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Managing Termination Shock Risk of Solar Geoengineering in a Warming World

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- Introduction
- Methods
- Theoretical analysis
- Numerical results
- Sensitivity Analysis
- Conclusion

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Solar Geoengineering (Solar Radiation Modification, SRM)

- A type of technology that **reflecting more sunlight back to the space** so that offsetting radiative forcing due to greenhouse gas (GHGs) emissions.
- **Rapid cooling at relative lower cost.**

However, deploying SRM may introduce a new risk **"termination shock"**

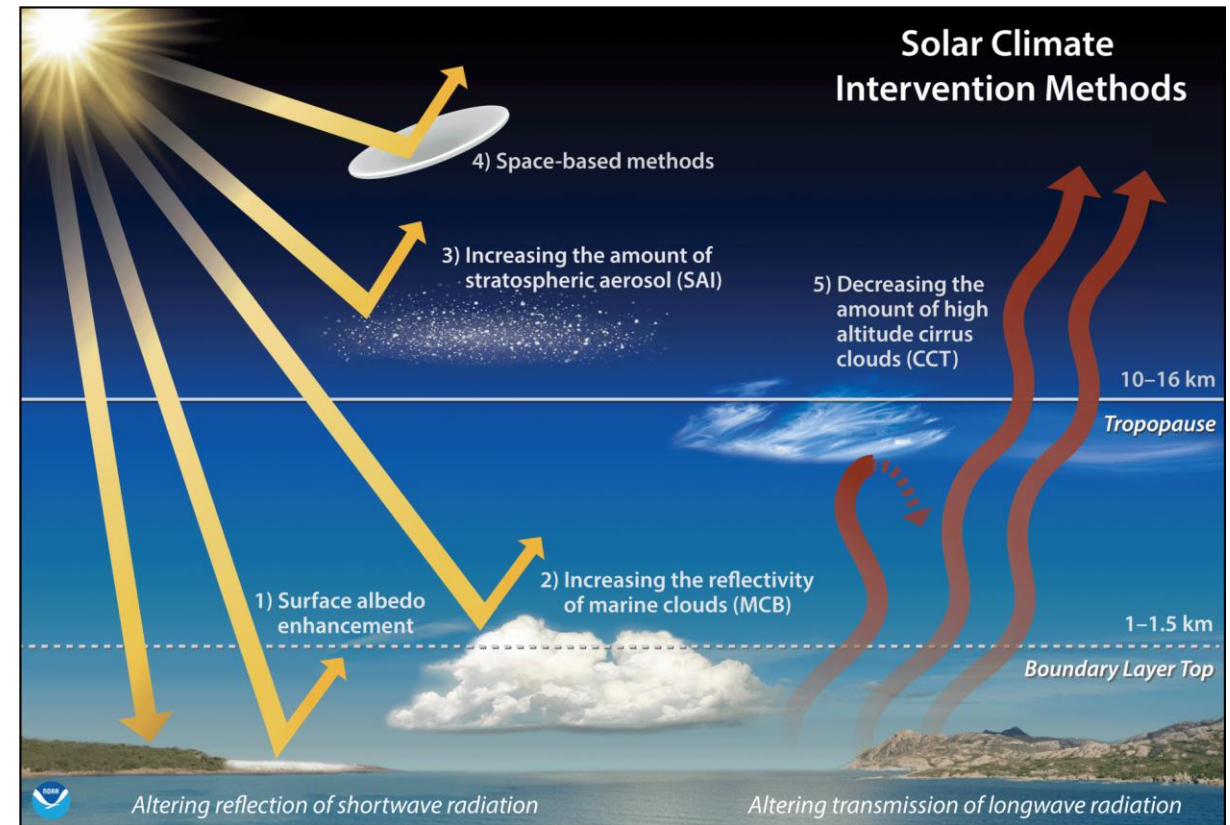
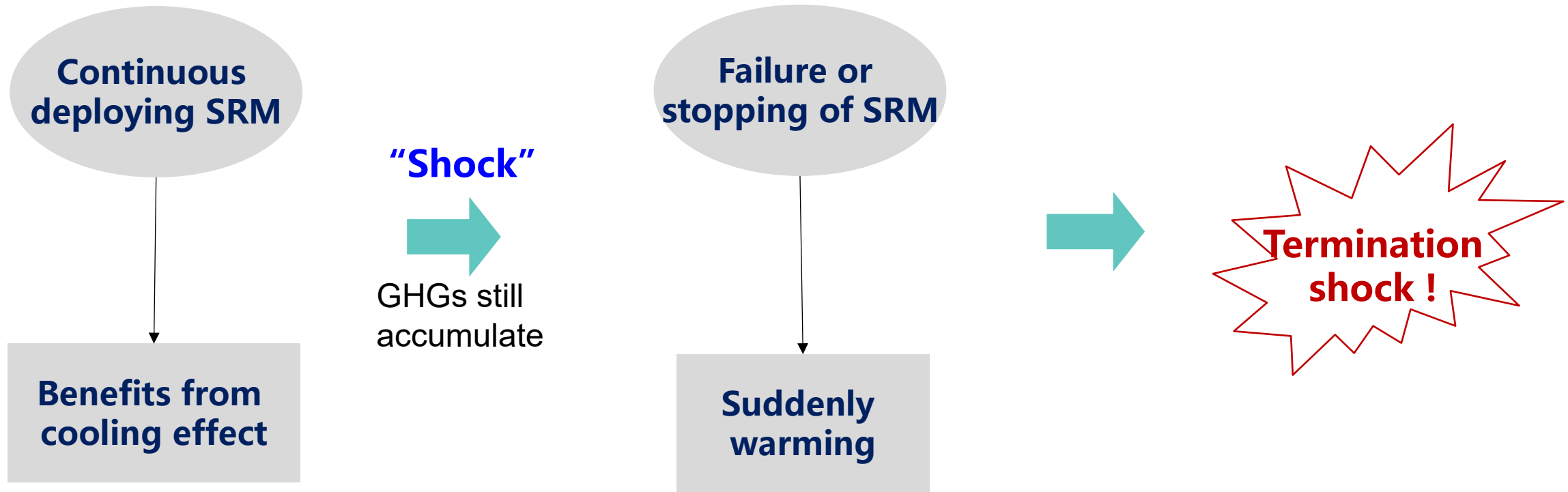


