Tipping points and ambiguity in the integrated assessment of climate change

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Climate science

Spin, science and climate change

Action on climate is justified, not because the science is certain, but precisely because it is not

Mar 18th 2010 | from PRINT EDITION

Leader (Editorial)

The possibility of tipping points has led media to urge rapid emission reductions,

TIME
IN PARTNERSHIP WITH CNN

Friday, Sep. 04, 2009

Is There a Climate-Change Tipping Point?

By Bryan Walsh

nature

A safe operating space for humanity

Identifying and quantifying planetary boundaries that must not be transgressed could help prevent human activities from causing unacceptable environmental change, argue **Johan Rockström** and colleagues.

impelled 2ºC temperature targets among scientists,

Abrupt Climate Change

R. B. Alley,[1] J. Marotzke,[2] W. D. Nordhaus,[3] J. T. Overpeck,[4] D. M. Peteet,[5] R. A. Pielke Jr.,[6] R. T. Pierrehumbert,[7] P. B. Rhines,[8,9] T. F. Stocker,[10] L. D. Talley,[11] J. M. Wallace[8]

Science 2003

AAAS

Civilization's last chance

Los Angeles Times

The planet is nearing a tipping point on climate change, and it gets much worse, fast.

By Bill McKibben

May 11, 2008

motivated advocates for ambitious policy,

Testimony of
John P. Holdren
Assistant to the President for Science and Technology and
Director of the Office of Science and Technology Policy,
Executive Office of the President of the United States,
before
The Select Committee on Energy Independence and Global Warming
U.S. House of Representatives
on
The Administration's View of the State of the Climate
December 2, 2009

and influenced the Obama administration and international climate accords.

How does the possibility of tipping points affect the social cost of carbon?
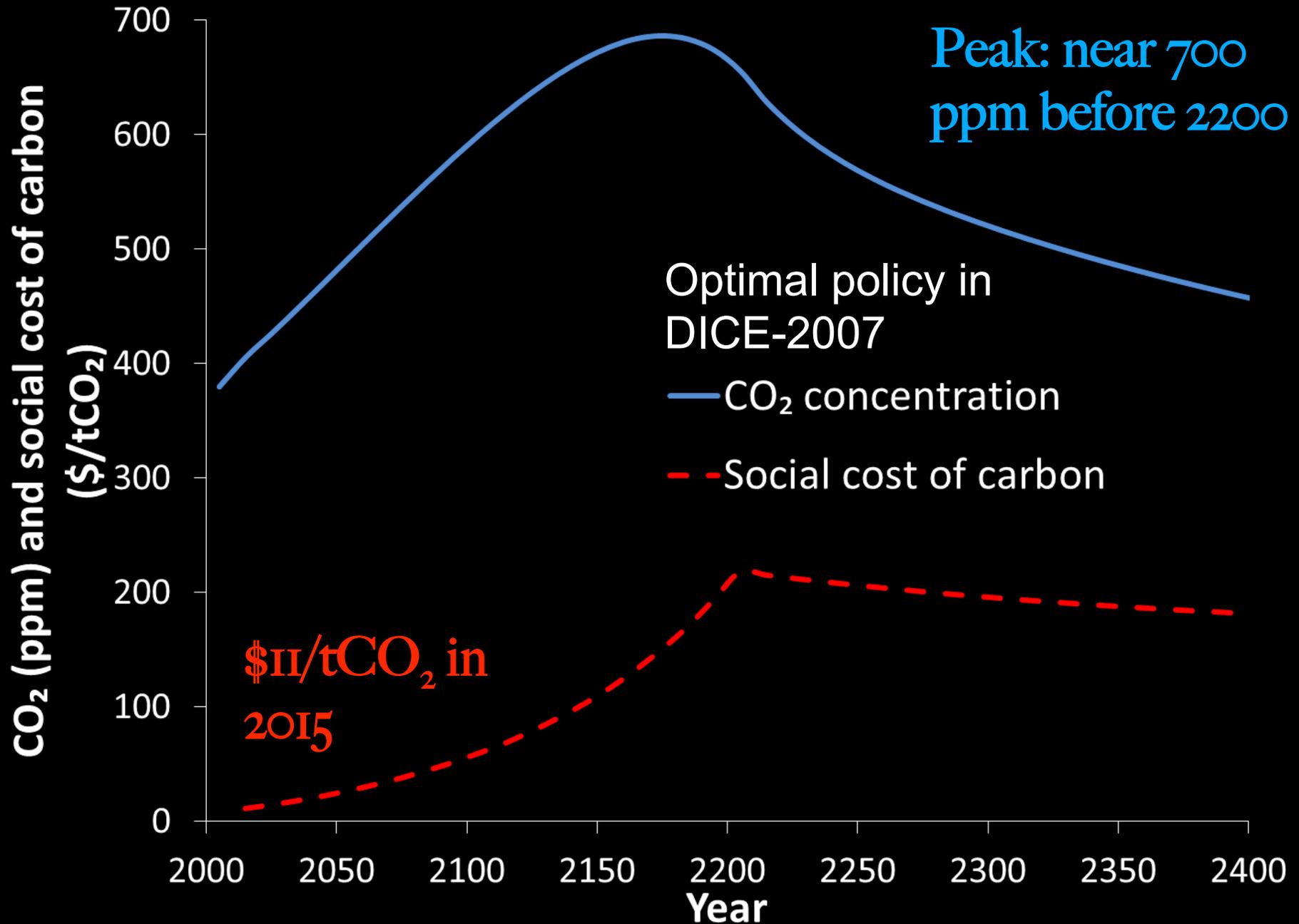
In the real world, temperatures along DICE's optimal path might cause relatively abrupt changes in system dynamics. DICE does not represent these possible changes.
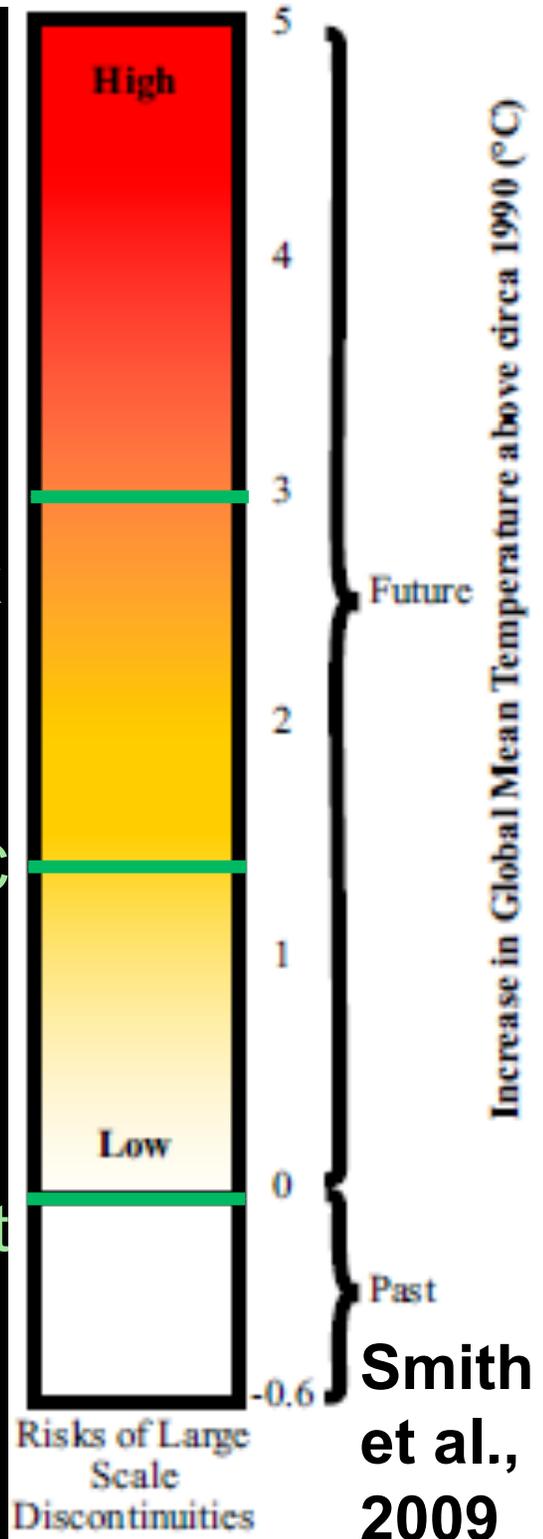
"Society may be lulled into a <u>false sense of security by smooth projections of global change</u>. Our synthesis of present knowledge suggests that a variety of tipping elements <u>could reach their critical point within this century</u> under anthropogenic climate change."
– Lenton et al., 2008

