Treatment of Uncertainty in Integrated Assessment Modeling

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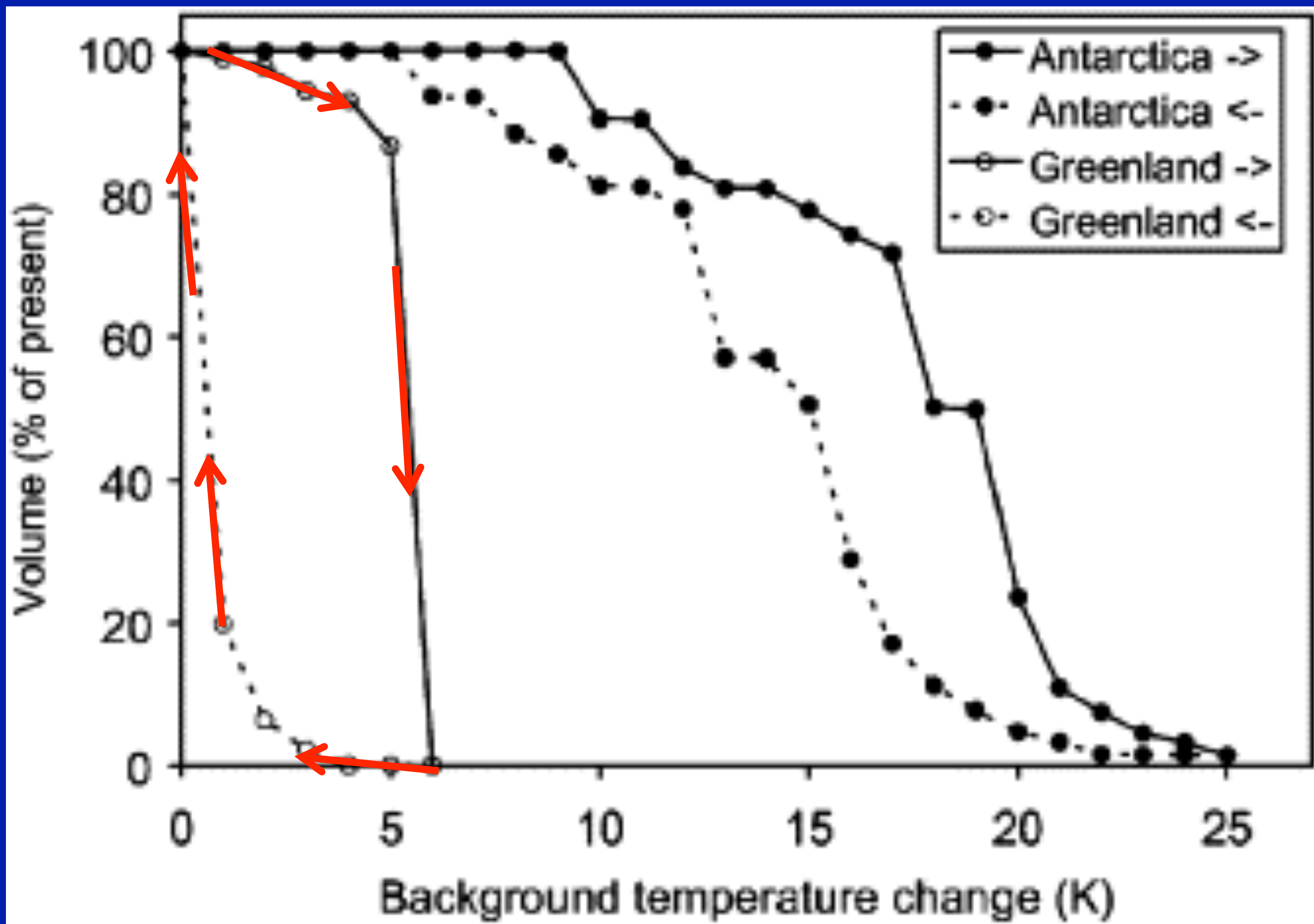
Outline of lecture

1. Treatment of uncertainty in integrated assessment models (IAM)
2. Results for DICE and RICE models

I. Dilemmas of uncertainty

- Uncertainty and the potential for catastrophic impacts are a major concern in global warming science and policy today.
- Some major risks include:
  - Reversal of North Atlantic deepwater circulation
  - Melting of Greenland and West Antarctic ice sheets
  - Abrupt climate change
  - Ocean carbonization
- How can we model risk and uncertainty in IAMs?

Hysteresis loops for Ice Sheets and the “Tipping Point”



Frank Pattyn, “GRANTISM: Model of Greenland and Antrarctica,” Computers & Geosciences, April 2006, Pages 316-325

Approach to Uncertainty: Monte Carlo/Subjective Probability Uncertainty Analysis

1. The approach we have used is to combine modeling, subjective probability theory, and Monte Carlo sampling.
2. Begin with a structure like DICE model equations. Can represent schematically as follows:

   (1) $\mathbf{y}_t = H(\mathbf{z}_t ; \boldsymbol{\theta})$

where

$\mathbf{y}_t$ = the endogenous variables (output, emissions, etc.)