Figure 1. Technology of Solar Geoengineering

Source: National Oceanic and Atmospheric Administration

Termination shock risks of Solar Geoengineering

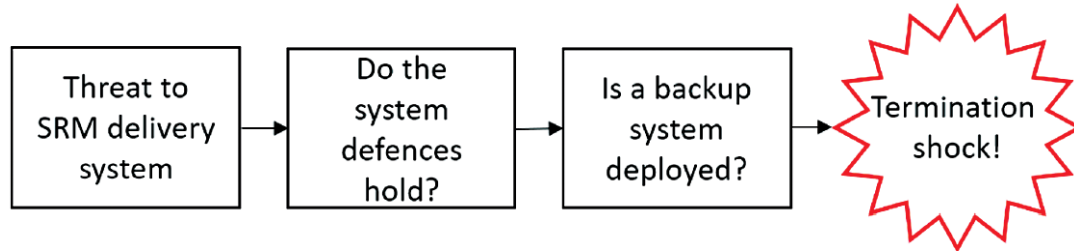


Reason of Termination shock

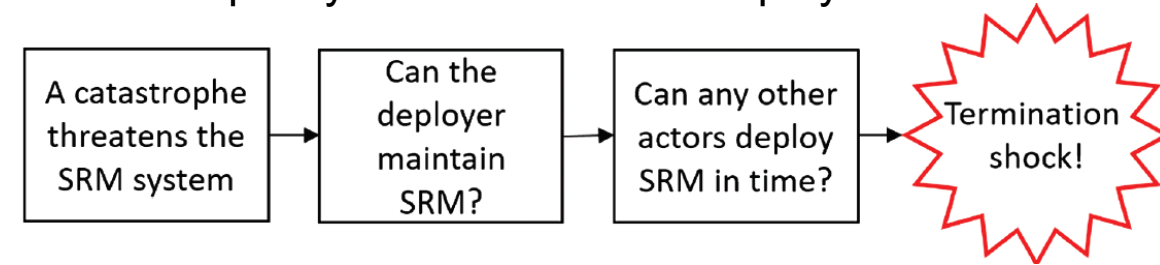
What may cause shock? (Parker, A., & Irvine, P. J., 2018)

