POTSDAM INSTITUTE FOR CLIMATE IMPACT RESEARCH

What role for uncertainty in the integrated assessment of climate change?

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Uncertainty analysis in Integrated Assessment Models
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Acknowledgment

Alexander Lorenz

Matthias Schmidt

Hermann Held

Lorenz A, Schmidt MGW, Kriegler E, Held H (2011): ***Anticipating Climate Threshold Damages***, Environmental Modeling and Assessment, online first. doi:10.1007/s10666-011-9282-2

Lorenz A, Kriegler E, Held H, Schmidt MGW (2011) ***How important is Uncertainty for the Integrated Assessment of Climate Change?,*** submitted.

Schmidt MGW, Lorenz A, Held H, Kriegler E (2010): ***Climate Targets under Uncertainty: Challenges and Remedies***, Climate Change Letters 104(3-4): 783-791. doi: 10.1007/s10584-010-9985-4

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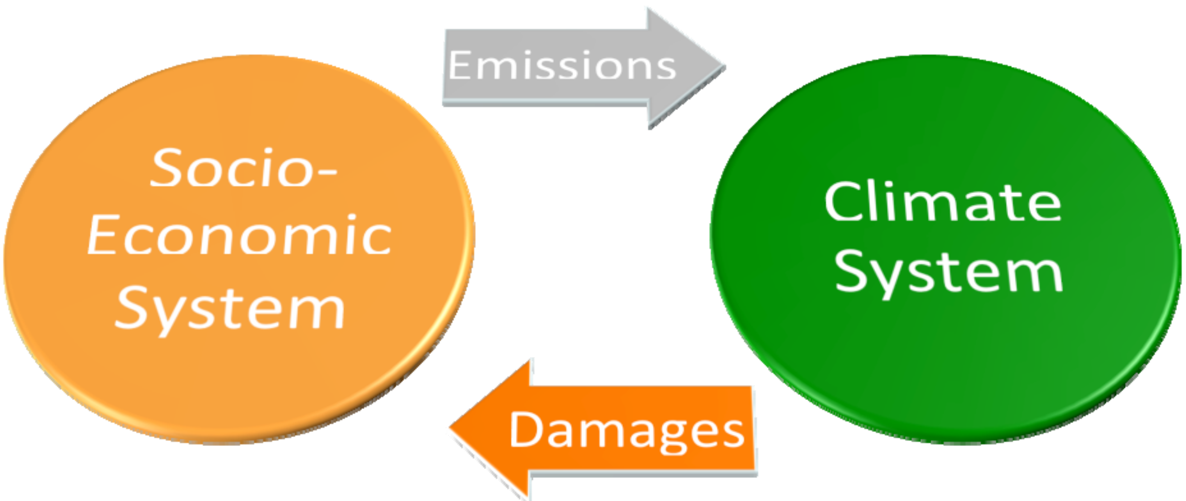
Research Question

How important is uncertainty and learning
for the integrated assessment of climate change?



The role of uncertainty for optimal abatement

Climate change is a problem of risk management of uncertain future damages (e.g. Stern Review, 2007).

But what influence of uncertainty on abatement levels?

Bill Nordhaus (2008, in his book "A question of balance"): ***"Based on the expected utility model, one finding of the uncertainty analysis in this book is that the best-guess policy is a good approximation to the expected-value policy. There appears to be no empirical ground for paying a major risk premium for future uncertainties beyond what would be justified by the averages (subject to the caveats about catastrophic outcomes …)."***

Surprising feature of non-linear integrated assessment models

(Assume Welfare $W(c, \theta)$ as function of policy c and uncertain parameters θ)

Why $\mathbf{\max_c W(c,E(\theta))}$ [value of best guess policy] close to

$\mathbf{\max_c E(W(c,\theta))}$ [value of expected-value policy]?

The Energy-Economy-Climate Model MIND

- Ramsey-type optimal growth model with capital, labor, energy as production factors (CES function)
- R&D sectors for labour and energy productivity
- Energy sector contains fossil fuel extraction, fossil energy generation and zero-carbon energy production with learning-by-doing
- 1 world region

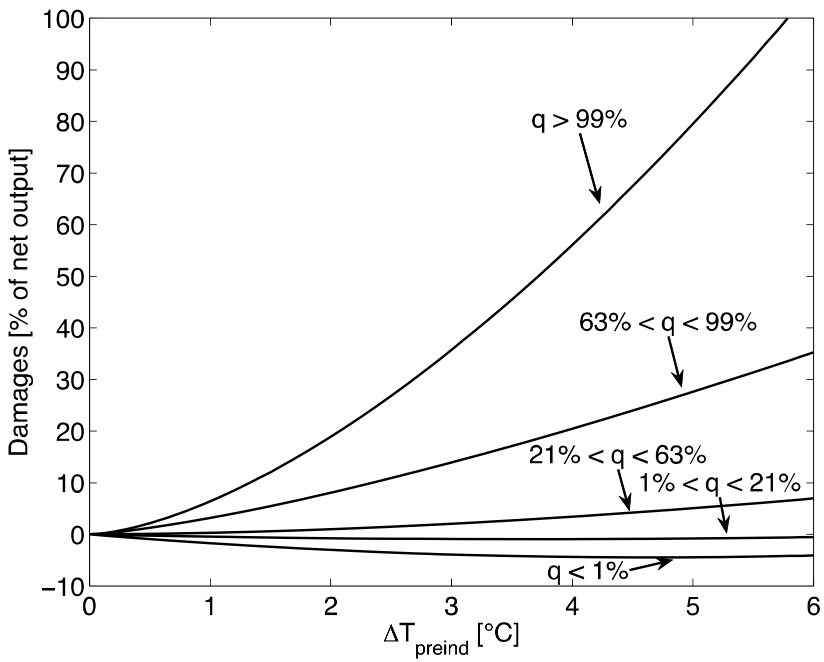
Model was adapted to stochastic and chance-constrained programming with and w/o learning

MIND1.0: Edenhofer, Bauer, Kriegler, 2005, Ecological Economics 54, 277-292

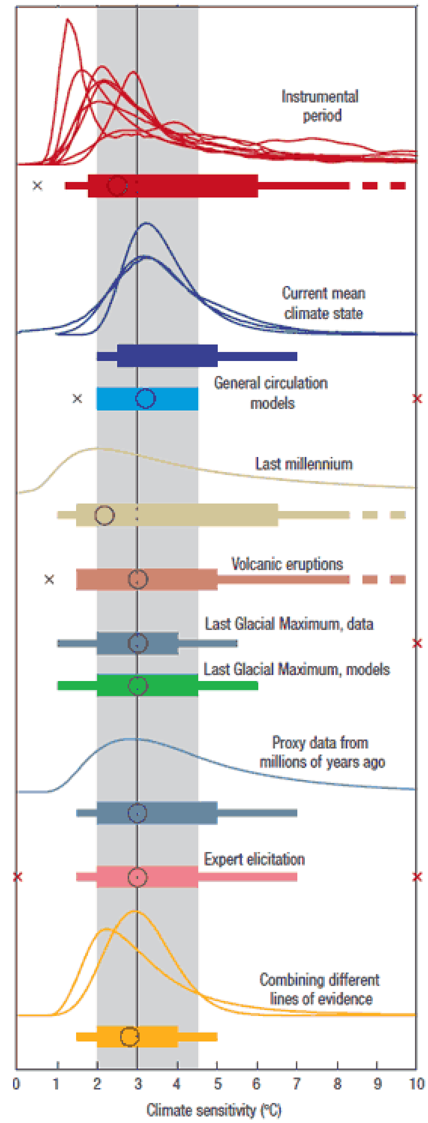
Uncertainty

We consider uncertainties about

- the climate response to emissions (e.g. climate sensitivity, transient climate response, etc.)
- climate change induced economic damages.



Roughgarden & Schneider (1999)



Knutti & Hegerl (2008)

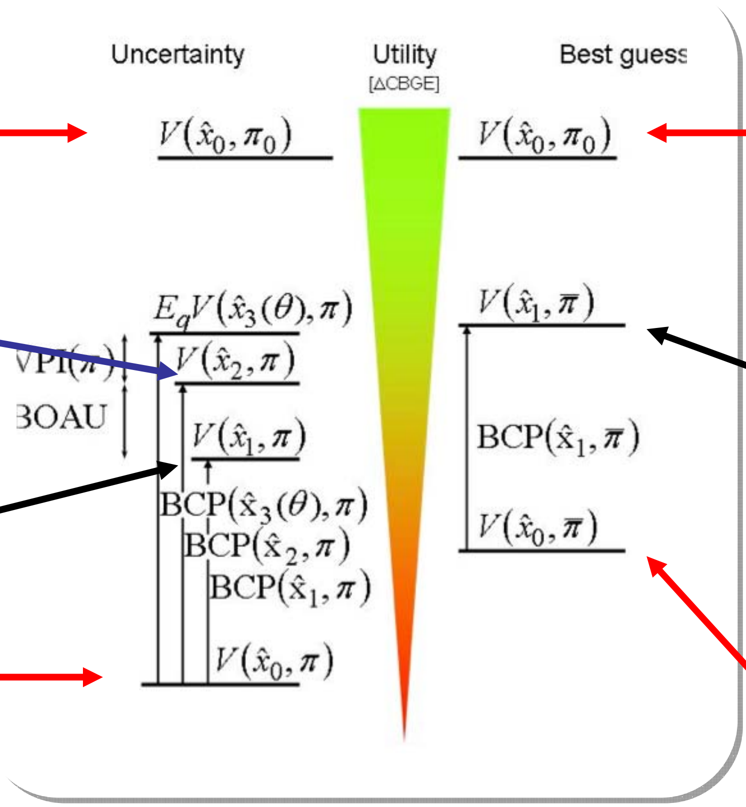
Benefit of climate policy (BCP)

optimal policy (x_0) if there was no climate change (π_0)

optimal climate policy (x_2) for uncertain climate damages (π)

value of best guess climate policy (x_1) for uncertain climate damages (π)

sticking to a no climate change policy in the face of uncertain climate damages (π)



optimal policy (x_0) if there was no climate change (π_0)

