# A Liability Model for Regional Solar Radiation Management Impacts

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# Introduction

- SRM is probably very cheap but produces regional differences (Barrett 2008, Robock et al. 2008)
- 'Free-driver' problem (Weitzman 2015)
- Liability Regimes
  - are one potential means of governance
  - receive great attention (e.g. Horton et al. 2014, Saxler et al. 2015, Reynolds 2015)
  - No quantitative analysis of the incentives different liability regimes provide for a SRM provider so far

# Introduction

- Liability regime: SRM provider's incentives are determined by
  - What has to be compensated for: Definition of harm
  - In which cases it has to be compensated for: Liability standard
- The two components constitute a liability regime in my model
- Not in the paper:
  - uncertainty
  - coalitions

# Introduction: Special characteristic of SRM

- Given metrics of mean temperature or mean precipitation, studies (Moreno-Cruz et al. 2012, Kravitz et al. 2014) suggest: most regions benefit from moderate SRM levels and only suffer from large SRM levels
- Different to standard liability setting: Positive and negative externality to same agent

# The Model

- $n$ agents
- level of SRM provision: $x$
- $d_i(x)$ agent $i$'s damage function, $d_i$ convex
- $x_i$ agent $i$'s optimal provision point, $x_i > 0$ for at least some agents
- SRM provider/Injurer (highest $x_i$) can provide SRM at negligible direct costs
- Social optimization problem:

$$\min_x \left[ \sum_i d_i(x) \right]$$

- Liability regime:
  - Definition of harm
  - Liability standard

# SRM Liability Regimes: Definition of Harm

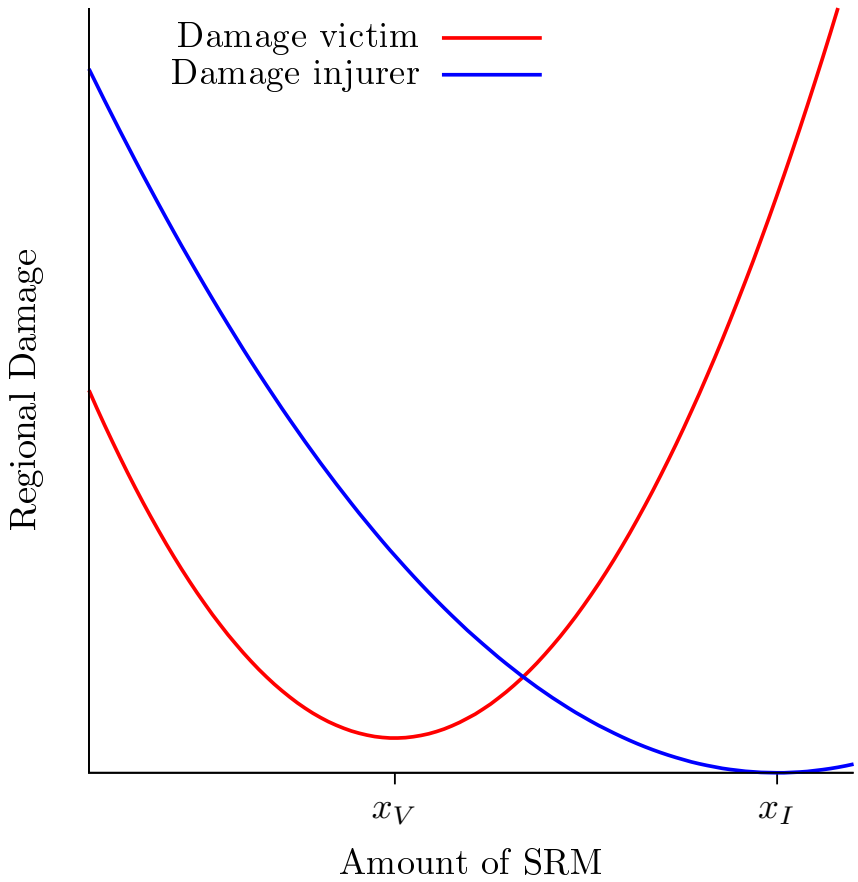


Figure: $x_V$: Victim's optimal SRM provision point. $x_I$: Injurer's optimal SRM provision point (Free-Driver Outcome).