(1) Forced Termination of SRM (Exogenous)

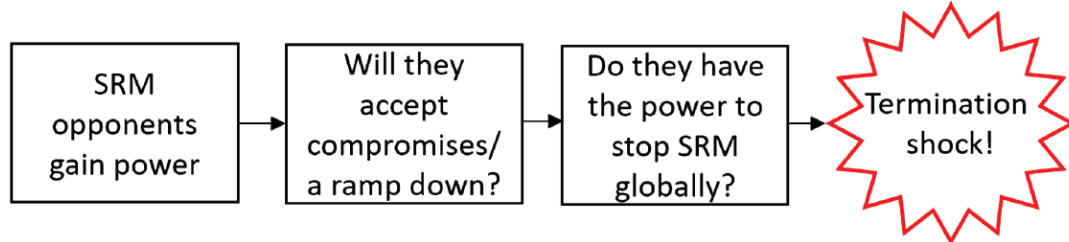
- **Destruction** of SRM Deployment Infrastructure (such as **terrorist attack**)



- Catastrophe (such as a natural disaster, an economic collapse, or a war), or Destruction of Economic or Political Capacity to maintain SRM deployment

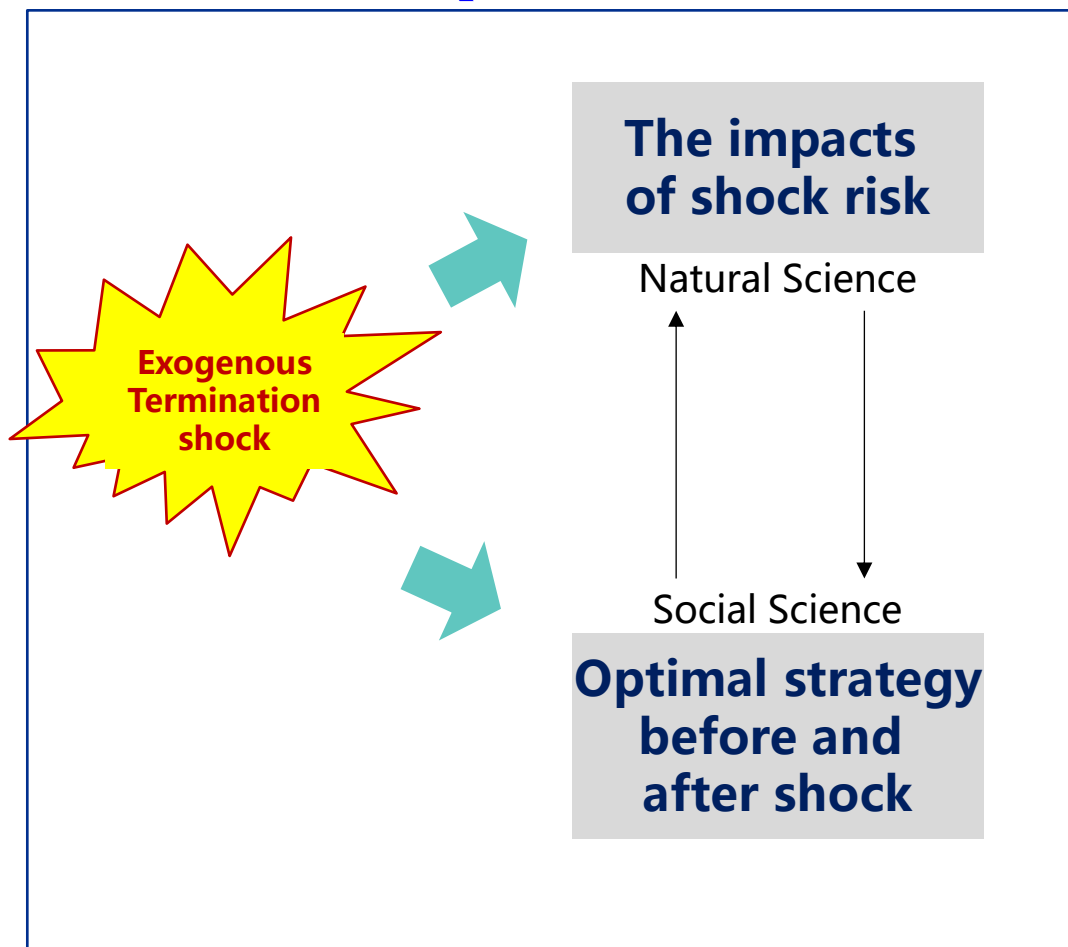


(2) Elective Termination of SRM/ Political choice (Endogenous)



Questions and Methods

Research Questions

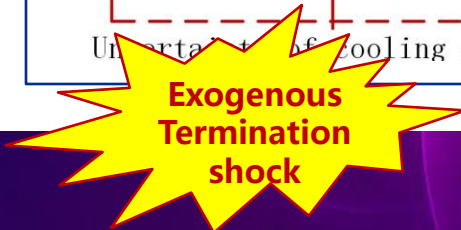
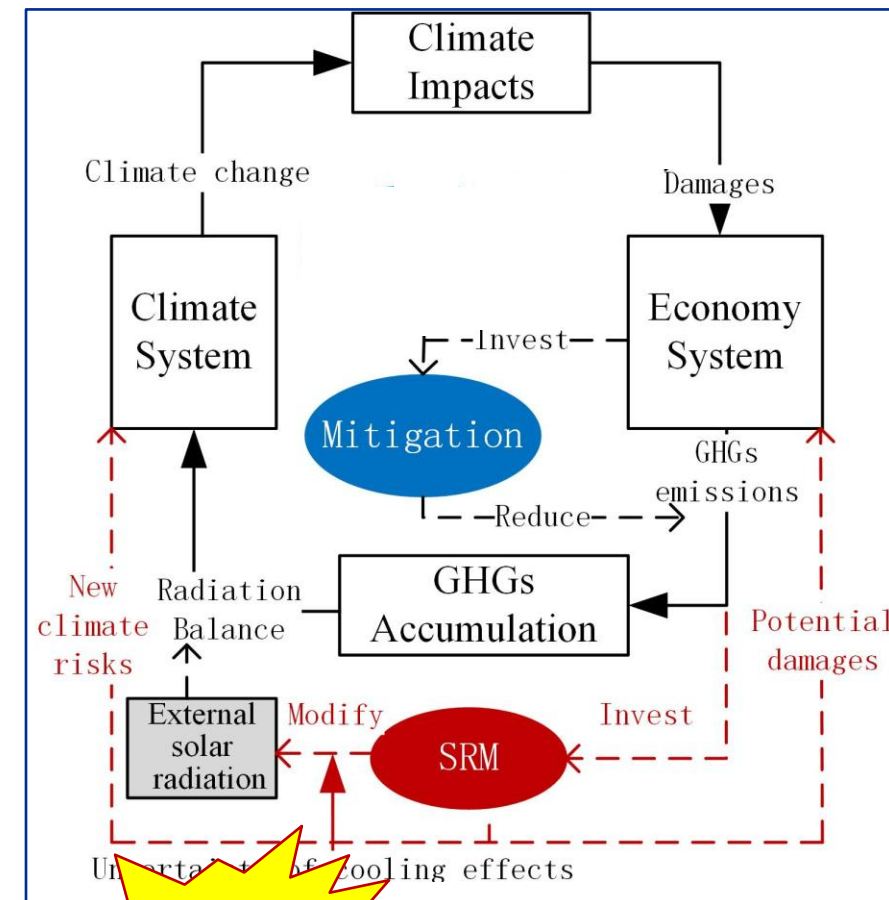


