Climate Change Impacts & Climate Economics

SIPTA School 2014, Montpellier
25. 7. 2014

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Hermann Held

Also Guest at

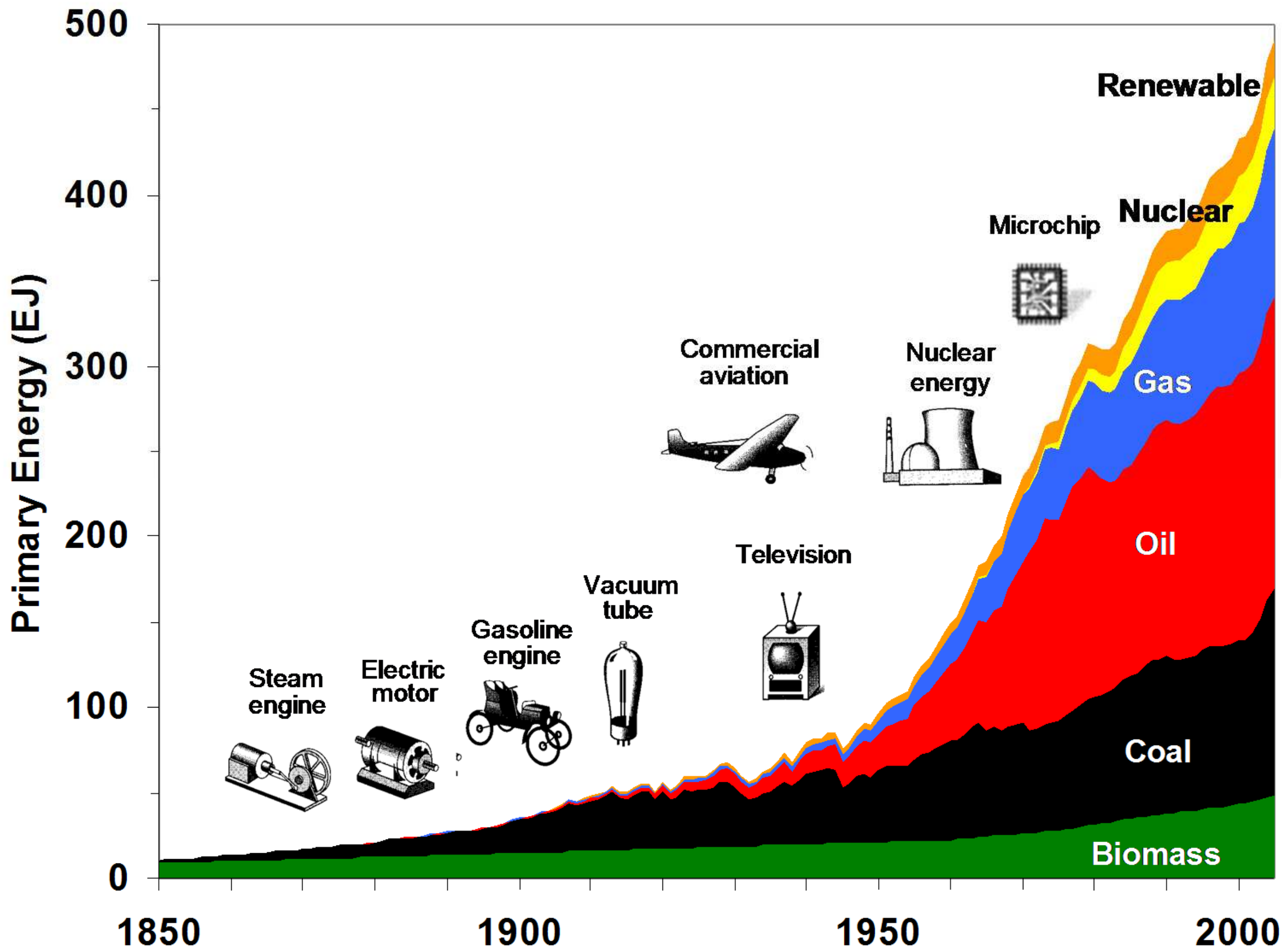
Potsdam Institute for Climate Impact Research (PIK)

POTSDAM INSTITUTE FOR CLIMATE IMPACT RESEARCH

Table of Contents

- In what sense could global warming be regarded a climate ‘problem’?
- Two competing schools within climate economics:
  Cost benefit versus cost effectiveness analysis
- Integrated energy-climate-economic modelling
- An archetypical IP model on climate model uncertainty

Global Primary Energy Consumption



(Nakicenovic 2009)

Carbon Dioxide Impact Cascade

Larger & more frequent impacts of global warming

↑

Increase of global mean temperature

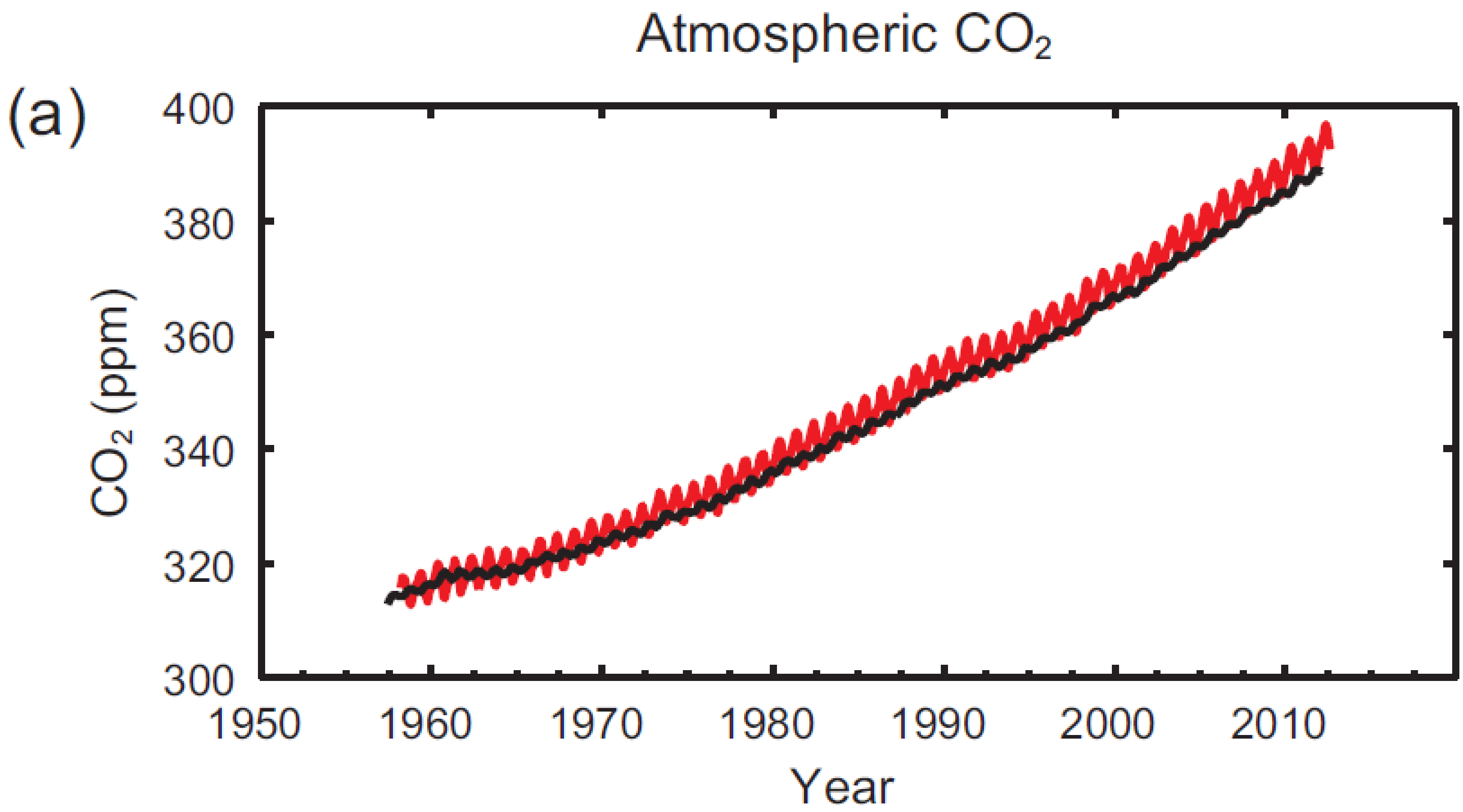
↑

Increase of CO_2-concentration in the atmosphere

↑

CO_2-emissions

Time Evolution of Atmospheric CO_2 Concentration



IPCC AR5 WG-I SPM (2013)

Box:
IPCC

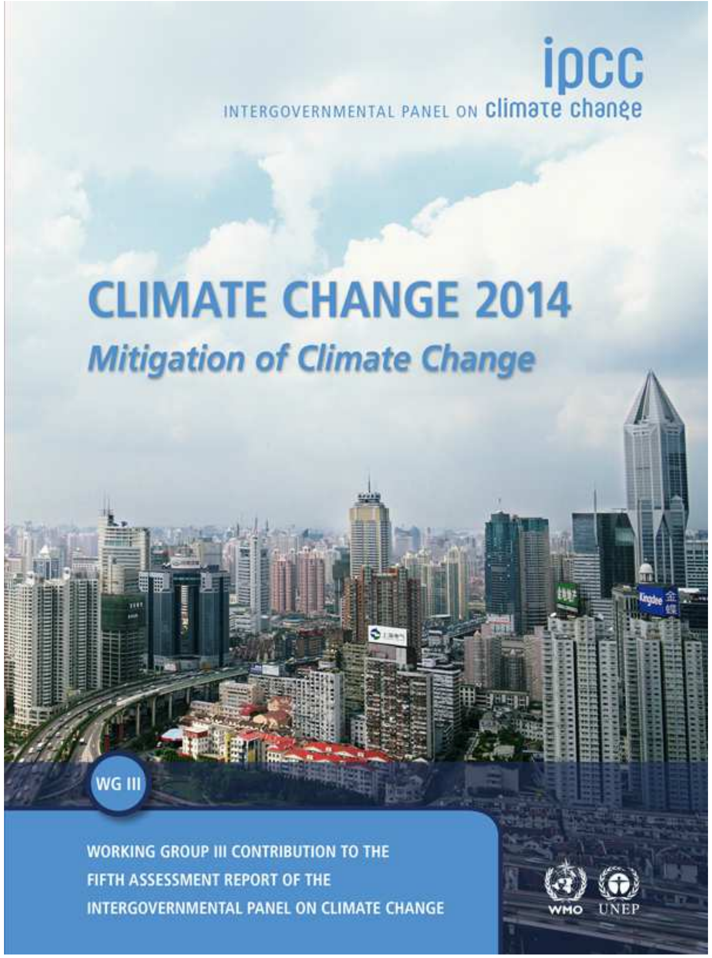
- Intergovernmental panel on climate change
- Triggered by UN & WMO
- “Assessment reports” delivered in 1990, 1995, 2001, 2007, 2014 (hence in 2014: “AR5”)
- 3 working groups
  I. Physical basis
  II. Global warming impacts & adaptation
  III. Mitigation

IPCC reports are the result of extensive work of many scientists from around the world.

Report by WGIII

1 Summary for Policymakers
(jointly by experts & governments)
1 Technical Summary

16 Chapters
(incl. Executive Summaries)
235 Authors
900 Reviewers
More than **2000** pages
Close to **10,000** references
More than **38,000** comments



-> 4 Levels of aggregation

ipcc
INTERGOVERNMENTAL PANEL ON climate change

Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties

IPCC Cross-Working Group Meeting on Consistent Treatment of Uncertainties
Jasper Ridge, CA, USA
6-7 July 2010

Core Writing Team:
Michael D. Mastrandrea, Christopher B. Field, Thomas F. Stocker,
Ottmar Edenhofer, Kristie L. Ebi, David J. Frame, Hermann Held, Elmar Kriegler,
Katharine J. Mach, Patrick R. Matschoss, Gian-Kasper Plattner, Gary W. Yohe,
and Francis W. Zwiers

- ‘Uncertainty’ used in the sense of ‘partial lack knowledge’
- Includes models like precise probability measures
- ‘Peaceful co-existence’ of frequentistic & subjective probability approaches
- Only sparse mentioning of imprecise measures
- → Room for re-analyses & elevated statistical analysis of data?
- Formal uncertainty assessment, followed by ‘confidence’ statement on the overall procedure requested

End of Box on IPCC

We cannot explain temperature rise without anthropogenic forcings

IPCC AR5 WG-I SPM (2013)