High

DICE max

2°C

Low

Current

Risks of Large Scale Discontinuities

Increase in Global Mean Temperature above circa 1990 (°C)

Future

Past

Smith et al., 2009

Research questions

1) How strongly do different kinds of tipping points affect the social cost of carbon?

   Extension: Change the climate system to include endogenous regime shifts.

2) How does optimal policy respond to prior beliefs about temperature thresholds?

   Extension: Make DICE a dynamic programming problem to model learning.

3) Does ambiguity aversion significantly increase the near-term social cost of carbon?

   Extension: Generalize the welfare evaluation to use the smooth ambiguity model.

Preview of results

- Tipping point possibilities can increase the year 2015 social cost of carbon by over 50% and lower the peak CO_2 concentration by over 100 ppm.

- Optimal policy is most sensitive to tipping points that affect climate sensitivity.

- Tipping points that affect the decay rate of CO_2 are the least important for optimal policy in this model.

- Aversion to tipping point ambiguity only has a strong effect late in this century as tipping points become more likely.
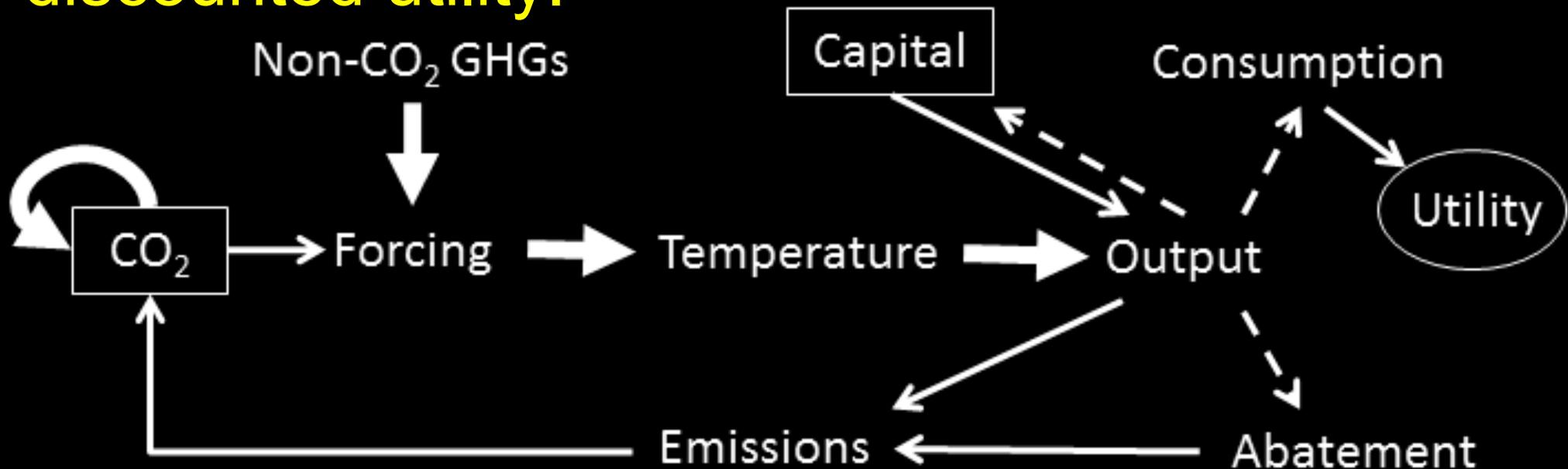
Extending DICE: Tipping points

The goal is to choose a sequence of consumption and abatement policies to maximize present discounted utility.