$\mathbf{z}_t$= exogenous and non-stochastic variables (financial meltdown, land-based emissions, etc.)

$\boldsymbol{\theta} = [\theta_1, \ldots, \theta_n]$ = uncertain parameters (including functional forms)

H = model structure

3. We then develop subjective probabilities for major parameters, $f(\theta)$.
4. Final step is Monte Carlo simulation to obtain distribution of important endogenous variables (T, Y, SCC, …)

Uncertainty analysis in DICE model

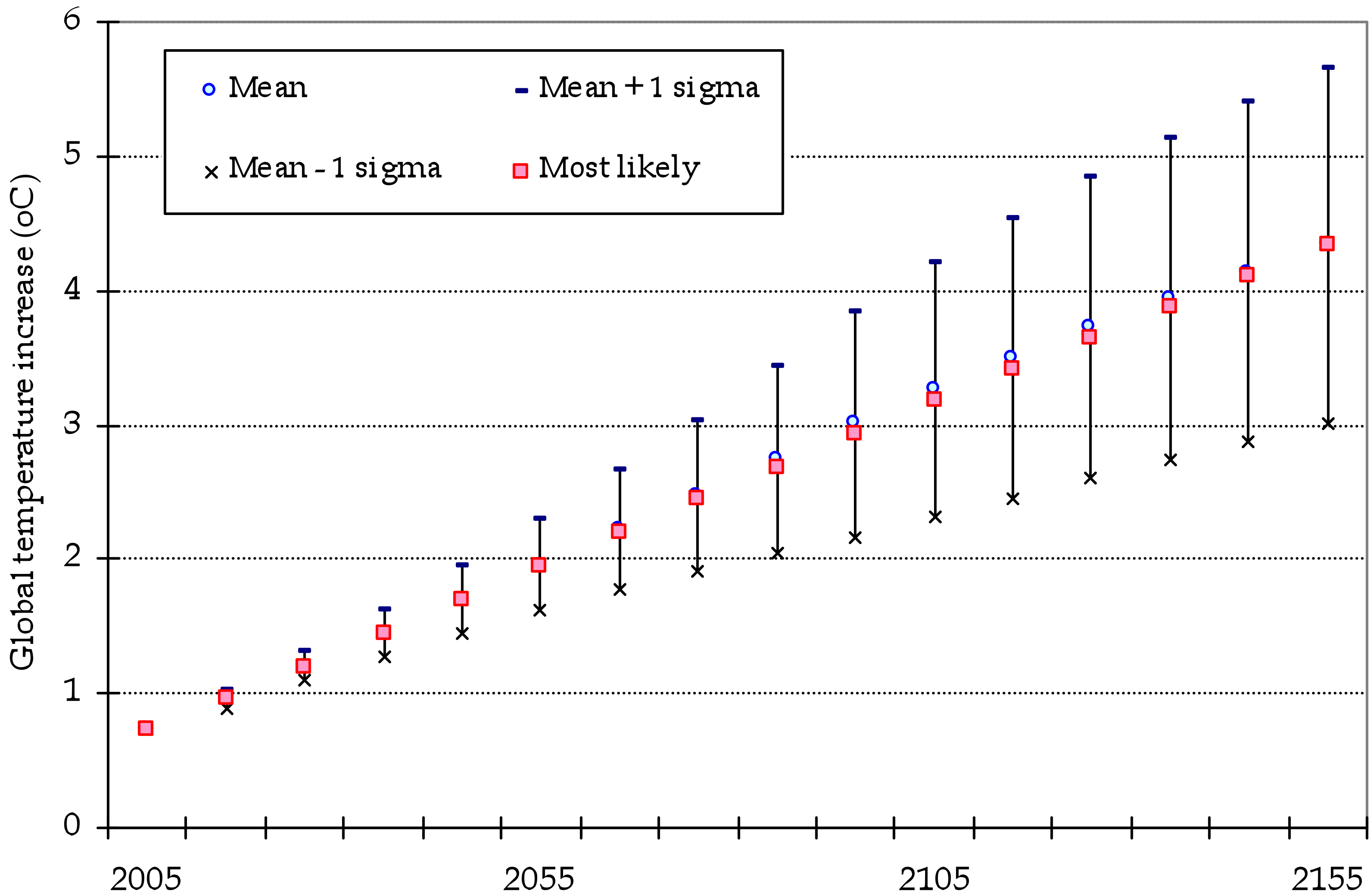
Implementation in DICE-2007

- For DICE model, we examine 100 random runs, where these are baseline for 8 uncertain parameters.
- Then fit a “response-surface model” that estimates major outcomes as function of uncertain parameters
- These provide information about what the uncertainties are for major variables.

