Virtual Seminar on Climate Economics

Federal Reserve Bank of San Francisco

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Economic impacts of tipping points in the climate system

Simon Dietz[1,2], James Rising[3], Thomas Stoerk[1], Gernot Wagner[4]

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This work represents only the views of the authors.

Climate tipping points are one of the principal reasons for concern about climate change

According to IPCC, there are five “reasons for concern” about climate change:

- Impacts on unique and threatened systems
- Extreme weather events
- Distribution of impacts (i.e. impacts on the poor)
- Global aggregate impacts
- **Large-scale singular events (a.k.a. climate tipping points)**

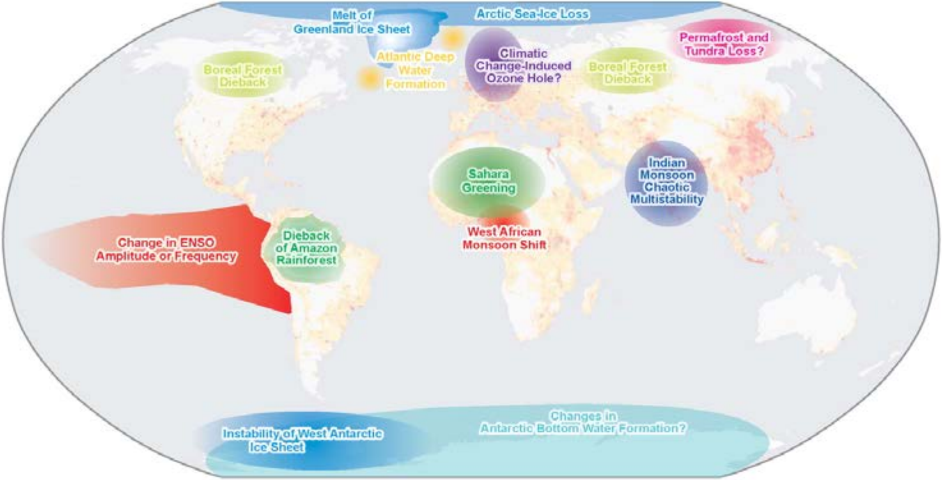
What are tipping points in the climate system?

Plenty of scholarship on this in geoscience (e.g. Lenton et al., 2008; Lenton, 2013; Kopp et al., 2016)

Best-known definition: "subsystems of the Earth system that are at least subcontinental in scale and can be switched – under certain circumstances – into a qualitatively different state by small perturbations." (Lenton et al., 2008)

Broad class encompassing a variety of geophysical responses, including non-linear feedbacks and both reversible and irreversible phase changes (key point: not limited to abrupt, discontinuous changes)

What are tipping points in the climate system?



Source: Lenton et al. (2008)

Climate tipping points in economics

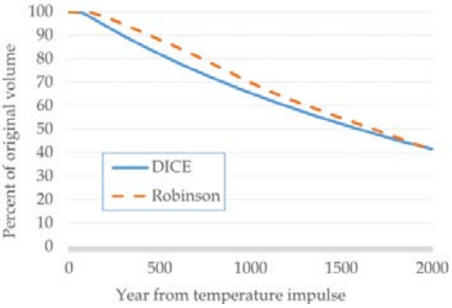
We undertook a systematic literature review at the outset of this study. We found that:

- Most studies either ignore climate tipping points or have very indirect/partial coverage
- We found 52 papers that explicitly model the economic consequences of at least one climate tipping point
- Most of these studies represent climate tipping points in a highly stylised way that is nearly impossible to calibrate
- But we identified 21 studies that are based on geophysical foundations, i.e. with at least a reduced-form representation of the key underlying geophysical relationship(s) that govern the tipping point

What do you mean by geophysical foundations?

In "Economics of the disintegration of the Greenland ice sheet" (PNAS, 2019), Nordhaus builds a reduced-form model of melting of the Greenland ice sheet in response to global warming.

This model can be meaningfully calibrated on results from ice sheet modelling...



...and then coupled to DICE.

So what's the problem?