DICE: Dynamic Integrated model of Climate and the Economy

- Dates back to Nordhaus (1992,1993). We extend DICE-2007 from Nordhaus (2008).
- The primary welfare-optimizing integrated assessment model
- Transparent, available, and widely studied
- Aims to represent high-level economic impacts: one commodity, one actor, one climate variable, and one damage function

We model four tipping points as irreversible shifts in system dynamics.

- A tipping point occurs once a temperature threshold is crossed.

- The probability of a tipping point is endogenous in the sense that it depends on the chosen emission path.

- Once a tipping point occurs, the decision-maker reacts. Prior to its occurrence, the decision-maker anticipates its possibility.

- Keller et al. (2004) extended DICE to include possible collapse of the Gulf Stream. However, they only modeled exogenous learning about the threshold.

Temperature

T^*

Pre-threshold regime

Post-threshold regime

Time
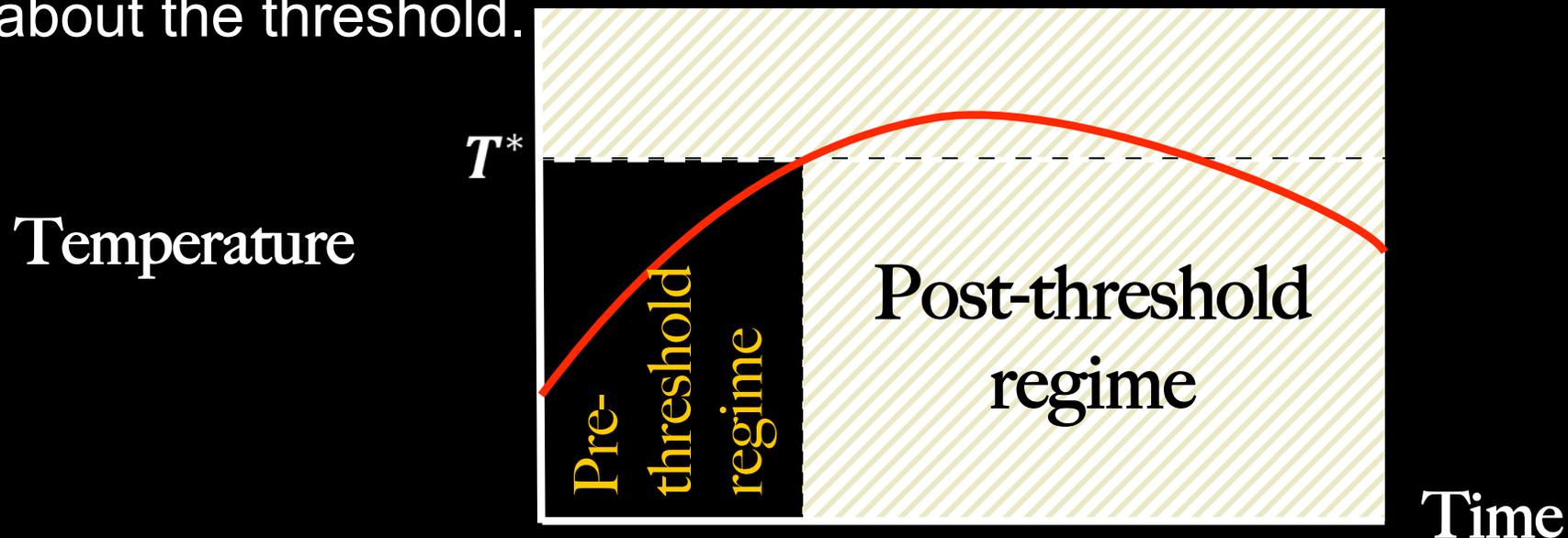
We model each of the tipping points as irreversibly changing a parameter in DICE.
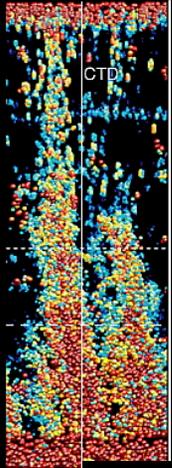
a) Climate sensitivity doubles 6°C