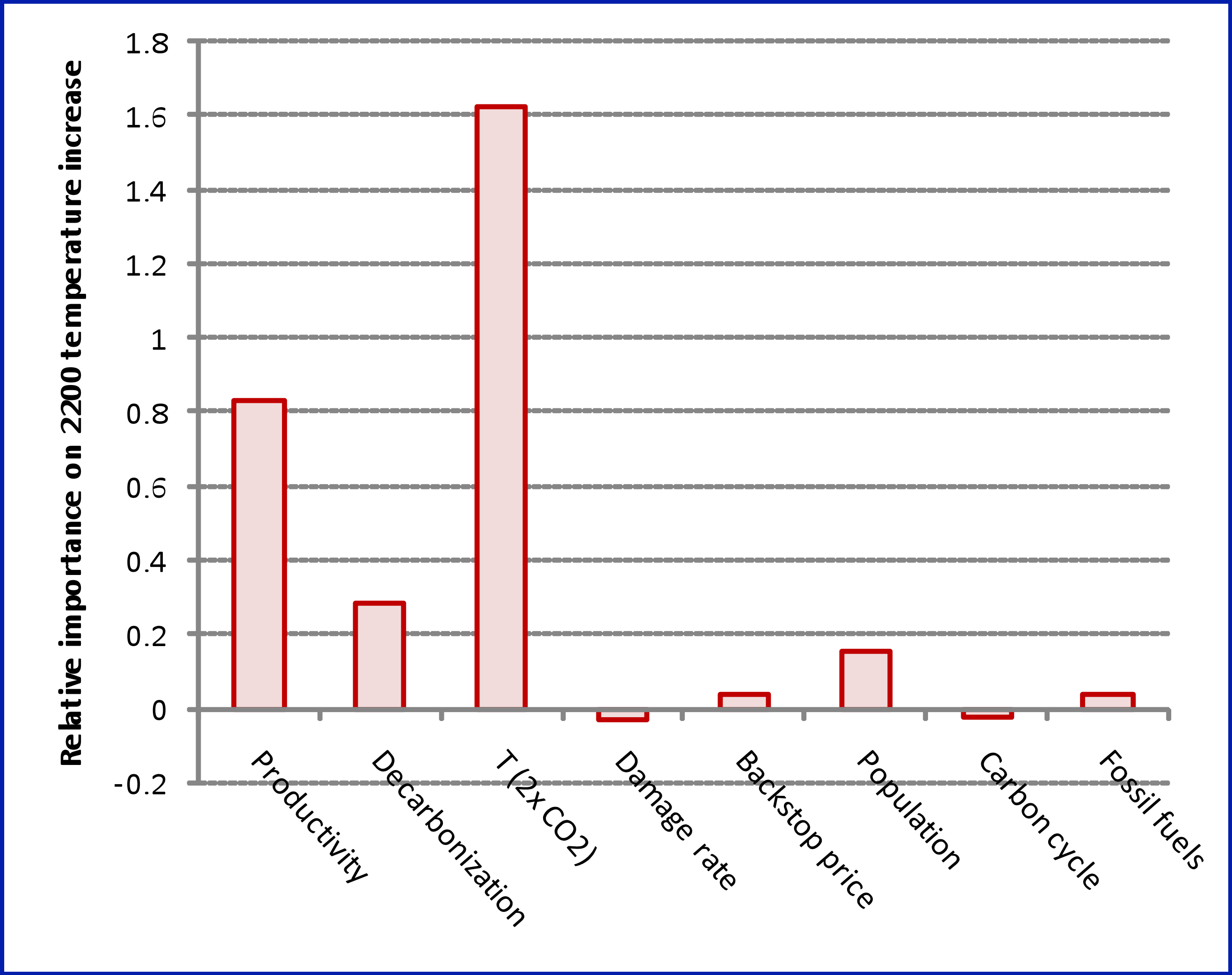
Major uncertain variables

Variable	Mean	Standard deviation
Rate of growth of total factor productivity (% per year)	0.0092	0.004
Rate of decarbonization (% per year)	-0.0070	0.002
Equilibrium temperature-sensitivity coefficient (°C per CO2 doubling)	3.00	1.11
Damage parameter (intercept of damage equation)	0.0028	0.0013
Price of backstop technology ($ per ton C removed at 100 % removal)	1,170	468
Asymptotic global population (millions)	8,600	1,892
Transfer coefficient in carbon cycle	0.189	0.017
Total resources of fossil fuels (billions of tons of carbon)	6,000	1,200