The studies with geophysical foundations are fragmented – each takes an individual tipping point and employs a particular IAM with its idiosyncratic structure

Consequently no unified estimates exist – with geophysical foundations – of the economic impacts of climate tipping points

Because of this, tipping points are largely excluded from key economic studies/policy processes (e.g. the Stern Review; the US federal Social Cost of Carbon)

Our aim

We try to produce unified estimates of the economic impacts of climate tipping points, synthesising studies that are geophysically realistic

Basic methods of literature synthesis/meta-analysis don't work:

- Different IAMs, different boundary conditions, different parameterisations (e.g. different discount rates), inconsistent welfare metrics
- Possible interaction effects between tipping points

Our approach

So we build a 'meta-analytic' IAM (called 'META' - Model for Economic Tipping point Analysis):

- Modular structure (c.f. 2017 US National Academies report on "Valuing Climate Damages")
- Each study in the literature that models a tipping point is replicated – the replica is a module in the IAM
- An IAM in its own right
  - FAIR climate model (designed to emulate complex earth system models of CMIP)
  - National-level resolution based on empirical temperature damage functions (Burke et al. 2015 *Nature*)
  - Sea-level rise-damages based on high-resolution CIAM model (Diaz 2016 *Climatic Change*)

Preview of main results

Eight climate tipping points collectively increase the social cost of carbon (SCC) by $\sim$25% in our main specification.

Tipping points increase global economic risk. We estimate a $\sim$10% chance of tipping points more than doubling the SCC. We also show that tipping points increase the variance of global mean consumption/capita.

A spatial analysis shows that tipping points increase economic losses almost everywhere. They do not meaningfully alter the heterogeneous effects of climate change across countries.

The tipping points with the largest effects are dissociation of ocean methane hydrates and thawing permafrost.

Given missing tipping points, missing damage processes etc., most of our numbers should be seen as probable underestimates, but hopefully a step forward.

Tipping models replicated and synthesised

Tipping point	Papers	IAM	Model of TP
1) Permafrost carbon feedback (PCF)	Kessler (2017, *Clim. Chge. Econ.*) Hope & Schaefer (2016, *Nat. Clim. Chge.*) Yumashev et al. (2019, *Nat. Comms.*)	DICE PAGE09 PAGE-ICE	Process-based Process-based Process-based
2) Ocean methane hydrates (OMH)	Ceronsky et al. (2011, unpublished) Whiteman et al. (2013, *Nature*)	FUND PAGE09	Tipping event Tipping event
3) Arctic Sea Ice/Surface Albedo Feedback (SAF)	Yumashev et al. (2019, *Nat. Comms.*)	PAGE-ICE	Process-based
4) Amazon dieback	Cai et al. (2016, *Nat. Clim. Chge.*)	DSICE	Tipping event
5) GIS disintegration	Nordhaus (2019, *PNAS*)	DICE	Process-based
6) WAIS disintegration	Diaz and Keller (2016, *AER P&P*)	DICE	Tipping event
7) AMOC slowdown	Anthoff et al. (2016, *AER P&P*)	FUND	Tipping event
8) India summer monsoon (ISM) variability	Belaia (2017, unpublished), based on Schewe and Levermann (2012, *ERL*)	RICE	Process-based