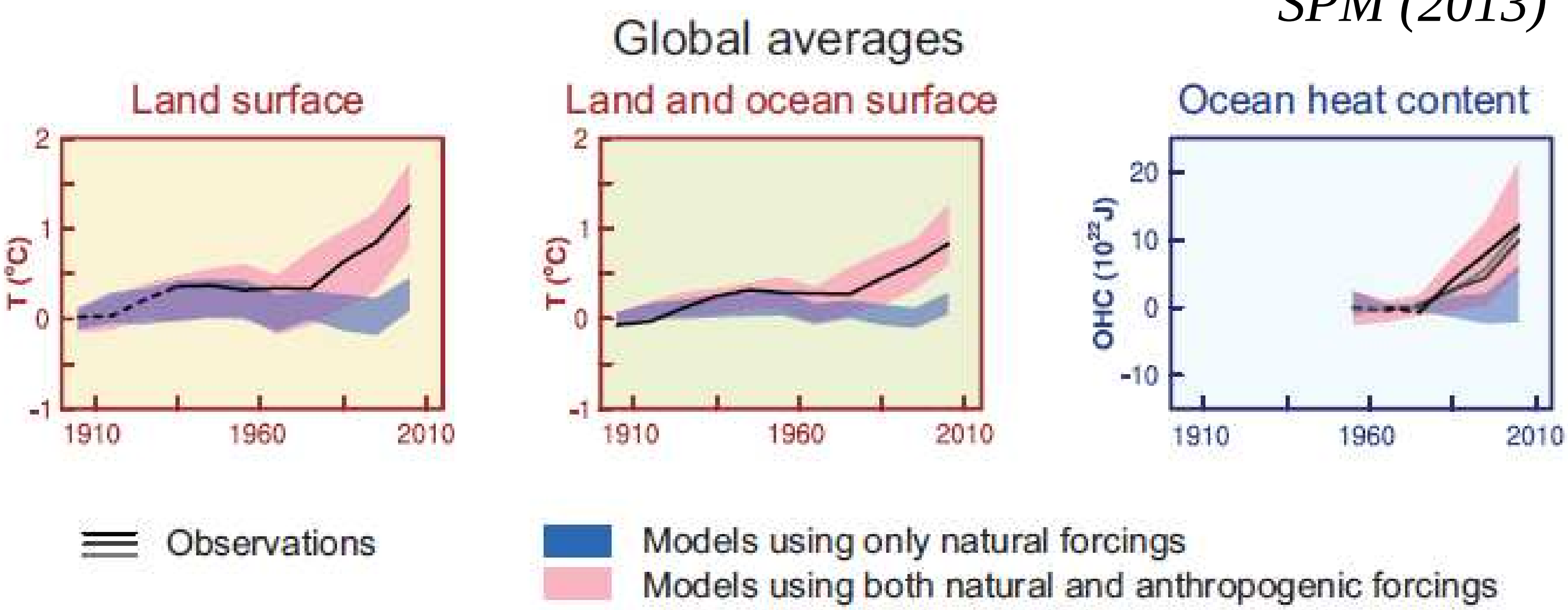


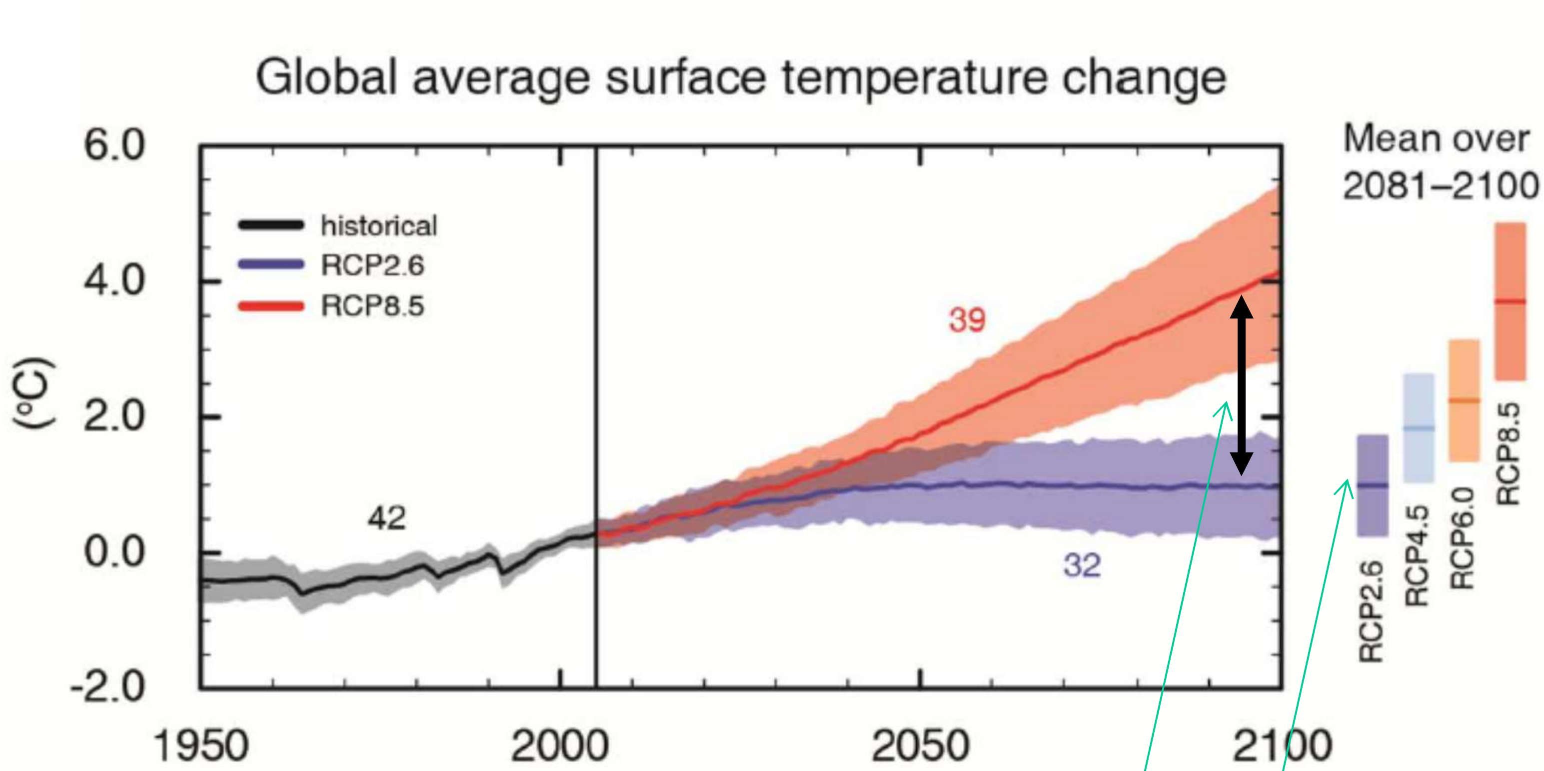
Figure SPM.6 | Comparison of observed and simulated climate change based on three large-scale indicators in the atmosphere, the cryosphere and the ocean: change in continental land surface air temperatures (yellow panels), Arctic and Antarctic September sea ice extent (white panels), and upper ocean heat content in the major ocean basins (blue panels). Global average changes are also given. Anomalies are given relative to 1880–1919 for surface temperatures, 1960–1980 for ocean heat content and 1979–1999 for sea ice. All time-series are decadal averages, plotted at the centre of the decade. For temperature panels, observations are dashed lines if the spatial coverage of areas being examined is below 50%. For ocean heat content and sea ice panels the solid line is where the coverage of data is good and higher in quality, and the dashed line is where the data coverage is only adequate, and thus, uncertainty is larger. Model results shown are Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model ensemble ranges, with shaded bands indicating the 5 to 95% confidence intervals. For further technical details, including region definitions see the Technical Summary Supplementary Material. {Figure 10.21; Figure TS.12}

Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes (see Figure SPM.6 and Table SPM.1). This evidence for human influence has grown since AR4. It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century. {10.3–10.6, 10.9}

In this Summary for Policymakers, the following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms (extremely likely: 95–100%, more likely than not >50–100%, and extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, e.g., *very likely* (see Chapter 1 and Box TS.1 for more details).

IPCC AR5 WG-I SPM (2013)

Future Temperature Rise: Climate Policy´s Room for Manoeuvre



- What policy could influence
- Climate science-induced uncertainty

IPCC AR5 WG-I SPM

For later…

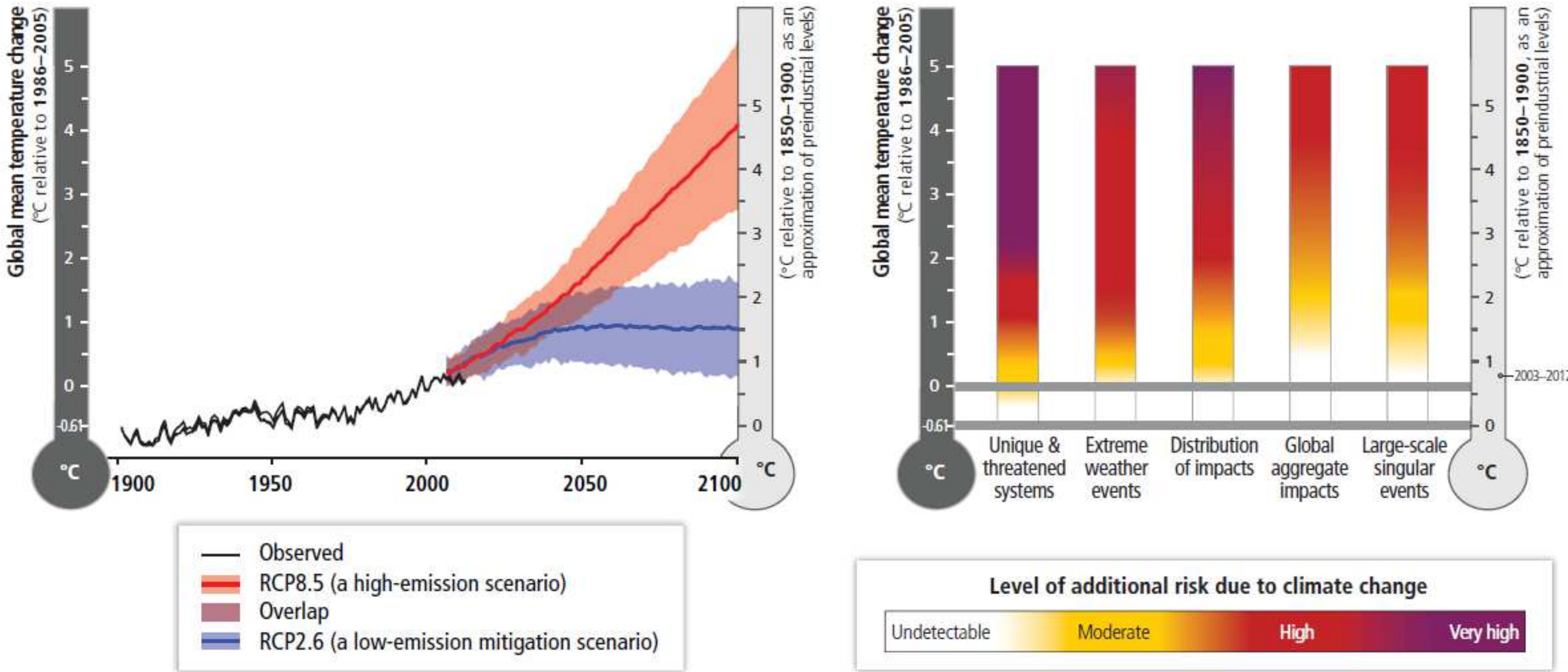
- Uncertainty in temperature response is on the same order of magnitude than the very effect.

- Hence, uncertainty should become part of the climate policy decision-calculus.

Two Lines of Argument behind Global Warming Mitigation Policies

- Explicitly projected impacts of global warming might be ‘too large’

- Precautionary principle
  - beyond certain regimes knowledge too poor to weigh costs and benefits



Assessment Box SPM.1 Figure 1 | A global perspective on climate-related risks. Risks associated with reasons for concern are shown at right for increasing levels of climate change. The color shading indicates the additional risk due to climate change when a temperature level is reached and then sustained or exceeded. Undetectable risk (white) indicates no associated impacts are detectable and attributable to climate change. Moderate risk (yellow) indicates that associated impacts are both detectable and attributable to climate change with at least *medium confidence*, also accounting for the other specific criteria for key risks. High risk (red) indicates severe and widespread impacts, also accounting for the other specific criteria for key risks. Purple, introduced in this assessment, shows that very high risk is indicated by all specific criteria for key risks. [Figure 19-4] For reference, past and projected global annual average surface temperature is shown at left, as in Figure SPM.4. [Figure RC-1, Box CC-RC; WGI AR5 Figures SPM.1 and SPM.7] Based on the longest global surface temperature dataset available, the observed change between the average of the period 1850–1900 and of the AR5 reference period (1986–2005) is 0.61°C (5–95% confidence interval: 0.55 to 0.67°C) [WGI AR5 SPM, 2.4], which is used here as an approximation of the change in global mean surface temperature since preindustrial times, referred to as the period before 1750. [WGI and WGII AR5 glossaries]

(IPCC AR5 WGII SPM)

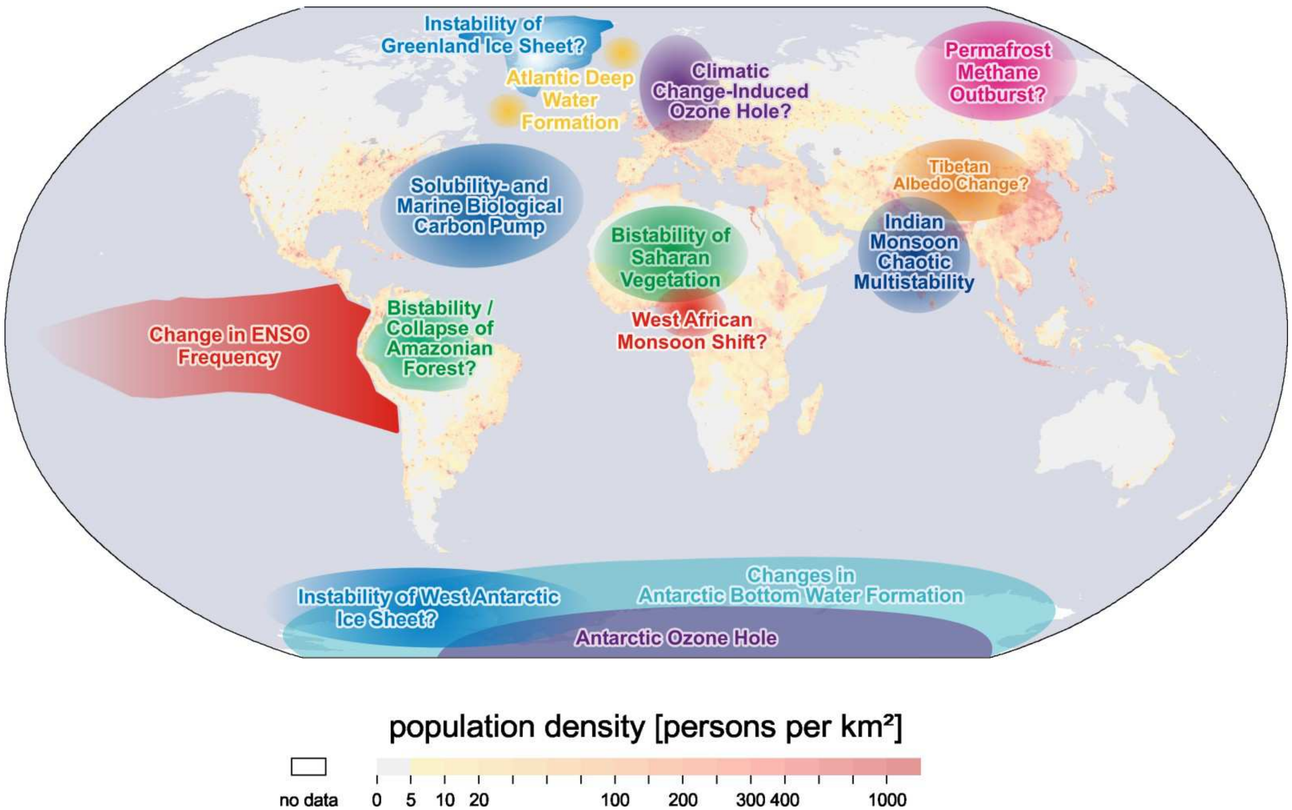
Explaining the Color Code

Hereby, necessary condition for at least moderate risk:

- Detectable (null-hypothesis rejected a climate without global warming could explain the impact phenomenon)

- Attributable (in a linear multi-causal model, significant contribution of global warming)

Potential Tipping Elements in the Climate System

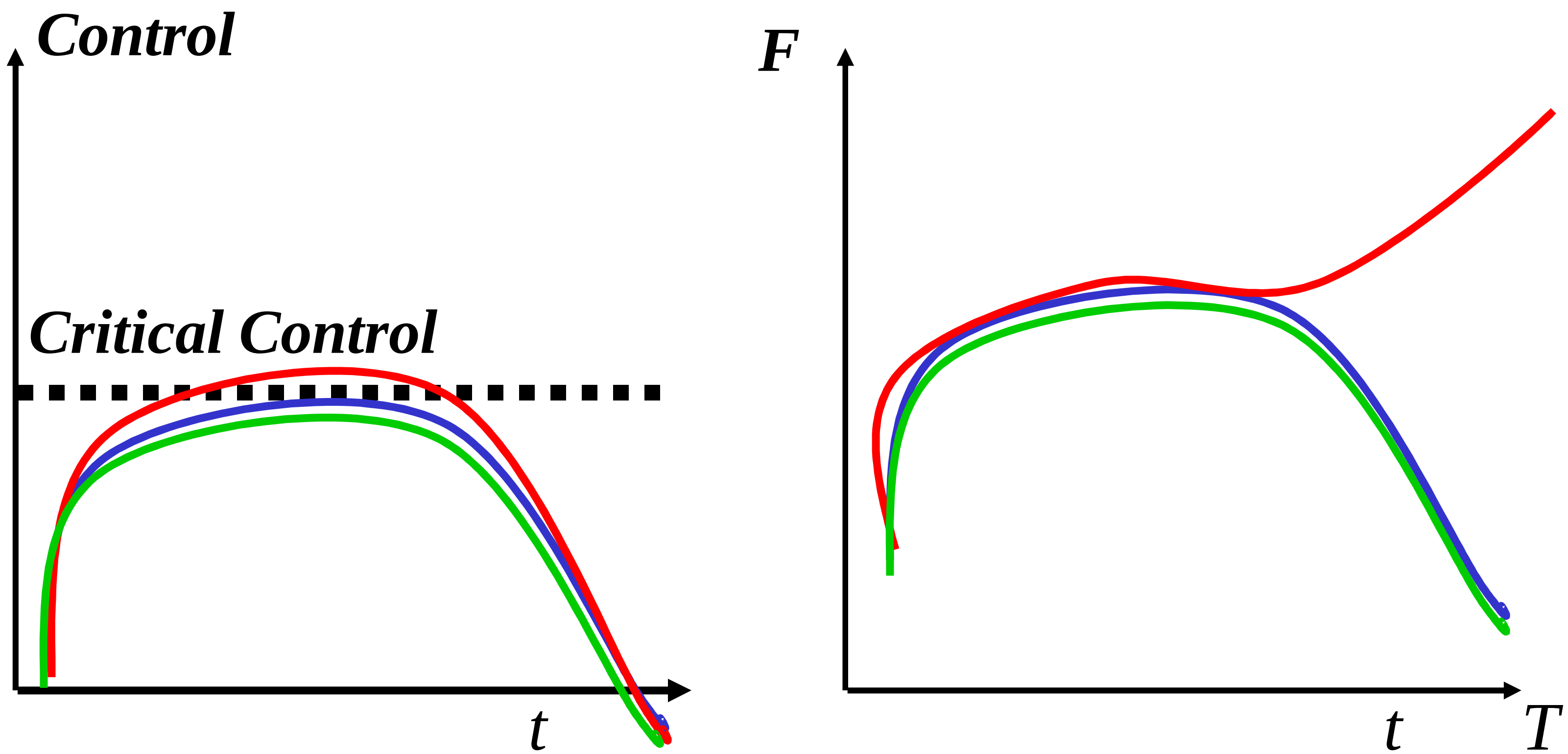


(Schellnhuber & Held 2002;
Lenton, Held, Kriegler, Hall, Lucht, Rahmstorf, Schellnhuber, PNAS, 2008;
Dakos, Scheffer, van Nes, Brovkin, Petoukhov, Held, PNAS 2008;
Kriegler, Hall, Dawson, Held, H. J. Schellnhuber, PNAS, 2009;
M. Scheffer, J. Bascompte, W. Brock, V. Brovkin, S. Carpenter, V. Dakos,
H. Held, E. van Nes, M. Rietkerk, G. Sugihara, Nature, 2009)

Tipping Element Definition

- Σ = sub-system (≥ sub-continental scale, e.g. MOC)
- F = $F(\Sigma)$ = feature of interest (e.g. overturning)
- ρ = forcing (e.g. global mean temperature)
- ρ_{crit} = critical value
- Small excursions $\delta\rho$ should induce large impacts $\hat{F}$

Tipping Element Definition
General Case



An Earth System Component Σ is called a *Tipping Element* if

(1) there are a macro-feature F of Σ, a control parameter ρ, and critical values F_{crit}, ρ_{crit} such that

$$| F(F_{crit}; \rho_{crit} + \delta\rho | T) - F(F_{crit}; \rho_{crit} | T) | \geq \hat{F} > 0,$$

where $\delta\rho$ is a small control variation, $\hat{F}$ a characteristic measure, and $T \geq 0$ an observation time;

(2) F_{crit}, ρ_{crit} are accessible through human interference with the present Earth System state.