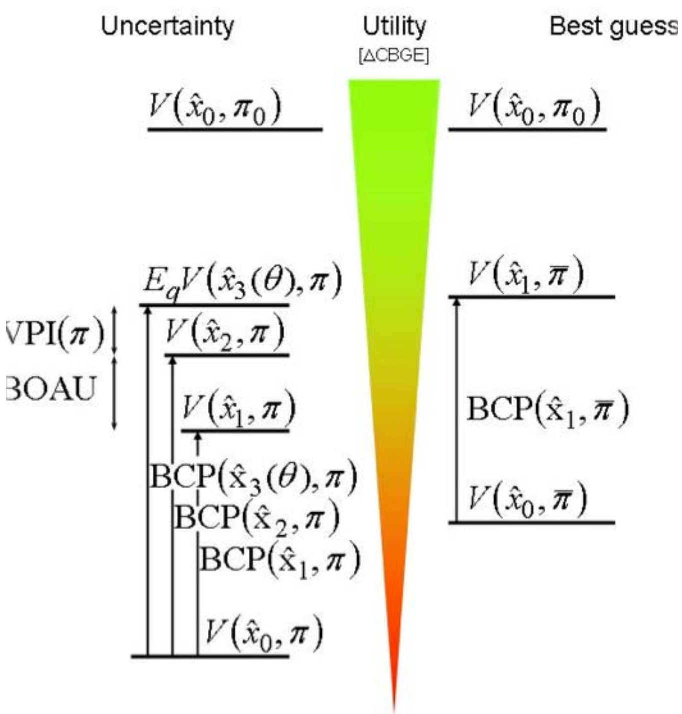
best guess climate policy (x_1) accounting for average climate damages (bar π)

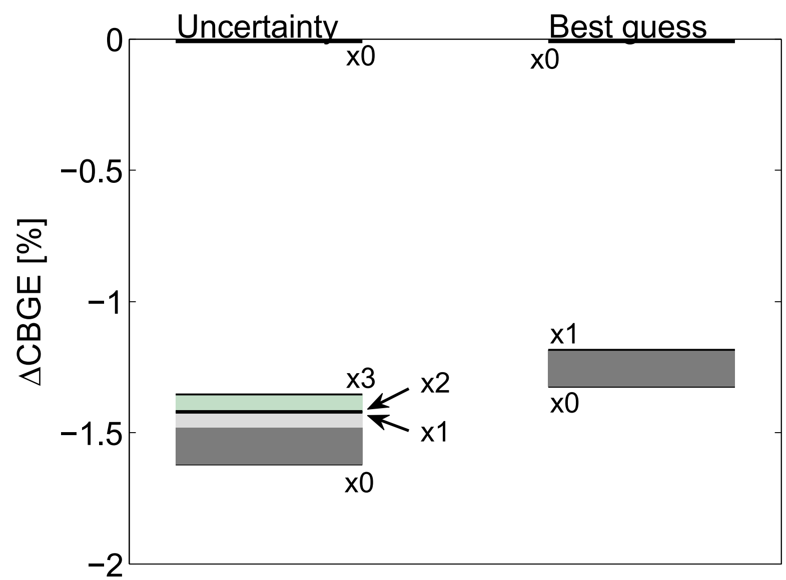
sticking to a no climate change policy in the face of average climate damages (bar π)

BCP = best guess BCP + re-evaluation of BCP under uncertainty
+ benefit of adjusting to uncertainty (BOAU)

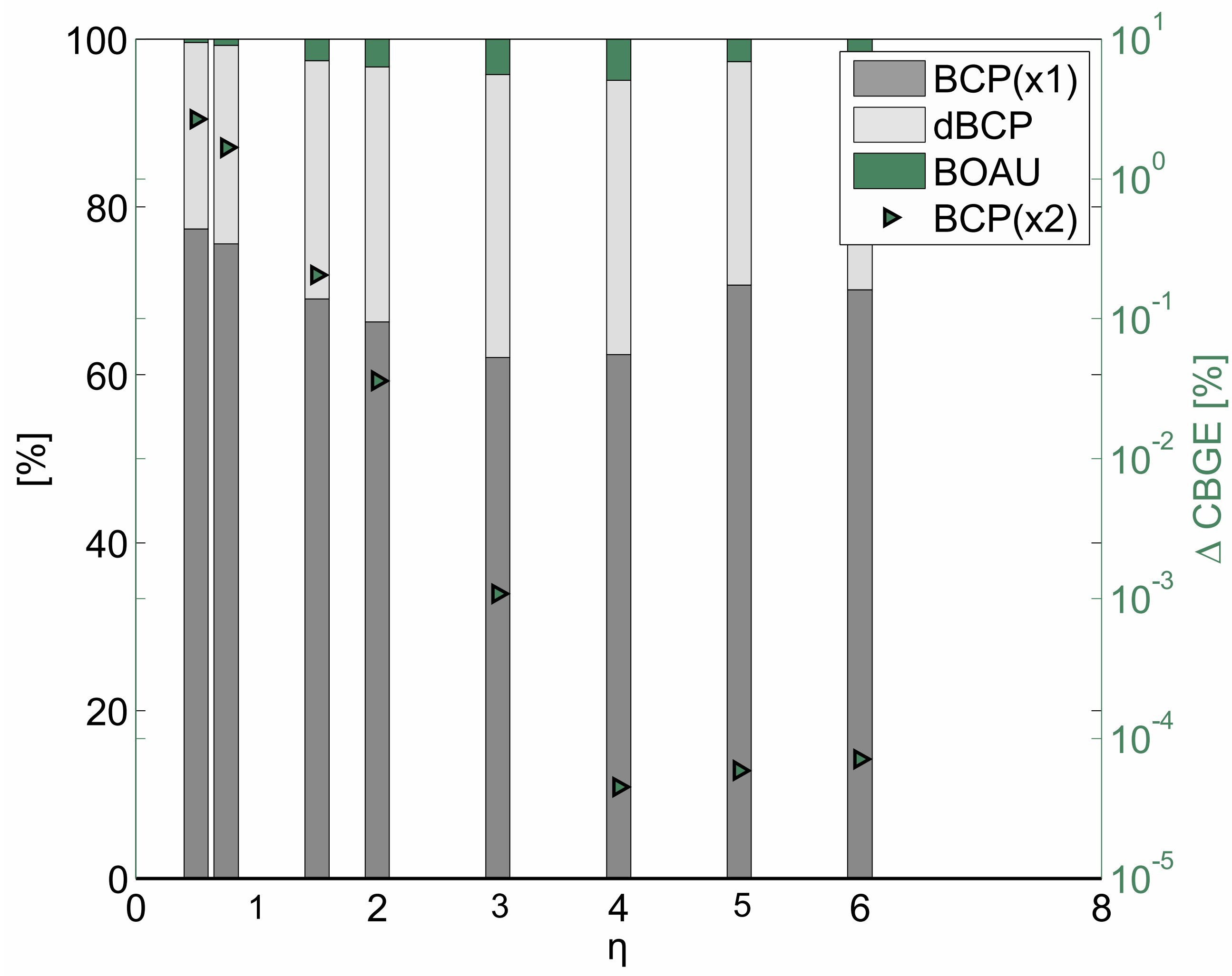
Pizer (1997) uses BOAU/BCP to assess relative importance of optimizing under uncertainty vs. best guess