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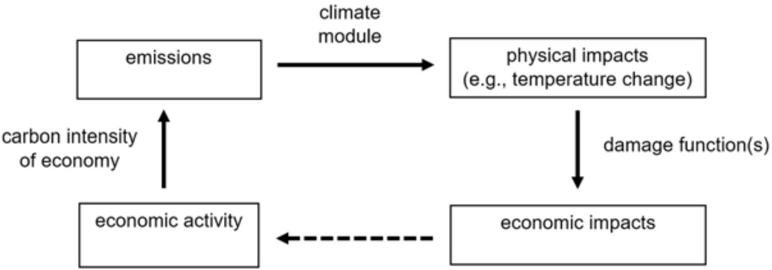
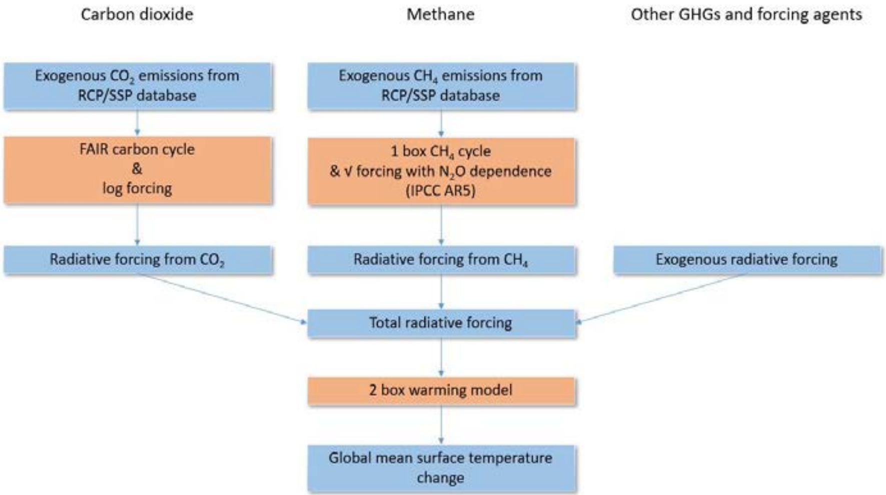
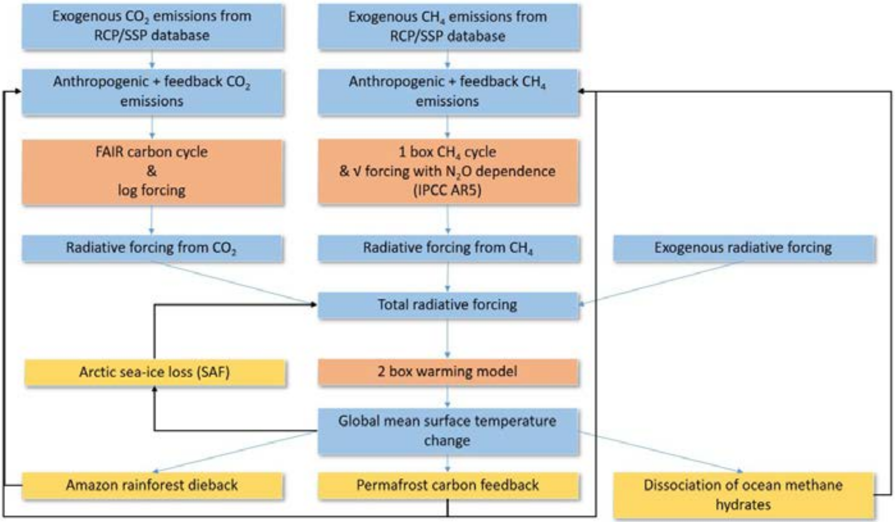
The essence of a climate-economy IAM