Methods

System thinking

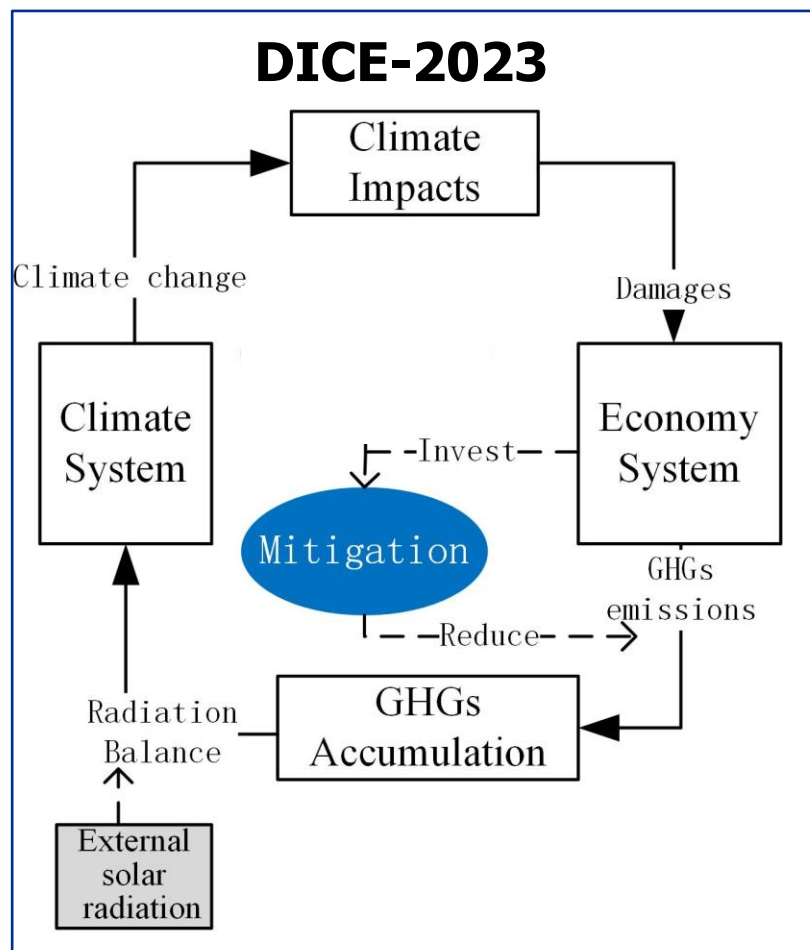
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Integrated Assessment Model (IAM)



- Introduction
- **Methods**
- Theoretical analysis
- Numerical results
- Sensitivity Analysis
- Conclusion

