Uncertainty Analysis in Integrated Assessment Models

Approach for Development of PDFs

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Our Three Uncertain Input Parameters

We are looking for a PDF for each of the three parameters:

1. Population growth
2. Productivity growth
3. Temperature sensitivity

The State of the Literature Differs Greatly for Each

1. Population growth
   - Significant work on stochastic forecasts

2. Productivity growth
   - Many forecasts, but surprisingly no PDFs we could find

3. Temperature sensitivity
   - Extensive literature attempting to estimate PDFs

We Will Discuss Each in Turn

1. Population growth (me)

2. Productivity growth (Peter)

3. Temperature sensitivity (me)

Population Growth

Several groups have been working on stochastic forecasts

- UC Berkeley demography group
  - Has done some work in this area

- IIASA has a long history of work on demography
  - Great work in the past by Nathan Keyfitz (at IIASA 1983-1993)
  - Wolfgang Lutz has agreed to share with us new stochastic estimates of population out to 2100.
  - We expect to receive 10 indicators at three quantiles

Dependence Between Population and Productivity

Treating these two variables separately may not be a wise idea

- Ideally we would like a joint PDF
- We are open to suggestions on this
  - One possibility is an expert elicitation to elicit the entire joint distribution
  - Any literature already available on this?

Temperature Sensitivity

Such an extensive literature means it is almost difficult to know where to start!

Options:

- Take many PDFs from the literature and combine them ourselves
  - Challenge: How to best combine PDFs? Account for dependence?

- Use "combined PDFs" from other recent studies – *preferred*
  - Roe & Baker (2007)
  - Knutti & Hegerl (2008)
  - Otto et al. (2012)
  - IPCC PDFs in September

Suppose We Take Many PDFs From the Literature

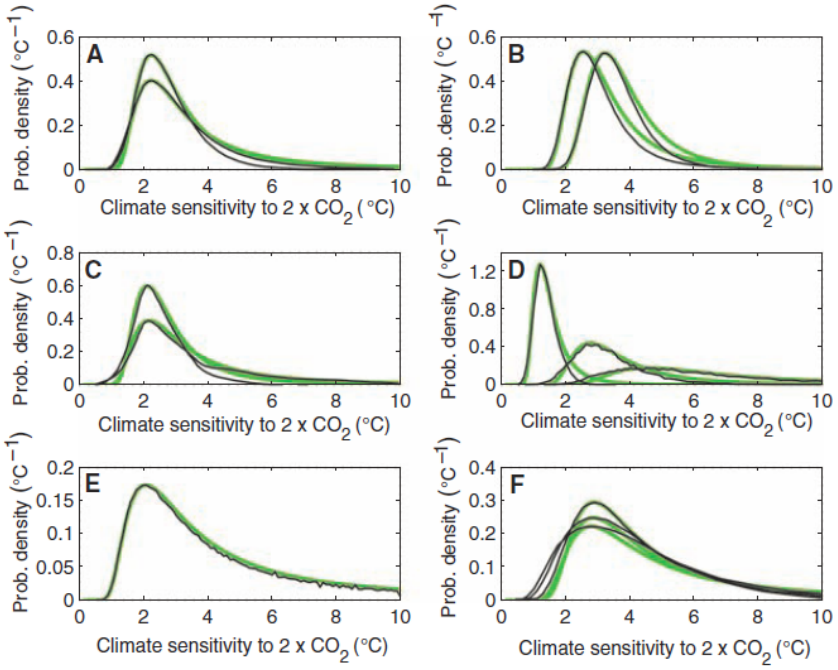
Combining them is not trivial

- How do we weight each PDF? Equally?
- Should we account for dependence in PDFs?
  - One could imagine weighting different PDFs equally
  - But some of the PDFs may derive from largely the same source, so we may not want to equally weight them
  - This raises the question: how do we weight them? Expert assessment?

Roe and Baker (2007)

Roe, G. and M. Baker (2007) Why is Climate Sensitivity So Unpredictable? *Science*, 318: 629-632