- (3) Effect within ‚ethical time horizon‘
- (4) ‚relevant‘ impacts

- Lenton, Held, Kriegler, Hall, Lucht, Rahmstorf, Schellnhuber,
  PNAS, Feb12, 2008

Imprecise probability assessment of tipping points in the climate system

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[a]Potsdam Institute for Climate Impact Research, PO Box 60 12 03, 14412 Potsdam, Germany; [b]Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA 15213-3890; [c]School of Civil Engineering and Geosciences, Newcastle University, Newcastle-upon-Tyne NE1 7RU, United Kingdom; [d]Tyndall Centre for Climate Change Research, University of Newcastle-upon-Tyne, Newcastle-upon-Tyne NE1 7RU, United Kingdom; [e]Environmental Change Institute, Oxford University, Oxford OX1 3QY, United Kingdom; and [f]Tyndall Centre for Climate Change Research, University of East Anglia, Norwich NR4 7TJ, United Kingdom

Edited by William C. Clark, Harvard University, Cambridge, MA, and approved February 2, 2009 (received for review September 16, 2008)

Major restructuring of the Atlantic meridional overturning circulation, the Greenland and West Antarctic ice sheets, the Amazon rainforest and ENSO, are a source of concern for climate policy. We have elicited subjective probability intervals for the occurrence of such major changes under global warming from 43 scientists. Although the expert estimates highlight large uncertainty, they allocate significant probability to some of the events listed above. We deduce conservative lower bounds for the probability of triggering at least 1 of those events of 0.16 for medium (2–4 °C), and 0.56 for high global mean temperature change (above 4 °C) relative to year 2000 levels.

making its future initiation inevitable.

In the Bayesian paradigm, subjective probabilities constitute a measure of degree of belief as reflected in an individual's disposition to act (as opposed to the frequentist paradigm in which probabilities are thought of as limiting frequencies) (7, 8). The use of subjective probabilities is closely linked to decision analysis, which tries to identify best courses of action based on quantified preferences and beliefs together with a set of normative criteria for rational decision making (*cf.* ref. 9). To better inform decision making processes, formal elicitation protocols have been developed for assessing subjective probabilities of experts in the field (see ref. 10 for an overview). Such protocols established procedures to avoid common biases in the assessment of probabilities, drawing on a large body of literature on heuristics and framing effects in decision making under uncertainty (11). A common criticism is that expert elicitations do not add to the body of scientific knowledge unless verified by data or theory. In the context of risk analysis and decision making, however, expert elicitations have proved to be a unique tool for systematically gathering and projecting scientific information in complex policy problems (12, 13). It is increasingly recognized that they can play a valuable role for informing climate policy decisions (14). Formal elicitations have already been con-

Author contributions: E.K., J.W.H., and H.-J.S. designed research; E.K., J.W.H., and R.D. performed research; E.K., J.W.H., and H.H. contributed new reagents/analytic tools; E.K., J.W.H., and R.D. analyzed data; and E.K. wrote the paper.

The authors declare no conflict of interest.

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This article contains supporting information online at www.pnas.org/cgi/content/full/0809117106/DCSupplemental.

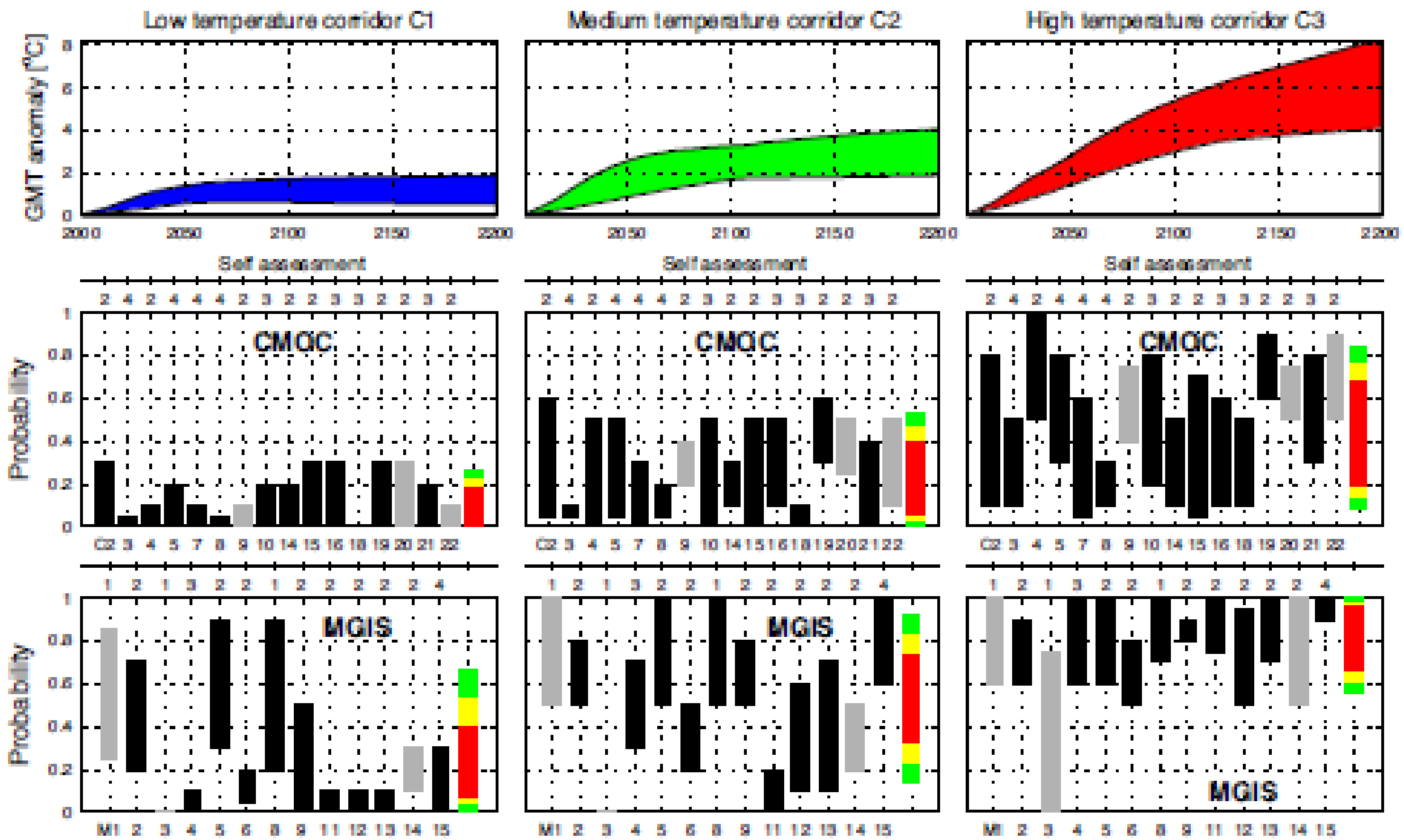
www.pnas.org/cgi/doi/10.1073/pnas.0809117106

PNAS | March 31, 2009 | vol. 106 | no. 13 | 5041–5046

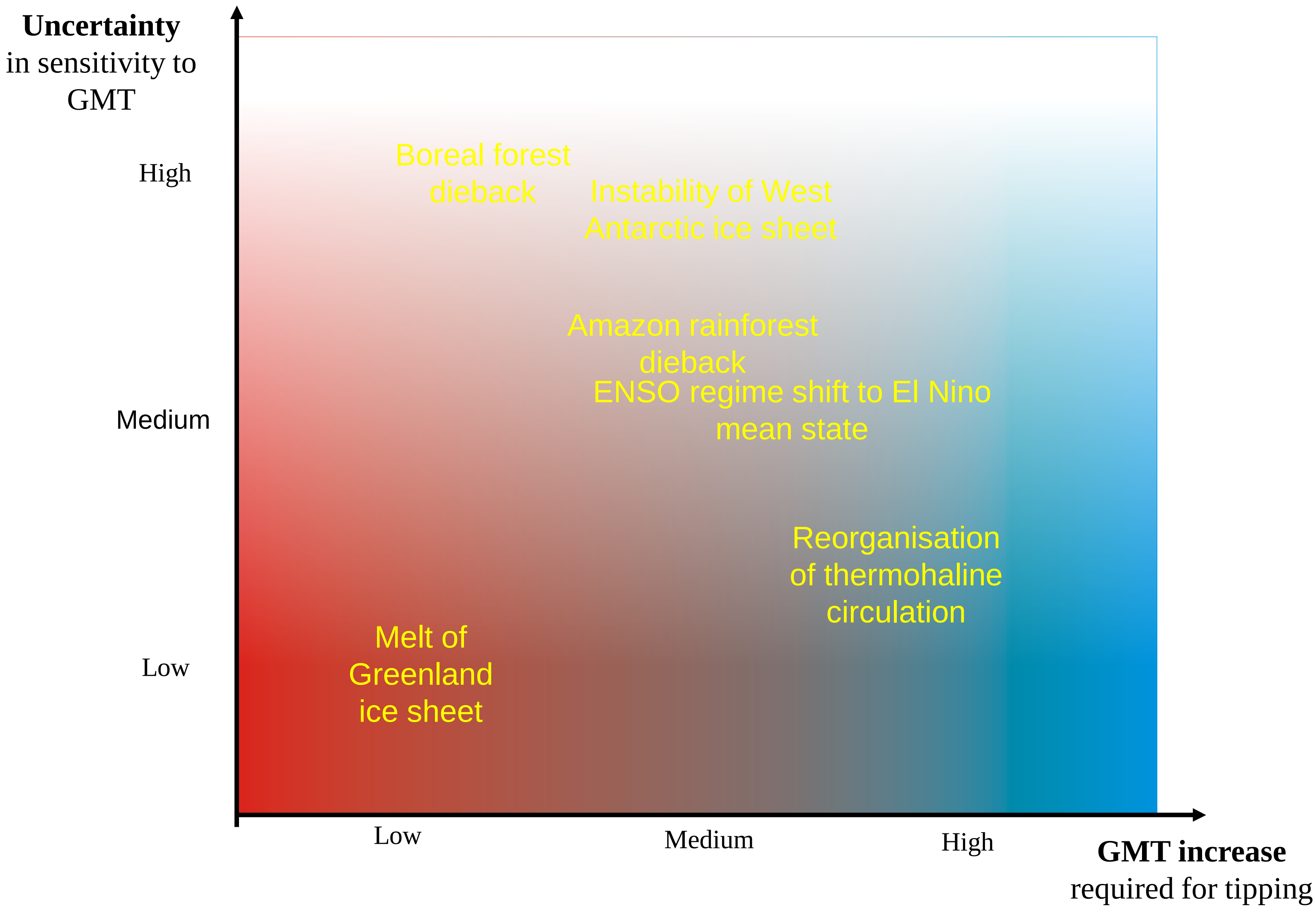
Allowing experts to specify IPs of Triggering as a function of Temp.

~North Atlantic Circulation

~Greenland Ice Sheet



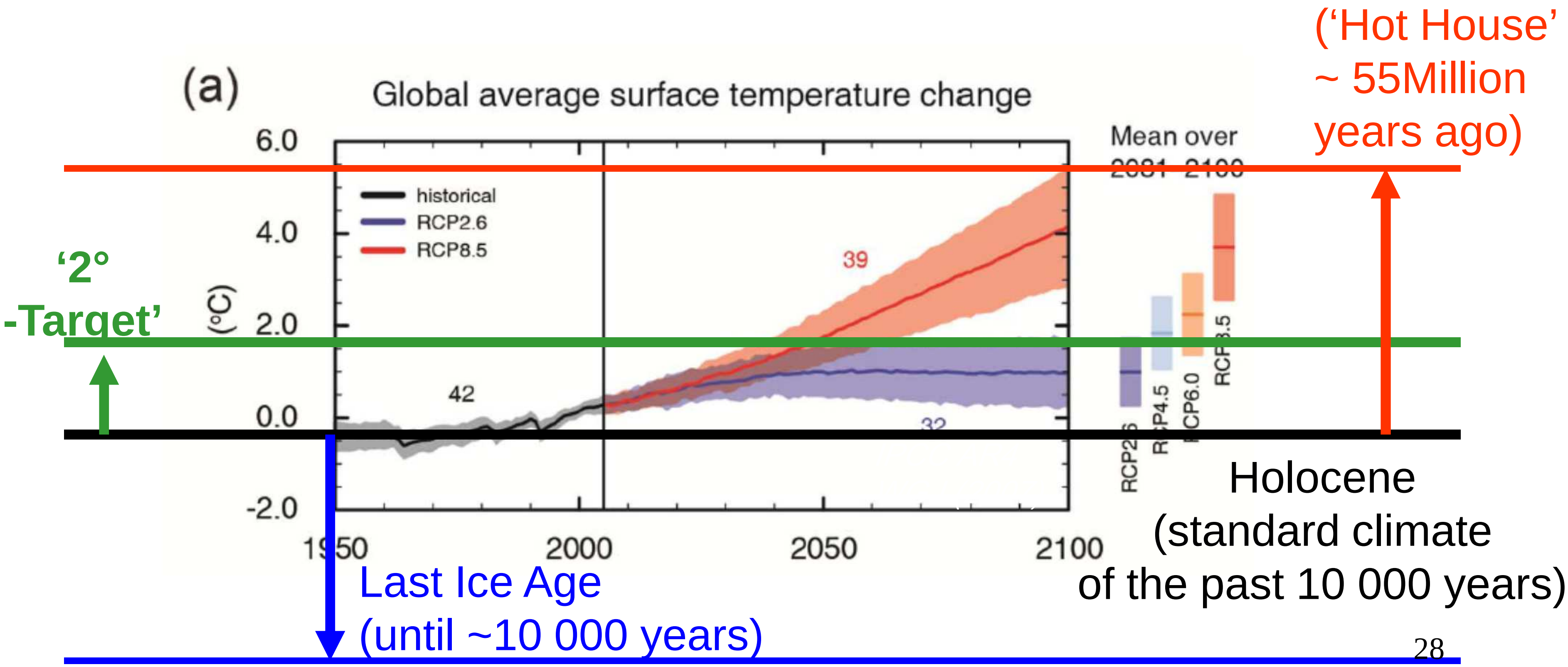
Proximity of Threshold vs Certainty



Data-Source: Expert-Elic. 50/200 , detailed descr. Kriegler, Hall, Dawson, Held, Schellnhuber, 2009

- Combining expert-interview-generated IPs & more objectively generated data?