d) Non-CO_2 forcing increased by 1.5 W m^{-2}

b) Damages more convex (cubic)
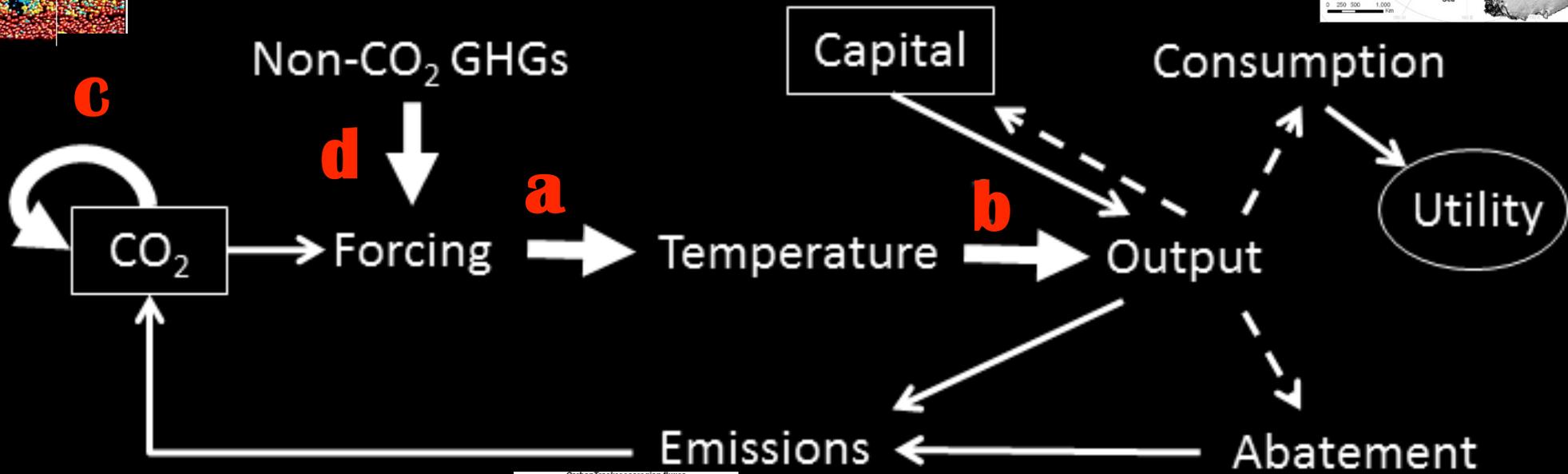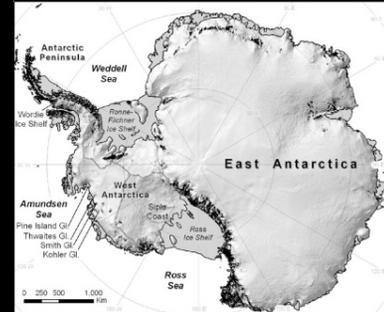
Non-CO_2 GHGs

c

d

a

b

CO$_2$

Forcing

Temperature

Output

Capital

Consumption

Utility

Emissions

Abatement
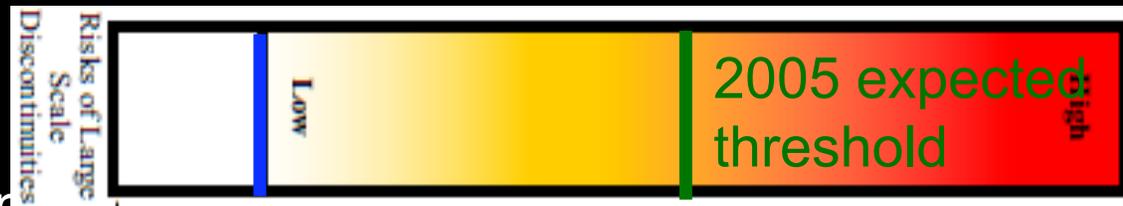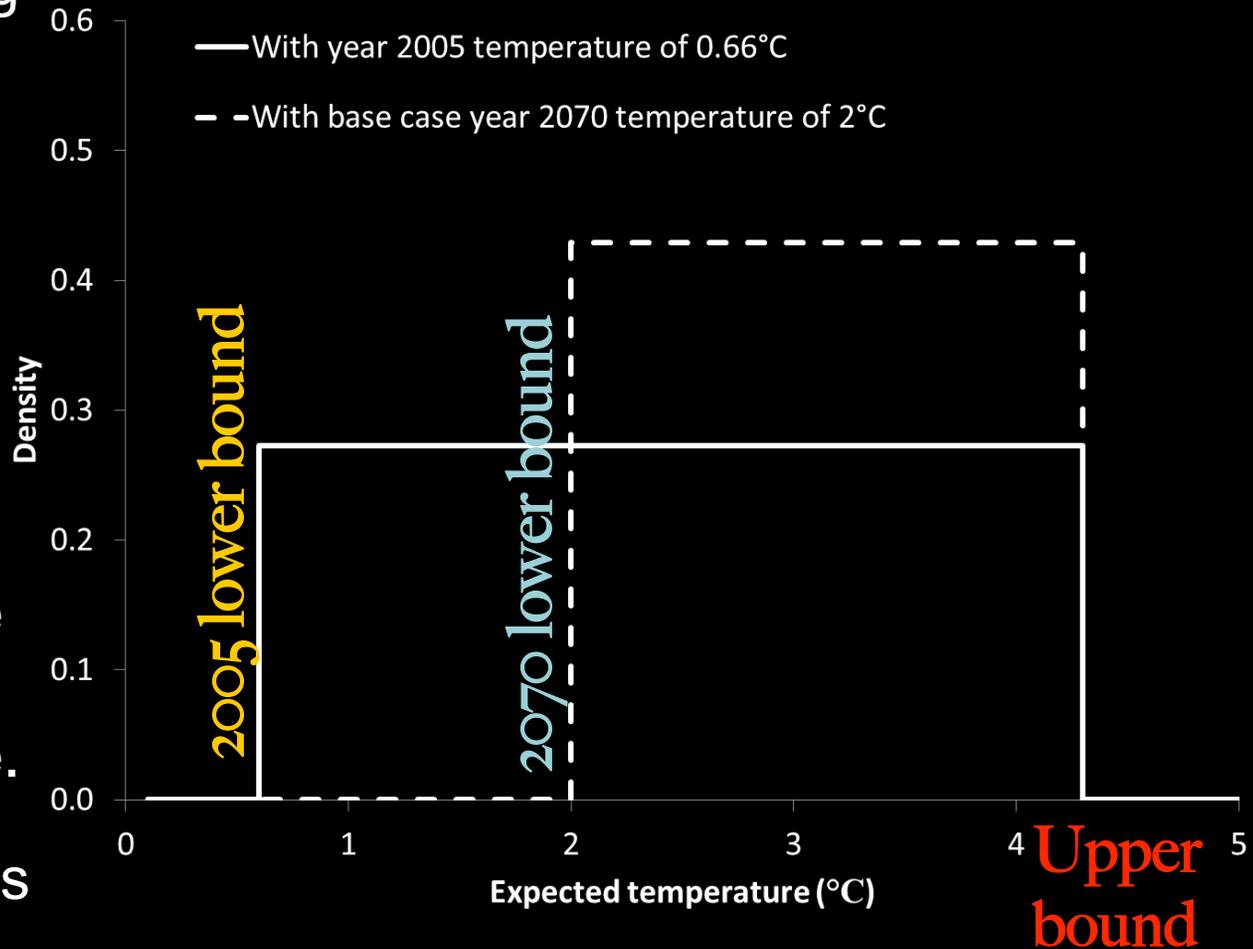
c) CO_2 decay rate decre... 75%
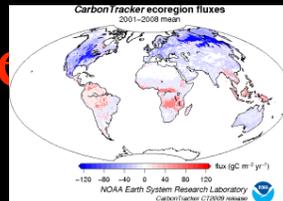
Giving DICE a recursive structure: Uncertainty and learning

We model the uncertain temperature threshold via a uniform distribution with initial expected value of 2.5°C.