- A good starting point, but doesn't provide a single PDF



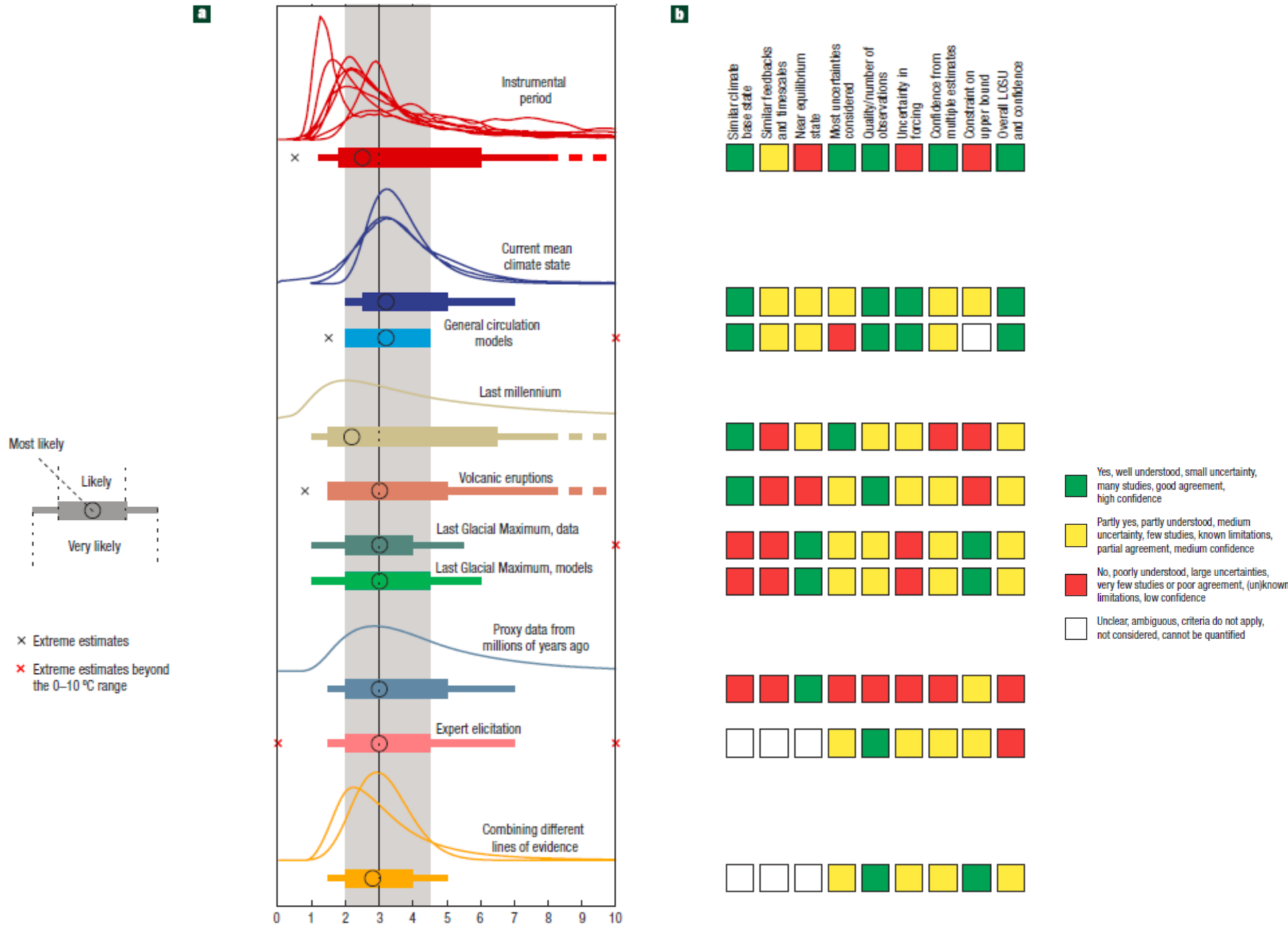
$$h_T(\Delta T) = \left(\frac{1}{\sigma_f\sqrt{2\pi}}\right)\frac{\Delta T_0}{\Delta T^2} \times exp\left[-\frac{1}{2}\left(\frac{(1-\bar{f}-\frac{\Delta T_0}{\Delta T})}{\sigma_f}\right)^2\right]$$

Fig. 4. Climate sensitivity distributions from various studies with the use of a wide variety of methods (black lines) and overlain with a fit of Eq. 3 (green lines), as described in Fig. 3: (**A**) from (*11*), fit with ($\bar{f}$, σ_f) = (0.58, 0.17) and (0.63, 0.21); (**B**) from (*8*), fit with ($\bar{f}$, σ_f) = (0.67, 0.10) and (0.60, 0.14); (**C**) from (*6*), fit with ($\bar{f}$, σ_f) = (0.64, 0.20) and (0.56, 0.16); (**D**) from (*4*), fit with ($\bar{f}$, σ_f) = (0.82, 0.11), (0.65, 0.14), and (0.15, 0.28); (**E**) from (*5*), fit with ($\bar{f}$, σ_f) = (0.86, 0.35) [see also (*29*)]; and (**F**) from (*12*), fit with ($\bar{f}$, σ_f) = (0.72, 0.17), (0.75, 0.19), and (0.77, 0.21).

Knutti and Hegerl (2008)

Knutti, R. and G. Hegerl (2008) The Equilibrium Sensitivity of the Earth's Temperature to Radiation Changes, *Nature Geoscience,* 1: 735-743

- Very nice review paper
- Brings together estimates from a many published papers
- Not entirely transparent in how they went from the many estimates to the "combining different lines of evidence" PDFs


a
Instrumental period
Current mean climate state
General circulation models
Last millennium
Volcanic eruptions
Last Glacial Maximum, data
Last Glacial Maximum, models
Proxy data from millions of years ago
Expert elicitation
Combining different lines of evidence
0
1
2
3
4
5
6
7
8
9
10
Most likely
Likely
Very likely
× Extreme estimates
× Extreme estimates beyond the 0–10 °C range
b
Similar climate base state
Similar feedbacks and timescales
Near equilibrium state
Most uncertainties considered
Quality/number of observations
Uncertainty in forcing
Confidence from multiple estimates
Constraint on upper bound
Overall LOSU and confidence
Yes, well understood, small uncertainty, many studies, good agreement, high confidence
Partly yes, partly understood, medium uncertainty, few studies, known limitations, partial agreement, medium confidence
No, poorly understood, large uncertainties, very few studies or poor agreement, (un)known limitations, low confidence
Unclear, ambiguous, criteria do not apply, not considered, cannot be quantified