One possible interpretation of the Precautionary Principle:
Avoid Historic Dimension of Temperature Rise



H Held

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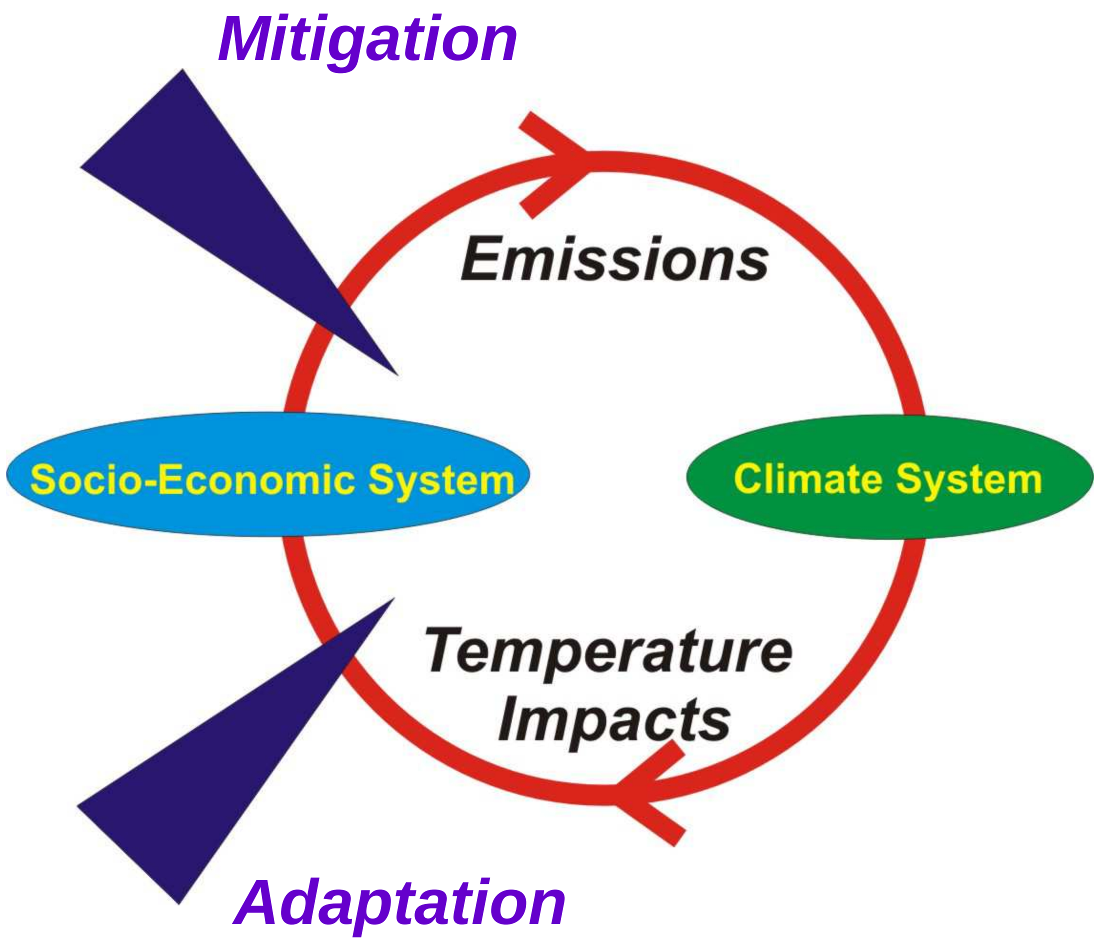
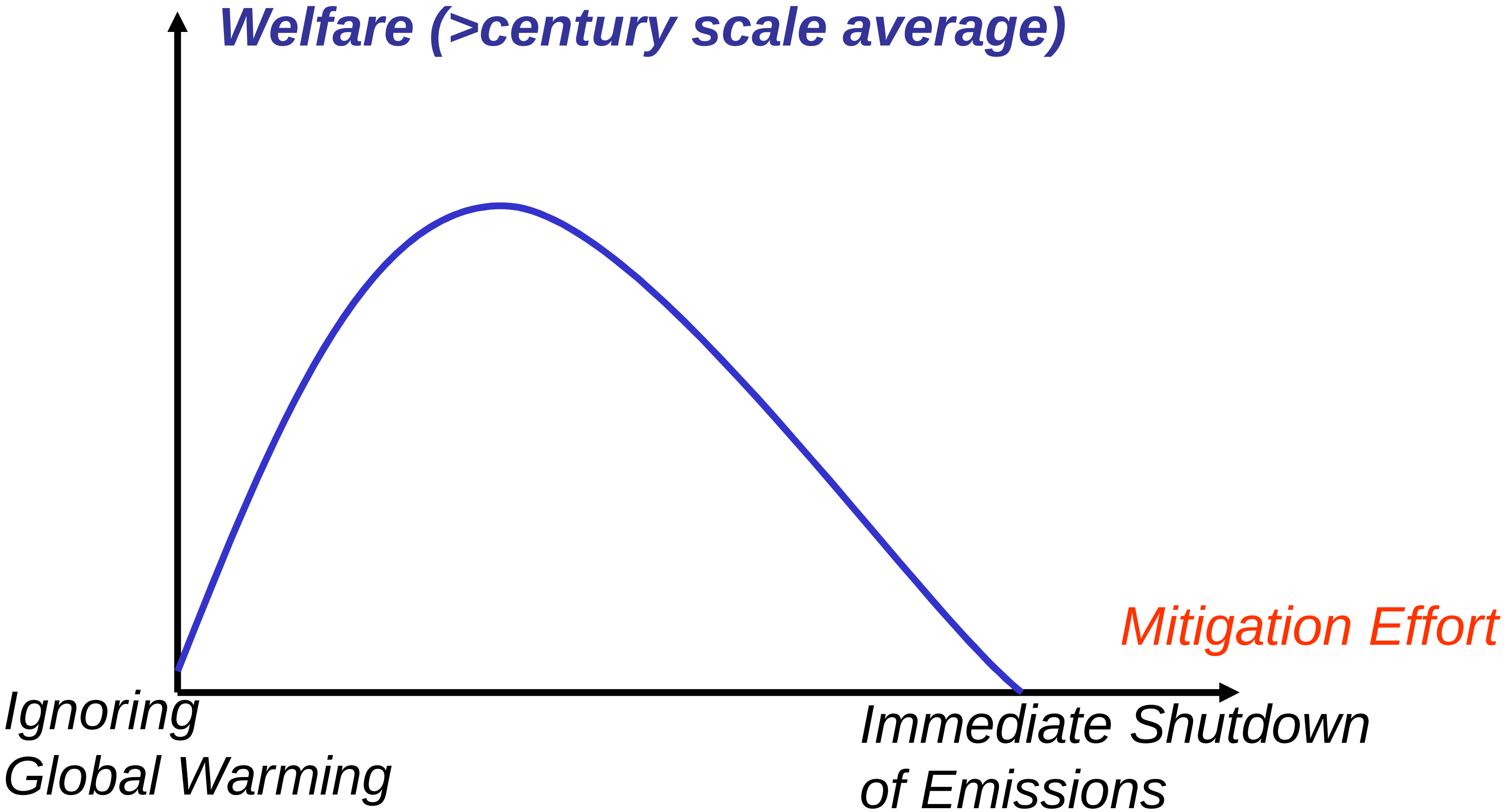
Climate Policies



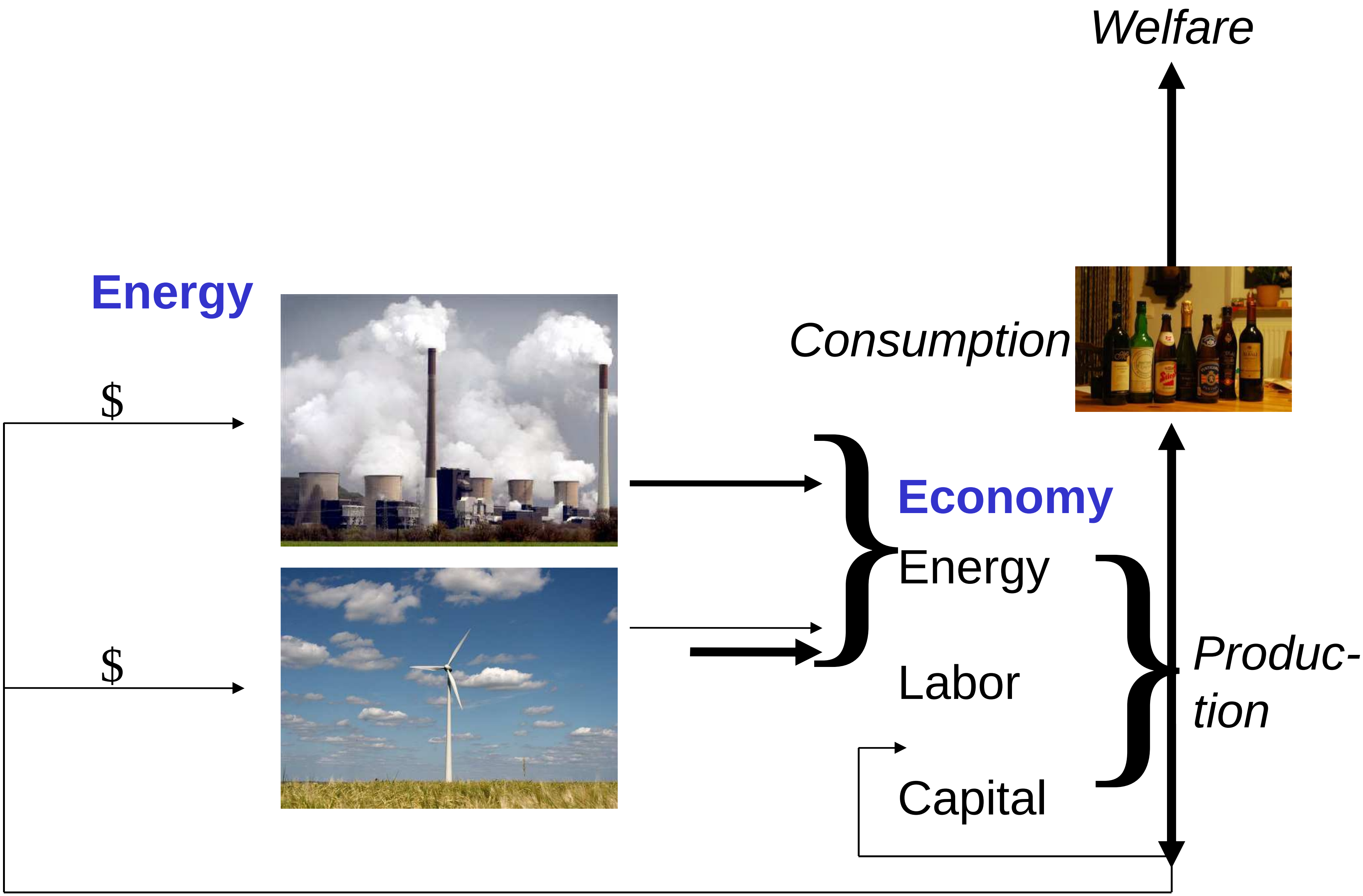
Limits of Adaptation?

- For simplicity of didactics, we do not consider adaptation in the remainder of today’s lecture…

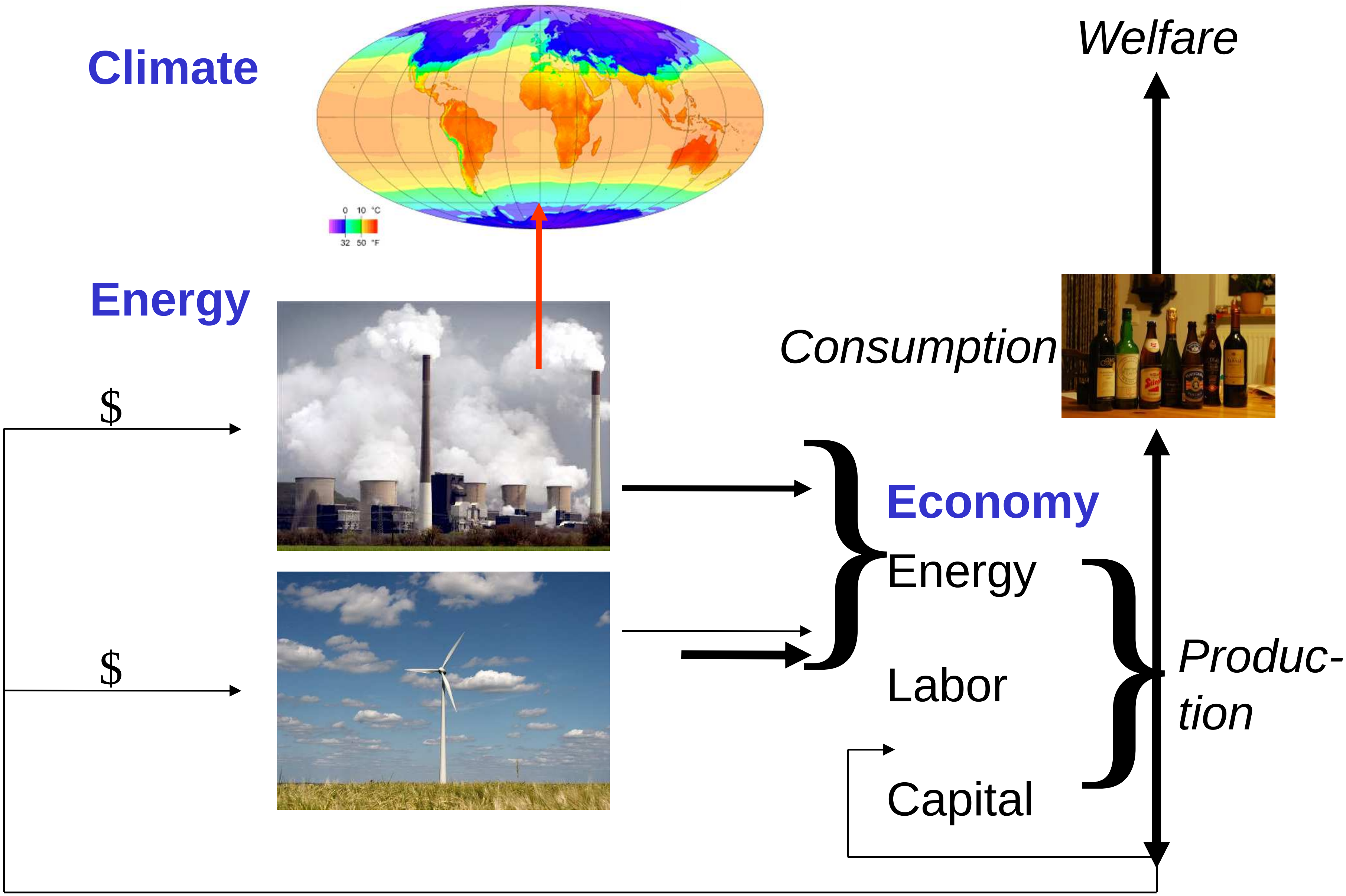
How much Mitigation is ‚Optimal'?



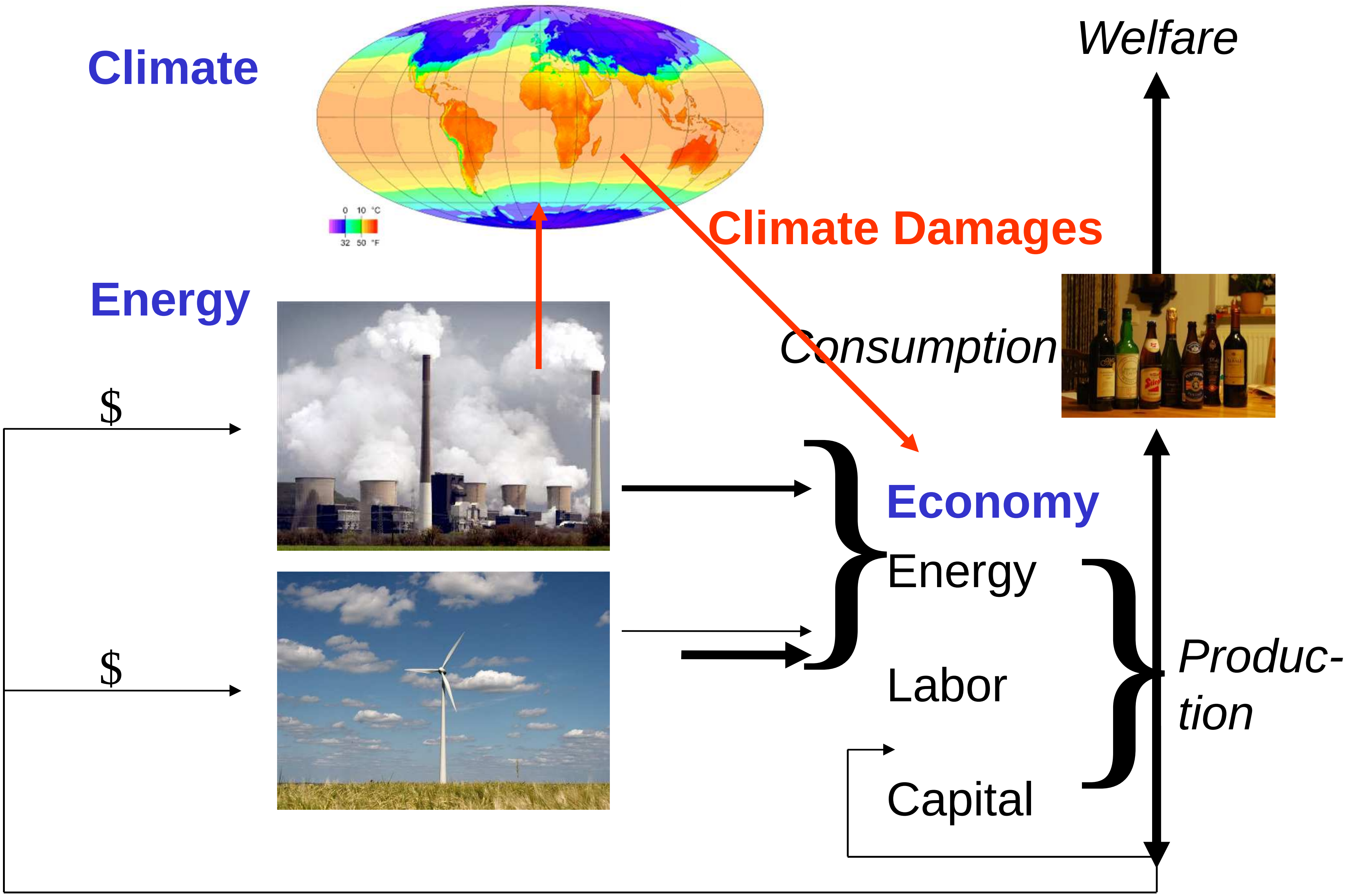
An interdisciplinary Optimisation Problem



An interdisciplinary Optimisation Problem



An interdisciplinary Optimisation Problem



How much mitigation is desirable?
Cost Benefit Analysis: The standard tool of environmental economics

Present-day mitigation costs

Future avoided damages

Conceptual Difficulties

- Impacts poorly known
  - Often poor natural science/engineering knowledge (at least today)
  - Need for valuation of goods

- Need to weigh
  - Present mitigation costs … against …
  - Future avoided damages

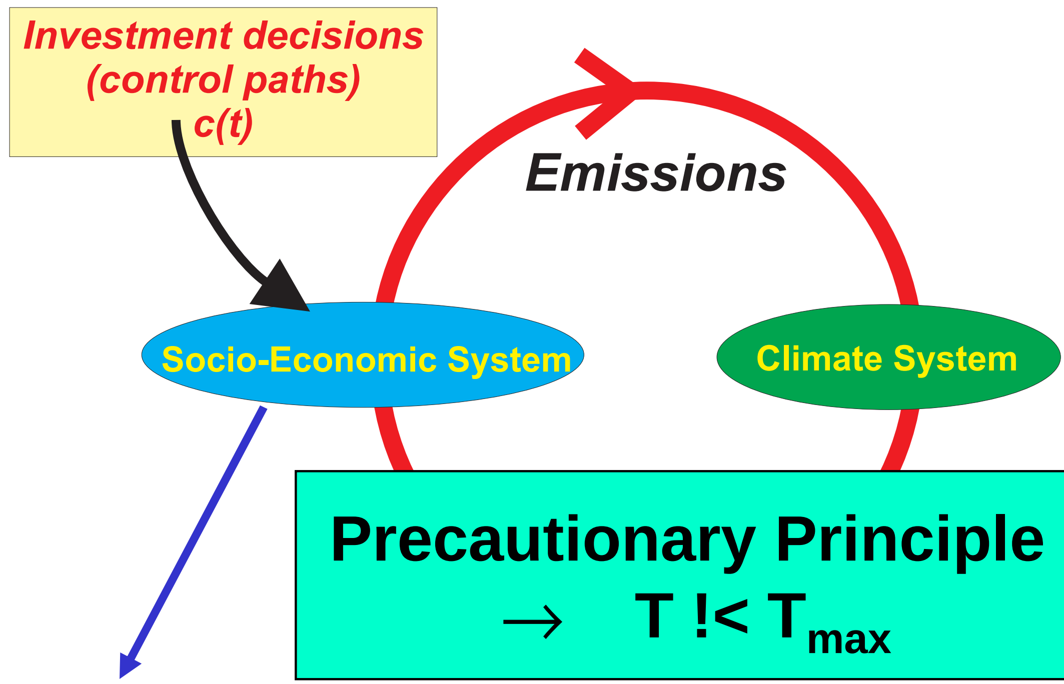
- An easier & better-posed alternative? …

When to Invest How Much into which Energy Technology?

