# Climate Engineering under Deep Uncertainty and Heterogeneity

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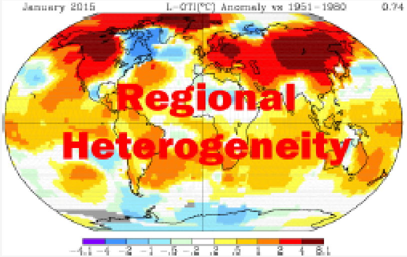
# Motivation


Nations Unies
Conférence sur les Changements Climatiques 2015
Cooperation?


Impacts


Attainable?
1.5 DEGREES
Alternatives?


January 2015
L-OTI(°C) Anomaly vs 1951-1980
0.74
Regional
Heterogeneity

# Uncertainty and the Environment

- General kind of uncertainty:
  a) Future costs
  b) Benefits of an action.
- Specific uncertainty:
  a) Evolution of the natural system
  b) Climate sensitivity
- Sources of uncertainty :
  a) Major gaps in knowledge
  b) Limited modeling capacity
  c) Lack of theories to anticipate thresholds
  d) Emergence of surprises and unexpected consequences.

# Knightian Uncertainty

- It might be difficult or even impossible to associate probabilities with uncertain shocks affecting the natural system evolution.
- **Knightian Uncertainty**:
  1. A situation where there is ignorance, or not enough information to assign probabilities to events.
  2. Knightian uncertainty is contrasted to risk (measurable or probabilistic uncertainty).
  3. The maxmin expected utility is used as a conceptual framework for designing management rules which adhere to a precautionary behavior.
  4. Under Knightian uncertainty the researcher cannot choose one prior to define expected utility as is done under risk.
  5. Compare solutions under risk and under ambiguity.

# Motivation

## Climate Engineering

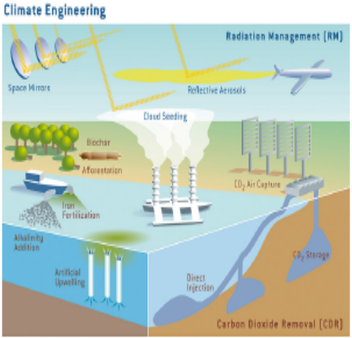
**Affecting the earth's climate through:**

* Carbon Dioxide Removal (CDR)
* Solar Radiation Management (SRM)

**Research and policy questions**:

* Technical feasibility and effectiveness
* Impacts and side-effects
* Global governance and regulation
* Relation with Mitigation and Adaptation

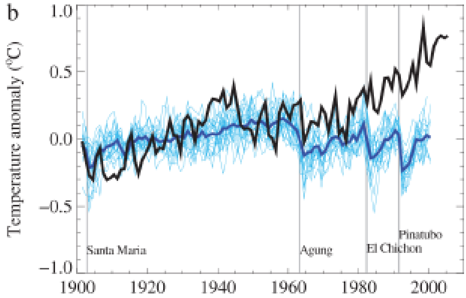
## Climate engineering options




Source: Kiel Earth Institute

# Solar Radiation Management (SRM)

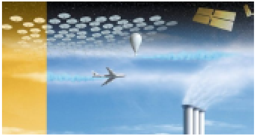
## Global mean temperature increase in the 20th century




Source: IPCC AR4, Hegerl et al. (2007)

## Sulfate aerosols cooling

## SRM technical options



# Uncertainty and SRM

- Robust decisions are obtained by introducing a fictitious adversarial agent (Nature).
- Ambiguity is modeled in terms of a robust control problem.
- The standard expected utility maximizing model could be derived as a special case of the robust control model when the regulator has no concerns about model misspecification and completely trusts the benchmark model.
- The methodology is applied to the optimal climate policy based on mitigation and SRM as policy options.

# Motivation - Scenarios

***Aim of this work:***

***Study strategic incentives for SRM and ambiguity effects***

**Different scenarios analyzed**

1. Cooperative vs. non-cooperative policy (Nash)
2. Risk (benchmark) and Deep Uncertainty (model misspecification)
3. Heterogeneity
   - Level of uncertainty / "confidence"

# Model misspecification

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- Damages from Climate Engineering

$$D_z(\mathbf{z}(t), u_i(t)) = u_i(t)\zeta \sum_{i=1}^{2} z_i(t) \qquad (2)$$

# Robust control problem

The multiplier robust control problem for each individual country $i$ and is given by

$$V_i = \max_{E_i, z_i} \min_{h_i} \int_0^{\infty} e^{-\rho t} \left[ U(E_i) - C(z_i) - D_T(T) + D_z(z_i, u_i) + \frac{1}{2} \theta h_i^2 \right] dt \qquad (3)$$