Follows from initially knowing only that a tipping point definitely occurs by a high enough temperature.

The threshold is not stochastic: as long as the threshold is not crossed, the decision-maker knows that the threshold must be above the highest expected temperature reached to date.

Since the temperature path is a quasiconcave function of time, the distribution only depends on the currently expected temperature and on the sign of its change.

— With year 2005 temperature of 0.66°C

- - With base case year 2070 temperature of 2°C

Density

Expected temperature (°C)

2005 lower bound

2070 lower bound

Upper bound

Risks of Large Scale Discontinuities

Low

2005 expected threshold

High

2005 temperature

Smith et al., 2009

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Demonstration of the recursive setting

No uncertainty or tipping points

Current value

$$V_t = \max_{c_t, \mu_t} \{u(c) + \beta V_{t+1}\}$$

Utility from current consumption

Discount factor

Continuation value

No tipping points, but with temperature uncertainty

$$V_t = \max_{c_t, \mu_t} \{u(c) + \beta \int V_{t+1} dP\}$$

Integrates over temperature states

Tipping point known to occur before the next period

$$V_{t, \psi=0} = \max_{c_t, \mu_t} \{u(c) + \beta \int V_{t+1, \psi=1} dP\}$$

$\psi = 1$ indicates a value function in the post-threshold regime

Temperature threshold is uncertain

$$V_{t, \psi=0} = \max_{c_t, \mu_t} \{u(c) + \beta \int [h V_{t+1, \psi=1} + (1-h) V_{t+1, \psi=0}] dP\}$$

h is the hazard rate, a function of expected temperature at time $t+1$

Allowing for ambiguity aversion

Temperature threshold is uncertain

$$V_{t,\psi=0} = \max_{c_t,\mu_t} \left\{ u(c) + \beta \int \left[h \, V_{t+1,\psi=1} + (1-h)V_{t+1,\psi=0} \right] dP \right\}$$

h is the hazard rate, a function of expected temperature at time $t+1$

Allow for additional aversion to risk of using the wrong distribution for tipping points

$$V_{t,\psi=0} = \max_{c_t,\mu_t} \left\{ u(c) \right.$$
$$\left. + \beta \int f_{amb}^{-1} \left[h \, f_{amb}[V_{t+1,\psi=1}] + (1-h)f_{amb}[V_{t+1,\psi=0}] \right] dP \right\}$$

f_{amb} concave captures smooth ambiguity aversion

Results

Different types of model runs assess the effects of tipping points and ambiguity aversion.

