Climate Investments Optimized under Uncertainty

Isaac Newton Institute – CLPW04: Uncertainty in Climate Prediction: Models, Methods and Decision Support
Cambridge, 9Dec2010

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Also Guest at

Potsdam Institute for Climate Impact Research (PIK)

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• The climate ‘problem’

• Cost Effectiveness Analysis of optimal energy investments

• Optimisation under uncertainty
Two Lines of Argument behind Global Warming Mitigation Policies

• Explicitly projected impacts of global warming ‘too large’

• Precautionary principle
  – beyond certain regimes knowledge too poor to weigh costs and benefits
Historic Dimension of Temperature Rise

- 2° Guardrail of EU
- Last Ice Age (until ~10,000 years)
- Holocene

("Hot House" ~ 55 Million years ago)
Potential Tipping Points – Aspects of both Categories

Schellnhuber & Held 2002;
Lenton, Held, Kriegler, Hall, Lucht, Rahmstorf, Schellnhuber, PNAS, 2008;
Dakos, Scheffer, van Nes, Brovkin, Petoukhov, Held, PNAS 2008;
Kriegler, Hall, Dawson, Held, H. J. Schellnhuber, PNAS, 2009;
M. Scheffer, J. Bascompte, W. Brock, V. Brovkin, S. Carpenter, V. Dakos,
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- The climate ‘problem’
- **Cost Effectiveness Analysis of optimal energy investments**
- Optimisation under uncertainty
CO$_2$-Emissions
Business as Usual (BAU) vs 2°C-Target

![Graph showing CO$_2$ emissions comparison between BAU and 2°C Target. The graph illustrates the mitigation gap and the overshoot beyond the 2°C target.](image-url)
‘Social Planner Perspective’

Gain from climate policy
= Avoided damages
- mitigation costs
- adaptation costs

…as if ‘global society as a whole’ could behave / has behaved as single-actor.

A very ‘quick and dirty’ statement, unclear
- when &
- in what sense damages and costs enter the quality of life for whom.
- nevertheless captures some of the essence of the mitigation/adaptation discussion.
- will be refined on the next slides
When to Invest How Much into which Energy Technology?
Phrasing as a Control Problem

Investments in
- Renewables
- Efficiency
- Fossil Fuels
- CCS

Investment decisions (control paths) \( c(t) \)

\[
\text{Max!}_{c(t_0), \ldots, c(\infty)} \text{ Welfare} := \int_{t_0}^{\infty} dt \text{ Utility}(t)[(c(t_0), \ldots, c(t))] e^{-\rho t}
\]

‘Society’s Happiness’

‘Path’ = Economists’ lingo for ‘time series’

One school’s approach: ‘Cost-Benefit-Mode’
Conceptual Difficulties

• Impacts poorly known
  – Often poor natural science/engineering knowledge (at least today)
  – Need for valuation of goods

• Need to weigh
  – Present mitigation costs … against …
  – Future avoided damages
• An easier & better-posed alternative? …
When to Invest How Much into which Energy Technology?
Phrasing as a Control Problem

**Investments in**
- Renewables
- Efficiency
- Fossil Fuels
- CCS

**Investment decisions (control paths)**
\( c(t) \)

**Emissions**

**Socio-Economic System**

**Climate System**

**Precautionary Principle**
\[ T < T_{\text{max}} \]

Max!\(_{(c(t_0),...,c(\infty))} \) Welfare := \( \int_{t_0}^{\infty} dt \text{Utility}'(t)[(c(t_0),...,c(t))] e^{-\rho t} \)

subject to \( \forall t \) \( T(t)[(c(t_0),...,c(t))] < T_{\text{max}} \)

‘Cost-Effectiveness-Mode’
The REMIND-R Model:
Basic characteristics of a coupled climate-energy-economy-model

Edenhofer et al.
Options for CO$_2$ emissions abatement

Bruckner, Edenhofer, Held et al., 2009
Higher Resolved Energy System
(for 450ppm-eq)

Based on IEA-Daten (1971-2005) and REMIND-Results for 450ppm-eq (ADAM); Graphics by Jan Steckel (PIK)
Mitigation Costs & Value added by Individual Technologies

(for 450 ppm (~50% 2°-Target) & 2050 equal per-capita emission rights)

Discounted at 3%

All Technologies Available
- Nuclear frozen
- Biomass frozen
- No CCS
- Renewables frozen
- No CCS, Nuclear frozen

Consumption Losses [%]
Energy System-Investments

Baseline

450 ppm CO₂

• No investments into conventional fossils after 2015

• ½ ... 1% GDP into renewables

RECIPE 2009
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• The climate ‘problem’

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Hedging Strategy needed in view of ‘Irreversibility Effect under Uncertainty‘

• Our actions may have irreversible effects:
  – Investing too early in a specific energy technology or adaptation measures may lead to stranded investments.
  – Waiting too long on mitigation may trigger irreversible climate system or ecological effects.