Importance of Uncertainty in the MIND model

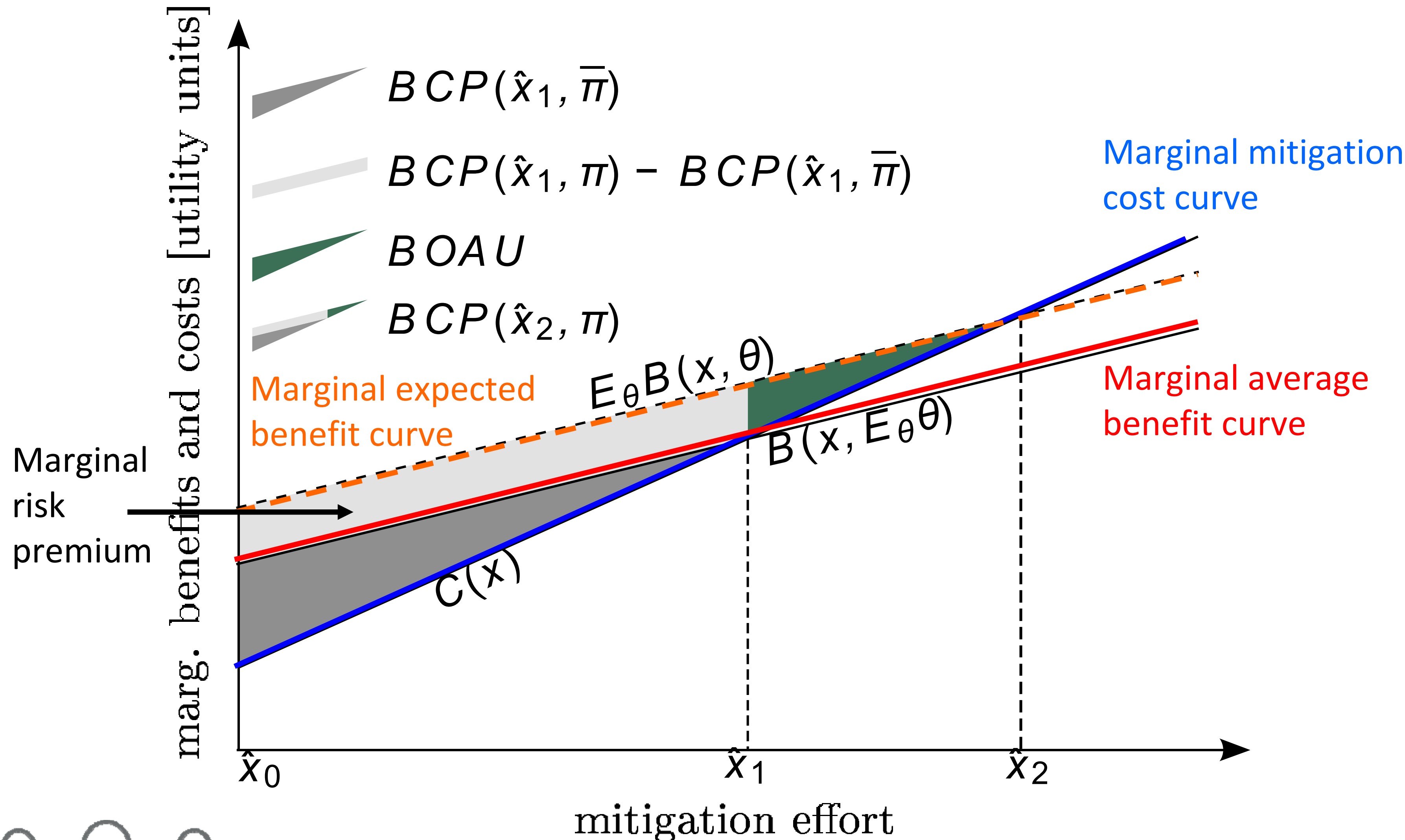




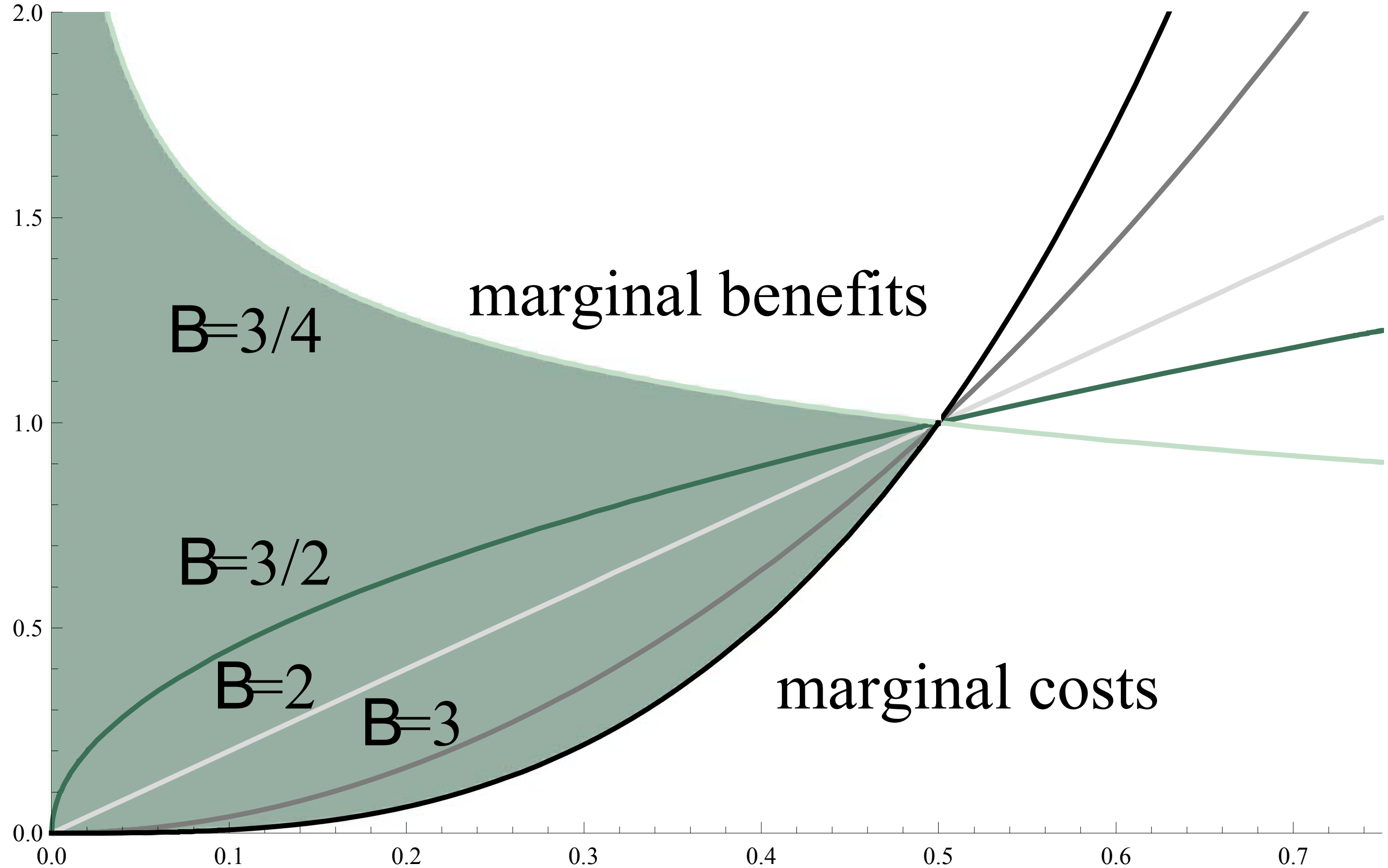
Sensitivity to risk aversion



Marginal cost-benefit picture

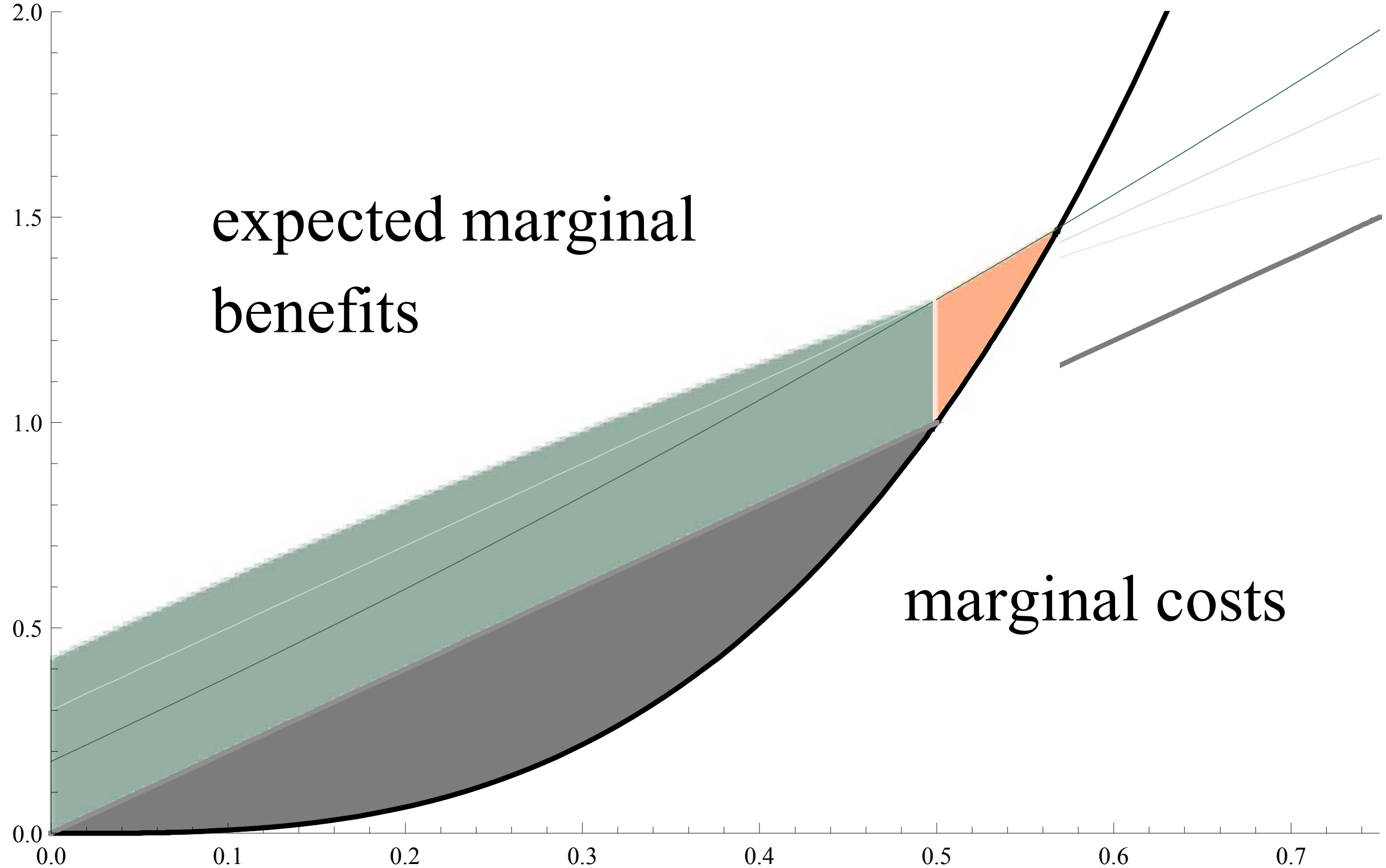


Marginal cost-benefit picture



Decreasing marginal benefits lead to a larger BCP (assuming the same optimal mitigation effort)

Marginal cost-benefit picture



Convex increasing marginal risk premium or decreasing convexity in marginal mitigation costs increase the relative weight of the BOAU

How to derive cost-benefit information from integrated assessment models?