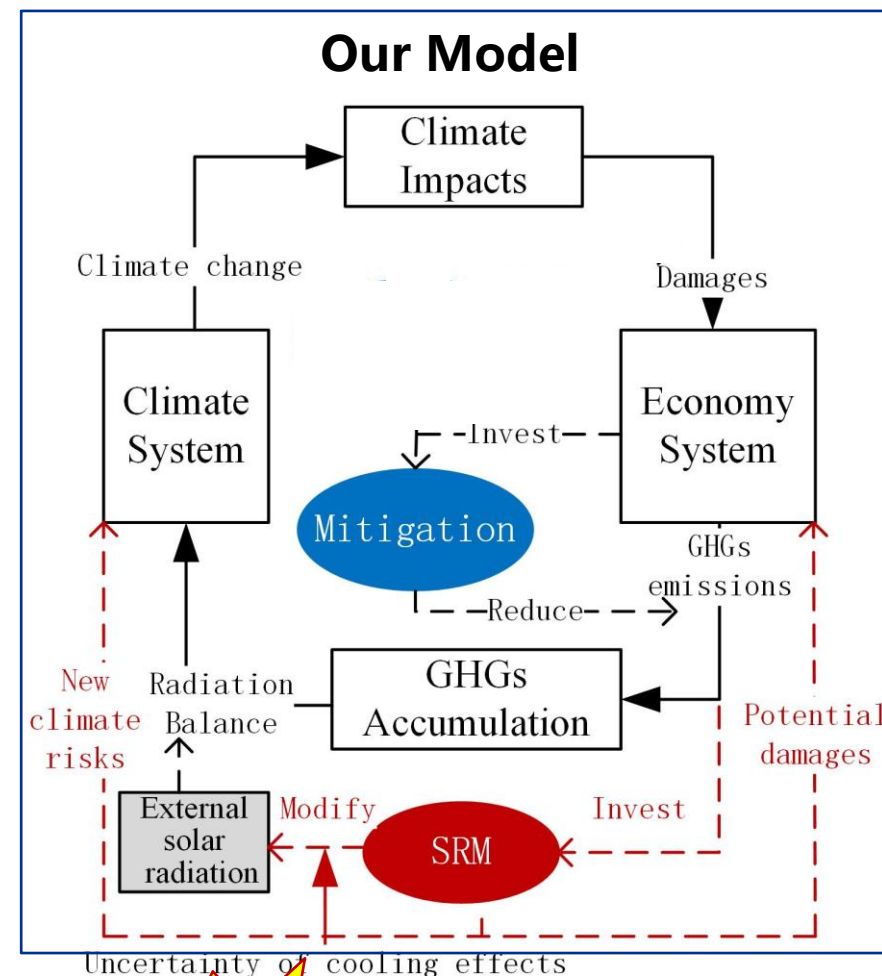
Overview: Integrated Assessment Model (IAM)



Cost & benefit IAM

SRM Policy
(Heutel et.al, 2018)

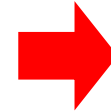
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Termination shock



Termination shock

Model the stochastic termination shock

- The cooling effects of SRM.
(following heutel, et.al 2018)



Total Radiative Forcing of GHGs

$$F_t = TF_t(M_t^{at}) \cdot (1 - g_t)$$

SRM policy:
Radiation control rate

- Introduce the uncertainty of cooling effects.



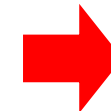
Binary Variable

Before shock $I_t = 1$

After shock $I_t = 0$

$$F_t = TF_t(M_t^{at}) \cdot (1 - I_t \cdot g_t)$$

- Model the shock dynamics by Markov Process.



Markov Process

$$\begin{bmatrix} 1 - p_t & p_t \\ 0 & 1 \end{bmatrix}$$

$$p_t = 1 - e^{-vt}$$

The shock probability $p_t \in (0, 1)$,
with an exponential form

Economic Dynamics

$$\max_{s, \mu, g} \mathbb{E} \left\{ \int_0^T e^{-\rho t} U(c(t)) dt + e^{-T\rho} V_{T+1} \right\}$$

$$\dot{K}_t = s_t * Q(t, \mu_t, g_t, K_t, Tat_{i,t}, \overline{Tat}_t) - \delta_k K_t \quad \text{Capital}$$

$$Q_t = Y(t, K_t) (1 - \Lambda_t - \Phi_t^g - D_t^g - D_t^L - \boxed{D_t^S}) \quad \text{GDP}$$

$$E_t = (1 - \mu_t) * (\sigma_t * Y_t + E_t^{land}) \quad \text{Carbon emission}$$

$$\Lambda_t = \theta_t^a * \mu_t^{\theta_2} \quad \text{Abatement cost}$$

$$D_t^L = \beta_1 (T_t^{at})^2 \quad \text{Climate damages (long-term)}$$

$$D_t^S = \beta_2 \left(\frac{T_t^{at} - \overline{T}_{s,t}^{at}}{\omega * s} \right)^2 \quad \text{Climate damages (short-term)}$$

$$\Phi_t^g = (\theta_1^g + \omega^g) * g_t^2 \quad \text{SRM damage and cost}$$

Climate Dynamics

Carbon accumulation

$$\dot{R}_{j,t} = \xi_j \frac{E(t, \mu_t, K_t)}{co2c} - \frac{1}{\tau_j \psi(t, C_{acc,t}, R_{j,t}, Tat_{i,t})} R_{j,t}$$