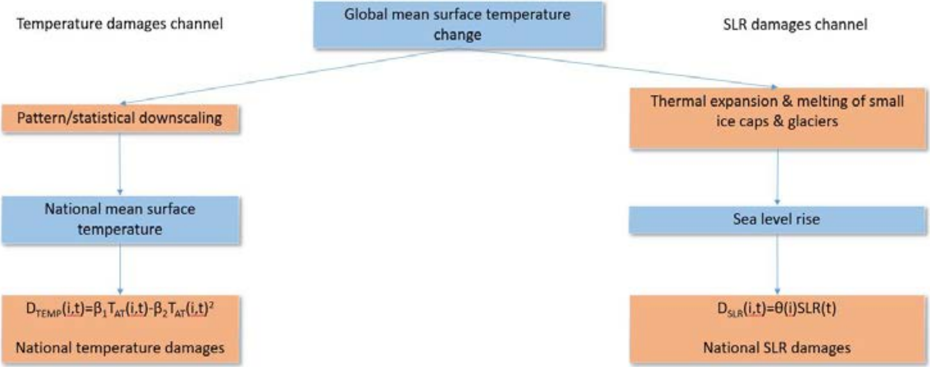
Climate model



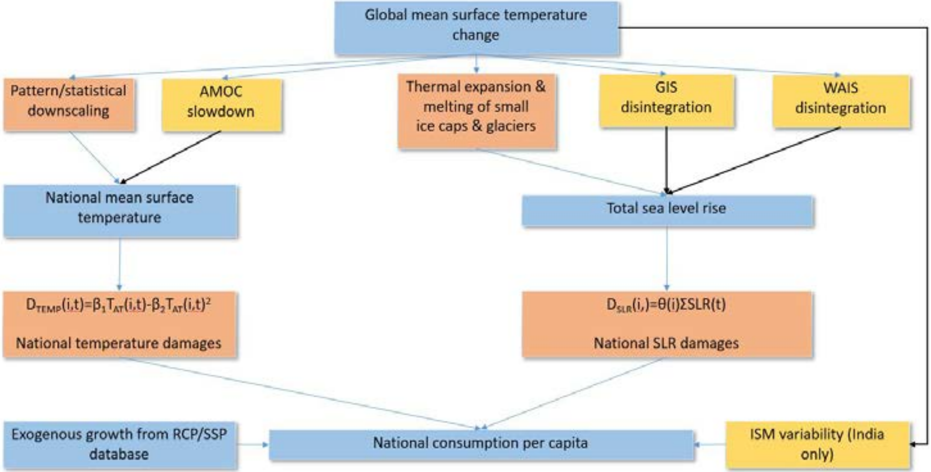
Climate model including tipping points



Separate, national-level temperature and SLR damages



Temperature and SLR damages including tipping points



n.b. option to add non-market damages module from MERGE

Dealing with uncertainty

We model uncertainty in four ways:

1. Some tipping points are modelled using survival analysis, so occur with a hazard rate
2. Many other parameters are probabilistic (e.g. temperature damage function 'betas') and drive uncertainty in our main specification
3. Some parameters are deterministic/fixed (e.g. discount rate) but varied in sensitivity analysis
4. Scenario uncertainties (e.g. emissions) are included in sensitivity analysis

Effect of TPs on the social cost of carbon

TP	Expected SCC (USD/tCO_2)	% increase due to TP
None	52.03	-
PCF	56.41	8.4
OMH	58.85	13.1
SAF	51.14	-1.7
Amazon	52.07	0.1
GIS	52.97	1.8
WAIS	53.57	2.9
AMOC	51.28	-1.4
ISM	52.70	1.3
All TPs	64.80	24.5

Notes on specification: RCP4.5/SSP2; Hope & Schaefer PCF; Whiteman et al. beta OMH; IPSL AMOC hosing, PRTP=1%, $\varphi = 0.5$

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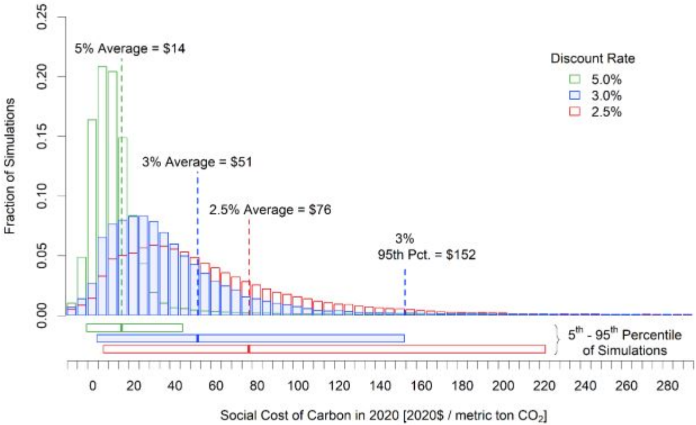
ISM	52.70	1.3
All TPs	64.80	24.5
$\sum$ Individual TPs	-	24.5