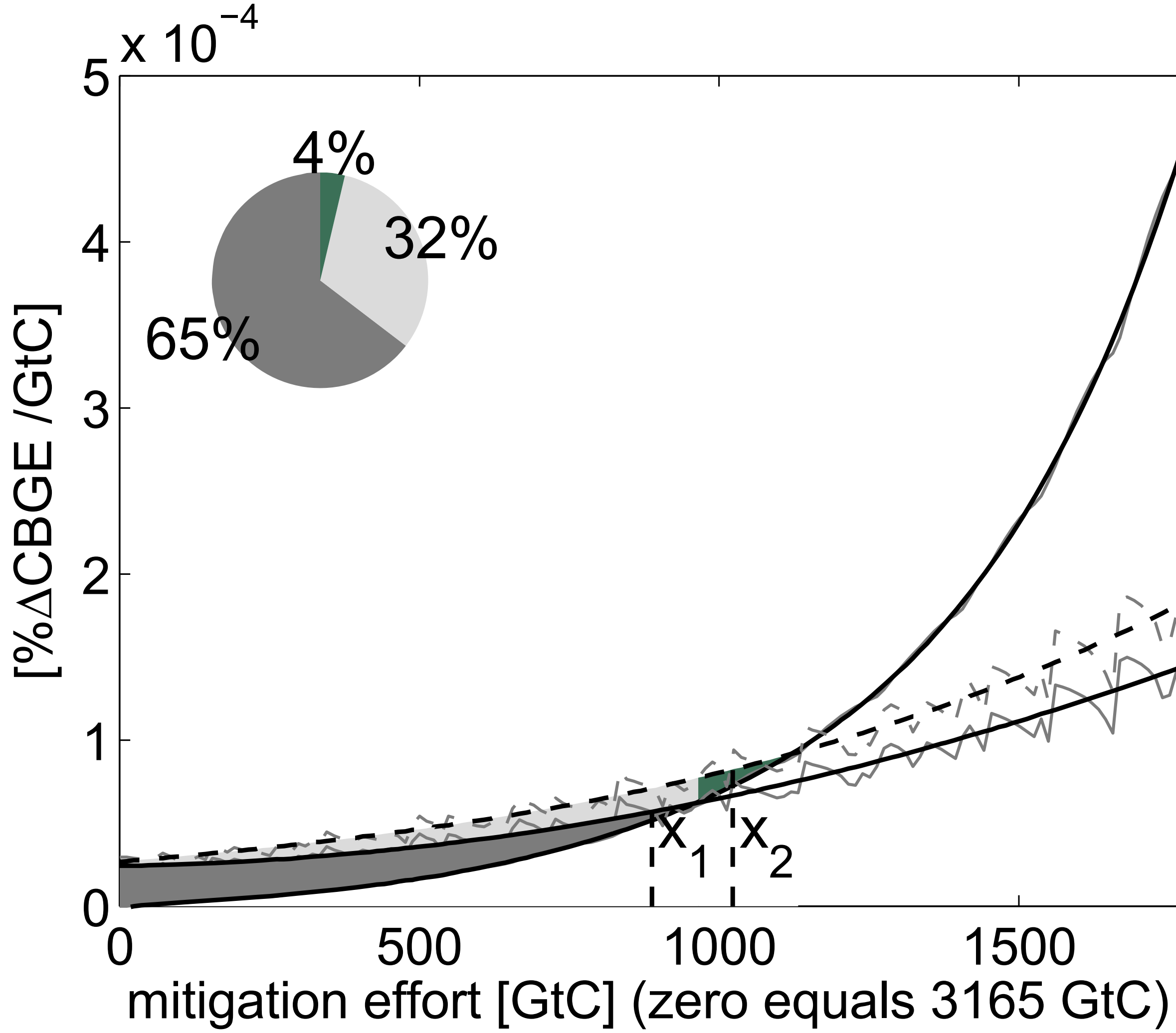
- Calculate welfare in reference case without climate change: $W(x_0,\pi_0)$
- Calculate welfare of no climate policy case under climate change: $W(x_0,\pi)$
- Calculate welfare of policy x if there was no climate change: $W(x,\pi_0)$
- Calculate welfare of policy x under climate change: $W(x,\pi)$

- Mitigation costs for policy x: $\mathbf{C(x) = W(x_0,\pi_0) - W(x,\pi_0)}$
- Damage from not acting on climate change: $W(x_0,\pi) - W(x_0,\pi_0)$
- Damage from climate change assuming policy x: $W(x,\pi) - W(x,\pi_0)$
- Benefit of climate policy = damage reduction:

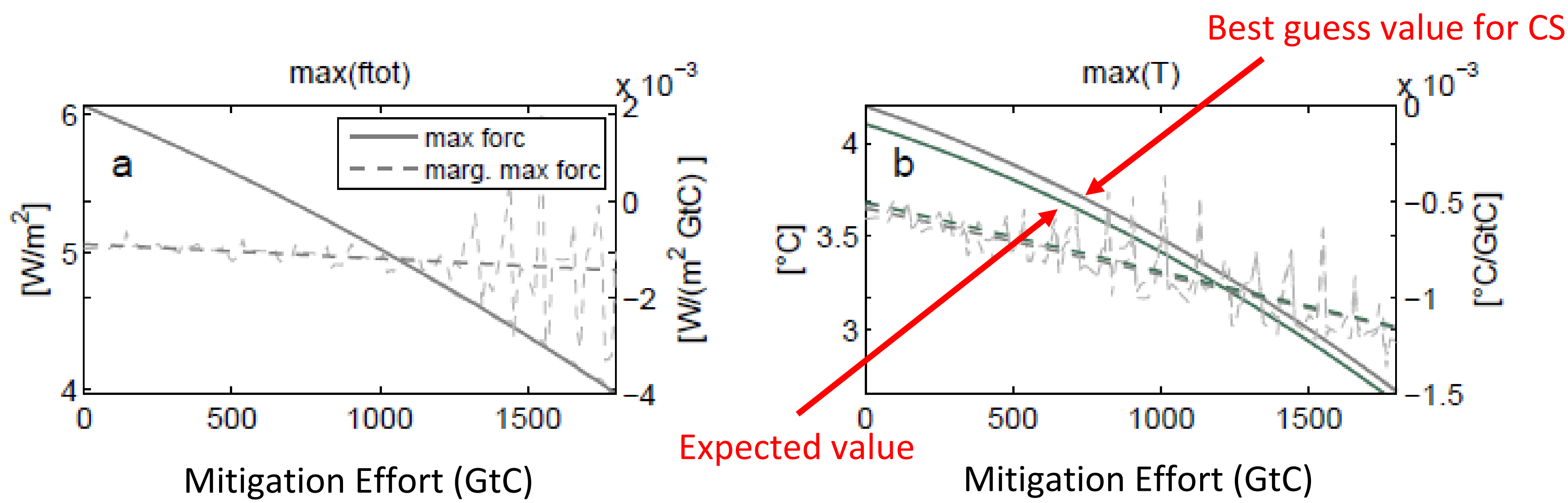
  $\mathbf{B(x,\pi) = (W(x,\pi) - W(x,\pi_0)) – (W(x_0,\pi) - W(x_0,\pi_0))}$