$$C_{acc,t} = \frac{E(t, \mu_t, K_t)}{co2c}$$

Net Radiation forcing caused by GHG emission

$$F_t = \left[\eta \cdot \log_2 \left(\frac{M_t^{at}(R_{j,t})}{M_*^{at}} \right) + F_{GHG,t} + F_t^{ex} \right] \cdot (1 - \boxed{I_t} \cdot g_t) \quad \text{Binary Variable}$$

$$\dot{F}_{GHG,t} = \psi_1 (1 - \mu_t) E_{GHG,t} - \psi_2 F_{GHG,t}$$

Average warming of atmosphere temperature

$$\dot{Tat}_{i,t} = \frac{1}{\kappa_i} [F(t, g_t, I_t, R_{j,t}, F_{GHG,t}) \cdot \chi_i - Tat_{i,t}]$$

$$\dot{\overline{Tat}}_t = \bar{\chi} \cdot (\sum_i Tat_{i,t} - \overline{Tat}_t) \quad \text{Moving average Tat}$$

Economic Dynamics

$$\max_{s, \mu, g} \mathbb{E} \left\{ \int_0^T e^{-\rho t} U(c(t)) dt + e^{-T\rho} V_{T+1} \right\}$$

$$\dot{K}_t = s_t * Q(t, \mu_t, g_t, K_t, Tat_{i,t}, \overline{Tat}_t) - \delta_k K_t \quad \text{Capital}$$

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$$\Phi_t^g = (\theta_1^g + \omega^g) * g_t^2 \quad \text{SRM damage and cost}$$

Function structure: Goes et al. (2011) and Lempert et al. (2000)

Parameter calibration: Parker and Irvine (2018) suggested a maximum acceptable warming rate of 0.2°C per decade (based on RCP2.6 scenario.) Therefore, the cumulative acceptable warming rate over the past 5 (s = 5) years is 0.1°C, i.e., $\omega * s = 0.1$.

In addition, we assume that $\beta_2 = 1\%$, implying that it causes 1% damage if approach the maximum acceptable warming rate

Climate Dynamics

Carbon accumulation

$$\dot{R}_{j,t} = \xi_j \frac{E(t, \mu_t, K_t)}{co2c} - \frac{1}{\tau_j \Psi(t, C_{acc,t}, R_{j,t}, Tat_{i,t})} R_{j,t}$$

$$\dot{C}_{acc,t} = \frac{E(t, \mu_t, K_t)}{co2c}$$

Net Radiation forcing caused by GHG emission

$$F_t = \left[\eta \cdot \log_2 \left(\frac{M_t^{at}(R_{j,t})}{M_*^{at}} \right) + F_{GHG,t} + F_t^{ex} \right] \cdot (1 - I_t \cdot g_t)$$

$$\dot{F}_{GHG,t} = \psi_1 (1 - \mu_t) E_{GHG,t} - \psi_2 F_{GHG,t}$$

Average warming of atmosphere temperature

$$\dot{Tat}_{i,t} = \frac{1}{\kappa_i} [F(t, g_t, I_t, R_{j,t}, F_{GHG,t}) \cdot \chi_i - Tat_{i,t}]$$

$$\dot{\overline{Tat}}_t = \bar{\chi} \cdot (\sum_i Tat_{i,t} - \overline{Tat}_t) \quad \text{Moving average Tat}$$

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Age-structured Formulation of stochastic model

s.t.

