Geoengineering and abatement: a 'flat' relationship under uncertainty

Johannes Emmerling\(^1\) and Massimo Tavoni\(^1\)

\(^1\)Euro-Mediterranean Center on Climate Change (CMCC), CIP Division & FEEM

Motivation - About Geoengineering

- What is Geoengineering (GE)?

Carbon Dioxide Removal (CDR) and Solar Radiation Management (SRM)
Motivation - About GE

Why?

- Reducing emissions is the best climate policy, “but it is not happening”
- GE potentially could counteract anthropogenic global warming
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How it could work
- Eruption of Mount Pinatobu in 1991 (ejection of $10^{12}$ gS) led to a drop of global temperature by 0.5°C

Implementation costs of SRM: 5-50 billion USD annually
But: considerable risks and side effects
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SRM via $SO_2$ injection (Crutzen, 2006) could offset global warming (Lenton and Vaughan, 2009), cost-effective and easily implementable (Robock et al., 2009).

Uncertainty about climate sensitivity (Ricke et al., 2012), the relation with expected sea-level rise (Irvine et al., 2012), precipitation (Moreno-Cruz et al., 2012), and dynamic responses (Driscoll et al., 2012).

Strategic Geoengineering: Barrett (2008); Millard-Ball (2012); Ricke et al. (2013); Weitzman (2012)
Literature on GE

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- Geoengineering vs. Mitigation:
Research approach

- Geoengineering is fast, inexpensive, but uncertain and not yet implementable
- How much does this affect the optimal mitigation effort? CEA vs. CBA?
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Probability $p$ of Geoengineering

becoming a technically feasible/acceptable/reasonable climate policy option

- $p = 0$: mitigation (and adaptation) only option
- $p = 1$: no need for mitigation / GE as insurance
- $0 < p < 1$: When becomes mitigation unnecessary?
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(Delicately) optimistic view:

- perfectly effective to offset global warming
- no risks or side effects
- minimizing expected costs & risk neutrality
Outline

1 Introduction

2 Uncertain effectiveness of Geoengineering

3 Multiple uncertainties

4 Application using WITCH

5 Conclusion
Uncertain effectiveness of GE

Basic framework used throughout the paper (here: CEA):

- Express all variables in radiative forcing potential
- Uncertain effectiveness of Geoengineering $0 \leq \tilde{\phi} \leq 1$ (Bernoulli) and carbon-climate response $\tilde{x}\lambda (E \tilde{x} = 1)$

$$\Delta T \equiv \tilde{x}\lambda (S^{bau} - A_1 - A_2 - \tilde{\phi} G) \leq \Delta T^{max}$$
Uncertain effectiveness of GE

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  \[\Delta T \equiv \tilde{x} \lambda (S^{bau} - A_1 - A_2 - \tilde{\varphi} G) \leq \Delta T^{max}\]
- Two-period model: only uncertainty about Geoengineering

\[
\min_{A_1} V(A_1, p) = C_A(A_1) + \beta (p C_G (S^{gap} - A_1) + (1 - p) C_A (S^{gap} - A_1))
\]

where $S^{gap} = S^{bau} - \lambda \Delta T^{max}$
Assumption 1: $C'_G(x) \leq C'_A(x) \forall x$ (ensures that $G = 0$ or $A_2 = 0$)
Uncertain effectiveness of GE

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- $A_1^*(p)$ is decreasing in $p$ if and only if $V_{A_1p} \geq 0$ (A1)

- (Lemma 1) If $V_{A_1p}$ is non-negative, the function $A_1^*(p)$ is strictly concave in $p$ if and only if the following condition holds:

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\frac{V_{A_1A_1A_1}}{V_{A_1A_1}} > 2 \frac{V_{A_1A_1p}}{V_{A_1p}}.
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- Lemma 1 can be applied for a wide set of abatement cost functions, including $C_A(A) \propto A^\alpha, \alpha \in [2,3]$ (Eyckmans and Cornillie, 2000)
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- CBA with damage function instead: less stringent; for a fully quadratic specification, $A_1^*(p)$ is linear in $p$
Multiple Uncertainties

- fully quadratic specification (parameters $c_A$, $c_G$, and $d$)

$$A^*_1 = \frac{S^{bau} - \Delta T^{max}}{1 + \frac{1}{\beta E\Omega(\tilde{\phi})}} \left( \lambda \frac{E[\bar{x}\Omega(\tilde{\phi})]}{E\Omega(\tilde{\phi})} \right)$$

where $\Omega(\tilde{\phi}) = \frac{c_G/\tilde{\phi}^2}{c_G/\tilde{\phi}^2 + c_A}$.