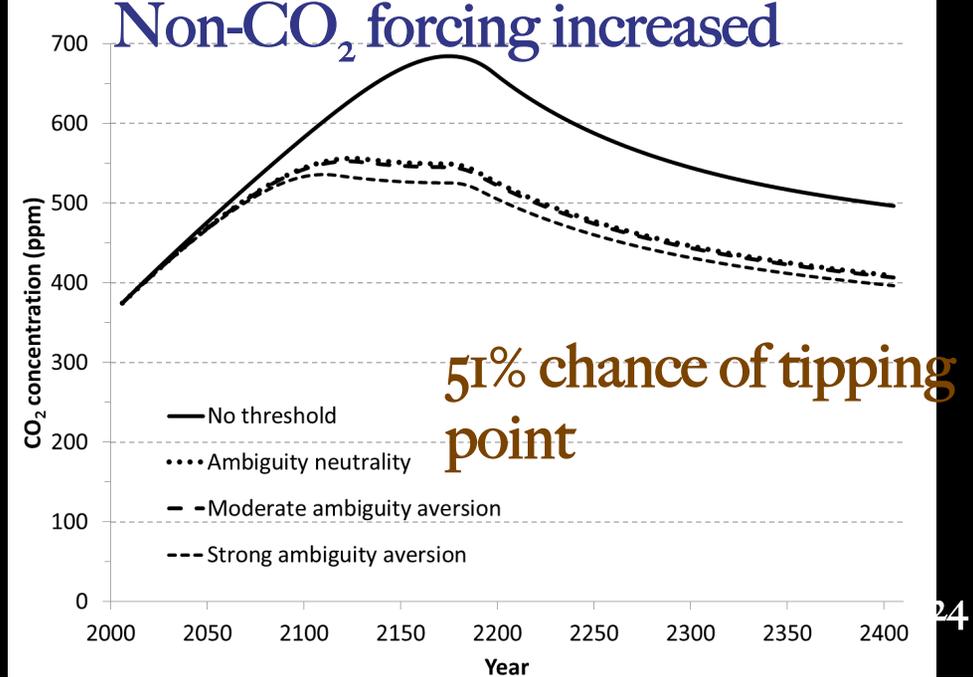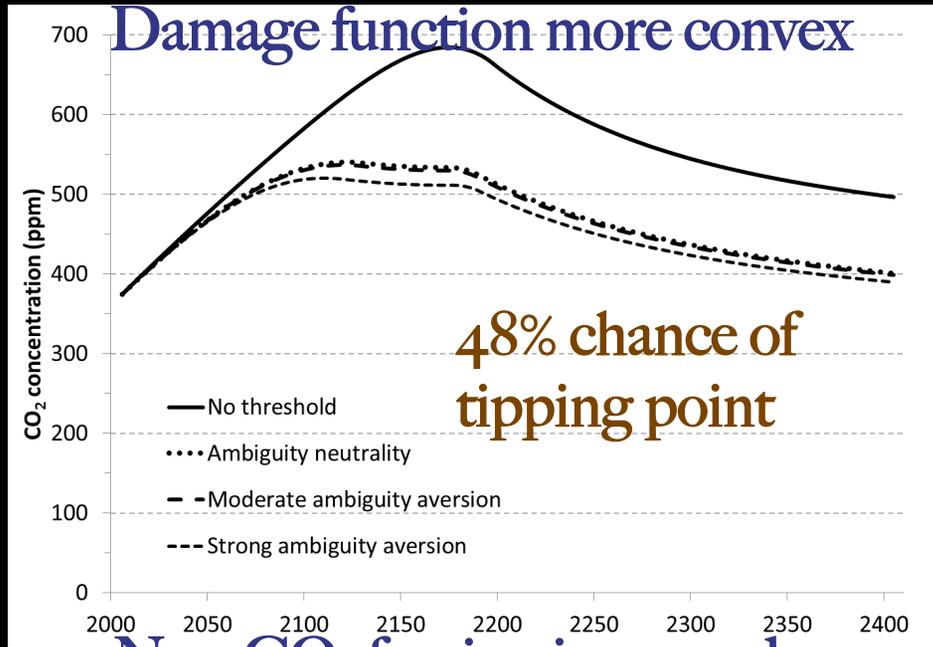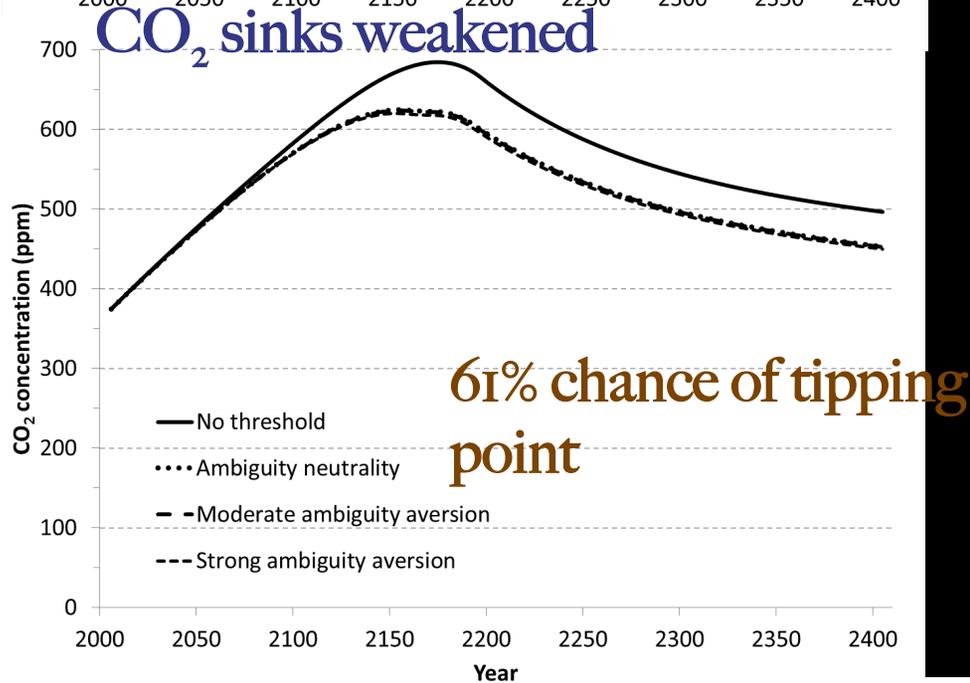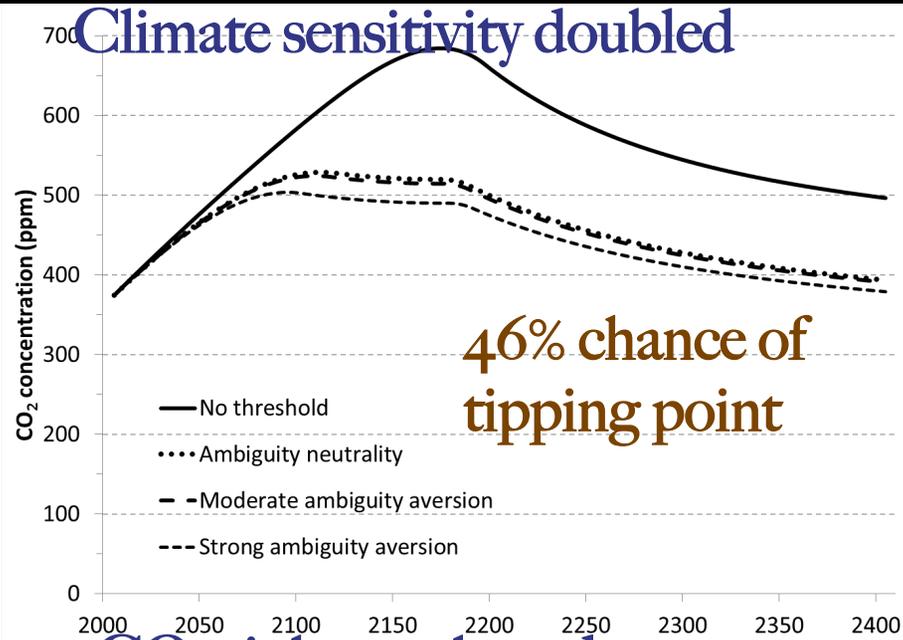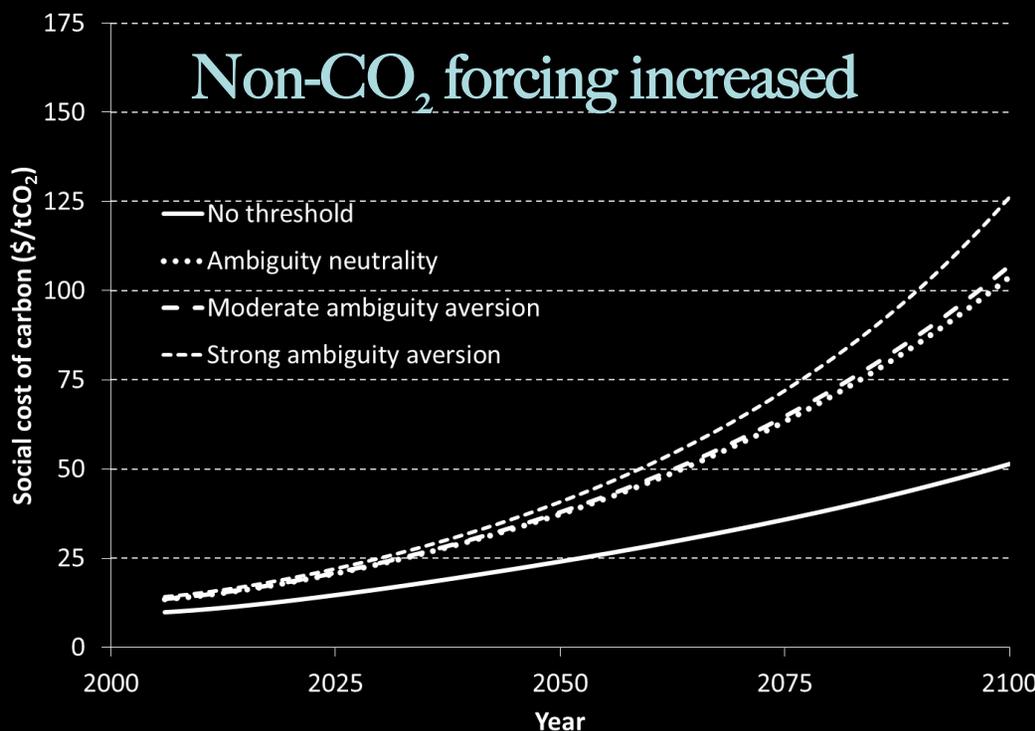|	
Base case	No thresholds
Certain threshold	Controls exactly when and whether a threshold is crossed
Uncertain threshold	Controls the probability that a threshold is crossed
Ambiguity aversion	Additional aversion to threshold uncertainty