➔ $\mathbf{max_x\, B(x,\pi) – C(x) = max_x\, W(x,\pi) – W(x_0,\pi)}$

Marginal Cost-Benefit picture of MIND



Climate cause-effect chain in MIND



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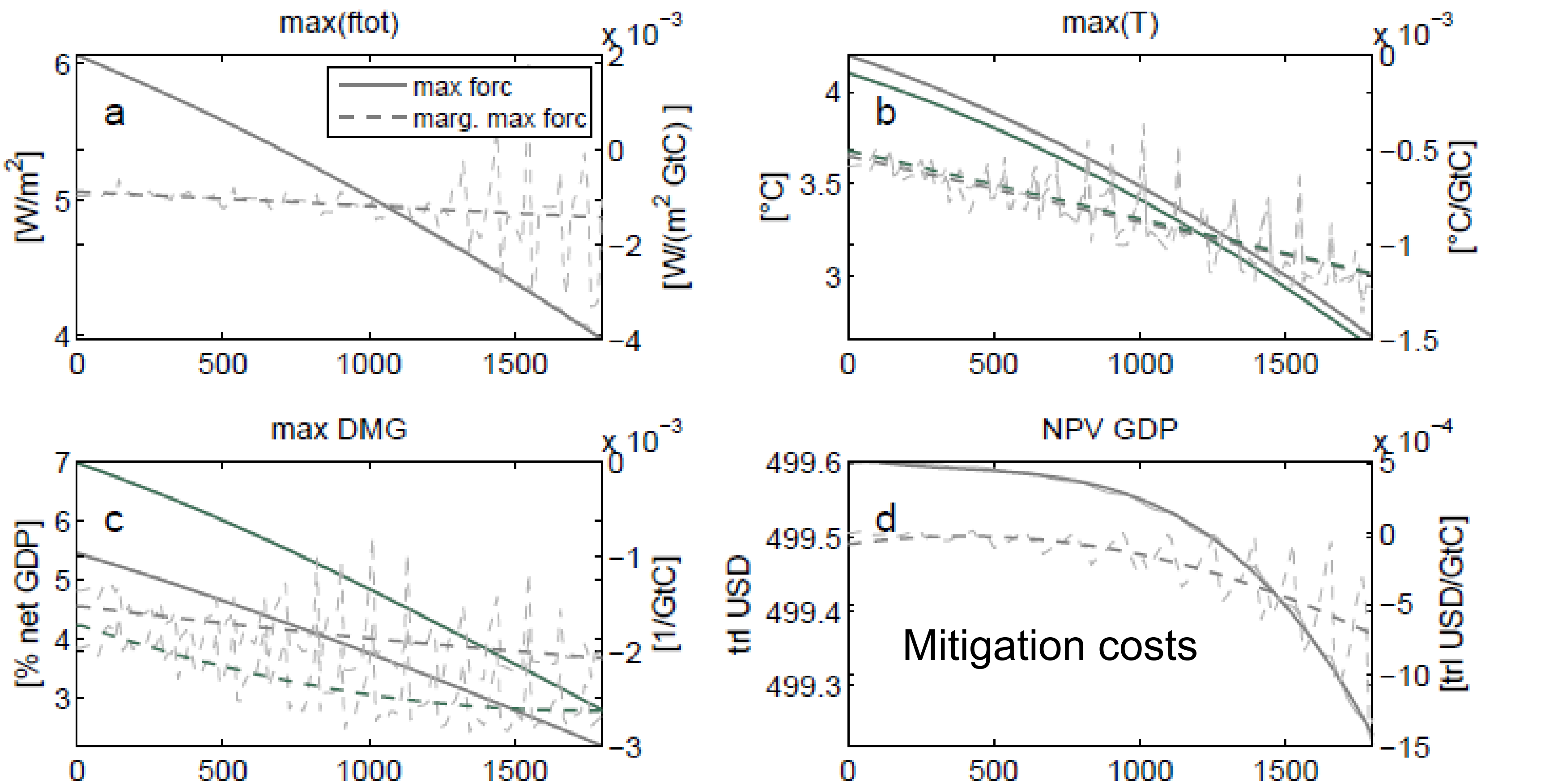
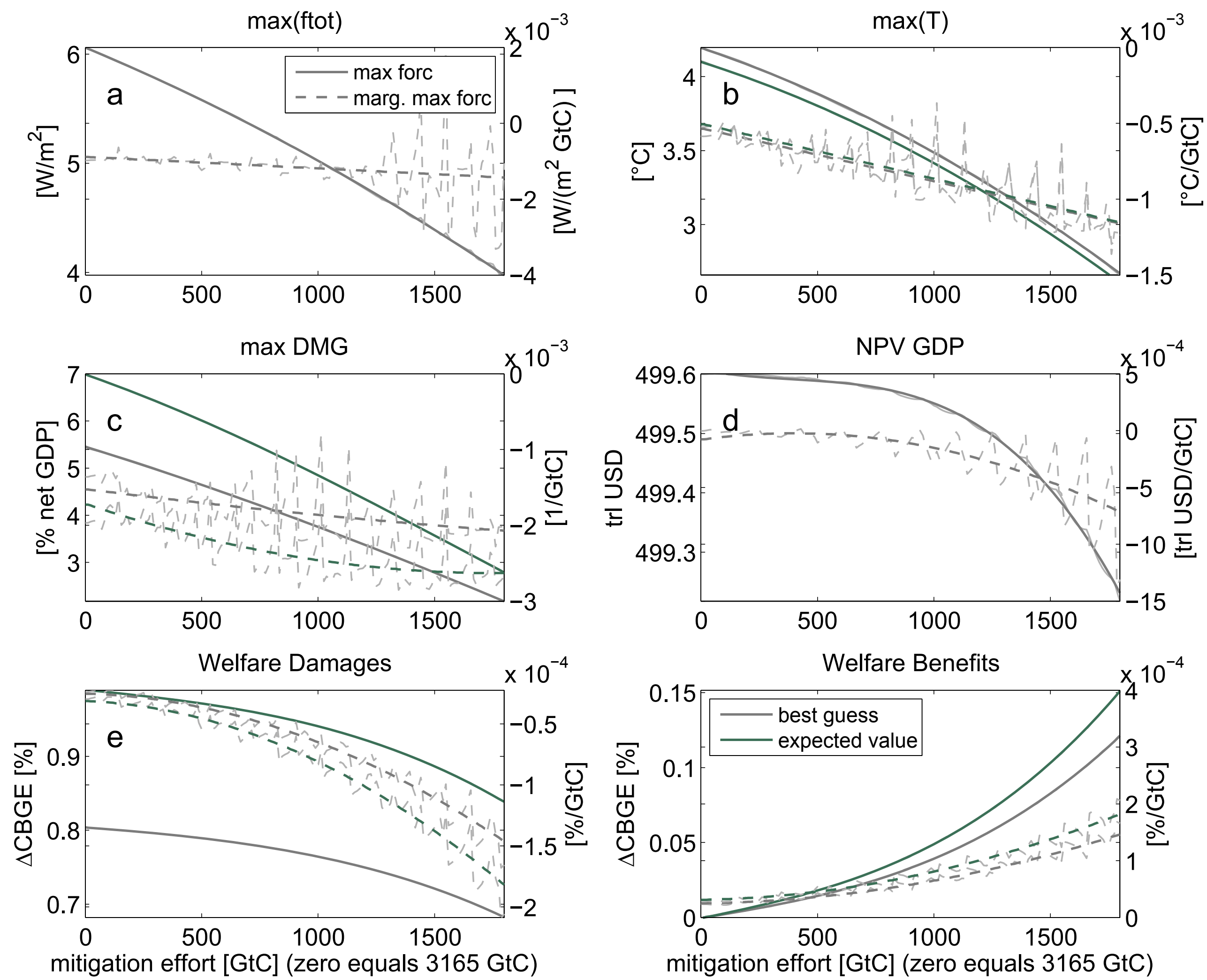


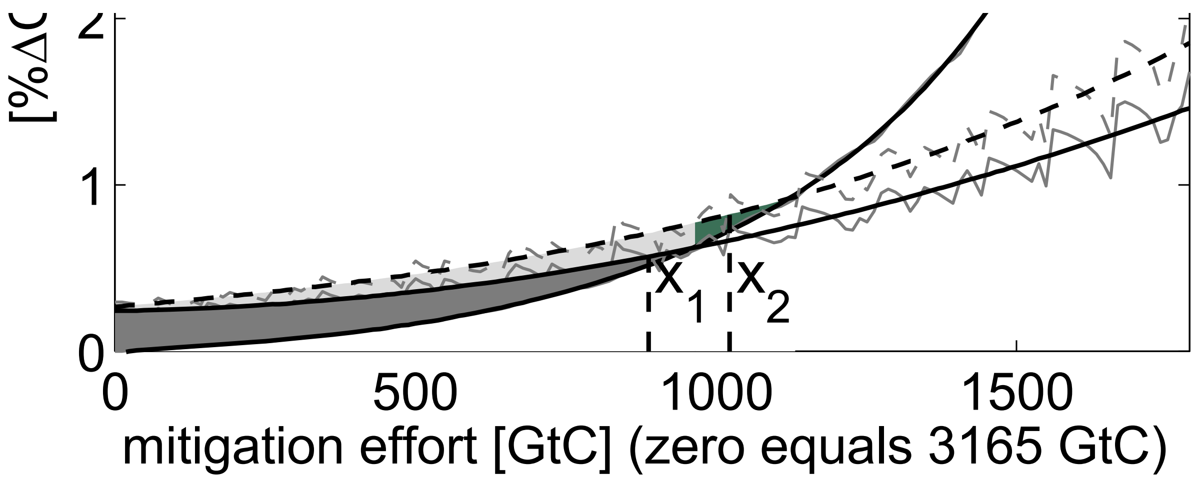
Mitigation Effort (GtC) Mitigation Effort (GtC)

Climate cause-effect chain in MIND



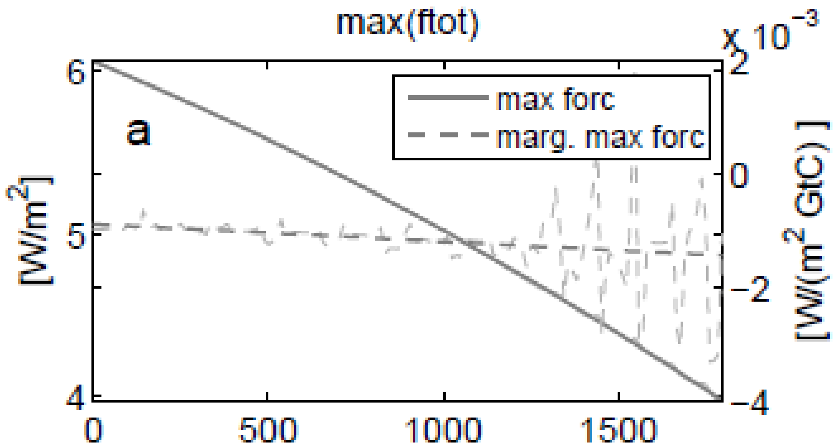
Why is explicitly accounting for uncertainty not important in the standard MIND setting?

- Overall benefit of climate policy is constrained by the saturation of the emissions to temperature change relationship compensating for the non-linearity in the climate damage function and by the consumption smoothing property of the welfare function.
- Uncertainty does not change much because the additional marginal welfare benefit of reducing a unit of emissions becomes only significant for large mitigation effort, where mitigation costs are already high.
- The welfare gains from adjusting the mitigation policy under uncertainty are limited because of the strongly increasing mitigation costs.



When does uncertainty become important?

