Uncertainty and IAMs: ongoing work at FEEM&CMCC
## Uncertainty and IAMs: needs and challenges

<table>
<thead>
<tr>
<th>Reasons for including uncertainty in IAMs</th>
<th>Challenges of including uncertainty into IAMs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncertainty is pervasive (climate, socio-economics, technology etc.)</td>
<td>For some drivers it is difficult to quantify (or has not been quantified)</td>
</tr>
<tr>
<td>Large multi model ensembles with a lot of scenarios</td>
<td>Scenarios cannot be interpreted statistically to provide uncertainty ranges</td>
</tr>
<tr>
<td>Better algorithms and faster computing (parallel)</td>
<td>Curse of dimensionality</td>
</tr>
<tr>
<td>Policy makers demand for robust strategies</td>
<td>Difficulty of communicating uncertain outcomes</td>
</tr>
</tbody>
</table>
Model redefined on nodes of the scenario tree. Non-anticipativity is implicitly defined through characterization of predecessor/successor relationships among nodes.

<table>
<thead>
<tr>
<th>Parallel computing</th>
<th>Cooperative solution (joint optimization)</th>
<th>Competitive solution (single region optimization and iterations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deterministic</td>
<td>9 hrs</td>
<td>5 mins</td>
</tr>
<tr>
<td>Stochastic (2 SOW)</td>
<td>30 hrs</td>
<td>20 mins</td>
</tr>
</tbody>
</table>
SRM is economical but potentially disruptive: assume it is viable on a large scale from 2050 onward with a given probability. Would this hamper mitigation?

Emmerling and Tavoni, 2012
SP application: SRM (solar radiation management)

Emmerling and Tavoni, 2012
Uncertainty on the effectiveness of an R&D programme to develop a carbon free ‘breakthrough’ technology:

Bosetti and Tavoni, 2009
The purpose of this project is to develop a framework for:

1. Integrating the large and growing data sources on technology supply derived from expert elicitations
2. Communicating the integrated data in a way that is useful to policymakers and IAM modelers.
3. Study the effect of uncertain technical change in IA models
## Expert judgment of technology prospects: DB

<table>
<thead>
<tr>
<th>Technology:</th>
<th>CCS</th>
<th>Solar</th>
<th>Nuclear</th>
<th>Biofuels</th>
<th>Electricity from biomass</th>
<th>Battery/ Electric vehicles</th>
<th>Utility scale storage</th>
<th>Wind, geothermal, hydrogen</th>
<th>Building energy efficiency</th>
<th>IGCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>UMass</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Harvard</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>FEEM/CMCC</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>DOE EERE</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>CMU</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>NAS</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Chung et al</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
CDF on future (2030) costs of technology for different levels of R&D

ICARUS survey, Bosetti et. al 2012
Research Question: What is the optimal/robust energy R&D portfolio?

- **Data**: Elicitation from FEEM/CMCC, Harvard, Umass on Solar PV, Nuclear, CCS, Liquid fuels from biomass, Electricity from biomass
- **Modelling tools**: GCAM, Markal US, WITCH
- **Type of Analysis**: MonteCarlo analysis with post-processing to generate pdfs
- **Scenarios**: unconstrained, 450, 550ppm climate policies

- Assess IAMs payoffs for different technology costs (and associated R&D expenditures) and devise optimal R&D allocation
Example of WITCH sampling outcome

![Graph showing carbon price fluctuations over runs]

- Price of carbon: $ C02
- Runs: 0 to 600
- 2100 price of carbon: $ ton C02

- Blue diamonds: 450
- Red square: Worst Case 450
- Green triangles: 550
Approximate Dynamic Programming in WITCH

Alternative: use Hermite interpolation (Cao and Judd, 2012) to fit value function and then run a SP programme

G. de Maere et. al.
Preferences

\[
\text{Social Welfare} = \sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-\alpha}}{1-\alpha}
\]

Restricts the coefficient of relative risk aversion ("CRRA Coefficient") to equal the inverse of the elasticity of intertemporal substitution ("EIS"). More aversion to climate risks, implies a higher discount rate and greater disinterest in the future.

\[
U_t = \frac{1}{1-f} \left( (1 - \beta)C_t^{1-s} + \beta((1 - f)E_t U_{t+1})^{\frac{1-s}{1-f}} \right)^{\frac{1-f}{1-s}}
\]

Generalize utility function to separate time preference and risk aversion (Epstein and Zinn, 1989). Recently introduced into IAMs (Kaufmann, 2012, Ackerman, 2012). Introduced in the stochastic WITCH with limited additional computational burden.
Ambiguity over experts opinion

Athanassoglou, Bosetti and de Maere 2012
Way forward

Research to further integrate uncertainty into IAMs:

• Advanced stochastic programming techniques (e.g. ADP)
• Global sensitivity analysis
• Alternative decision models to expected utility (ambiguity aversion, minmax regret, etc)
• Simplified models which can summarize large model ensemble runs and build meta-models upon them

Activities and projects:

• ADVANCE project: 2013-2017, PIK (Coordinator), FEEM, IIASA, PBL, JRC, ..
  • Work-package on technical change and uncertainty: FEEM/CMCC to develop uncertainty module applicable to IAMs