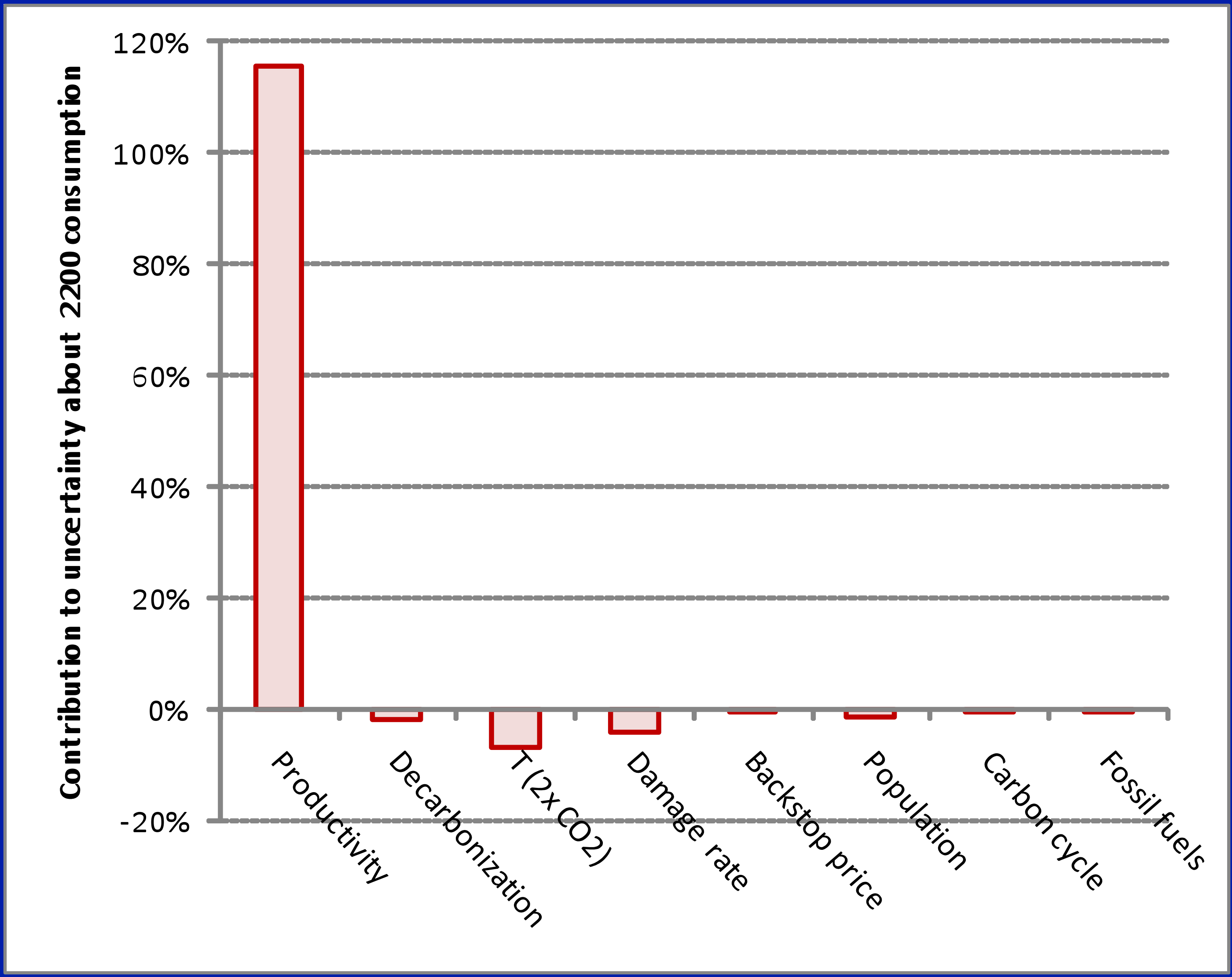
Uncertainty for future temperature: DICE 2007 baseline