Phrasing as a Control Problem

Investments in

- ***Renewables***
- ***Efficiency***
- ***Fossil Fuels***
- ***CCS***



Precautionary Principle

$\rightarrow$ T !< T_{max}

$$\mathrm{Max!}_{(c(t_0),\ldots,c(\infty))}\ \mathrm{Welfare} := \int_{t_0}^{\infty} dt\, \boxed{\mathrm{Utility'}}(t)[(c(t_0),\ldots,c(t))]\ \mathrm{e}^{-\rho t}$$

$$\text{subject to}\quad \forall_t\ T(t)[(c(t_0),\ldots,c(t))] < T_{\mathrm{max}}$$

‘Cost-Effectiveness-Mode’

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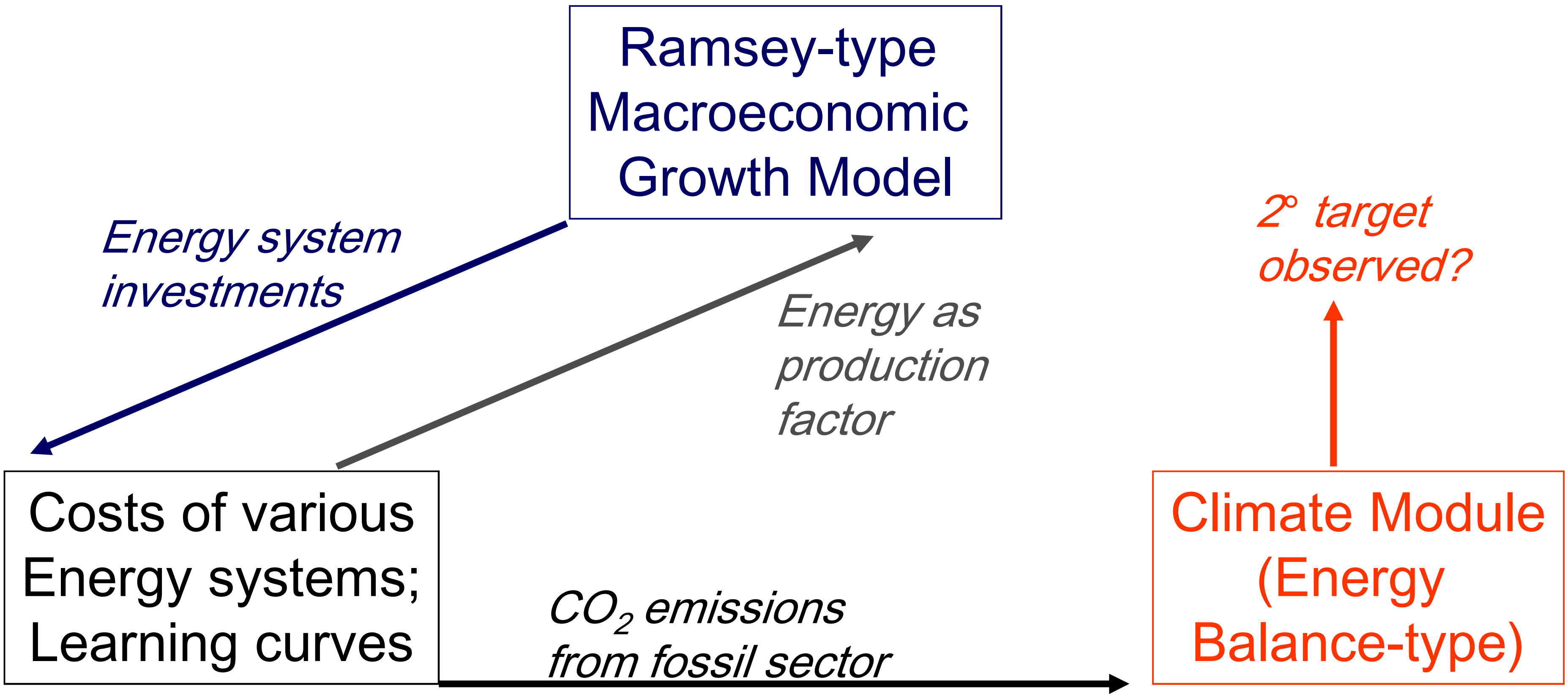
Our Research Question

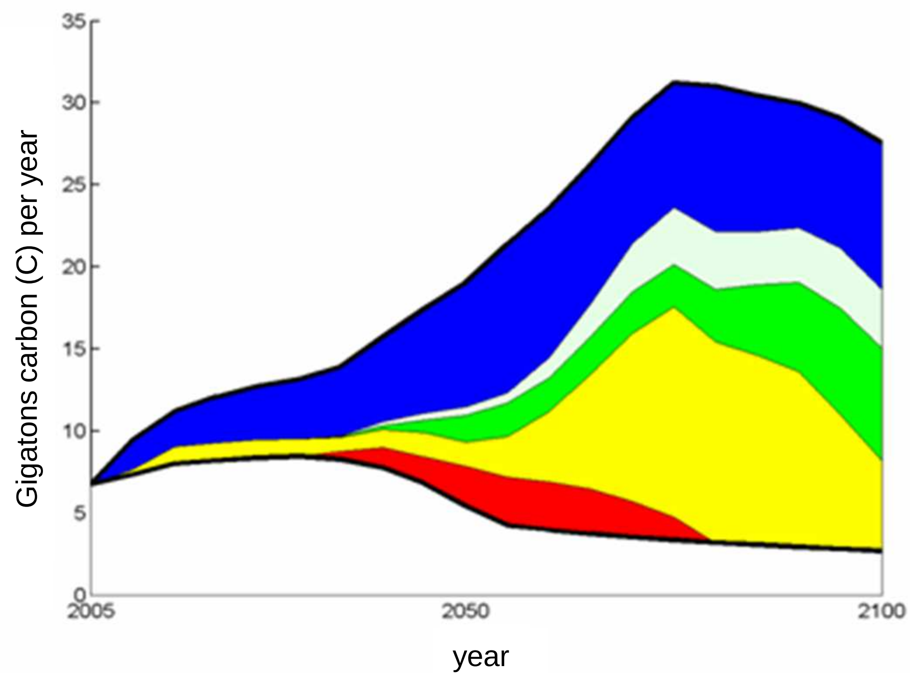
- **When** to invest **how much** into **what energy** technology, given the 2°C (X°-)target?
- Options:
  - – Renewable sources
  - – Energy efficiency
  - – Carbon capture & sequestration (CCS)
  - – Nuclear
- $\Rightarrow$ coupled economy – climate modules.

Costs of Climate Targets?
Our Model Setup



Edenhofer et al. (MIND / ReMIND; 2005-2012)

Bridging the Mitigation Gap



Energy-induced emissions

- **nuclear**
- renewables
- biomass + CCS
- fossil + CCS
- efficiency

Coal/Oil/Nat.Gas cheap, pure time preference rate 1%

From REMIND-G (0D-Model)

Bruckner, Edenhofer, Held et al., 2009

Costs of Mitigation?

IPCC AR5 WGIII (April 2014) assessed ~1000 energy-economic scenarios, published since AR4 (2007)

Economic Welfare Effects of 450ppmeq (~2°C) Target?

- Economic reference case:

  Scenario without climate damages and without climate policy
- This is characterized by global economic growth of 1,6 - 3 % / year.

- 2°-oriented scenarios compatible with continued global economic growth.
- Annual growth rate reduced by 0.06 %- points .

- Hereby avoided warming-induced net damages not yet included.

- *(After IPCC AR5 WGIII SPM)*

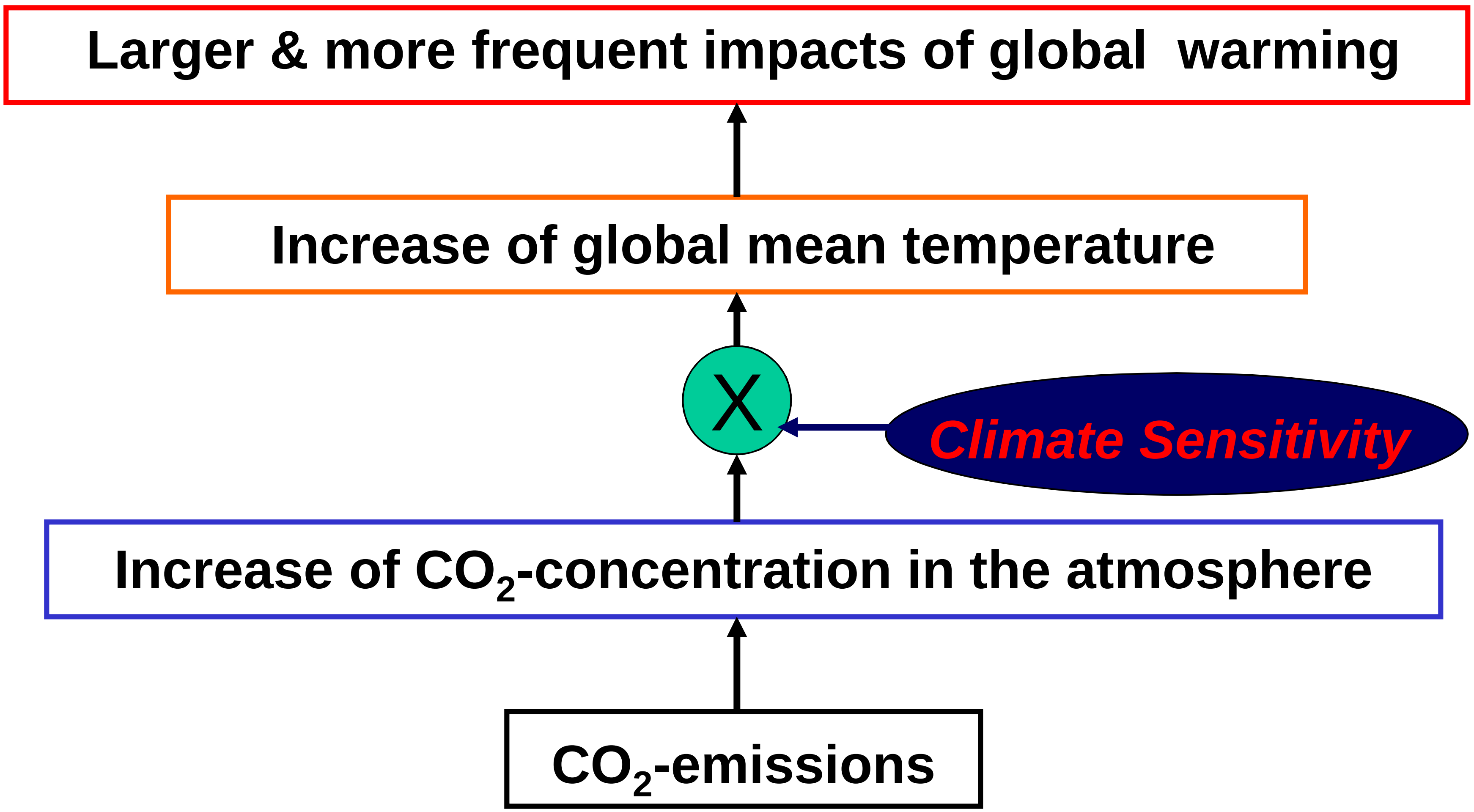
- 2° target '~insurance premium against unpredictable warming damages'

Hedging Strategy needed in view of ‘Irreversibility Effect under Uncertainty‘

- Our actions may have irreversible effects:
  - Investing too early in a specific energy technology or adaptation measures may lead to stranded investments.
  - Waiting too long on mitigation may trigger irreversible climate system or ecological effects.

$\rightarrow$ Again an application for optimisation, if uncertainty is reflected in the welfare function.

Key Factor Climate Sensitivity



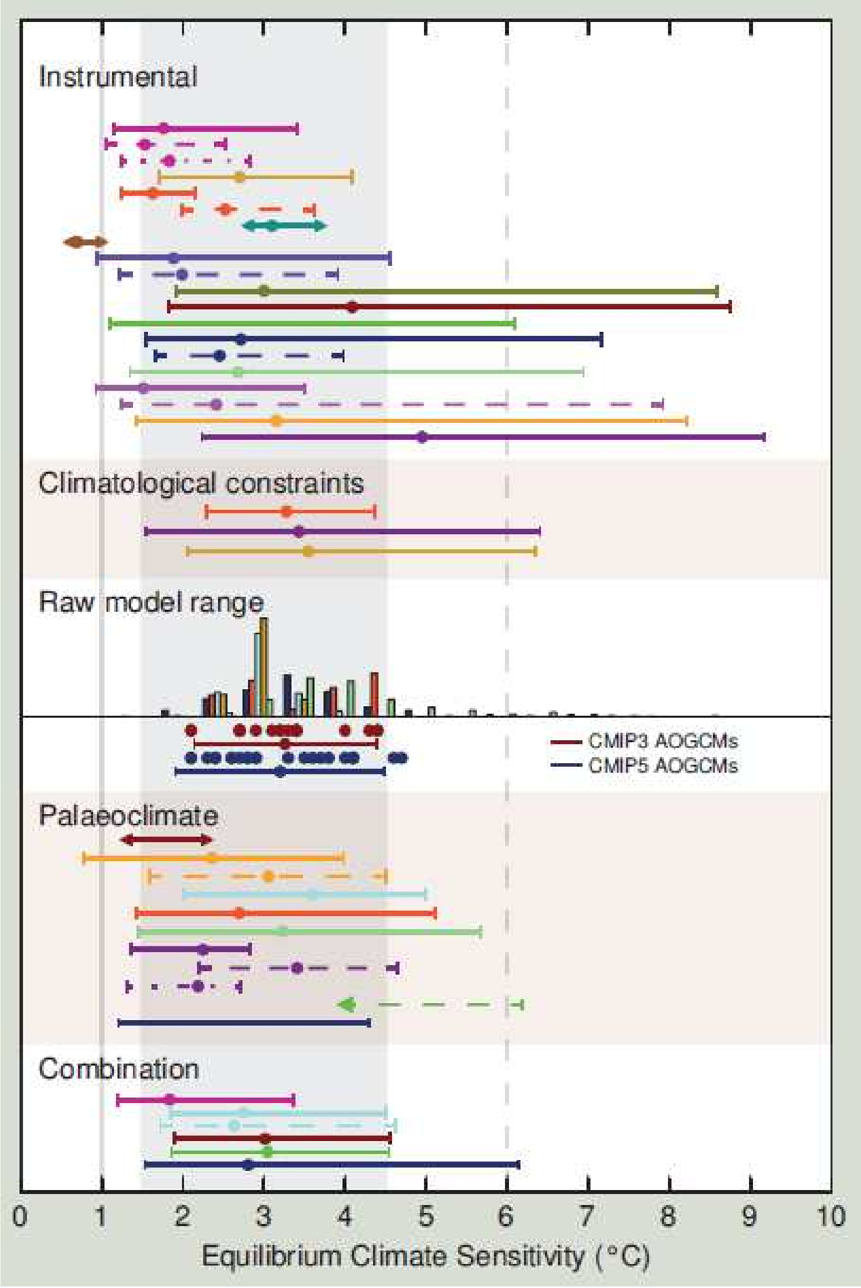
Definition of Climate Sensitivity

- CS:= Change in global mean surface temperature for doubling pre-industrial CO_2 concentration, i.e.