Change relationship of marginal damages vs. mitigation effort



Assume exponential damages:

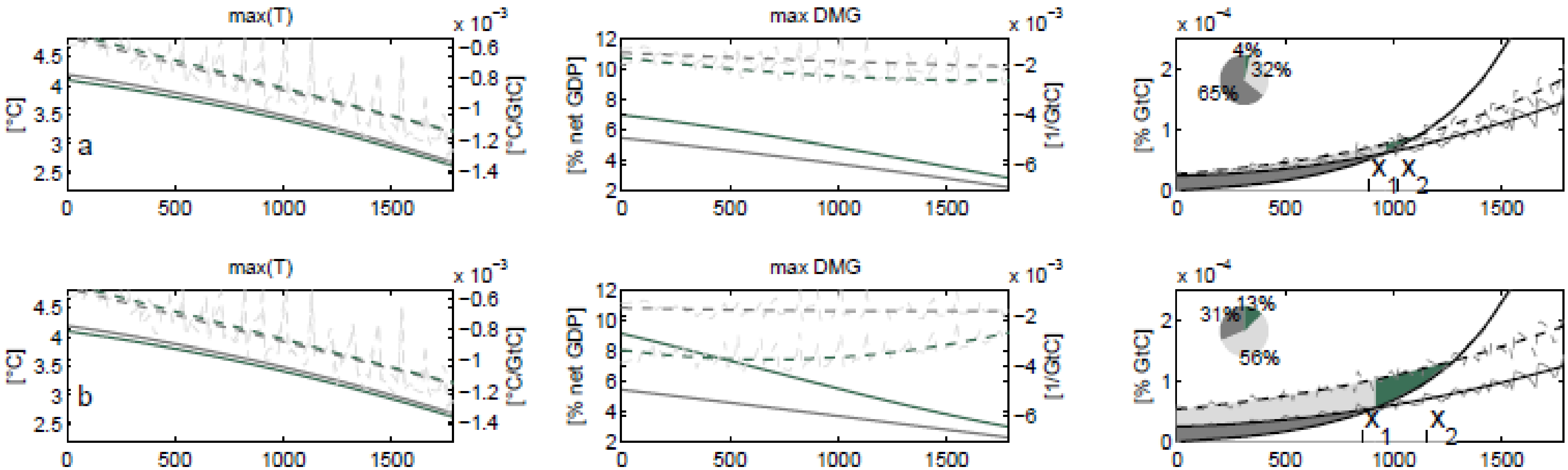
Standard formulation:

$$\mathrm{DF}_e = \frac{1}{1 + k \cdot \exp(\frac{T}{l}) - k} \; .$$

$$DF(T) = \frac{1}{1 + a \cdot T^b} \; .$$

Calibrated to roughly match for best guesses of a and l

The effect of exponential damages



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LETTERS

The proportionality of global warming to cumulative carbon emissions

H. Damon Matthews[1], Nathan P. Gillett[2], Peter A. Stott[3] & Kirsten Zickfeld[2]

Postulate carbon-climate response (CCR)

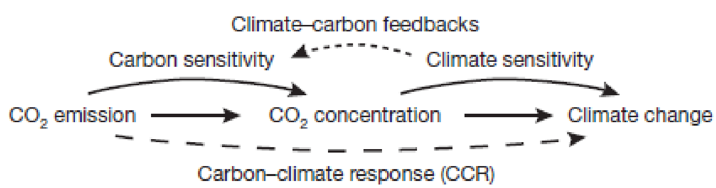
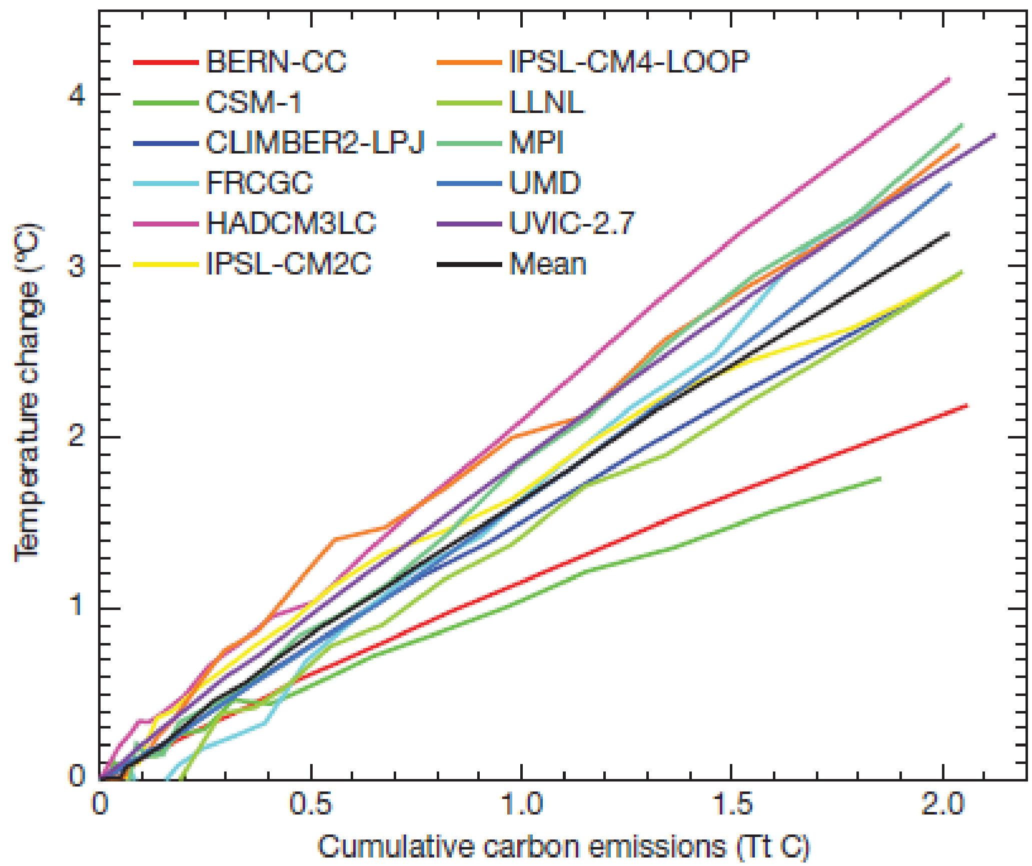
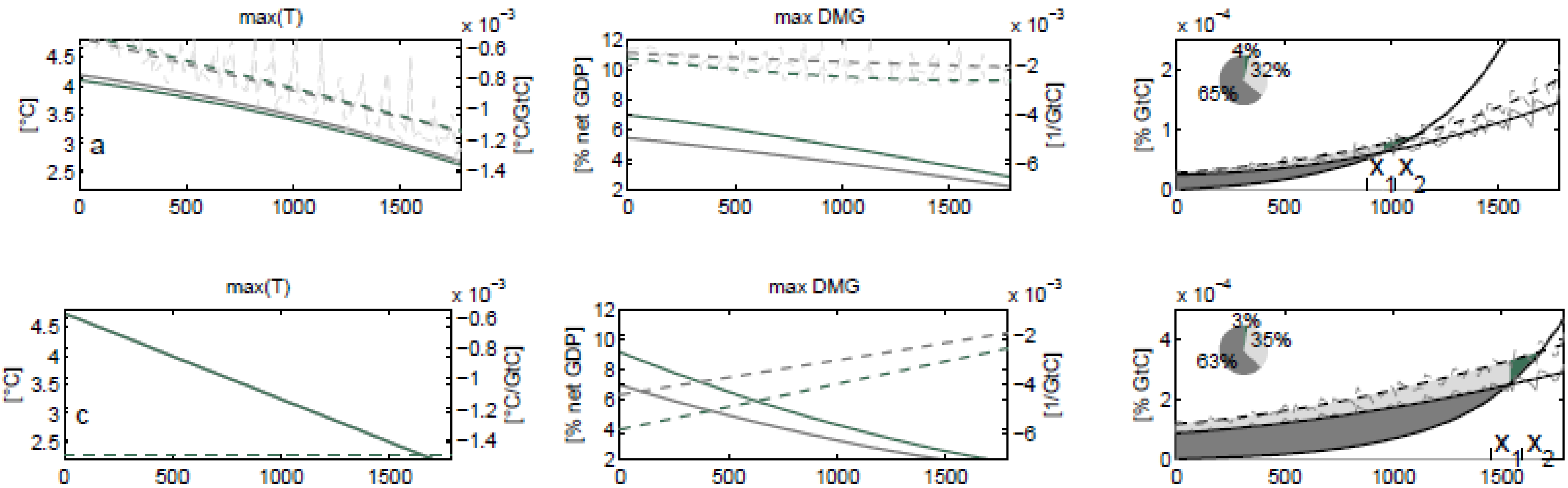


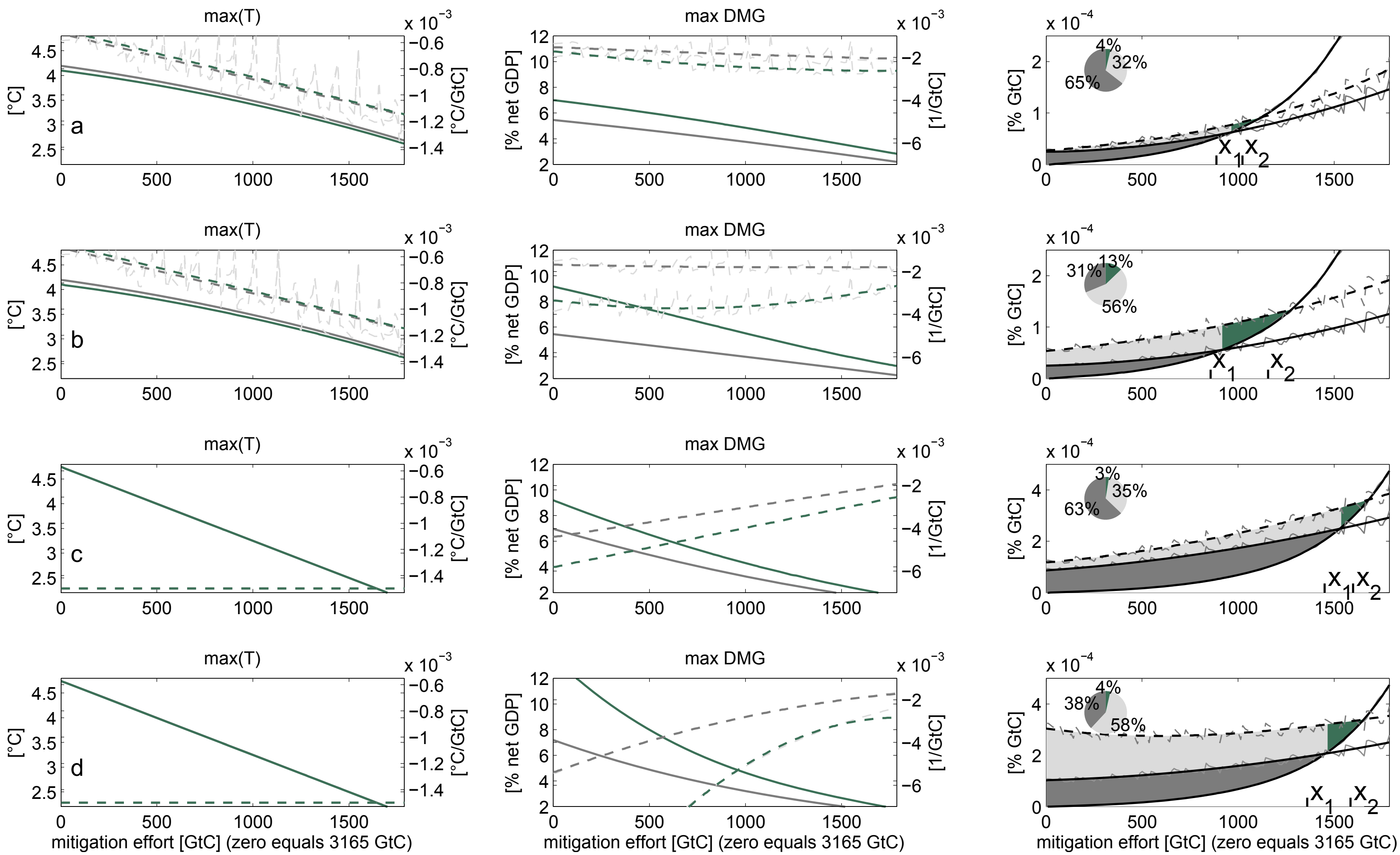
Figure 1 | Schematic representation of the progression from CO_2 emissions to climate change. We define 'carbon sensitivity' as the increase in atmospheric CO_2 concentrations that result from CO_2 emissions, as determined by the strength of natural carbon sinks.