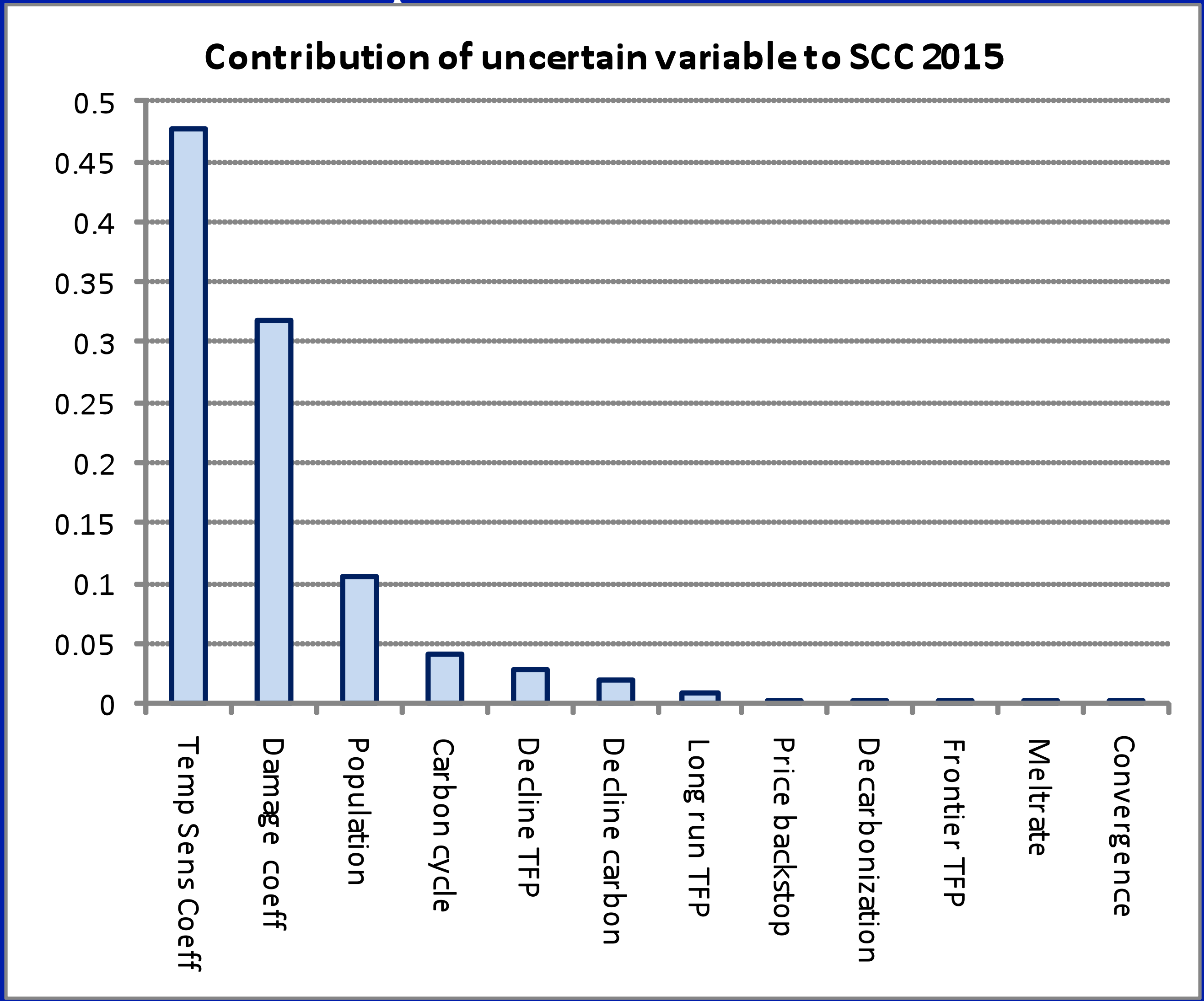
Normalized contribution of uncertain variable: impact on temperature, 2200



Normalized contribution of uncertain variable: impact on per capita consumption, 2200