subject to

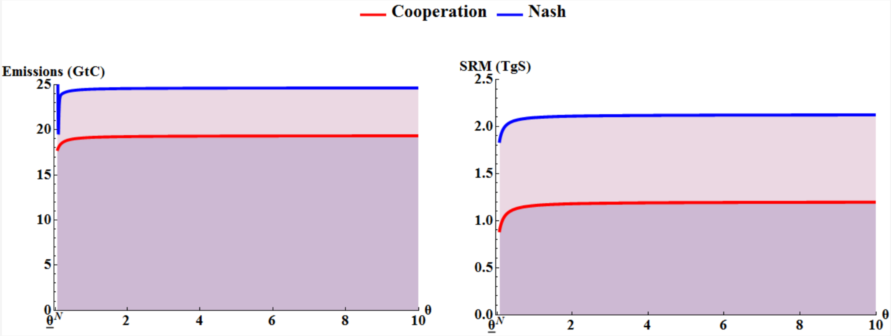
$$T = \frac{1}{\delta} \left( \lambda \sum_{i=1}^{2} E_i + \phi \sum_{i=1}^{2} z_i \right)$$

and

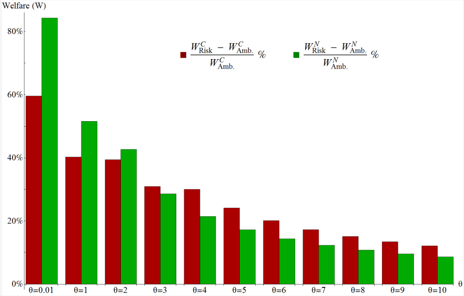
$$du_i = \left[ \eta (1-\gamma) \sum_{i=1}^{2} z_i - m u_i + \sigma h_i \right] dt + \sigma dW_i \ , \ i = 1,2$$

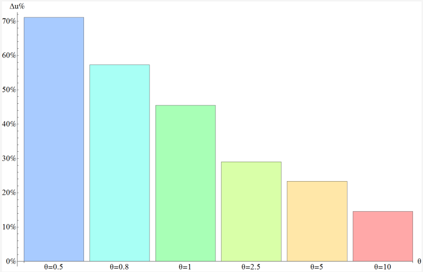
# Results under Symmetry

- Emissions and SRM lower under cooperation



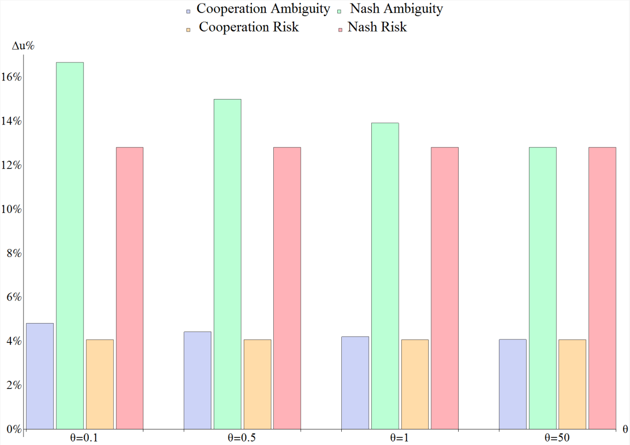
# Quantification of Ambiguity




- Left Figure: The quantification of the uncertainty concerns in terms of welfare effects.
- Right Figure: Relation between the choice of the maximal deviation of the SRM damages that the regulator will consider implicitly ($\Delta u\%$) & the value of the robustness parameter ($\theta$).

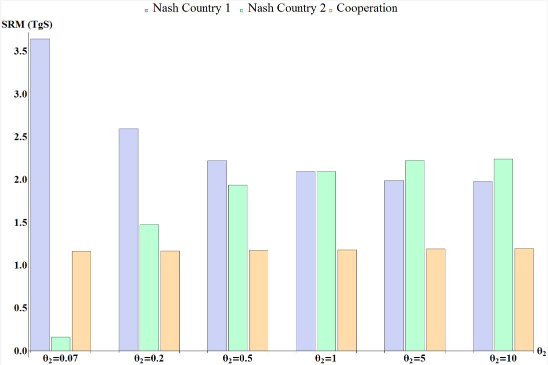
# The impact of model misspecification - SRM Damages




- Damages from SRM (in % of GDP) for different degrees of $\theta$ (confidence in the model).

# The impact of model misspecification - Heterogeneity

Heterogeneity in ambiguity aversion (model confidence)




- The precautionary policy induced by uncertainty aversion can be counteracted if only one actor is sufficiently confident in the future costs and potential impacts from climate-engineering.

# Conclusions

- Deep uncertainty leads to low SRM effort (more relevant in strategic interaction).
- Heterogeneity is crucial and leads to unilateral SRM implementation.
- Deep uncertainty more relevant under non-cooperation and mitigated through cooperation on climate engineering policy.
- In Nash countries prefer a mix of policies with high emissions and high SRM. This mix of policies leads to higher damages from SRM than in global cooperation.

# Future Work

- Extend the basic model to incorporate non-symmetric games between agents and Nature with heterogeneity in spatial characteristics of agents.
- Study optimal climate policy with the presence of climate engineering under the occurrence of climate-change related calamities.
- Consider possible future interactions between SRM, tipping points and economic activity.

# *Thank you!!*

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