Each model run includes only one type of tipping point. The policymaker knows which that is.

These tipping points can reduce the peak CO_2 concentration by over 100 ppm. Each uncertain tipping point has about a 50% chance of eventually occurring (as opposed to 68% if unaware of the possibility).

Climate sensitivity doubled

46% chance of tipping point

- No threshold
- Ambiguity neutrality
- Moderate ambiguity aversion
- Strong ambiguity aversion

Damage function more convex

48% chance of tipping point

- No threshold
- Ambiguity neutrality
- Moderate ambiguity aversion
- Strong ambiguity aversion

CO_2 sinks weakened

61% chance of tipping point

- No threshold
- Ambiguity neutrality
- Moderate ambiguity aversion
- Strong ambiguity aversion

Non-CO_2 forcing increased

51% chance of tipping point

- No threshold
- Ambiguity neutrality
- Moderate ambiguity aversion
- Strong ambiguity aversion

Each tipping point increases the next decades' social cost of carbon, but the magnitude of the effect varies.

Climate sensitivity doubled

- No threshold
- Ambiguity neutrality
- Moderate ambiguity aversion
- Strong ambiguity aversion

Social cost of carbon ($/tCO$_2$)

Damage function more convex

- No threshold
- Ambiguity neutrality
- Moderate ambiguity aversion
- Strong ambiguity aversion

Social cost of carbon ($/tCO$_2$)

CO$_2$ sinks weakened

- No threshold
- Ambiguity neutrality
- Moderate ambiguity aversion
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Social cost of carbon ($/tCO$_2$)

