Uncertainty Analysis and Impact Assessment

John Reilly,
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Why Formal Uncertainty Analysis?

- Relate forecast uncertainty to underlying parameters whose uncertainty can be investigated and characterized.
  - The let Monte Carlo analysis combine “cascading” uncertainties.
  - Even economic models have parameters for which statistical evidence is available...History not perfect guide but better than completely ungrounded speculation.

- Inclusion of Policy Choices
  - Uncertainties conditional on specific policy choices.
    - No policy, CCSP Level 1...4
  - Policy strength and efficacy uncertain—or Meta analysis.

- Regional/Downscaling
  - This remains the difficult task.

- Runaway climate change, surprises, unmodeled processes, Structural uncertainty.
  - Formal Monte Carlo analysis can only include whats in the model—flexible models that cover the full range but too simplified.
  - Complementary expert elicitation.
To forecast probabilities of climate change, we need to couple the human & natural components of the Earth System.
Estimate probability distributions for input parameters controlling the emissions and climate projections in IGSM sub-models:

(1) Emissions Uncertainties:
   Elasticities of Substitution
   GDP Growth (based on Labor Productivity Growth)
   Autonomous Energy Efficiency Improvement (AEEI)
   Fossil Fuel Resource Availability, Population Growth
   Urban Pollutant Trends, Future Energy Technologies
   Non-CO₂ Greenhouse Gas Trends, Capital Vintaging

(2) Climate System Response Uncertainties (constrained by observations):
   Climate Sensitivity
   Rate of Heat uptake by Deep Ocean
   Radiative Forcing Strength of Aerosols

(3) Greenhouse Gas Cycle Uncertainties:
   CO₂ Fertilization Effect on Ecosystem Sink
   Rate of Carbon Uptake by Deep-Ocean
   Trends in Rainfall Frequency on natural CH₄ & N₂O emissions

Five Cases indicated by GHG levels (ppm-equivalent CO₂, ppm CO₂ and change in Radiative Forcing relative to ~1990 (W/m²) in ~2100:

- No Policy (1400 ppm CO₂-eq; 870 ppm CO₂; 9.7 W/m²)
- Level 4 (900 ppm CO₂-eq; 710 ppm CO₂; 7.1 W/m²)
- Level 3 (790 ppm CO₂-eq; 640 ppm CO₂; 6.3 W/m²)
- Level 2 (660 ppm CO₂-eq; 560 ppm CO₂; 5.3 W/m²)
- Level 1 (550 ppm CO₂-eq; 480 ppm CO₂; 4.2 W/m²)

Generate 400 member ensembles (Monte Carlo with Latin Hypercube Sampling) for each case
PROBABILITY DISTRIBUTIONS of GLOBAL ANTHROPOGENIC EMISSIONS of CO₂, CH₄ and SO₂ WITH NO CLIMATE POLICY
95% PROBABILITY BOUNDS OF GLOBAL AVERAGE GHG MOLE FRACTIONS AND RADIATIVE FORCING from 1981-2000 to 2090-2100, WITHOUT (1400 ppm-eq CO₂) & WITH A 550, 660, 790 or 900 ppm-eq CO₂ GHG STABILIZATION POLICY?
Cumulative PROBABILITY OF GLOBAL AVERAGE SURFACE AIR WARMING from 1981-2000 to 2091-2100, WITHOUT (1400 ppm-eq CO₂) & WITH A 550, 660, 790 or 900 ppm-equivalent CO₂ GHG STABILIZATION POLICY (Ref: Sokolov et al, Journal of Climate, 2009)

<table>
<thead>
<tr>
<th>Policy Level</th>
<th>ΔT &gt; 2°C (*Values relative to 1860/pre-industrial)</th>
<th>ΔT &gt; 4°C</th>
<th>ΔT &gt; 6°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Policy at 1400</td>
<td>100%(*100%)</td>
<td>85%</td>
<td>25%</td>
</tr>
<tr>
<td>Stabilize at 900 (L4)</td>
<td>100%(*100%)</td>
<td>25%</td>
<td>0.25%</td>
</tr>
<tr>
<td>Stabilize at 790 (L3)</td>
<td>97%(100%)</td>
<td>7%</td>
<td>&lt; 0.25%</td>
</tr>
<tr>
<td>Stabilize at 660 (L2)</td>
<td>80%(*97%)</td>
<td>0.25%</td>
<td>&lt; 0.25%</td>
</tr>
<tr>
<td>Stabilize at 550 (L1)</td>
<td>25%(*80%)</td>
<td>&lt; 0.25%</td>
<td>&lt; 0.25%</td>
</tr>
</tbody>
</table>

WITH THESE PROBABILITIES FOR WARMING EXCEEDING 2°C, HOW FEASIBLE IS A POLICY TARGET TO LIMIT WARMING TO LESS THAN 2°C ABOVE PRE-INDUSTRIAL?
## Cumulative Probability of Global Sea Level Rise from 1981-2000 to 2091-2100, Without & With A GHG Stabilization Policy