→ Again an application for optimisation, if uncertainty is reflected in the welfare function.
The simplified Model (for Uncertainty Study)

Differences of MIND as against REMIND

- Endogenous technical change over both learning-by-doing and R&D in labor- and energy-efficiency.
- Crudely resolved energy sector with renewables, fossils, and fossil extraction.
Perturbing a 2 Important Climate Parameters

<table>
<thead>
<tr>
<th>Climate Sensitivity</th>
<th>$\propto$ Temp ($t \to \infty$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean Heat Uptake</td>
<td>$\propto$ Lin. Temp – Response Time Scale</td>
</tr>
</tbody>
</table>
300-Member Climate Parameter Ensemble
Compatible with 20th Century Climatology

(derived from Frame et al., Geophys.Res. Lett. 2005)
Addressing also Technological Uncertainty

Factorial Design
- 10 Rogner Parameter (fossil resource base)
- $\times$ 10 Learning Rate of Renewables
- $\times$ 300 Climate (correlated climate sensitivity & ocean heat uptake)

$\Rightarrow$ 30 000 ‘Parallel Worlds’
Lower Climate Sensitivity implies Cost Reduction for 2° Target

Held et al., Energy Economics (2009)
Lower Climate Sensitivity implies Cost Reduction for 2° Target

$\frac{1}{4} \ldots \frac{1}{2} \% \text{ GDP per } ^\circ\text{C in CS}$

*Held et al., Energy Economics (2009)*
Climate Science’s evergreen: Knowledge on CS
5...95% Quantiles

2001-2005
After Parameter Perturbations

Until 2001
No Parameter Perturbations

Climate sensitivity $\Delta T_{2x}$ [$^\circ$C]
Reducing Uncertainty by Opening a Qualitatively New Data Channel

Schneider von Deimling, Held, Ganopolski, Rahmstorf, Clim. Dyn., 2006
Paleo Observations → Climate Modules → Economic Growth Model

**Economic value of paleo information?**

- **LGM → Climate sensitivity** (Schneider von Deimling, Held, Ganopolski, Rahmstorf, 2006)

- **8k-event → ocean time scales** (Lorenz, Held, Bauer, Schneider; 2010; Heraeus-Prize 2008)
The following graphs are also from

- Hermann Held, Elmar Kriegler, Kai Lessmann, Ottmar Edenhofer:

  Efficient Climate Policies under Technology and Climate Uncertainty

  Energy Economics – special issue on induced technological change & uncertainty, 2009

  ..utilising the precursory, numerically less demanding model MIND (Edenhofer et al., 2005)
Strong Influence of Climate Sensitivity on Economically Optimal Emission Paths
Economic Optimisation internalising Uncertainty

Factorial Design
• 10 Rogner Parameter (fossil resource base)
• $\times$ 10 Learning Rate of Renewables
• $\times$ 300 Climate (correlated climate sensitivity & ocean heat uptake)
• $\Rightarrow$ 30 000 ‘Parallel Worlds’

• Optimise Expected Utility
• Under $P(T<2^\circ) = 75\%$ boundary condition
Two Guardrail Versions

• Version I: \( P(\forall_t \ T(t) \leq T_{\text{max}}) = 0 \) – stricter condition
• Version II: Given \( t \), \( P(T(t) \leq T_{\text{max}}) = 50\% \) or 100\%
• Version I observed \( \Rightarrow \) Version II observed
Probabilistic Guardrail
‘Chance Constrained Programming’ (CCP)

Deterministic Guardrail
- Single Investment Strategy
- Single Temperature Profile keeping the Guardrail

Probabilistic Guardrail
- Single Investment Strategy
- Multiple Temperature Profiles due to Uncertainties
- p% keep the Guardrail
- (1-p)% may exceed the Guardrail
PDFs on Climate Sensitivity

IPCC-AR4

Held et al., 2009
Economic Losses disaggregated over time

Output.Guardrail \((n, t)\) - Output.BAU\((n.t)\)

Output.BAU\((n.t)\)
Optimal Investments into Renewable Energy $| \ P(T<2^\circ) = 75\% $
‘Uncertainty under Learning’

- We will certainly reduce uncertainty in the long run.