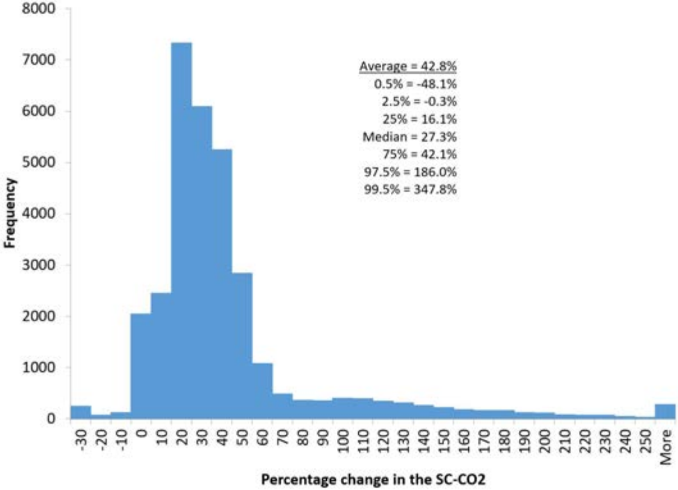
Notes on specification: RCP4.5/SSP2; Hope & Schaefer PCF; Whiteman et al. beta OMH; IPSL AMOC hosing, PRTP=1%, $\varphi = 0.5$

Recall the spread in no-TP SCC estimates



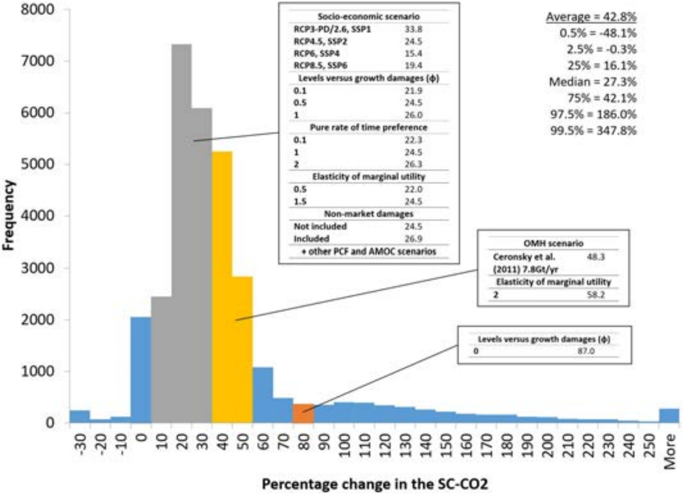
Source: Interagency Working Group, 2021

Sensitivity analysis



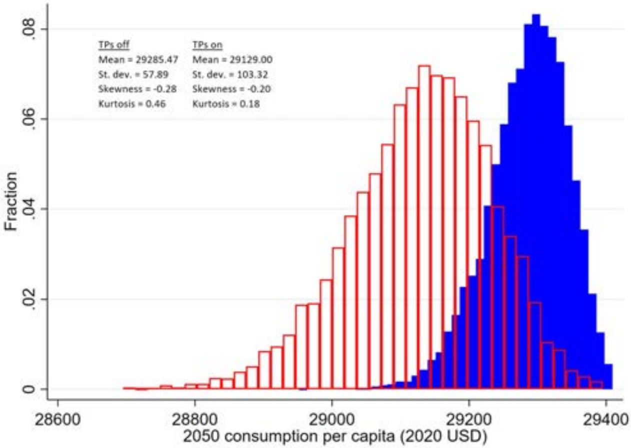
Note: Pooled sample of 32,000 Monte Carlo draws from fractional factorial design