- T(560 ppm CO_2) – T(280 ppm CO_2)

- *Convenient climate system surrogate: Uncertainty in CS explains > 50% of uncertainty in global warming projections*

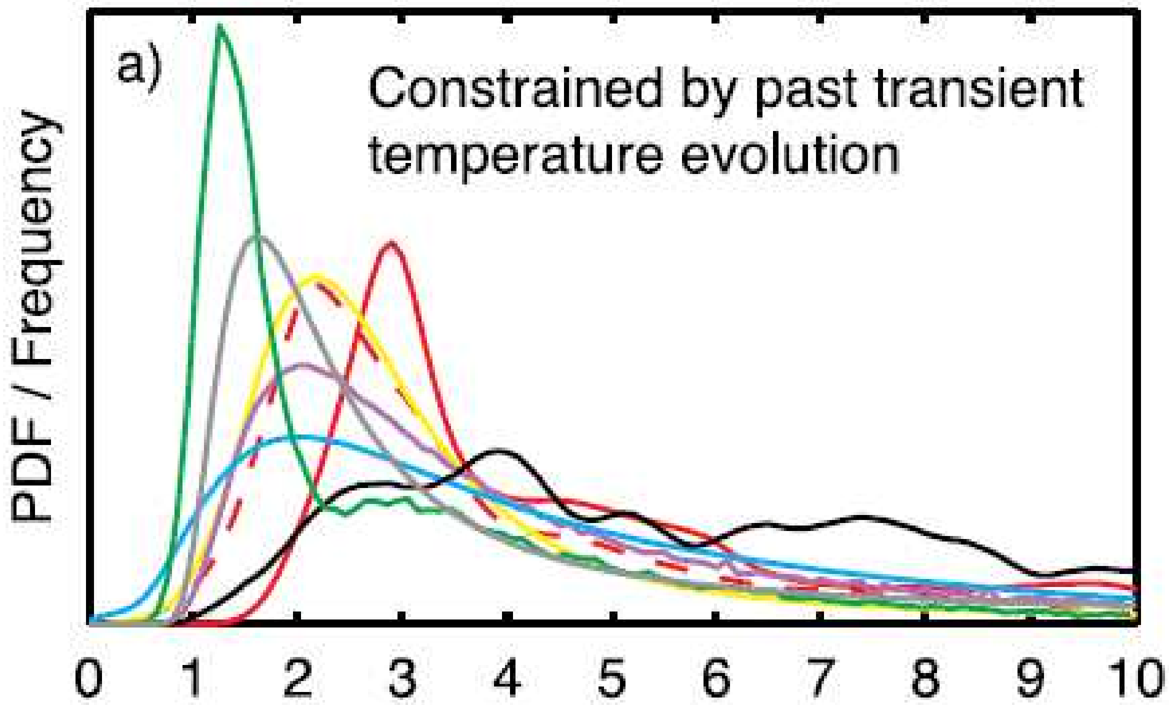
Estimates of Climate Sensitivity (CS)



IPCC AR5 TS (2013)

None of the reconstruction methods opens room for '0' climate sensitivity.

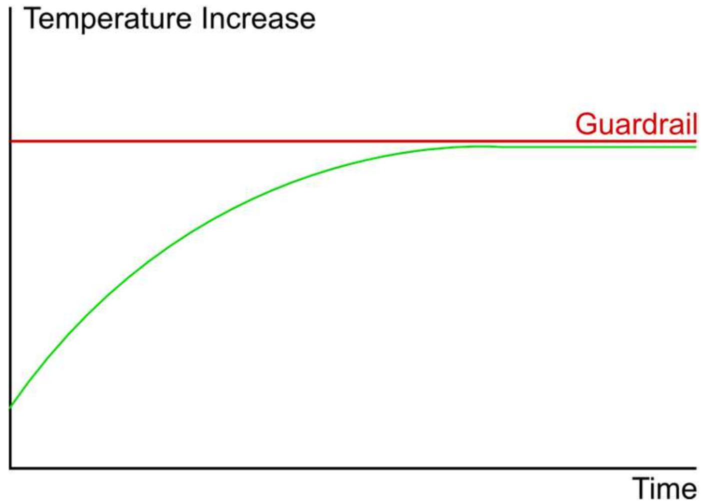
TFE.6, Figure 1 | Probability density functions, distributions and ranges for equilibrium climate sensitivity, based on Figure 10.20b plus climatological constraints shown in IPCC AR4 (Box AR4 10.2 Figure 1), and results from CMIP5 (Table 9.5). The grey shaded range marks the *likely* 1.5°C to 4.5°C range, grey solid line the *extremely unlikely* less than 1°C, the grey dashed line the *very unlikely* greater than 6°C. See Figure 10.20b and Chapter 10 Supplementary Material for full caption and details. {Box 12.2, Figure 1}



IPCC AR4 WGI

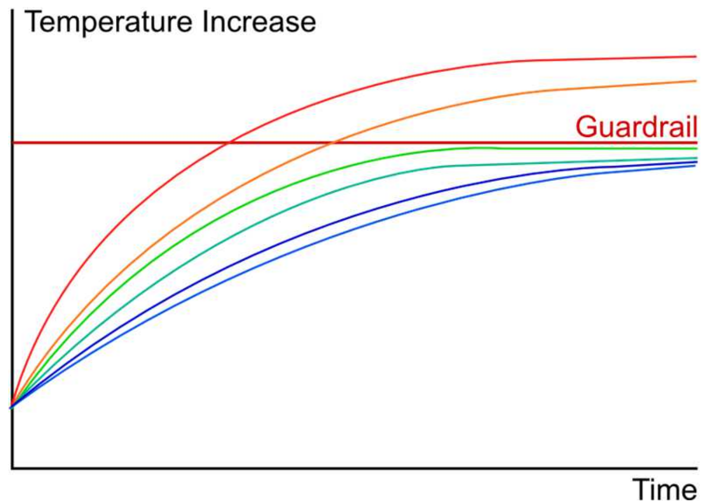
We can always find CS-values such that a temperature limit is overshot.

As Climate Sensitivity could be arbitrarily large:
⇒ The Need for Probabilistic Guardrail
‘Chance Constrained Programming’ (CCP)



Deterministic Guardrail

- Single Investment Strategy
- Single Temperature Profile
  keeping the Guardrail



Probabilistic Guardrail

- Single Investment Strategy
- Multiple Temperature Profiles
  due to Uncertainties
- p% keep the Guardrail
- (1-p)% may exceed the Guardrail

den Elzen and van Vuuren 2007, H. Held et al. 2009

Need decades earlier investments into low-C technologies, if we request a chance of compliance of at least 2/3.

(Held et al., 2009)

However when also anticipating future learning about climate response, CCP displays conceptual problems….

1^{st} Problem with CCP: Risk of Infeasible Solution

- In order to prepare for high-end cases after learning, the allowed cumulative amount of emissions before learning gets too restricted
- -> *infeasible solution!*

  – Because an upper bound for allowed Cumulative Emissions scales with **$(2^{T / CS} - 1)$** in 1^{st} order as a function of Asymptotic Temperature T

    (Kriegler&Bruckner, Clim. Change, 2004)

2^{nd} Problem with CCP:

By construction, a damage function is missing ,

- hence Expected Value of Information could be negative

The Need for Cost Risk Analysis

- Then we may need a hybrid approach derived from both cost effectiveness / cost benefit analysis

- We developed such a tool (price in probability of overshoot).
- 'Cost Risk Analysis'
- Calibrate it at the 2° target.

- Derive that expected economic gain from perfect climate information is up to

  hundreds of billions of €/year under 2° target.
  (Neubersch, Held, Otto, subm. *Climatic Change*)

For the future:

- ***Replace crude target-based approach by proper IP-model on climate impacts?***

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The need for the Representation of Imprecision

- Since the 90s:
  - Ensemble-based climate projections
    Precise Priors & Bayesian statistics,
  - Probability-based technology parameters
  - Most of those do not yet use imprecise measures.

- Problems with precise probabilities modelling expert knowledge
  - Conceptually: Bertrand’s paradox
  - Empirically: Ellsberg’s experiment

- We link to both communities:
  - Work in the ‚standard Bayesian‘ paradigm,
  - while successively upgrading for imprecise measures

- The following is adapted from

  - H. Held, T. Augustin, E. Kriegler,

    Bayesian Learning for a Class of Priors with Prescribed Marginals, International Journal of Approximate Reasoning, **49**, 212-233, DOI 10.1016/j.ijar.2008.03.018,

    (2008)

- An informal expert elicitation within climate, ecology & economics @PIK reveals...

Expert Knowledge on Multivariate Deterministic Model Parameters

1. Experts notoriously know better about marginals than about joint distributions.
   - They would not like to specify the correlation structure.

2. For the marginals, an imprecise model may be more adequate.

This talk: Addressing the 1st Issue

- Imprecise model for multivariate subjective knowledge:
  - Precise marginals
  - No information otherwise

$$\Theta = \{P \mid \quad \forall_{x_1} \int dx_2 \; P(x_1, x_2) = P_1(x_1)$$

$$\& \, \forall_{x_2} \int dx_1 \; P(x_1, x_2) = P_2(x_2)\}$$

(after Tchen, 1980; Lavine et al., 1991)

- Behaviour under Bayesian updating?

A Conceptual Model

- Uncertain parameters x_1, x_2 .
- Bayesian learning under the observation

$$y \sim N(\kappa x_1 + x_2 \, , \sigma_\eta)$$

- We are interested in the probability of ruin

$$P^* = \int_{x_1^*}^{\infty} dx_1 \int_{-\infty}^{\infty} dx_2 \; P(x_1, x_2)$$

Restricting the Class of Priors

- Any prior should be unimodal .
- (Later on:) The gradient of any priors should be limited
  - Equivalent to the maximum resolution an expert´s sophistication could reach.

- Observe unimodality by simple analytically accessible case – Gaussian priors only with

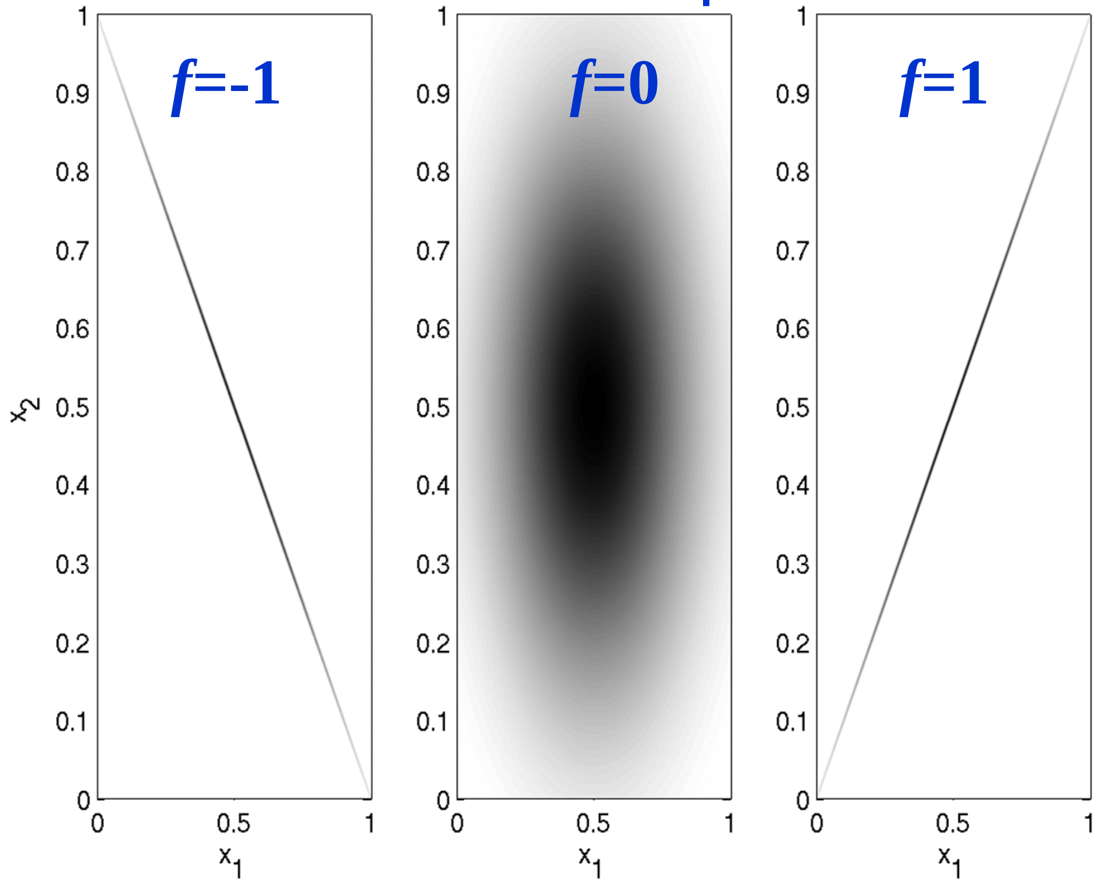
$$P_1 \equiv P_2 \sim N(\mu, \sigma), \quad \mu = 1/2, \sigma = 1/4$$

$$\sigma_\eta = \sigma/10$$

Class allows for Parameterisation

$$\forall_{P\in\Theta}\, Mean(P) = (\mu,\mu) \quad \& \quad Cov(P) = \sigma^2 \begin{pmatrix} 1 & f \\ f & 1 \end{pmatrix},\ f\in[-1,1]$$

- 3 elements of the class of priors Θ



Versions of Generalised Bayesian Learning under Observation y

- GBR (Generalised Bayes Update Rule; after Walley)
  - Update any member of the class of priors .
  - For any posterior determine the probability of ruin.
  - Aggregate that set by the sup / inf – operation.

- MLU (Maximum likelihood update rule; after Gilboa & Schmeidler):
  - Select subset of priors that maximise prior expectation for y.
  - On that subset apply GBR

GBR vs MLU: Pro´s & Con´s

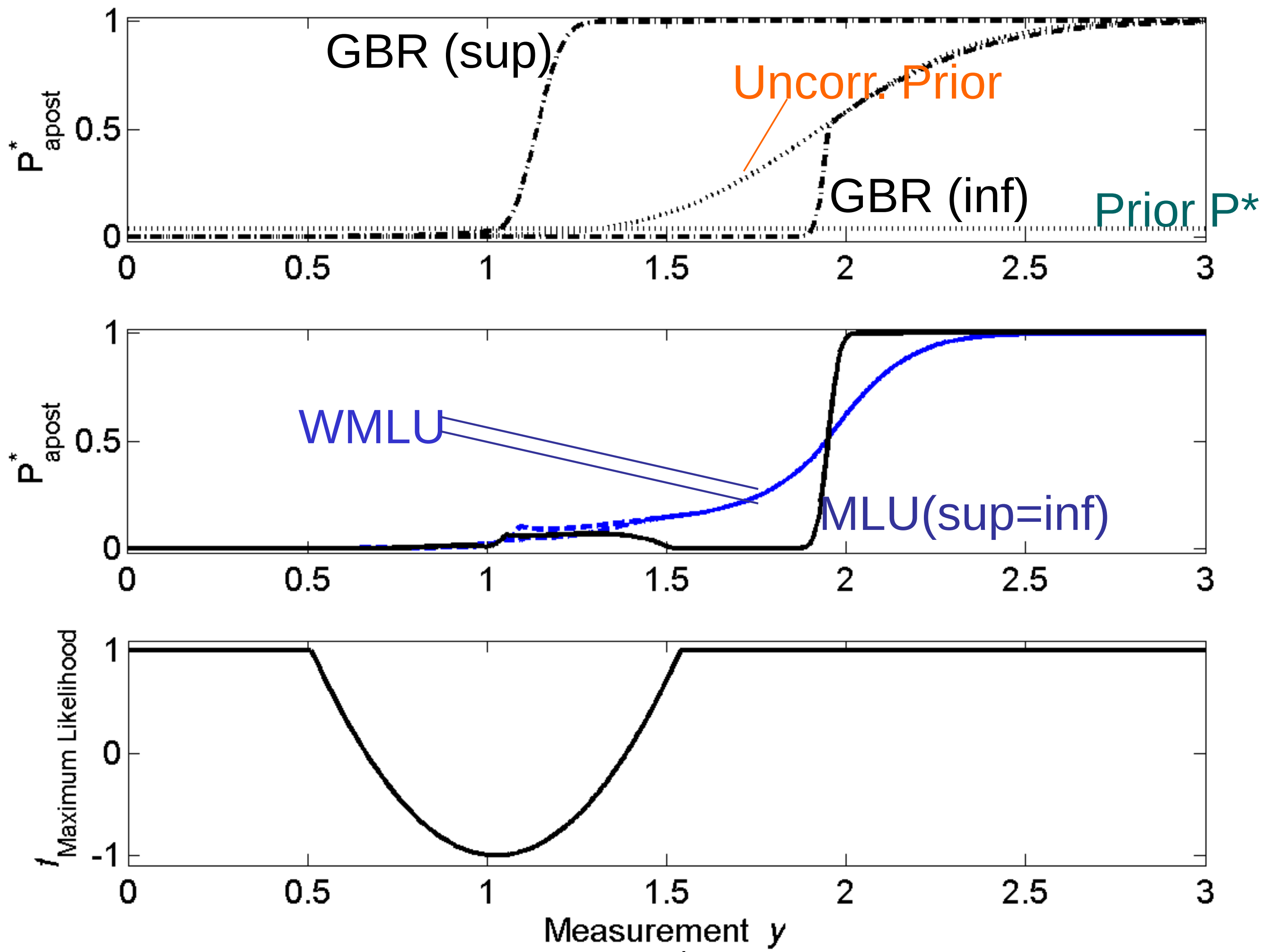
	Pro´s	***Con´s***
GBR	Conservative wrt ‚false priors‘	May result in non-informative inferences
MLU	Generically more informative than GBR	May produce spurious information under false priors; Counterintuitive that priors with mildly lower expectations of y are completely disregarded

WMLU: A new Learning Rule

- WMLU:= Weighted MLU
  - Decompose Θ in terms of level sets of prior expectations of y .
  - Apply GBR for each level set.
  - Average over level set-results, linearly weighted w.r.t. prior expectations of y .