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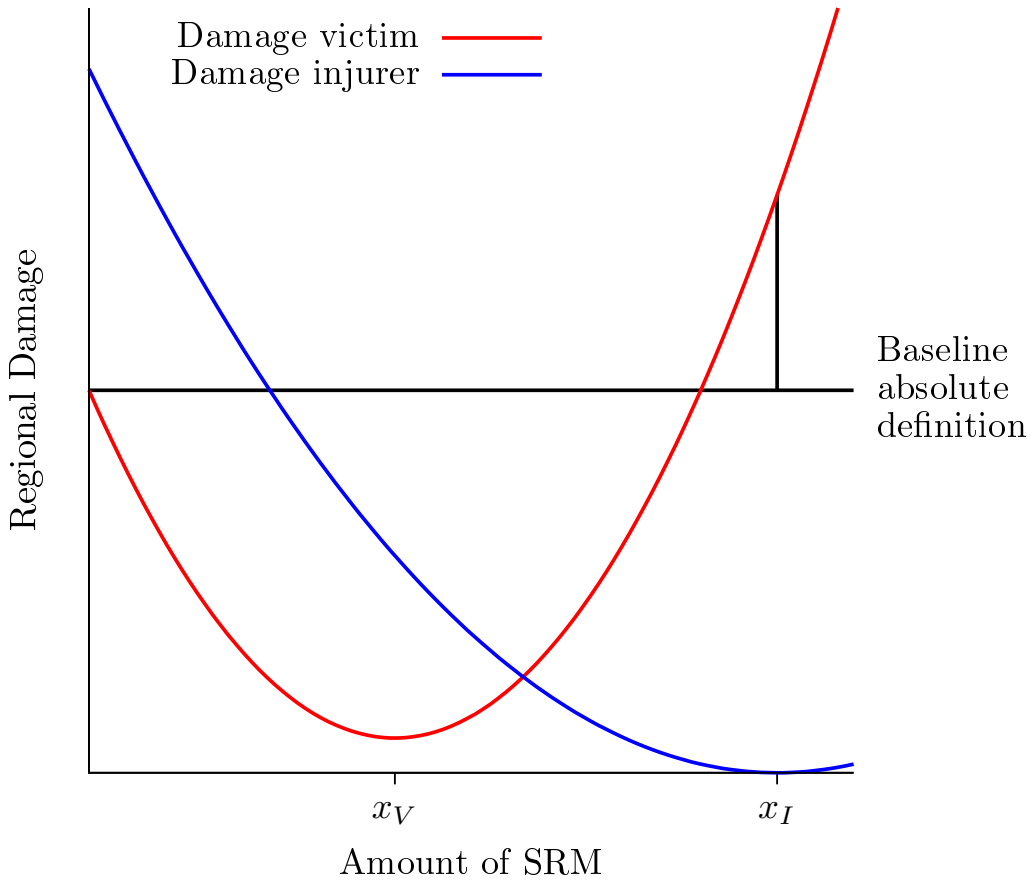


