic activity. Fankhauser and Tol (2005) study the effects of climate change on economic growth. Estrada

[1] A Sverdrup (Sv) is a million cubic meters per second.

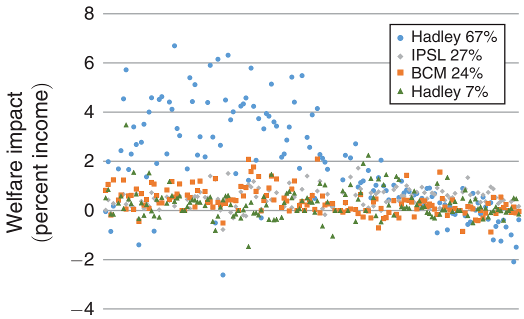

Figure 2. The Impact of a Thermohaline Circulation Shutdown by Country According to the Meta-analytic Function

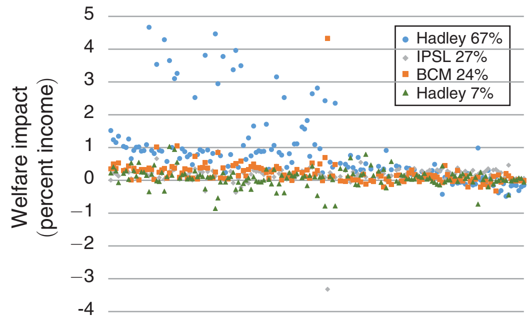

Figure 3. The Impact of a Thermohaline Circulation Shutdown by Country According to FUND

and Tol (2015) model the economic effects of climate change and year-to-year weather variability.

III. Results

A. *Meta-Analysis*

The meta-analysis assumes a piecewise linear impact function, by far the best fit for the global data (Tol 2015). The impact of warming (or cooling) depends on whether it pushes a country toward or away from its climate optimum. The combined effect of greenhouse warming and THC cooling further depends on the relative size of the two effects.

Figure 2 shows the effects on all countries. Global warming is assumed to be 3.2°C, with greater warming closer to the poles and further inland. The THC slowdown in Figure 1 is for the year 2085. As the cooling is small relative to the assumed warming, and as 3.2°C of global warming would push most countries beyond their climate optimum, THC cooling is best seen as reduced warming. The effects on welfare are therefore by and large positive.

This is confirmed by Table 1, which shows the global aggregate impacts. If the THC slows down a little, the global impact is a positive 0.2–0.3 percent of income. This goes up to 1.3 percent for a more pronounced slowdown.

B. *FUND*

Figure 3 shows the results according to FUND. The THC slowdown scenario is phased in linearly between 2050 and 2085; see Figure 1. The results in Figure 3 are averages for 2085–2090. Although FUND is far more complicated than the meta-analytic function, the mechanisms are the same. The impact depends on whether a THC slowdown leads to reduced warming or absolute cooling, on the shape of the impact function, and on the position on that function when the THC slows down.

The FUND results in Figure 3 are qualitatively similar to the meta-analytic results in Figure 2. The background warming is 3.2°C. A THC slowdown decelerates warming at a point in time when additional warming is mostly harmful. A THC slowdown thus brings welfare gains. The FUND results tend to be smaller. This is, first, because the impacts in FUND are driven not just by climate change but also by the atmospheric concentration of carbon dioxide and the level of the sea, which are hardly affected by a THC slowdown. Furthermore, in FUND, people are assumed to be richer in 2085 than they are now and therefore, by and large, less vulnerable to climate change.

Table 1 shows the global impacts, which range between 0.1 and 0.2 percent of income for a modest THC slowdown but may go up to 0.8 percent for a more pronounced slowdown.

IV. Discussion and Conclusion

We show four scenarios of a slowdown of the thermohaline circulation, and find that it modestly decelerates warming. We estimate the impact using two alternative models, and find that reduced warming means a small gain in welfare.

Table 1—Global Impact of a Thermohaline Circulation Shutdown

	Hadley 67%	IPSL 27%	BCM 24%	Hadley 7%
Meta-analysis	1.29	0.32	0.20	0.16
FUND	0.84	0.19	0.17	0.05

Note: Impacts are welfare-equivalent income gains, measured as a percentage of global income in 2085.

Source: Authors' calculations

The qualitative results are intuitive and probably robust. The quantitative results are of course no stronger than the underlying models. Other models should run the same scenarios, but as they have a similar structure, we would expect similar results. Only very nonlinear impact functions would drastically change our findings. More importantly, the models should be improved. Impacts as modeled are largely driven by the level of climate change rather than by its rate. Ocean acidification, for instance, would continue apace if the thermohaline circulation slows down. A change in ocean currents may well affect the upwelling of nutrients from the bottom of the ocean. It would bring about a shift in the patterns of wind and rain. Integrated assessment models often assume that other climate variables scale with temperature, but the relationship may be different for greenhouse warming and THC cooling. There may be enhanced drought in Europe, Central America, and Southeast Asia (Stouffer et al. 2006), and more frequent and intense winter storms in Europe (Jackson et al. 2015). The pattern of sea-level rise may also be affected by changes in the thermohaline circulation. Adaptation to climate change, as modeled, ignores the heightened uncertainty that a thermohaline circulation slowdown would bring. Therefore, although the results presented here are small but benign, these findings may be overturned by future research.

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