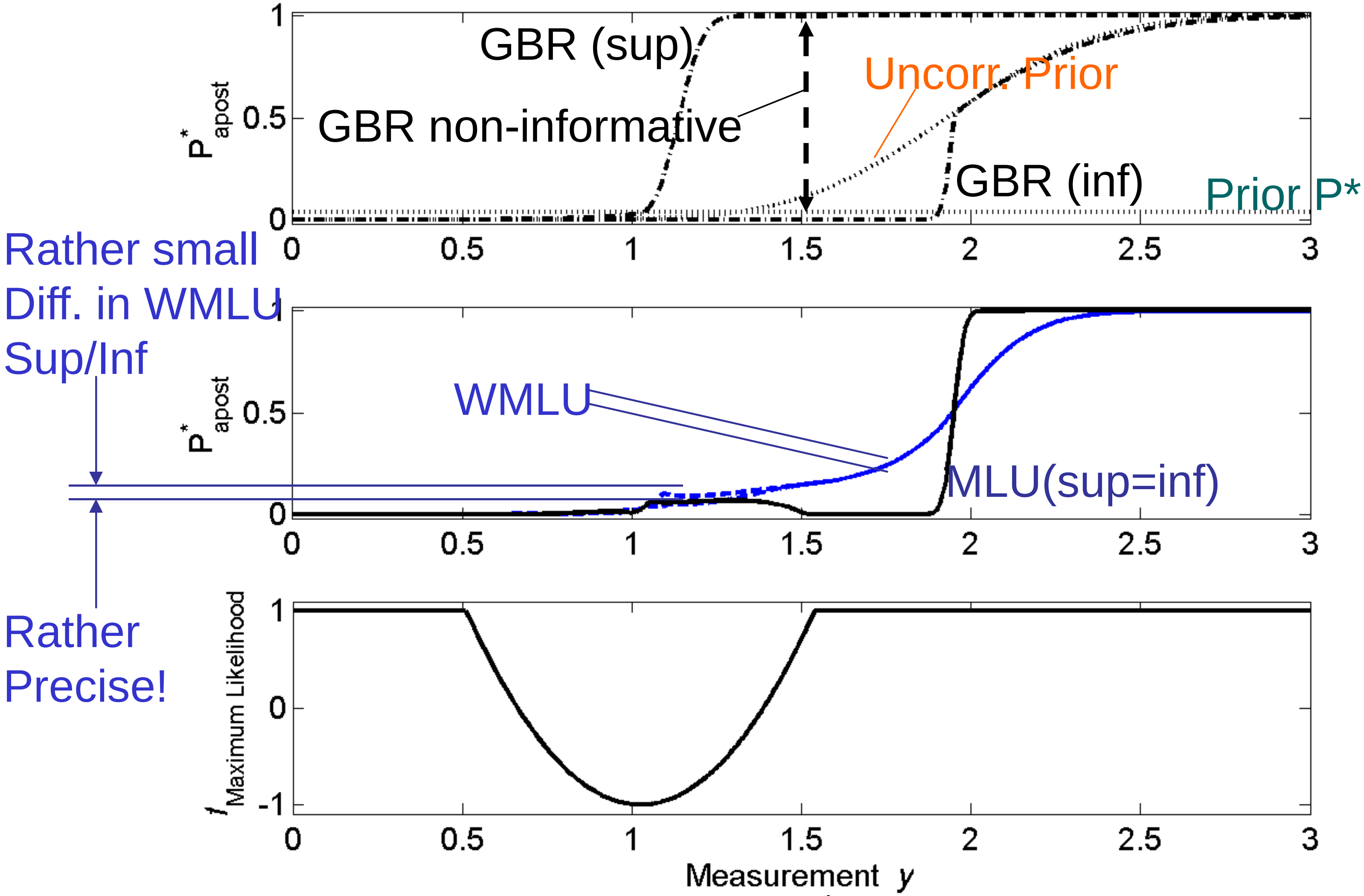
$$P^*_{\text{aposterior},y} = \sum_j w_{j,y} \cdot \sup_{P \in \mathcal{P}_{i,y}} (P^*_{\text{aposterior},y}(P))$$

Results for our Class of Priors



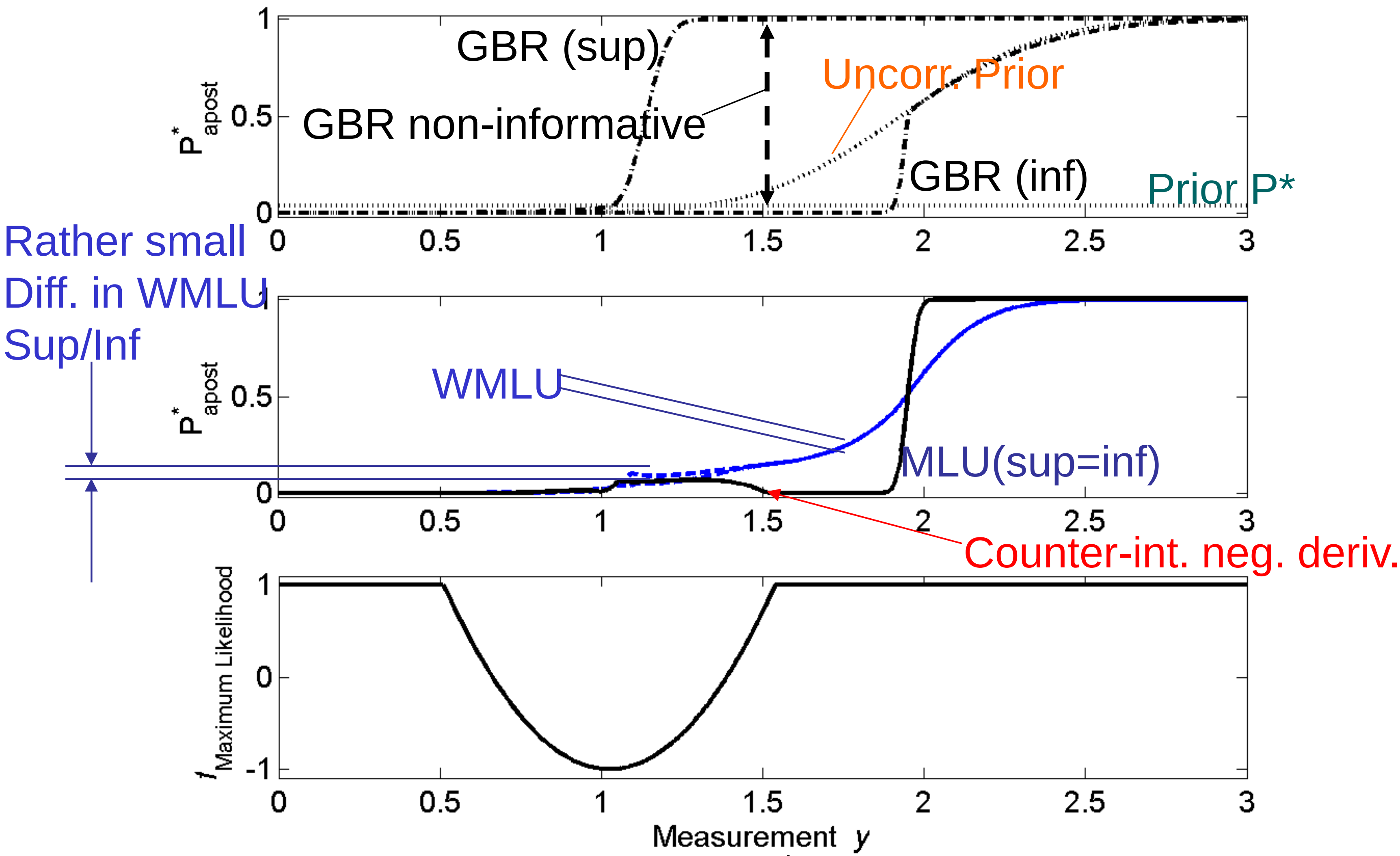
$$\kappa := 1.05; \quad x_1^* := 0.95;$$