Normalized contribution of uncertain variable: Impact on SCC 2015*

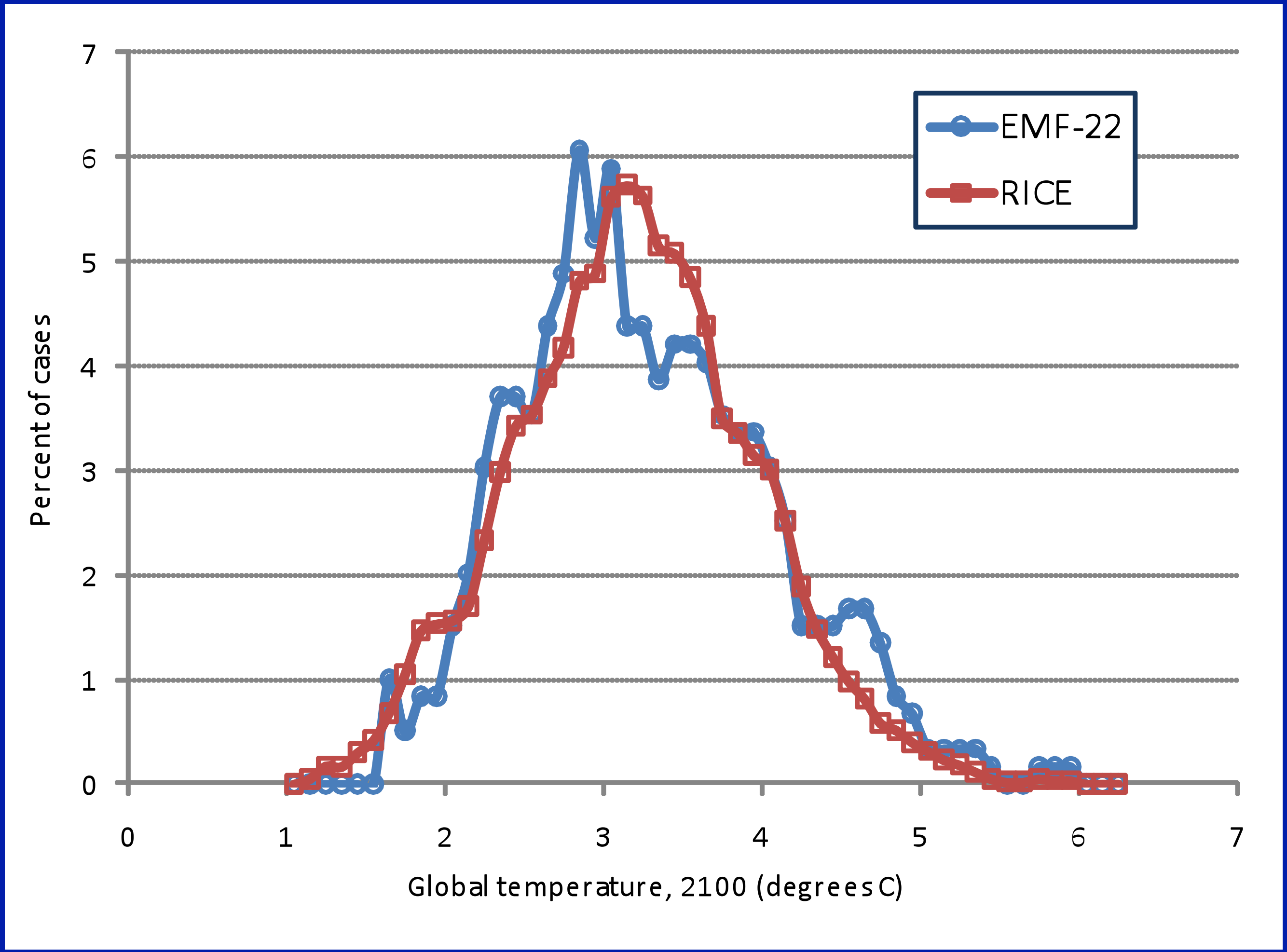


*Note that elasticity of consumption and rate of time preference are not included.

Uncertainty estimates for the T(2100)

- Looked at two different approaches:
  - 1. Used the approach above of Monte Carlo for RICE-2011
  - 2. Used a combination of uncertainty of economic and climate models
- Latter requires some explanation:
  - Took 12 models from EMF-22 reference cases
  - Took 17 climate models from IPCC AR4 with simple parameterization
- Looked only at CO2 concentrations
- Results surprisingly similar (next slide)

Histogram of T(2100) under two approaches



The macro risk question: theory

Should we be paying a large risk premium on high-climate scenarios? The idea is that we would we invest more than the certainty equivalent to prevent the high-climate outcome.

Earlier studies generally assume yes. These approaches applied a risk-averse utility function to the damages. (This was the approach in Nordhaus-Boyer 2000 and Stern 2007.)

This is a partial-equilibrium approach. The correct approach would be to apply modern risk analysis in the consumption capital asset pricing model.

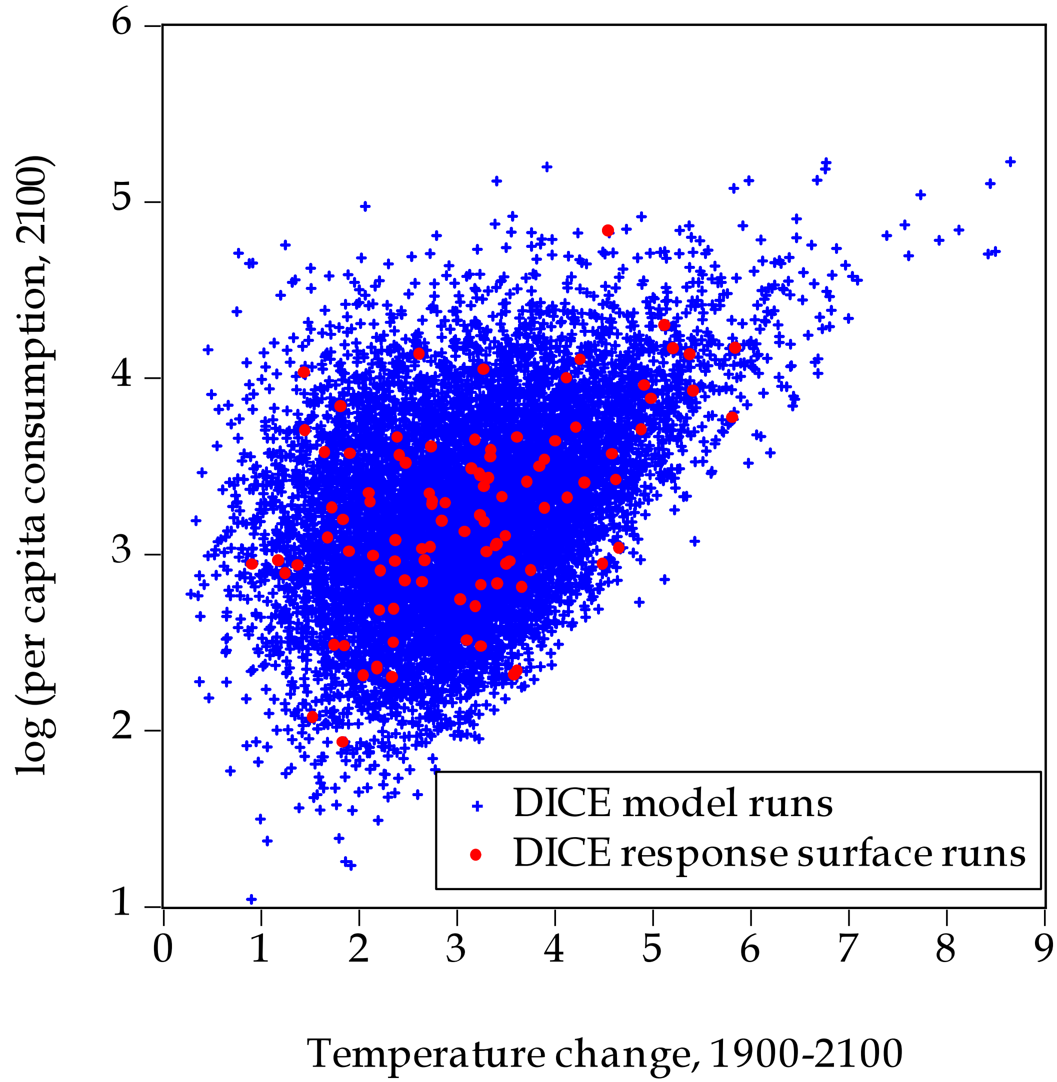
In this framework, want to pay a risk premium ↔ the high-climate outcome is positively correlated with high MU consumption (or negatively correlated with consumption).