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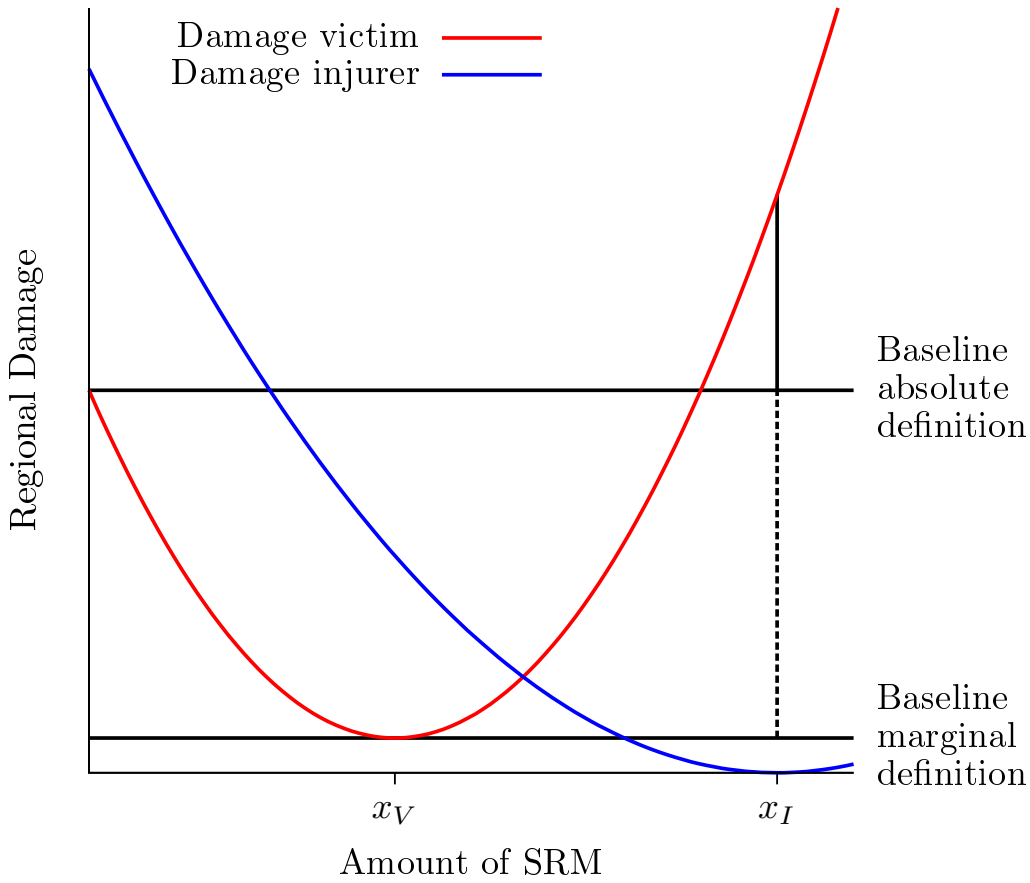


Figure: $x_V$: Victim's optimal SRM provision point. $x_I$: Injurer's optimal SRM provision point (Free-Driver Outcome).

# Result 1

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*Any SRM liability regime employing the absolute definition of harm is not able to fully internalize the negative externality. Those regimes therefore can not implement the socially optimal SRM provision level in general.*

# SRM Liability Regimes: Liability Standards

- Generally two main types of liability standards:
- *Strict Liability* (SL): injurer liable for any harm caused by SRM; has liability payments of $L_{SL}$

$$L_{SL} = \sum_i h_i(x)$$

  - harm fully internalized, positive externality not
  - bias towards too low levels of SRM (on top of potential bias from definition of harm)

# SRM Liability Regimes: Liability Standards

- *Negligence Standards*: injurer is only liable in case a certain behavioral standard $x_N$ is not met; in our case

$$L_N = \begin{cases} 0 & \text{if} \quad x \leq x_N \\ h(x) & \text{if} \quad x > x_N \end{cases}$$

- Injurer complies with standard in order to escape liability payments: $x_N^* = x_N$
- Economic interpretation of negligence standard: balances harm and costs of avoiding harm
- In SRM setting: Whose harm? Which costs?

# Three Interpretations of the Negligence Standard

- Normative criterion: Consider all parties' welfare: *benefit-harm negligence standard* (BHN)
  - Standard $x_{BHN}$ encompasses the negative and the positive externality $\rightarrow$ no bias
  - But: consideration of parties not being part of a trial (third-party beneficiaries) is not allowed in international law

- *Aggregate harm negligence standard* (AHN)
  - Notion: joint trial of all countries harmed against the injurer
  - Can show: bias towards too low SRM levels; $x^*_{AHN} = x^*_{SL}$

- *Individual harm negligence standard* (IHN)
  - Notion: individual trials of each country harmed against the injurer
  - Individual standard $x_{IHN}(i)$ for each victim $i$
  - Can show: Bias might be towards too low or too high SRM levels

# Result 2

## Result 2

*Only liability regimes employing the benefit-harm negligence standard can implement the socially optimal SRM provision level in general.*

