Hedging the climate sensitivity risks of the 2°C target

International Energy Workshop 2015

Tommi Ekholm
VTT Technical Research Centre of Finland

The 2°C limit and climate sensitivity (Cs)

Uncertainty in climate sensitivity (Cs)
⇒ uncertainty in future temperature
⇒ 2°C target cannot be met with certainty

Source: Meinshausen et al. (Climatic Change 109, 2011)
Learning and sequential decision making

- Uncertainty over Cs decreases gradually through learning
  - new observations over time
  - improved modelling

- Emission pathways can be sequentially readjusted to adapt to this new information

- In principle, possible to meet the 2°C target with certainty
Intertemporal cost-efficiency problem, – a recursive formulation

Cost efficiency problem for a temperature limit under uncertainty:

\[
\min_r \left\{ E_t \left[ \sum_{\tau=t}^{\infty} \beta^\tau c_\tau(r_{\tau,s}) \right] \right\} \quad \Delta T \text{ limit}
\]

\[
T(x_{\tau,s}) \geq 0, \quad \text{State transfer function}
\]

\[
x_{\tau+1,s} = f_s(x_{\tau,s}, r_{\tau,s}), \quad \forall s, \tau \geq t,
\]

\[
r_{\tau,s_1} = r_{\tau,s_2} \quad \text{if } S(\tau, s_1) = S(\tau, s_2)
\]

Scenario-tree structure (non-anticipativity constraints)

Recursive formulation:
Minimize the current period’s and the expected future costs’ sum

\[
V_t(x_t) = \min_r \{ c_t(r_t) + \beta E_t \left[ V_{t+1,s}(f_s(x_t, r_t)) \right] \} \quad \text{if } T(f_s(x_t, r_t)) \geq 0, \forall s
\]

27/07/2015
Evolution of expected carbon price

- Solution through the recursive reformulation (see the paper) yields an equation for the expected evolution of carbon price:

\[
\begin{align*}
    c'_t(r_t) & = \beta E_t \left[ c'_{t+1,s}(r_{t+1,s}) \frac{\sum_{\tau=t+1}^{\infty} (I_s(t, \tau) \beta^{\tau-t-1} \lambda_{\tau,s})}{\sum_{\tau=t+2}^{\infty} (I_s(t+1, \tau) \beta^{\tau-t-1} \lambda_{\tau,s})} \right]
\end{align*}
\]
The numerical model

- **SCORE**: Stochastic Cost Optimization for Reducing Emissions
  - Marginal abatement cost (MAC) curves estimated from literature (for simplicity, no path-dependency assumed)
  - Simplified climate module for calculating $\Delta T$ (from DICE)
  - A stochastic information process describing learning on Cs, sequential decision making on emission reductions
  - 10 year time-steps, model runs up to 2200
Learning on climate sensitivity

- Binomial lattice:
  - 10 year time periods, the true value of Cs known in 2080
  - 7 end states corresponding to a distribution from Knutti and Hegerl (Nat. Geosci., 2008), 64 paths through the lattice
  - assumed to be exogenous
Emissions under sequential decision making

- Stochastic range
- Stochastic 67% range
- Stochastic average
- Deterministic, $Cs = 3^\circ C$
- $Cs = 1.0^\circ C$
- $Cs = 5.4^\circ C$
Carbon price under sequential decision making
Sensitivity analysis on the results for 2020

- Sensitivity of 2020 prices / emissions with regard to:
  - Discount rate
  - Cost assumptions
  - Inertia of capital for emission reductions
  - Treatment of non-CO\textsubscript{2} emissions

![Graph showing sensitivity analysis](image-url)

Legend:
- 7% discounting
- 5%
- 3%

Gases as CO\textsubscript{2}-eq
Separate cost curves for CO\textsubscript{2}, CH\textsubscript{4} and N\textsubscript{2}O
- no inertia
- 20 yr capacity lifetime
Main conclusions

- 2°C limit met with certainty through sequential decision making, although some of the tail-risk of Cs uncertainty is not captured.

- Uncertainty in Cs warrants more ambitions early action than what a deterministic case exhibits.

- Near-term policy guidance dependent on uncertain assumptions.

- Cs is a notable risk-factor for long-term carbon prices: annual volatility of optimal carbon prices around 10-20%.
Thank you!

Contact:
tommi.ekholm@vtt.fi