Begin with a utility function, U(C). Examine the expected utility in year t (say 2100). This is:

$$E(U) = \int_{\text{SOW } i} p^i U[C(\boldsymbol{\theta}^i)]$$

In this, p^i are probabilities, and $\boldsymbol{\theta}^i = [\theta_1^i, \ldots, \theta_8^i]$ are uncertain parameters, and i are uncertain states of the world (SOW). In general, we apply risk premia to SOWs where $U'[C(\boldsymbol{\theta}^i)]$ or the MU of consumption is high. The question is, when do these occur?

Consumption and 2100 Temperature

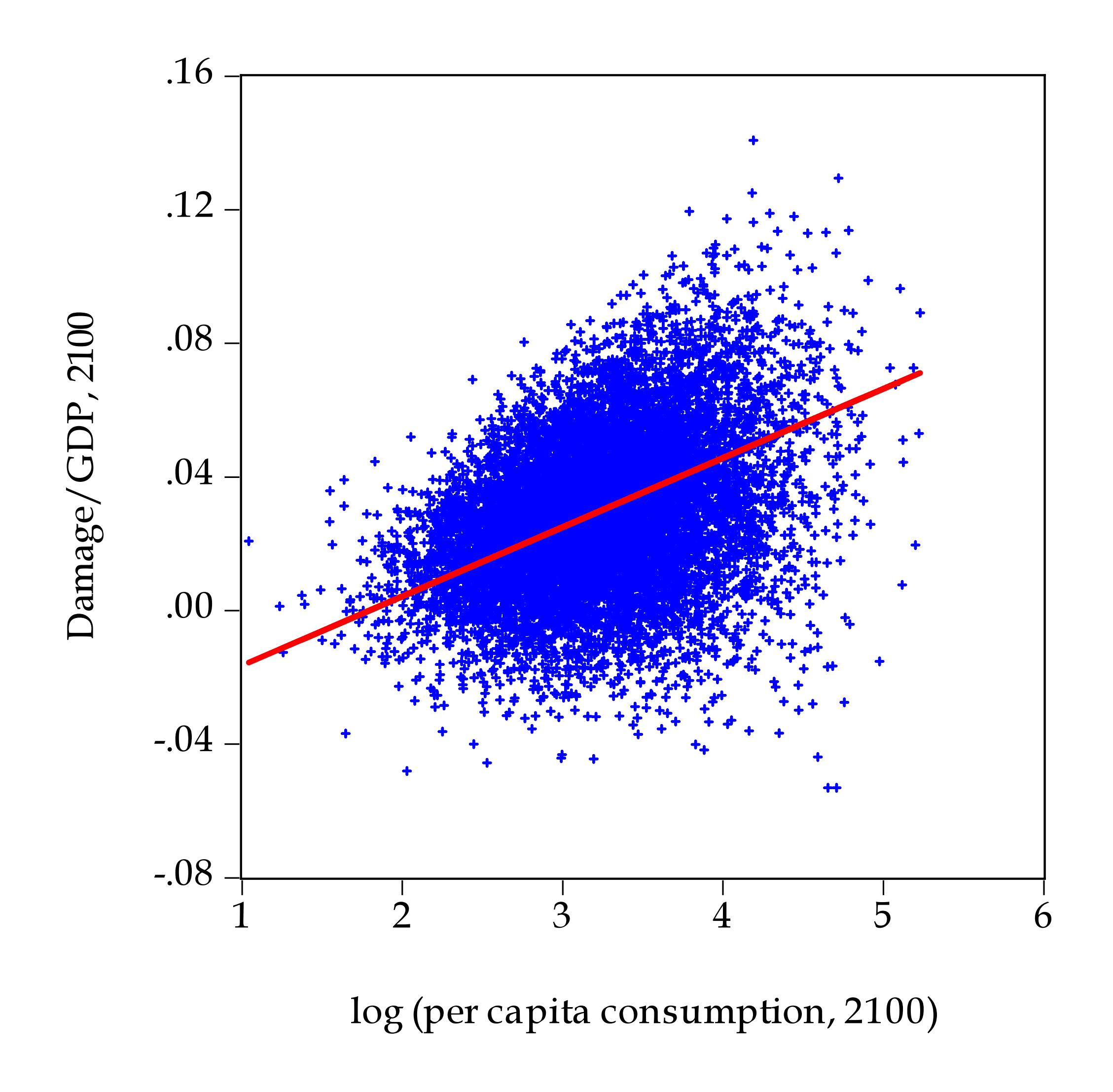


The red dots are 100 runs of DICE model with random draw of uncertain parameters

The blue dots are 10,000 runs of response-surface model.