# Result 3

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1. *A SRM liability regime employing the marginal definition of harm and the benefit-harm negligence standard makes the provider choose the social optimal provision level in equilibrium:* $x^*_{BHN}(M) = x_{BHN}(M) = x^*$.
2. *All other liability regimes can not implement the socially optimal SRM provision level in general.*

# Implementation: Regional Climate Response Model

- Two main interests
  - How bad is the free-driver outcome under no liability (NL)?
  - What are the equilibrium outcomes for the biased liability regimes?
- Moreno-Cruz et al. (2012) developed RCR model for assessing regional SRM impacts
- Agents are 22 regions as defined in Giorgi and Francisco (2000)
- Regional damages $d_i(x)$: quadratic damages relative to preindustrial in mean temperature or mean precipitation
- I use climate model date from the G1 experiment of the Geoengineering Model Intercomparision Project

# Implementation: Results - Temperature

| | Optimum | NL | BHN | SL & AHN | IHN |
|---|---|---|---|---|---|
| Marginal Harm | 0.2 | 1.8 | 0.2 | 0.3 | 0.3 |
| Absolute Harm | 0.2 | 1.8 | 1.8 | 1.8 | 1.8 |

Table: Results from the RCR model for temperature metric. Damages in percent of unmitigated climate change damages.

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# Implementation: Results - Precipitation

| | Optimum | NL | BHN | SL & AHN | IHN |
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| Marginal Harm | 5.1 | 658 | 5.1 | 5.8 | 5.1 |
| Absolute Harm | 5.1 | 658 | 18.7 | 12.1 | 19.6 |

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# Conclusions

- Liability regime: Definition of harm and liability standard
  - Two definitions of harm (absolute and marginal definition)
  - Strict liability plus three interpretations of the negligence standard
- Only the combination marginal definition of harm and benefit-harm negligence standard implements social optimum
  - But BHN standard the least likely to be applied in practice
- Numerical implementation suggests that
  - free-driver problem moderate for temperature metric, severe for precipitation metric
  - liability regimes can reduce this problem drastically
  - choice of definition of harm more consequential than choice of liability standard

# Implementation: Results - Temperature

| | | Optimum | NL | BHN | SL & AHN | IHN |
|---|---|---|---|---|---|---|
| Marginal Harm | SRM Level | 0.99 | 1.12 | 0.99 | 0.96 | 0.96 |
| | Damage | 0.2 | 1.8 | 0.2 | 0.3 | 0.3 |
| Absolute Harm | SRM Level | 0.99 | 1.12 | 1.12 | 1.12 | 1.12 |
| | Damage | 0.2 | 1.8 | 1.8 | 1.8 | 1.8 |

Table: Results from the RCR model for temperature metric. SRM levels are given as a fraction of the SRM level which restores global mean temperature to preindustrial. Damages in percent of unmitigated climate change damages. No SRM therefore corresponds to a residual damage of 100%.

# Implementation: Results - Precipitation

| | | Optimum | NL | BHN | SL & AHN | IHN |
|---|---|---|---|---|---|---|
| Marginal Harm | SRM Level | 0.81 | 2.93 | 0.81 | 0.74 | 0.80 |
| | Damage | 5.1 | 658 | 5.1 | 5.8 | 5.1 |
| Absolute Harm | SRM Level | 0.81 | 2.93 | 1.11 | 1.03 | 1.12 |
| | Damage | 5.1 | 658 | 18.7 | 12.1 | 19.6 |

Table: Results from RCR model for precipitation metric.

# SRM Liability Regimes: Harm

- Due to the additional dimension: SRM liability regime consists of a
  - definition of harm
  - liability standard
- $d_i(x)$ victim's welfare, $x_i$ victim's optimum
- Absolute definition: Baseline is climate without SRM

$$h_i^A(x) = \max[0, d_i(x) - d_i(0)]$$

- Marginal definition: Baseline is regional optimum

$$h_i^M(x) = d_i(x_i) - d_i(\max[x, x_i])$$

- Marginal definition captures all negative consequences on other parties' welfare, absolute definition only those beyond the absolute baseline