The effect of linear temperature response



Combined effect



Conclusions

- Explicit introduction of uncertainty about CS and damages is unimportant:
  - The marginal risk premium is only significant for high mitigation costs.
  - Due to the steep marginal costs of mitigation
- Uncertainty can become important for exponential damages, linear climate carbon response and slower increasing marginal costs

- **We have a framework for determining the origin of important uncertainty effects in complex integrated assessment models.**

Is this relevant for the planned uncertainty comparison project?

➔ Different perspective: Focus on decisions under uncertainty vs. input uncertainty

➔ Only accessible to a small subgroup of models (which can do stochastic programming)

➔ But parts of the marginal cost-benefit picture are more accessible (be aware of different metrics for the objective function)

Further responding to Bill‘s request

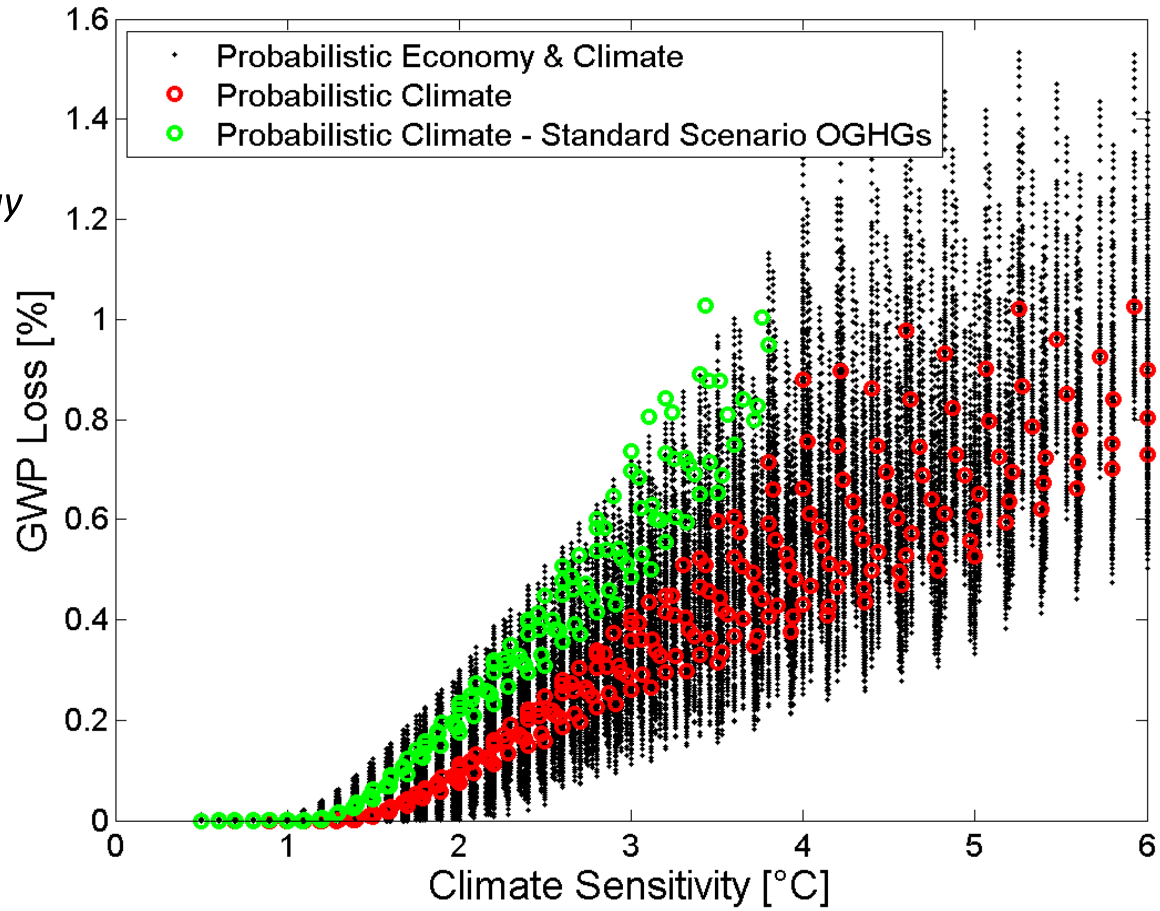
Sensitivity studies of model response to key input assumption that may be interesting for the workshop

- **Exploration of climate and technological uncertainty in MIND**
- **The RoSE project**

Sensitivity of mitigation costs to uncertain parameters

Strong dependence on uncertain climate system (climate sensitivity, ocean heat uptake) and techno-economic parameters (resource base, learning rate of renewable energies)

Held H, Kriegler E, Lessmann K, Edenhofer O (2009): *Efficient Climate Policy under Technology and Climate Uncertainty*. Energy Economics 31

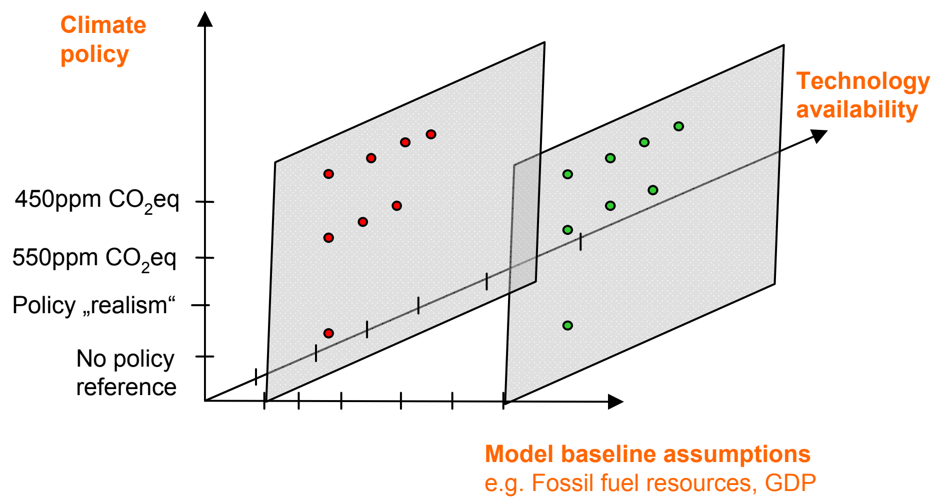


RoSE – The Concept

Overarching RoSE policy question:
What are *robust* scenarios for transforming the energy system to meet climate protection targets?

Tools of the analysis: *“Integrated assessment models” (IAMs)*
i.e. coupled global energy-economy-(land use)-climate models

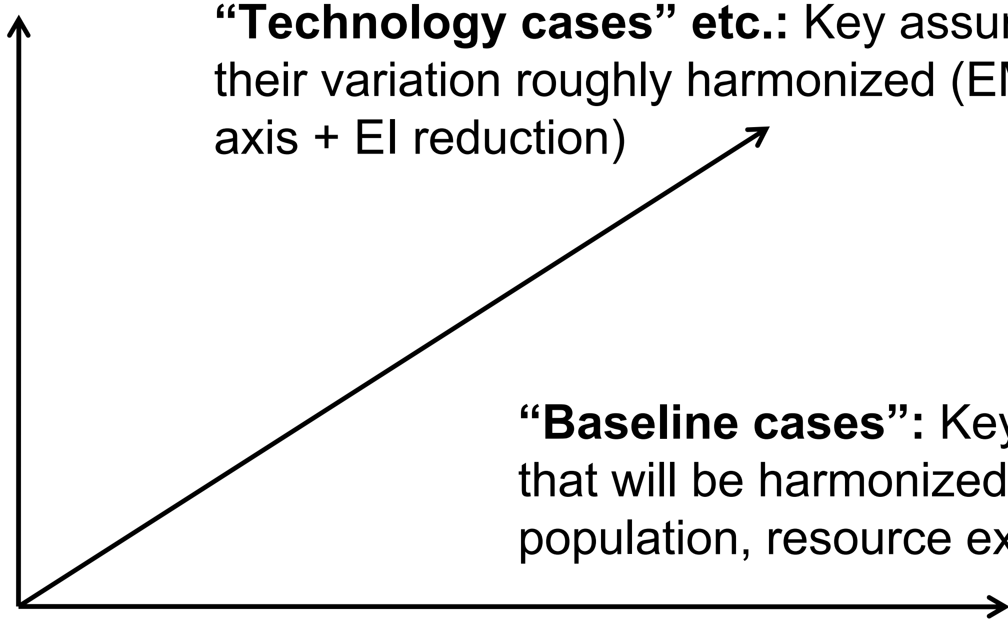
Assessing „robustness“:
Explore IAM scenarios w.r.t.
- differences across models
- key assumptions in models
- effects neglected in models