Key result is that per capita consumption is positively correlated with temperature.

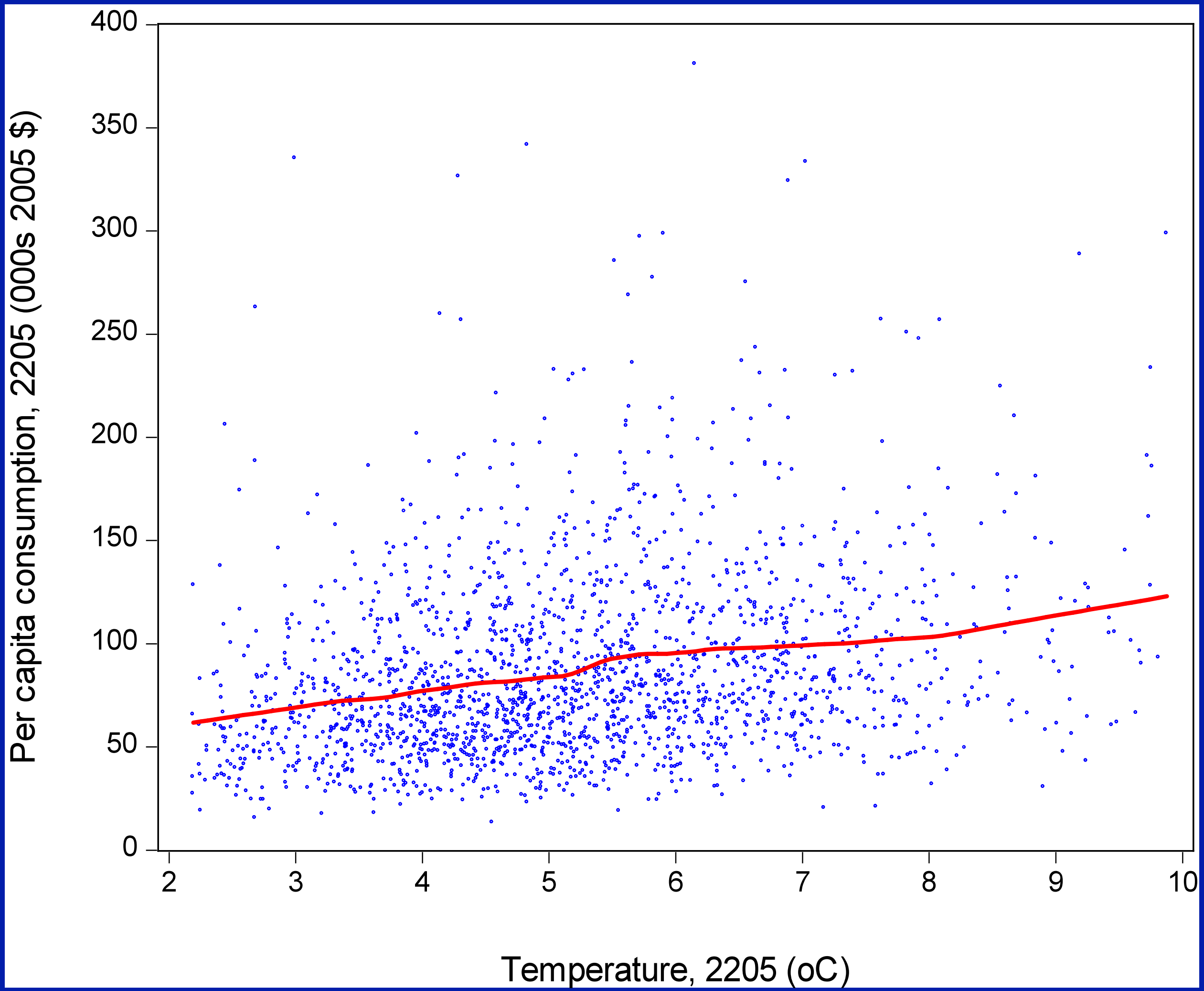
Consumption and damage ratio



The blue dots are 10,000 runs of response-surface model.

Key result is that damage ratio is high when per capita consumption is high.

Temperature and p.c. consumption (RICE-2011)



Update using RICE-2011 model

Implications for Risk Premium

Study suggests that the most important uncertainty in long-run is growth in productivity. High climate damages are associated with high growth rates of TFP.

- So good economic news = bad climate news in baseline.
- Think of the $2500 car.

But this also means that the worst climate cases are ones in which the world is *rich,* which is a situation where we are more likely to be able to afford more costly climate abatement.