Results for our Class of Priors



$$\kappa := 1.05; \quad x_1^* := 0.95$$

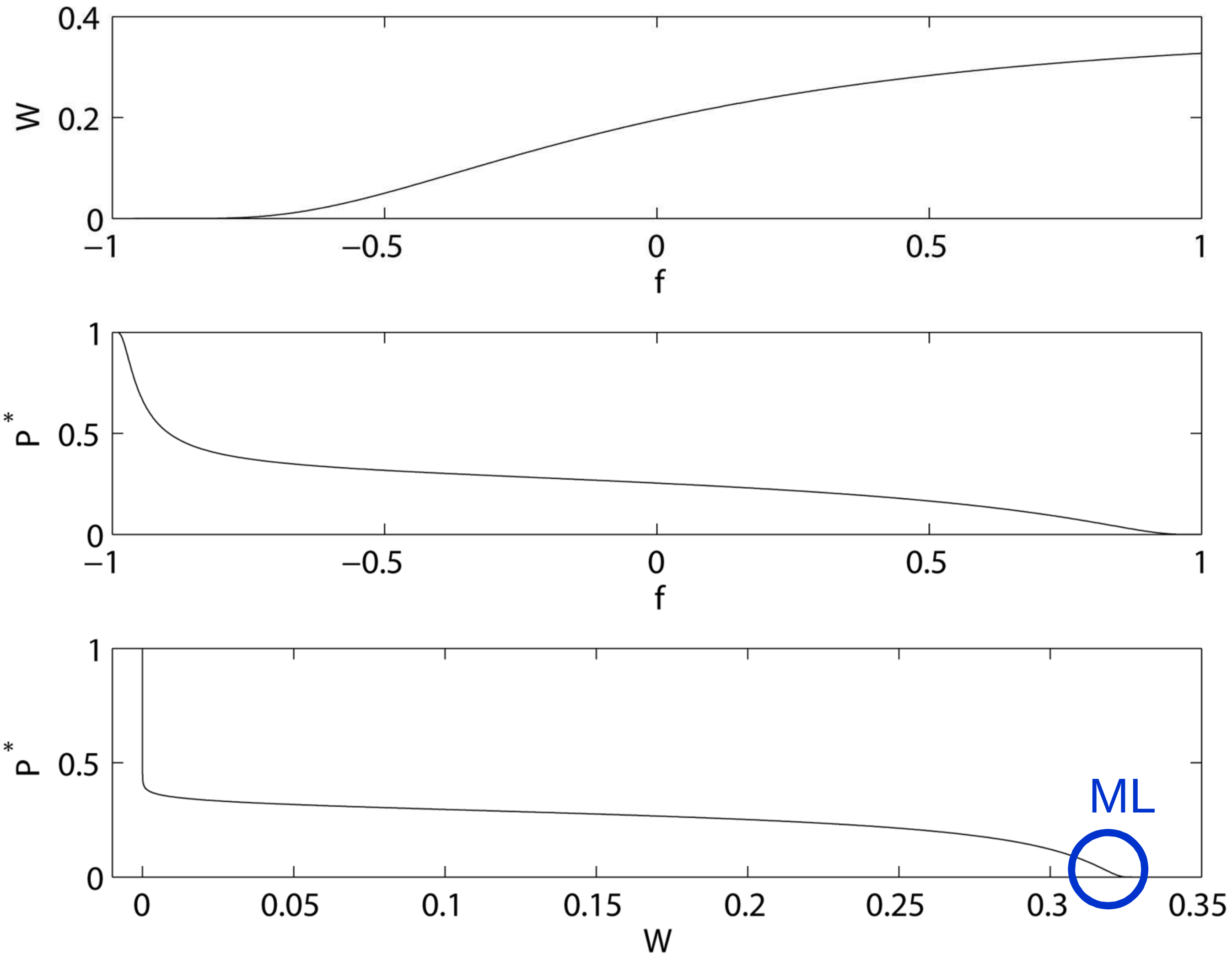
Results for our Class of Priors



$$\kappa := 1.05; \quad x_1^* := 0.95$$

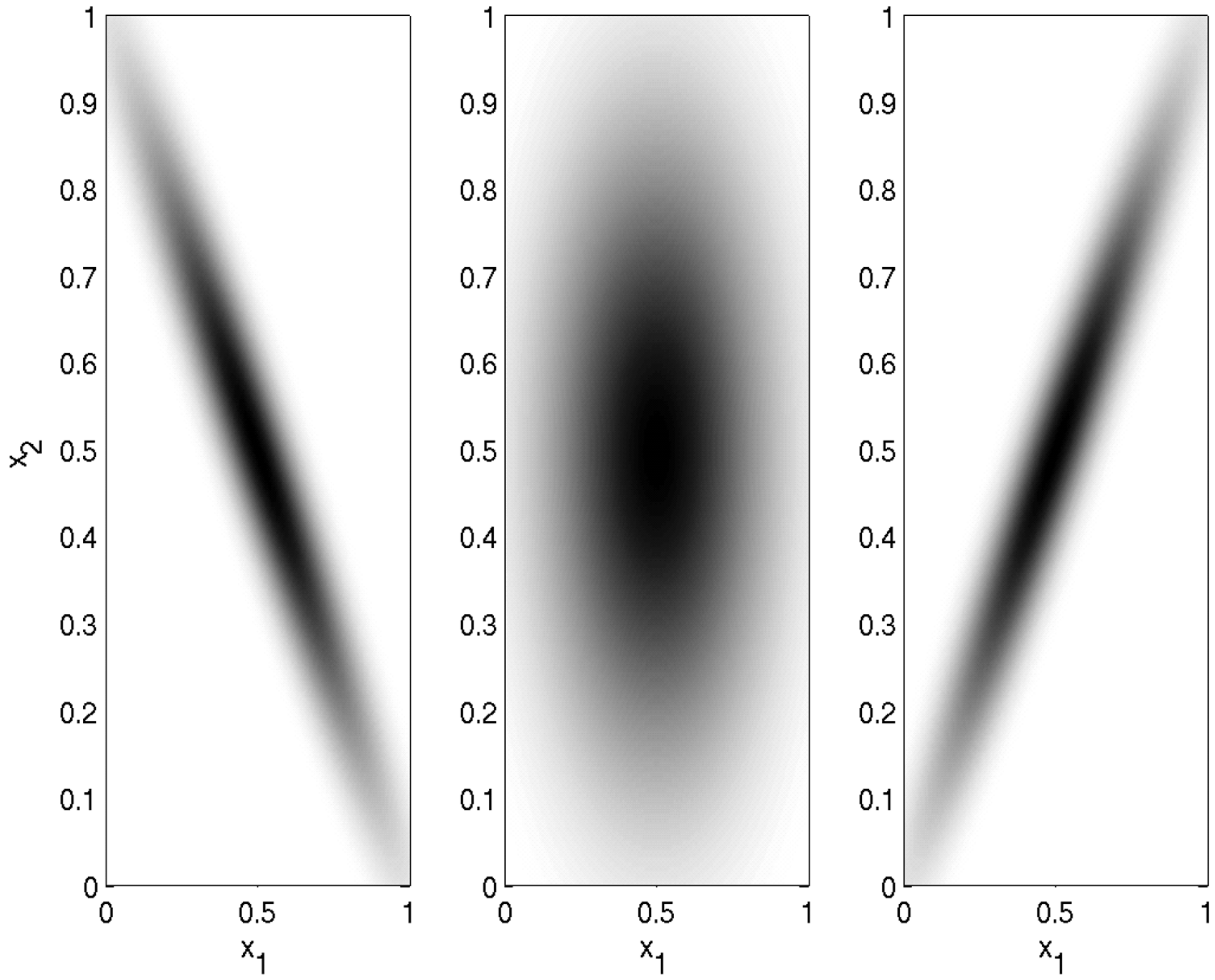
WML vs ML: sup(P*) across level sets

‚Weight‘
:=Prior
expec-
tation
of y:=1.7

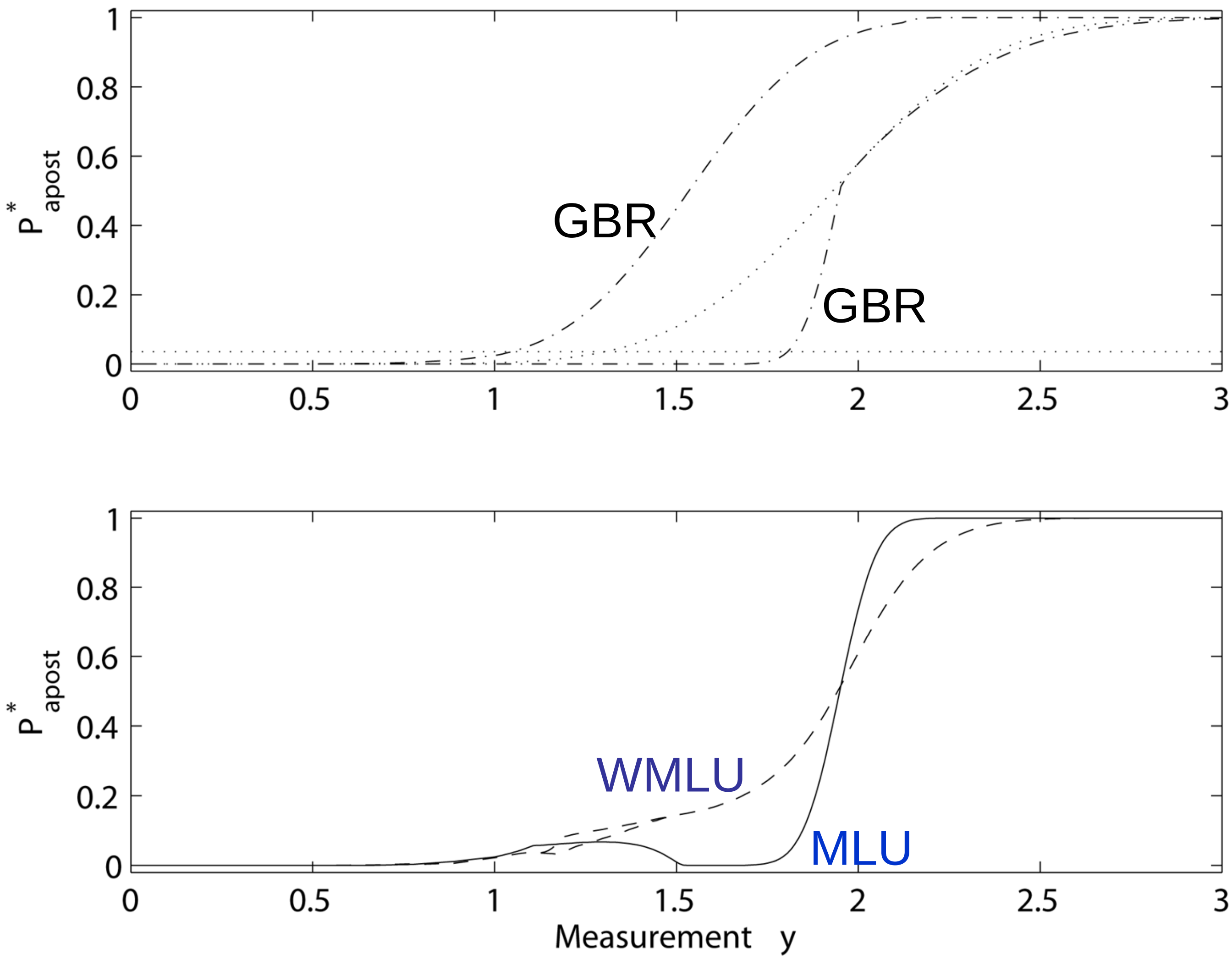


Imposing Gradient Constraints on Priors

5 X 5 Blocks in 2D Parameter Space



Related Probabilities of Ruin



Advantages of WMLU

- ~Monotonous w.r.t. y (as against MLU)

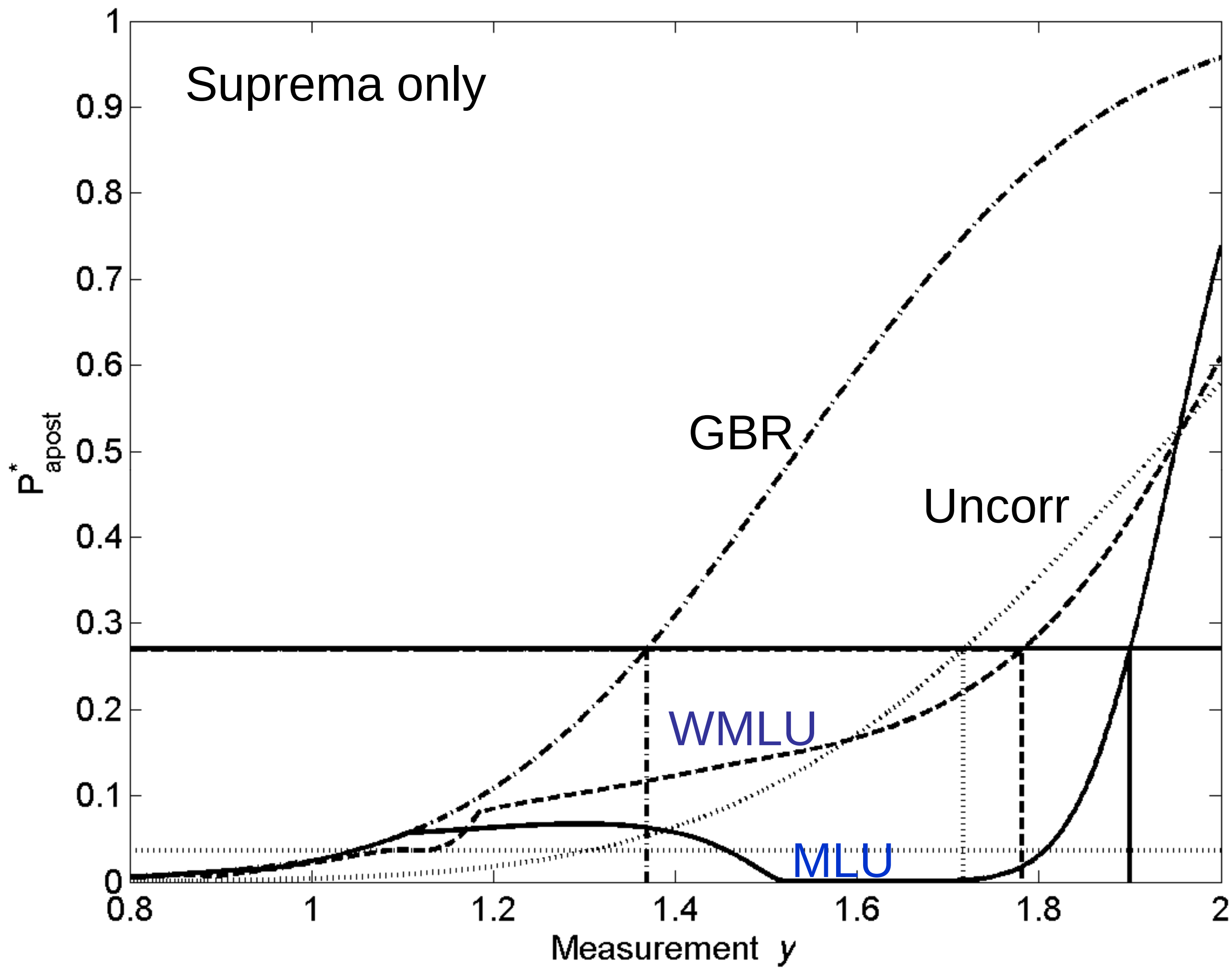
- Order(s) of magnitude more informative than GBR

Consequences for a Stylised Insurance Situation

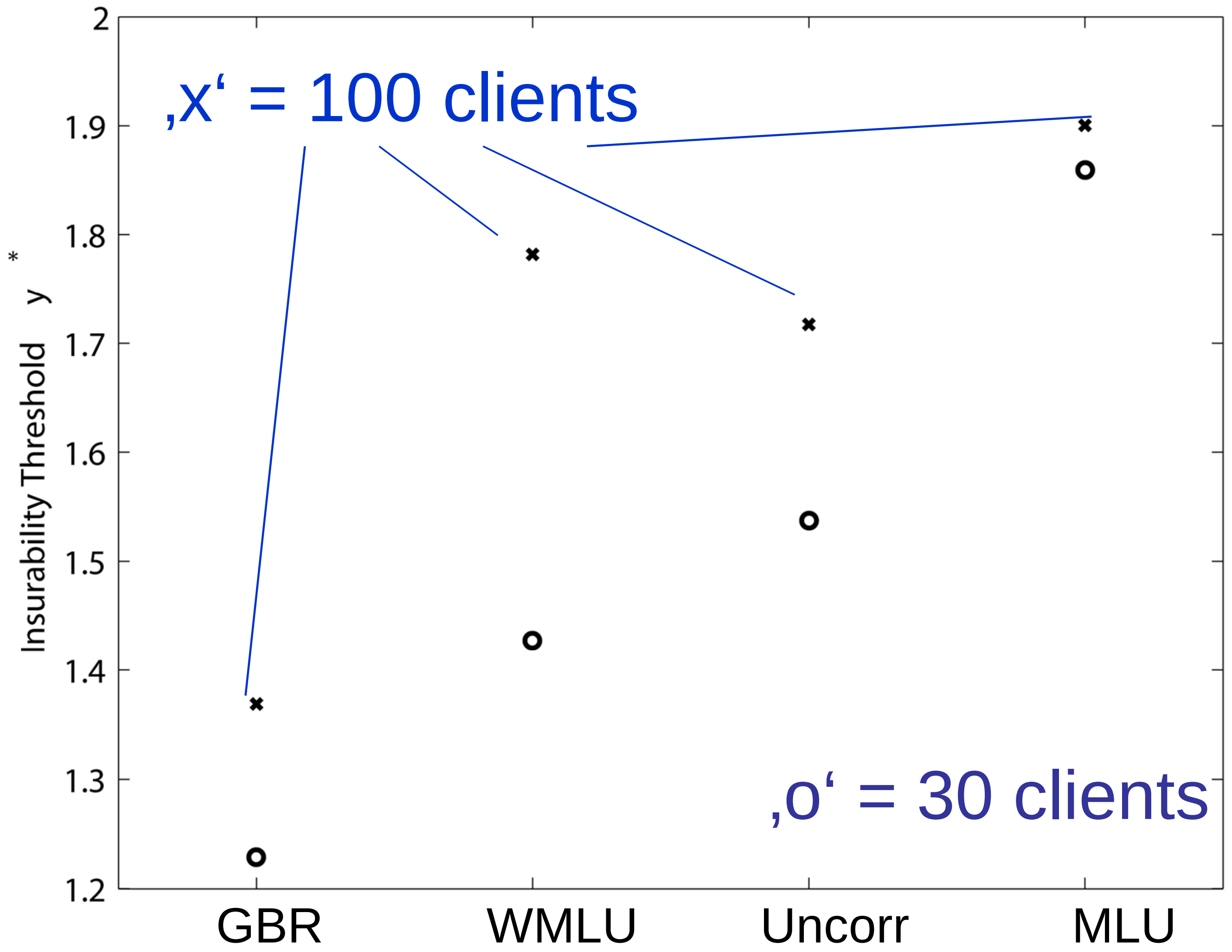
- An insurance company decides to operate with an upper probability of ruin of 1/1000 .
- 100 clients, each comes with a characteristic property y & subsequent P*.
- Then one can show that

  P*(client) <! 27% .
- Question: Clients with what y shall become insured?

Case 5 X 5 Blocks



Max y to be Insured



- WMLU allows to insure additional 30-70% – compared to GBR – in y on the y-scale spanned by MLU-GBR.

-

- WMLU allows to insure additional 30-70% – compared to GBR – in y on the y-scale spanned by MLU-GBR.

- The new WMLU has many attractive features, however, is not robust against ‚false priors‘ while GBR is.

Summary

- In an idealized economy, the 2°target is compatible with continued economic growth.
  - The corresponding reduction of growth rate is 1-2 orders of magnitude smaller than the very growth rate.
- Uncertainty in climate sensitivity requires a hybrid decision instrument of cost effectiveness and cost benefit analysis.
  - Climate targets then less absolute.
  - The expected value of perfect climate information could be on the order of hundreds of billions € / year under a 2°target.
- IP-based uncertainty representations are often perceived as a relief for experts interviewed.
  - Large field of applications in climate science & climate economics.
  - However they pose new conceptual difficulties.

A Promise

- *Slides circulated will contain*

  a summary slide about

  your potential entry slots

  within the climate community!

[added slide: potential applications for IPs]

- Making a good IP model for the process underlying slides #11+14+17
- Very big research question: how to make an IP model on global warming impacts? At least for the next 20 years…
- Scanning the 1000 mitigation scenarios reported in WGIII (see slide 45, mitigation2014.org)
- How to combine different approaches on climate sensitivity in one general IP model? (slide 50)

My Questions to the IP-Community

- Pros & cons of aggregation rules for expert interviews?
- Pros & cons of various (Bayesian) updating rules?
- Pros & cons of restriction rules to avoid dilation?
- Relation to economic decision community who seems to avoid IPs, uses the Klibanoff et al model to represent ‘ambiguity’ instead?

Literature I

Introductions for 'interested non-experts':

- H. Held, Dealing with Uncertainty – From Climate Research to Integrated Assessment of Policy Options, in: Climate Change and Policy in: The Calculability of Climate Change and the Challenge of Uncertainty, Gramelsberger, Gabriele; Feichter, Johann (Eds.), ISBN 978-3-642-17699-9, 113-126, (2011).

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- T. Bruckner, O. Edenhofer, H. Held, M. Haller, M. Lüken, N. Bauer, Robust Options to Combat Climate Change, in Global Sustainability – A Nobel Cause, Schellnhuber, H. J., M. Molina, N. Stern, V. Huber and S. Kadner (eds.), Cambridge University Press, Cambridge, United Kingdom and New York, USA, ISBN-13:9780521769341, 189-204 (2010).

- H. Held, O. Edenhofer, Re-structuring the problem of Global Warming Mitigation: "Climate Protection" vs. "Economic Growth" as a false Trade-off. In: G. Hirsch Hadorn, H. Hoffmann-Riem, S. Biber-Klemm, W. Grossenbacher-Mansuy, D. Joye, C. Pohl, U. Wiesmann, E. Zemp (eds.), Handbook of Transdisciplinary Research. Heidelberg: Springer, 191-204, ISBN: 978-1-4020-6698-6 (2008).

Peer-reviewed model descriptions:

- O. Edenhofer, N. Bauer, E. Kriegler, The Impact of Technological Change on Climate Protection and Welfare: Insights from the Model MIND, Ecological Economics, 54 (2–3):277–292 (2005).

- G. Petschel-Held, Schellnhuber, T. Bruckner, F. L. Tóth, K. Hasselmann, The tolerable windows approach: theoretical and methodological foundations. Climatic Change 41, 303–331 (1999).

Literature II

Peer-reviewed model intercomparison (state-of-the-art coupled energy-economy-carbon cycle models):

- G. Luderer, V. Bosetti, M. Jakob, M. Leimbach, J. C. Steckel, H. Waisman, O. Edenhofer, The economics of decarbonizing the energy system—results and insights from the RECIPE model intercomparison, Climatic Change, DOI 10.1007/s10584-011-0105-x .

Peer-reviewed literature on Decision under Uncertainty in the climate context

- M. G. W. Schmidt, H. Held, E. Kriegler, A. Lorenz, Stabilization Targets under Uncertain and Heterogeneous Climate Damages, Environmental & Resource Economics, in press.

- A. Lorenz, E. Kriegler, H. Held, M. G. W. Schmidt, How to measure the importance of climate risk for determining optimal global abatement policies? Climate Change Economics, in press.

- A. Lorenz, M. G. W. Schmidt, E. Kriegler, H. Held, Anticipating Climate Threshold Damages, Environmental Modeling and Assessment, 17 (1), 163-175, DOI: 10.1007/ s10666-011-9282-2, in Special Issue on Modeling Uncertainty in Energy Policy and the Economics of Climate Change (2012).

- M. G. W. Schmidt, A. Lorenz, H. Held, E. Kriegler, Climate Targets under Uncertainty: Challenges and Remedies, Climatic Change Letters, 104 (3-4), 783-791, DOI 10.1007/s10584-010-9985-4 (2011).

- H. Held, E. Kriegler, K. Lessmann, O. Edenhofer, Efficient Climate Policies under Technology and Climate Uncertainty, Energy Economics 31, S50–S61 (contribution in C. Böhringer, T. P. Mennel, T. F. Rutherford (Guest Eds.): Technological Change and Uncertainty in Environmental Economics), doi:10.1016/j.eneco.2008.12.012 (2009).

- A. Lange, N. Treich, Uncertainty, learning and ambiguity in economic models on climate policy: some classical results and new directions. Climatic Change 89 (1): 7–21 (2008).