RoSE scenario space

Policy cases

“Technology cases” etc.: Key assumptions with only their variation roughly harmonized (EMF24 technology axis + EI reduction)



“Baseline cases”: Key assumptions that will be harmonized (GDP, population, resource extraction costs)

RoSE Participants and Contributors

Coordination: Elmar Kriegler, Ottmar Edenhofer (PIK)

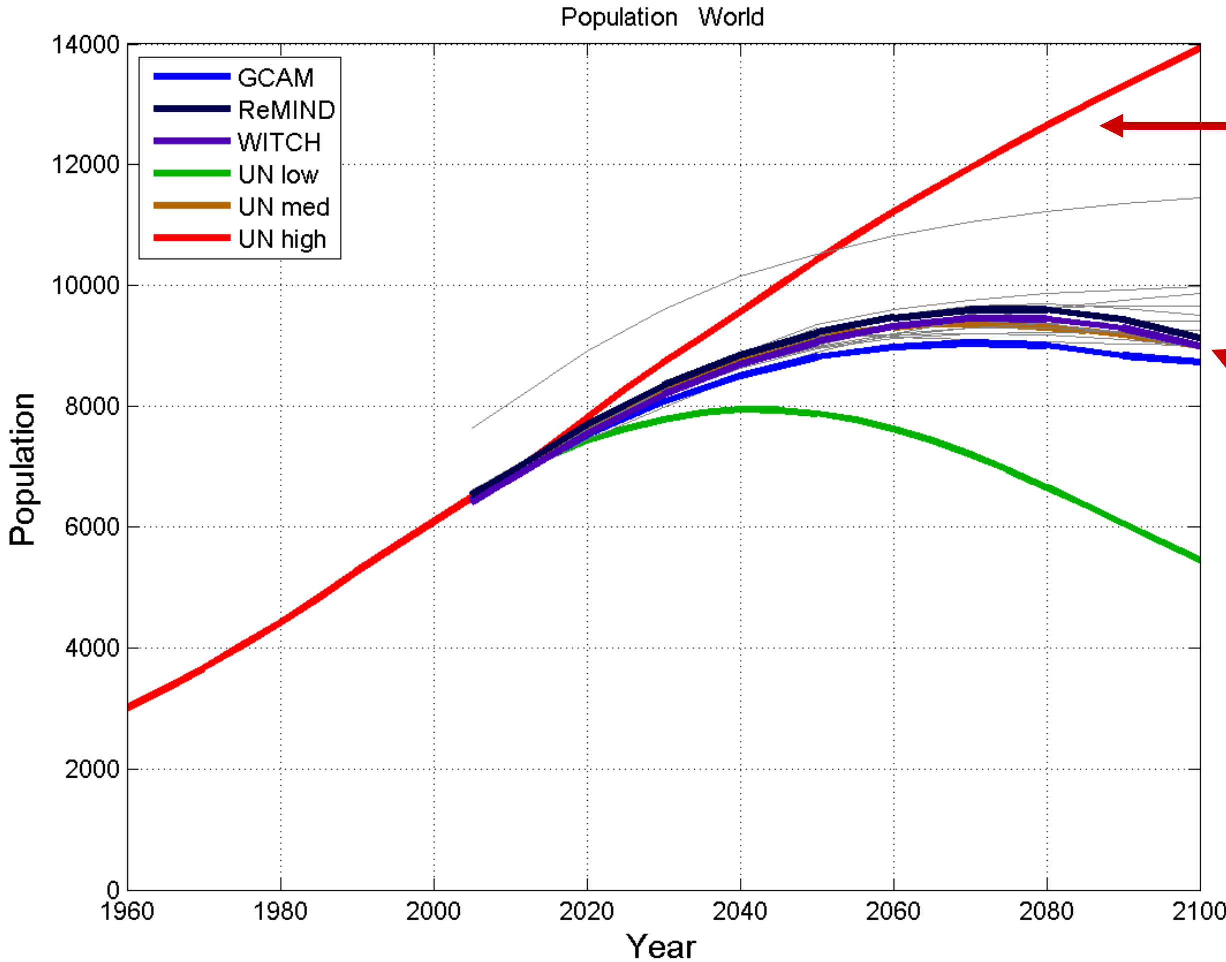
Integrated assessment modeling teams:

- **CMCC:** Carlo Carraro, Massimo Tavoni, Enrica DeCian, Fabio Sferra; (*WITCH*)
- **JGCRI/PNNL:** Jae Edmonds, Leon Clarke, Kate Calvin (*GCAM*)
- **ERI:** Jiang Kejun (*IPAC*)
- **PIK:** Gunnar Luderer, Ioanna Mouratiadou, Lavinia Baumstark, Jessica Strefler, Nico Bauer, Anastasis Giannousakis (*ReMIND*)
- **Tsinghua University:** Chen Wenying, Yin Xiang (*China-MARKAL*)

Domain experts:

- **Aleh Cherp** (Central European University; *Energy Security*)
- **Doyne Farmer** (Santa Fe Institute; *Technological Progress*)
- **Hans-Holger Rogner** (IAEA; *Energy Resources*)
- **Andreas Schäfer** (Stanford University; *Transport*)
- **Shonali Pachauri** (IIASA; *Energy Access and Hausehold Consumption*)
- Further topics still open: Water resources, Policy scenarios, Institutional needs, (Rare) Material supply for the energy transformation

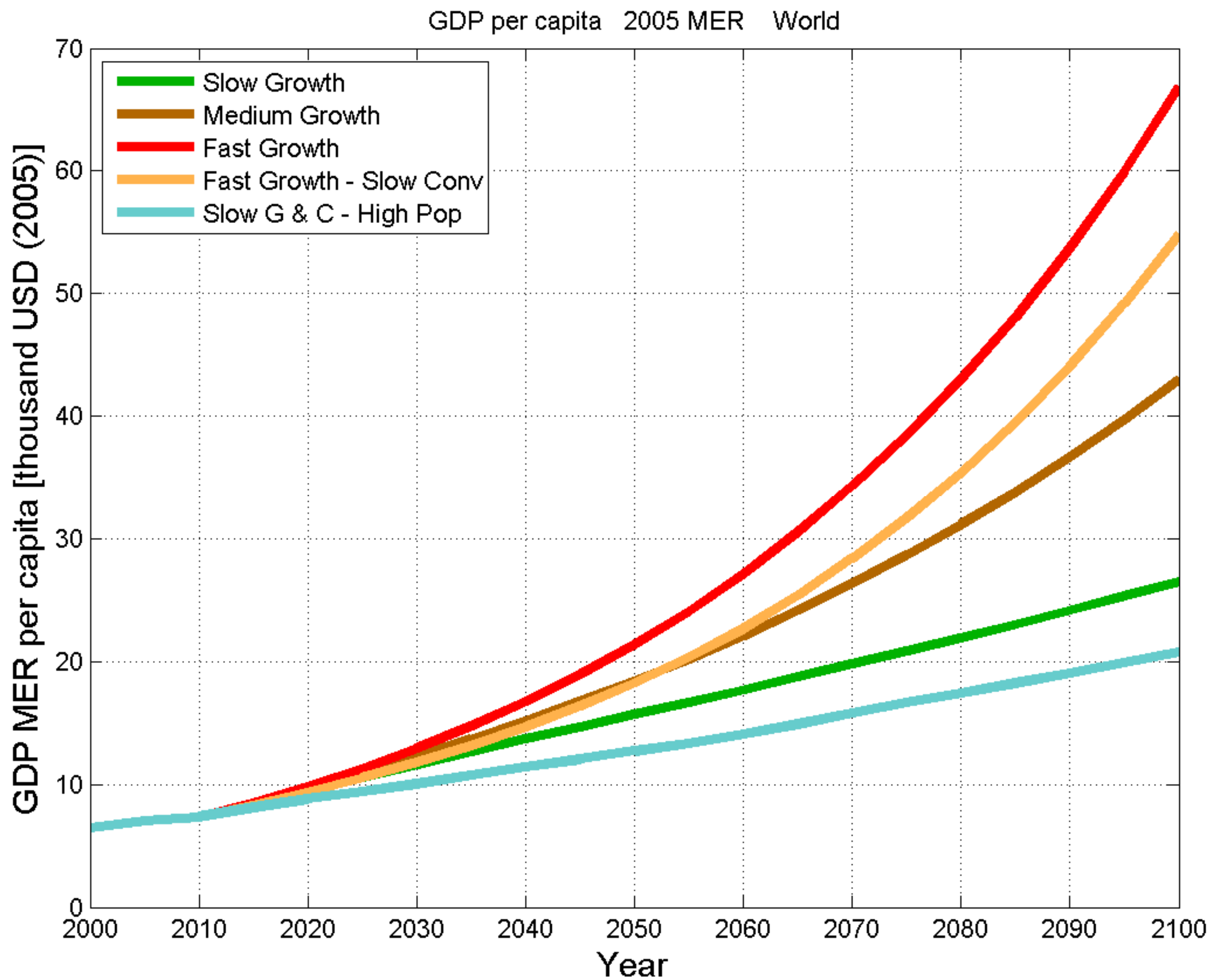
Harmonization: UN Population scenarios



RoSE harmonization: UN high scenario
(for slow growth scenario)

RoSE harmonization: UN medium scenario
(for all but one RoSE scenario)

RoSE GDP per capita scenarios - World



Thank you!