<table>
<thead>
<tr>
<th></th>
<th>( \Delta \text{sea level} &gt; 0.2 \text{m} )</th>
<th>( \Delta \text{sea level} &gt; 0.4 \text{m} )</th>
<th>( \Delta \text{sea level} &gt; 0.6 \text{m} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Policy at 1400</td>
<td>100%</td>
<td>65%</td>
<td>9%</td>
</tr>
<tr>
<td>Stabilize at 900 (L4)</td>
<td>99%</td>
<td>20%</td>
<td>&lt; 0.25%</td>
</tr>
<tr>
<td>Stabilize at 790 (L3)</td>
<td>97%</td>
<td>10%</td>
<td>&lt; 0.25%</td>
</tr>
<tr>
<td>Stabilize at 660 (L2)</td>
<td>90%</td>
<td>2%</td>
<td>&lt; 0.25%</td>
</tr>
<tr>
<td>Stabilize at 550 (L1)</td>
<td>70%</td>
<td>&lt; 0.25%</td>
<td>&lt; 0.25%</td>
</tr>
</tbody>
</table>

*rise includes oceanic thermal expansion & mountain glacial melting but not Greenland & Antarctic ice sheet melting*
Comparison to Range in CCSP 2.1A
Comparison to IPCC

Global mean temperature change (from 1981-2000 to 2091-2100); IPCC SRES scenarios (Meehl et al. 2007). Grey bars for IPCC results indicate 66% and 90% probability), and solid black line indicates the 5-95% range of AOGCM results (only provided for B1, A1B, and A2). This analysis shown as box plots, where box indicates the 50% range, median, outer whiskers indicate the 5-95% range, dots individual outliers beyond the 95% bounds.
Change in the probability of exceeding illustrative targets for global mean surface temperature change, as measured by the change between the average for 1981-2000 and the average for 2091-2100.
Mitigation Costs
WHAT ARE THE PROJECTED PATTERNS OF CHANGES IN TEMPERATURE (°C) AND RAINFALL (%) (e.g. FOR NORTH AMERICA)?

Top row: Annual mean, DJF and JJA temperature change between 1980 to 1999 and 2080 to 2099, averaged over 21 models with A1B emissions scenario (-1 to +10°C).

Bottom row: same as top, but for fractional change in precipitation (+/-50%).

Ref: IPCC 4th Assessment, Working Group 1, Chapter 11, 2007
FRAMEWORK FOR AIR POLLUTION IMPACTS ANALYSIS

- **Atmospheric modeling**
  - Pollutant transport
  - Atmospheric chemistry
  - Climate interactions

- **Economic modeling**
  - Economic activities and Policy choices

- **Integrated models & tools**

- **Pollutant transport**
- Concentrations of ozone, particulates, Hg deposition

- **Emissions of NOx, VOCs, SO2, BC, OC, Hg, GHGs**

- **Pollution controls**
- Technology changes

- **Population health impacts**
- Hospital visits
- Mortalities (acute/chronic)
- IQ deficits

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MIT EPPA HEALTH EFFECTS MODEL

Emissions Prediction and Policy Analysis model: general equilibrium economic model

Concentration of \(O_3\), [particulates] (data, model): Population-weighted concentration per global region (16 regions)

Morbidity and mortality outcomes and EUR costs, ozone (EU Extern-E, 2005)

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Exposure-response function(^1)</th>
<th>Cost (€2000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute mortality</td>
<td>0.03(^2)</td>
<td>25,000(^3)</td>
</tr>
<tr>
<td>Respiratory hospital admission</td>
<td>1.25E-5</td>
<td>2000</td>
</tr>
<tr>
<td>Respiratory symptom day</td>
<td>3.3E-2</td>
<td>38</td>
</tr>
<tr>
<td>Minor restricted activity day</td>
<td>1.15E-2</td>
<td>38</td>
</tr>
<tr>
<td>Asthma attack</td>
<td>4.29E-3</td>
<td>53</td>
</tr>
<tr>
<td>Bronchodilator usage</td>
<td>7.30E-2</td>
<td>1</td>
</tr>
<tr>
<td>Lower respiratory symptoms (wheezing) in children</td>
<td>1.60E-2</td>
<td>38</td>
</tr>
</tbody>
</table>

\(^1\) Units are cases yr\(^-1\) person\(^-1\) \(\mu g^{-1}\) m\(^3\)

\(^2\) Bickel and Friedrich (2005). Units are Δannual mortality rate \(\mu g^{-1}\) m\(^3\)

\(^3\) Assuming €50,000/year of life lost, and an average of 0.5 years lost per acute mortality

Loss of labor, capital and equilibrium economic effects (2000-2100)

[Matus et al., 2008; Nam et al., in prep; Selin et al., in prep.]
GLOBAL COSTS OF OZONE POLLUTION IN 2050

- O$_3$ from A1B scenario [Wu et al., 2008] to 2050
- Calculate change in welfare due to health impacts of ozone changes, separately for emissions and climate drivers

- 2050 welfare loss from O$_3$ health impacts, climate only scenario: €790 million (year 2000 €)
- 2050 welfare loss from climate+emission changes: €120 billion
- 2050 welfare loss from all O$_3$ above background: €580 billion

[Selin et al., in prep]
Uncertainty: Due to uncertainty in dose response relationships and economic modeling of impacts.
Summary

- Our work suggests the IPCC underestimates likely future climate change, especially because of low emissions scenarios that include implicitly policy measures.
- How much mitigation is economic to undertake depends on how bad impacts are if there is no policy.
- Appropriate adaptation measures depend on likelihood of successful mitigation policy.
- Significant unabated climate change even in the tightest policy cases.
- Uncertainty techniques also can be applied to impacts work—preliminary results suggest air pollution health effects due to climate a relatively insignificant effect—greater concern is emissions of ozone precursors themselves.
Compared with NO POLICY

What would we buy with STABILIZATION at 660 ppm-equivalent of CO$_2$?

A NEW WHEEL with lower odds of EXTREMES