- Ongoing work with M. Schmidt, A. Lorenz, E. Kriegler
Learning about climate sensitivity

- Strong dependence of optimal emissions on what is learned
- Much stronger emission reductions if learning is anticipated

1st Problem with CCP
‘Chance’ of Infeasible Solution

• Large - Climate Sensitivity ‘states of the world’ dominate the prior emission path.

• In order to prepare for the worst case after learning, the allowed cumulative amount of emissions before learning gets too restricted
  – (Cumulative allowed Emissions scale with $(2^{T^* / CS} - 1)$ in 1st order – Kriegler&Bruckner, Clim. Change, 2004)
2nd Problem with CCP:

- Optimisation under expected learning may not work within chance constrained programming, as damage function is missing & represented as constraint
  - hence EVPI could be negative
• Hence CCP works conceptually well without learning

• However conceptually flawed if ones allows for anticipated learning…
  – tricky issue, …
  – Then we may need a hybrid approach derived from both cost effectiveness / cost benefit analysis
  – Area of active research – so at present no easy solution!
Cost Benefit vs. Cost Effectiveness Analysis of the Climate Problem:

<table>
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<th>Pros</th>
<th>Cons</th>
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</table>
| **Cost Benefit Analysis** | • Absorbs conceptually easily optimization under uncertainty and anticipated learning.  
                                • If all the necessary data are supplied always politically informative as optimal trade-off is derived. | • Needs lots of input on climate damages and their evaluation – likely much more knowledge than we presently have*.  
                                                                              • Results strongly depend on pure rate of time preference $\rho$. |
| **Cost Effectiveness Analysis** | • Does not require knowledge on climate damages; results more robust w.r.t. $\rho$.  
                                • Politically still informative if climate target satisfies environmentalists and the target’s costs are low enough as not to bother ‘the economists’. | • Conceptually ill-posed when needing to address uncertainty in combination with anticipated learning.  
                                                                              • Does not resolve political conflict if the target’s costs are judged as too high. |

* ‘likely…have’ represents a personal judgment by HH.
Compromise: e.g.

- Use „Cost Risk Analysis“ (Schmidt, Lorenz, Held, Kriegler, CCL, in press)
  - \( U(t) := -\text{mitigation losses}(t) - a \ P(T>T^*)(t) \)
  - Is a utility function
  - Yet avoids having to monetarize all the damages.
Post Copenhagen 2009: Potential ‘Plan B’: Linking of Regional $CO_2$-Trading Systems

- US ETS
  - Max 7,000 Mt CO$_2$ eq
  - Start: ?

- Canada ETS
  - Max 740 Mt CO$_2$ eq
  - Start: 2010?

- RGGI ETS
  - 170 Mt CO$_2$
  - Started: 2009

- Midwestern GHG Accord
  - ? Mt CO$_2$ eq
  - Start: ?

- Mexico ETS
  - Max 640 Mt CO$_2$ eq
  - Start: 2012?

- EU ETS
  - 2,000 Mt CO$_2$
  - Started: 2005

- Swiss ETS
  - 3 Mt CO$_2$
  - Started: 2008

- South Korea
  - Max 590 Mt CO$_2$ eq
  - Start: 2013?

- Japan ETS
  - Max 1,400 Mt CO$_2$ eq
  - Start: ?

- Tokyo ETS
  - Max 55 Mt CO$_2$
  - Start: 2010

- Australia ETS
  - Max 560 Mt CO$_2$ eq
  - Start: 2011?

- NZ ETS
  - 98 Mt CO$_2$ eq
  - Start: ?

- WCI ETS
  - 800+ Mt CO$_2$ eq
  - Start: 2012

Stabilization of Climate Coalition through
- • Border-Tax-Adjustments
- • Creating ‘Club-Goods‘ – eg Technology Protocols

Source: Flachsland, Lessmann et al. (2009)

- Herald Tribune, Friday, January 23rd, 2009
Conclusions

• Costs of transforming the energy system in-line with a 2° target on the order of $1/2...2\%$ GDP (deterministic analysis)

• Inclusion of uncertainty without learning in cost effectiveness analysis suggests decades earlier investments into mitigation technologies
  – Most likely in part triggered by nonlinearities in the technology sector

• A hybrid approach of cost benefit and cost effectiveness analysis seems to be adequate if intertemporal learning under uncertainty is to be included.

• Hypotheses:
  Analyses with decision-dynamically consistent stylized approaches can help to
  – prepare stakeholder dialogues
  – accelerate funding for ‘directly decision-relevant’ research.