Non-CO$_2$ forcing increased

- No threshold
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- Moderate ambiguity aversion
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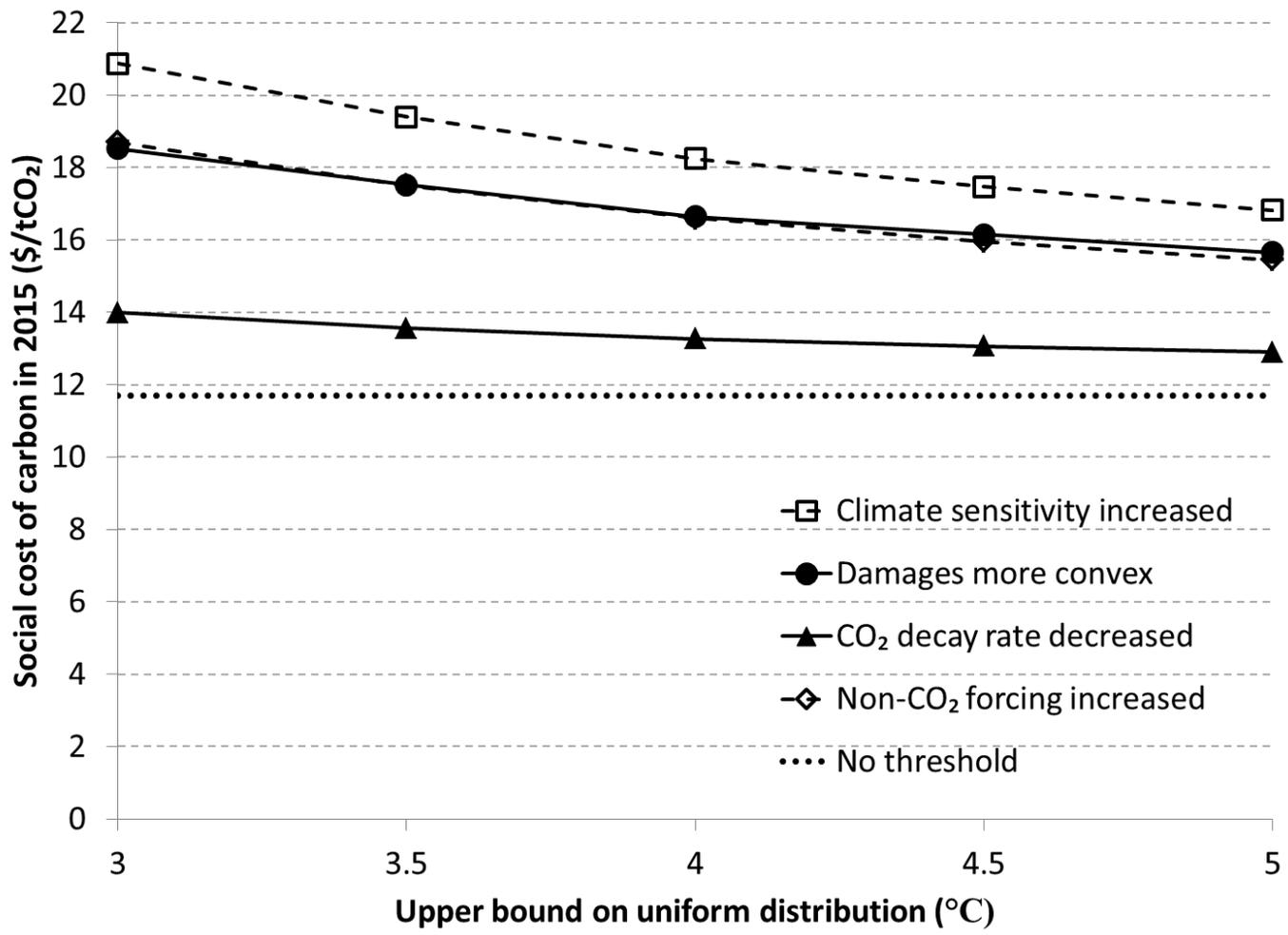Social cost of carbon ($/tCO$_2$)

Year

Year

Optimal policy is not highly sensitive to the specification of the uniform prior for threshold location.

Social cost of carbon in 2015

Peak CO$_2$

Peak CO$_2$ concentration (ppm) — axis from 0 to 700
Upper bound on

Social cost of carbon in 2015 ($/tCO$_2$) — axis from 0 to 22
Upper bound on uniform distribution (°C) — axis from 3 to 5
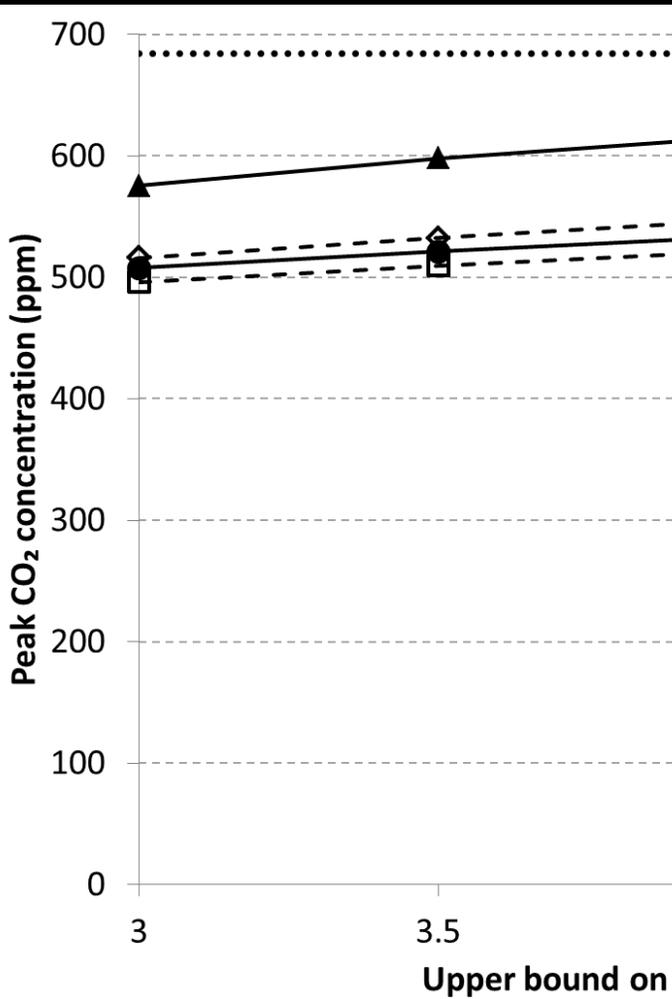
Legend:
- Climate sensitivity increased
- Damages more convex
- CO$_2$ decay rate decreased
- Non-CO$_2$ forcing increased
- No threshold

Conclusions

Conclusions

- Tipping point possibilities can increase the year 2015 social cost of carbon by over 50% and lower the peak CO_2 concentration by over 100 ppm.

- Optimal policy is most sensitive to tipping points that affect climate sensitivity.

- Tipping points that affect the decay rate of CO_2 are the least important for optimal policy in this model.

- Aversion to tipping point ambiguity only has a strong effect late in this century as tipping points become more likely.

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Implications

- The range of model estimates used to inform the social cost of carbon is biased downwards by the exclusion of tipping points. This bias can be significant.

- Modeling exercises should vary not just parameters but also the model structure and the decision-maker's information set.

- The change in the 2015 social cost of carbon could increase cost-effective abatement by 0.25 Gt CO_2 per year in the U.S. (Creyts et al., 2007). Fossil fuel emissions in the U.S. are around 5.6 Gt CO_2 per year (EPA, 2010).

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Because of a discontinuity in marginal benefit, optimal policy cannot equate the marginal benefit and marginal cost of abatement when it holds temperature constant.