Sensitivity analysis



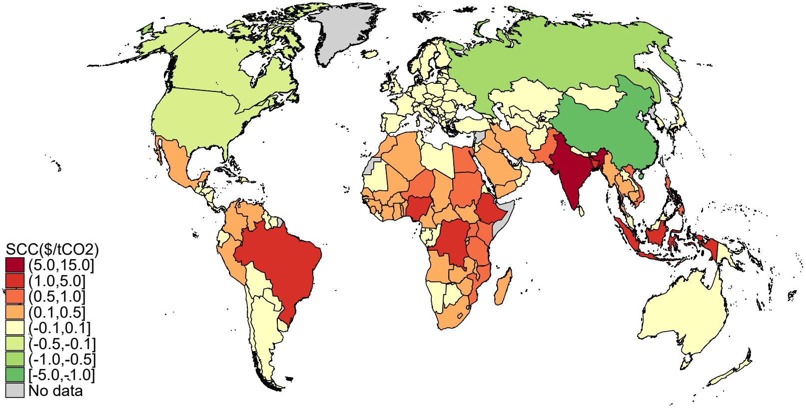
Note: Pooled sample of 32,000 Monte Carlo draws from fractional factorial design

Effect of TPs on global consumption risk in 2050



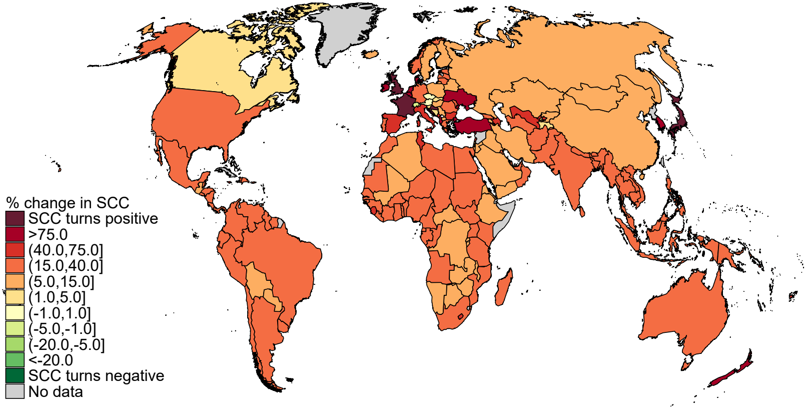
Notes on specification: Blue: without TPs. Red: with TPs. RCP4.5/SSP2; Hope & Schaefer PCF; Whiteman et al. beta OMH; IPSL AMOC hosing, $\varphi = 0.5$. Values reported are in 2020 US$.

Spatial distribution of the SCC *without* TPs



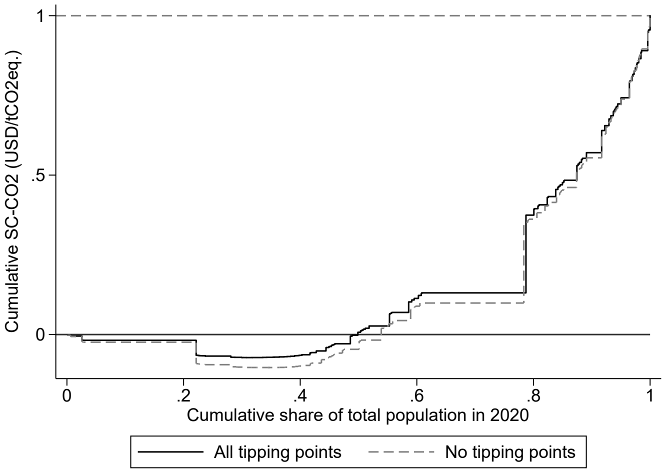
Notes on specification: RCP4.5/SSP2; Hope & Schaefer PCF; Whiteman et al. beta OMH; IPSL AMOC hosing, PRTP=1%, $\varphi = 0.5$

Effect of TPs on country-level SCC

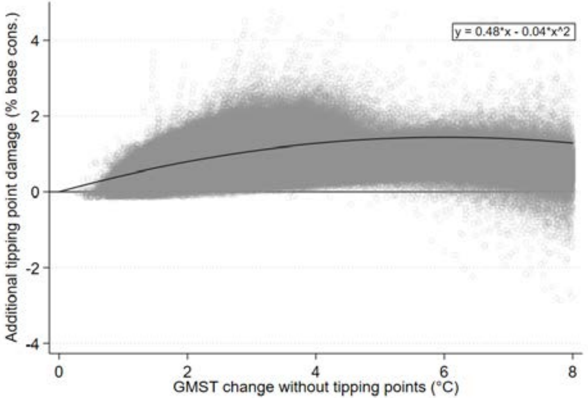


Notes on specification: RCP4.5/SSP2; Hope & Schaefer PCF; Whiteman et al. beta OMH; IPSL AMOC hosing, PRTP=1%, $\varphi = 0.5$

Effect of TPs on inequality in country-level SCC



TP add-on for standard IAM damage functions



Notes: Data sampled on a decadal interval using 1000 MC simulations under each of RCP4.5 and RCP8.5.