- $\Omega(\tilde{\phi})$: abatement in period two: decreasing and convex in $\tilde{\phi}$ if $c_G \ll c_A$ (C1)
Multiple Uncertainties

- fully quadratic specification (parameters $c_A$, $c_G$, and $d$)
  \[
  A_1^* = \frac{S^{bau} - \Delta T^{max} / \left( \lambda \frac{E[\bar{x}\Omega(\bar{\phi})]}{E\Omega(\bar{\phi})} \right)}{1 + \frac{1}{\beta E\Omega(\bar{\phi})}} \text{ where } \Omega(\bar{\phi}) = \frac{c_G}{\bar{\phi}^2} + c_A.
  \]

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Results

- denominator: cost effectiveness (independent of $\bar{x}$)
  - If $x$ independent of $\bar{\phi} \implies$ An increase in risk (SSD) in $\bar{\phi}$ increases $A_1^*$ if C1 holds (higher expected compliance costs)

- numerator: target stringency (insurance effect)
  - If $(\bar{x}, \bar{\phi})$ exhibit positive quadrant dependency (P.Q.D.), $A_1^*$ is lower than under independence
A numerical example

- Specify probability of geoengineering being feasible:
  \[ \tilde{\varphi} \sim \{1 : p; 0 : (1 - p)\} \]

- Numerical specification
  - \( c_A/c_G = 100 \) (McClellan et al., 2012)
  - \( \tilde{x} \sim U[0, 2] \)

- Relationship between \( \tilde{x} \) and \( \tilde{\varphi} \):
  - So far, little is known about the correlation
  - Think of \( \tilde{\varphi} \) as measure of public support: highly positive correlation possible
  - FGM copula allowing a Spearman’s \( \rho \) of \(-0.8/0/ +0.8\)
A numerical example

Share of first-period abatement for different values of $p$
Numerical model

- WITCH model (World Induced Technical Change Hybrid model) with a total radiative forcing target of $2.8 \frac{W}{m^2}$ in 2100
- Additional option of $SO_2$ Geoengineering from 2050 onwards
- Fixed probability $p$ of Geoengineering becoming available
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- Specification of GE
  - Linear cost function, 10 billion USD/TgS (Robock et al., 2009)
  - Radiative Forcing of $-1.75 \frac{W}{m^2 TgS}$ (Gramstad and Tjøtta, 2010)
  - Stratospheric residence time: 2 years
A remark: Risk Aversion

- Risk aversion maintaining intertemporal preferences (Epstein-Zin) \[ \Rightarrow \text{shifts the } A_1^*(p) \text{ unambiguously upwards} \]
- Implementation in regional IAM not obvious:
  - Aggregate over regions and states of nature (order matters unless \( \gamma = rra \) or i.i.d. multiplicative uncertainty)
  - Negishi weights: further complicate things (equalizing MU (Negishi) vs. “spreading it out” (Risk Aversion))
A remark: Risk Aversion

- Risk aversion maintaining intertemporal preferences (Epstein-Zin) \( \Rightarrow \) shifts the \( A_1^*(\rho) \) unambiguously upwards

- Implementation in *regional* IAM not obvious:
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\[
W_G^{EZ} = \sum_{t=1}^{T} P_t \frac{1}{1-\eta} \left( \left[ \sum_{s=1}^{S} \pi_{st} \left( \sum_{r=1}^{R} \frac{P_{rt}}{P_t} c_{rst}^{1-\gamma} \right) \right]^{\frac{1-\eta}{1-rra}} - 1 \right) (1+\rho)^{-t}
\]
Results - CEA, $p = 0.5$
Results - CBA, $p = 0.5$
Results - the shape of $A_1^*(\rho)$

- Risk Aversion ($rra = 20$): CEA: no effect; CBA, increase from 24.6% to 28.1%
Results - Relationship between $\tilde{x}$ and $\tilde{\phi}$

How big is the insurance effect of Geoengineering ($\rho = 0.5$)?

- Uncertain climate sensitivity of $\{2.5 : 0.5; 3.9 : 0.5\}$ (baseline: 3.2) with different correlation structures ($\rho$)
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Conclusion

- Geoengineering can have a strong impact on the optimal climate change policy.
- However, *uncertainty* and the *dynamic* decision model provide an argument for a substantial mitigation effort.
- Even disregarding risk/ambiguity aversion and side effects of GE.
- Analytical results confirmed by IAM implementation.
- Result hold qualitatively also when considering a sizable potential “insurance effect” of Geoengineering.
Thank you!

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