Otto et al. (2013)

Otto et al. (2013) Energy Budget Constraints on Climate Response, *Nature Geoscience,* 6: 415-416

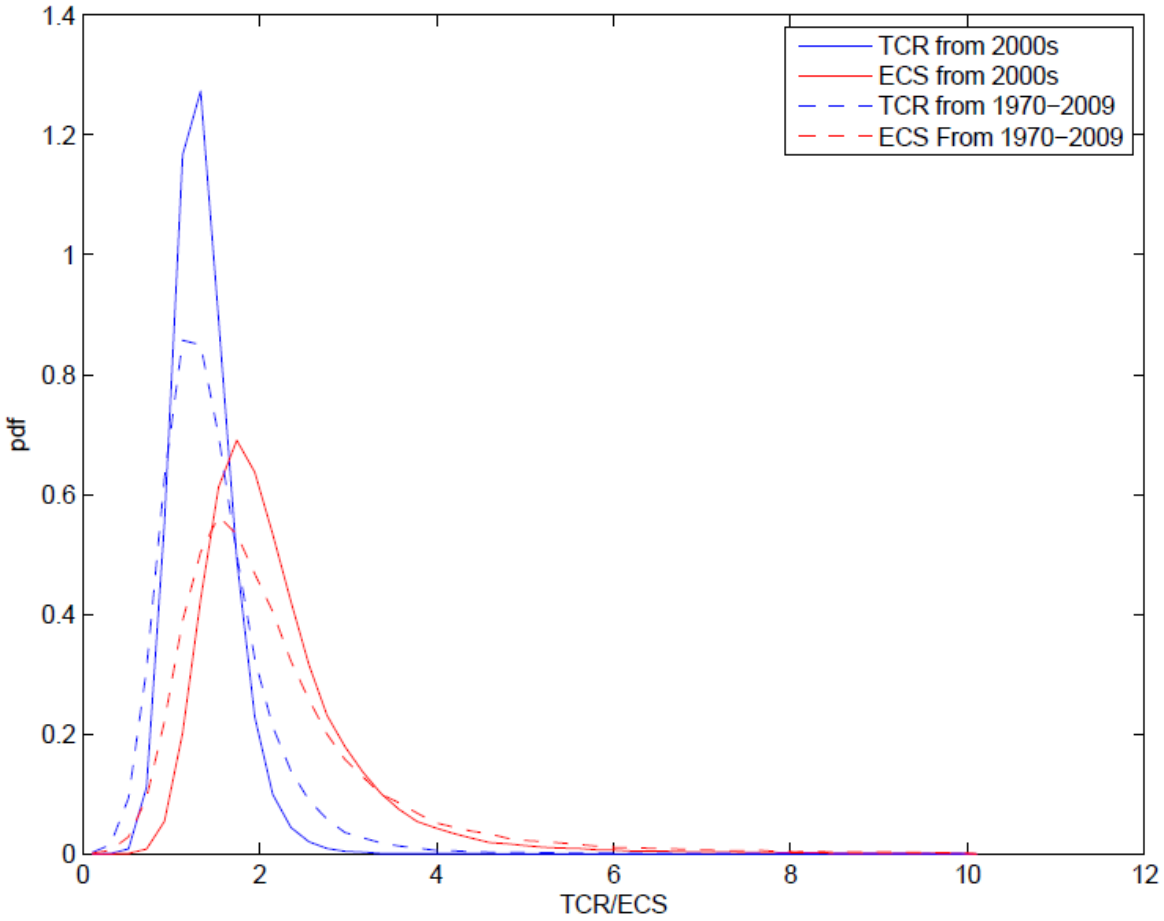
- Uses the HadCRUT4 ensemble data set to get ΔT, data on changes in earth system heat content to get ΔQ, and CMIP5 climate simulation ensemble data with RCP4.5 to get ΔF
- Calculates the equilibrium climate sensitivity (our TSC) and transient climate response

$$\mathrm{ECS} = \frac{F_{2x}\,\Delta T}{\Delta F - \Delta Q}$$

$$\mathrm{TCR} = \frac{F_{2x}\,\Delta T}{\Delta F}$$

Otto et al. (2013)

Otto et al. (2013) Energy Budget Constraints on Climate Response, *Nature Geoscience,* 6: 415-416



Our Inclination

At this stage our inclination for the TSC is to use one (or a few) of the PDFs from these studies

One path forward:

- Use the Knutti and Hegerl (2008) combined PDF and Otto et al. (2013) PDF as a starting point
- Reassess when the IPCC PDFs become publicly available in September