Conclusions

Eight climate tipping points collectively increase the SCC by $\sim$25% in our main specification.

Tipping points increase global economic risk. We estimate a $\sim$10% chance of tipping points more than doubling the SCC. We also show that tipping points increase the variance of global mean consumption/capita.

A spatial analysis shows that tipping points increase economic losses almost everywhere. They do not meaningfully alter the heterogeneous effects of climate change across countries.

The tipping points with the largest effects are dissociation of ocean methane hydrates and thawing permafrost.

We provide ready-to-use estimates and building blocks for the wider climate economics community.

Limitations and future research avenues

Given missing tipping points, missing climate impacts even of TPs that we do include, most of our numbers should be seen as probable underestimates, but hopefully a step forward.

Our coverage of TP interactions is incomplete (we omit 12 out of 56 two-way interactions).

Some of the TPs we cover are subject to large uncertainties, e.g. OMH.

Our meta-analytic IAM is affected by the usual controversies and uncertainties, including those in climate science (e.g. equilibrium climate sensitivity) and in economics (e.g. the discount rate). The structure of climate damages is a key sensitivity.

Links to published paper and model code

Dietz, Simon, James Rising, Thomas Stoerk, and Gernot Wagner (2021): "Economic impacts of tipping points in the climate system", *Proceedings of the National Academy of Sciences*, **118**(34):

- `https://www.pnas.org/content/118/34/e2103081118`

META (Model for Economic Tipping point Analysis)

- `https://github.com/openmodels/META-2021`

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Thank you!

Comments, suggestions, critiques:

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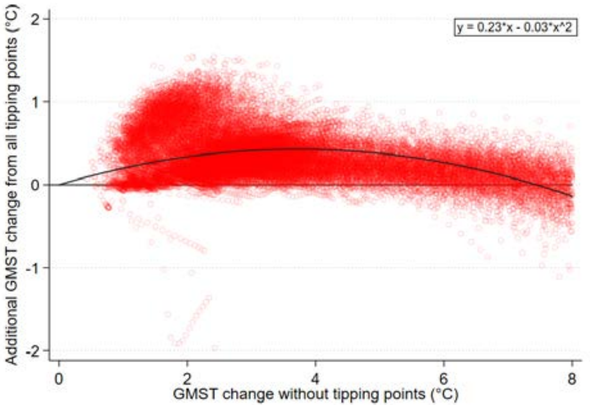
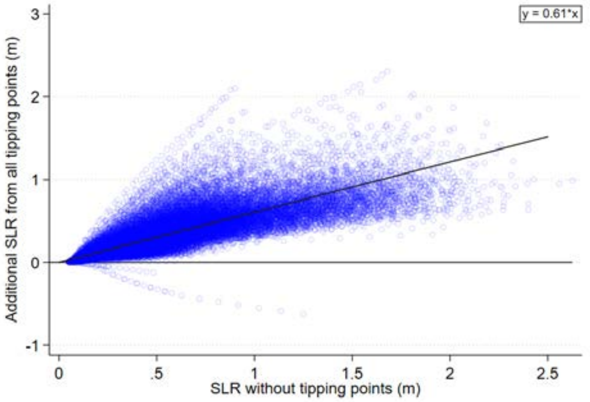
Effect of TPs on warming



Notes: Data sampled on a decadal interval using 1000 MC simulations under each of RCP4.5 and RCP8.5.

Effect of TPs on sea-level rise



Notes: Data sampled on a decadal interval using 1000 MC simulations under each of RCP4.5 and RCP8.5.