Stage 1

$$\max_{s, \mu, g} \int_0^T e^{-\rho t} [z_1(t)U(c_1(t)) + H(t)] dt$$

$$\dot{z}_1(t) = -\eta z_1 \quad z_1(0) = 1 \quad (1)$$

$$\dot{K}_1(t) = s_1 Q(t, \mu_1, g_1, K_1, T at_{i,1}, \overline{T at}_1) - \delta_K K_1 \quad (2)$$

$$\dot{R}_{j,1}(t) = \xi_j \frac{E(t, \mu_1, K_1)}{co2c} - \frac{1}{\tau_j \psi^0 \exp\left(\frac{iRRF_1^{100} + \Delta M_1 [c_{acc1} - \sum_j R_{j,1}] + \Delta T \cdot \sum_i T at_{i,1}}{\psi^1}\right)} R_{j,1} \quad (3)$$

$$\dot{c}_{acc1}(t) = \frac{E(t, \mu_1, K_1)}{co2c} \quad (4)$$

$$\dot{F}_{GHG1}(t) = \psi_1(1 - \mu_1)E_{GHG} - \psi_2 F_{GHG1} \quad (5)$$

$$T at_{i,1}(t) = \frac{1}{\kappa_i} [F(R_{j,1}, F_{GHG1})(1 - g_1) \cdot \chi_i - T at_{i,1}] \quad (6)$$

$$\overline{T at}_1(t) = \bar{\chi} \cdot (\sum_i T at_{i,1} - \overline{T at}_1) \quad (7)$$

$$\dot{z}_2(t, s) = 0 \quad (8)$$

$$\dot{K}_2(t, s) = s_2 Q(t, \mu_2, g_2, K_2, T at_{i,2}, \overline{T at}_2) - \delta_K K_2 \quad (9)$$

$$\dot{R}_{j,2}(t, s) = \xi_j \frac{E(t, \mu_2, K_2)}{co2c} - \frac{1}{\tau_j \psi^0 \exp\left(\frac{iRRF_2^{100} + \Delta M_2 [c_{acc2} - \sum_j R_{j,2}] + \Delta T \cdot \sum_i T at_{i,2}}{\psi^1}\right)} R_{j,2} \quad (10)$$

$$\dot{c}_{acc2}(t, s) = \frac{E(t, \mu_2, K_2)}{co2c} \quad (11)$$

$$\dot{F}_{GHG2}(t, s) = \psi_1(1 - \mu_2)E_{GHG} - \psi_2 F_{GHG2} \quad (12)$$

$$T at_{i,2}(t, s) = \frac{1}{\kappa_i} [F(R_{j,2}, F_{GHG2}) \cdot \chi_i - T at_{i,2}] \quad (13)$$

$$\overline{T at}_2(t, s) = \bar{\chi} \cdot (\sum_i T at_{i,2} - \overline{T at}_2) \quad (14)$$

$$H(t) = \int_0^t z_2(t, s) U(c_2(t, s)) ds \quad (15)$$



Setting up Hamilton

$$\mathcal{H} = z_1 \left[U \left((1 - s_1) Q(t, \mu_1, g_1, K_1, T at_{i,1}, \overline{T at}_1) / L \right) + H \right]$$

$$\begin{aligned} & -\lambda_z * \eta z_1 \\ & + \lambda_K * [s_1 Q(t, \mu_1, g_1, K_1, T at_{i,1}, \overline{T at}_1) - \delta_K K_1] \\ & + \sum_j \lambda_{R,j} * \left[\xi_j \frac{E(t, \mu_1, K_1)}{co2c} - \frac{1}{\tau_j \psi^0 \exp\left(\frac{iRRF_1^{100} + \Delta M_1 [c_{acc1} - \sum_j R_{j,1}] + \Delta T \cdot \sum_i T at_{i,1}}{\psi^1}\right)} R_{j,1} \right] \end{aligned}$$

$$\begin{aligned} & + \lambda_{cacc} * \frac{E(t, \mu_1, K_1)}{co2c} \\ & + \lambda_{F_{GHG}} * [\psi_1(1 - \mu_1)E_{GHG} - \psi_2 F_{GHG1}] \\ & + \sum_i \lambda_{T,i} * \left[\frac{1}{\kappa_i} [F(R_{j,1}, F_{GHG1})(1 - g_1) \cdot \chi_i - T at_{i,1}] \right] \end{aligned}$$

$$+ \lambda_{\overline{T at}} * \left[\bar{\chi} \cdot \left(\sum_i T at_{i,1} - \overline{T at}_1 \right) \right]$$

$$\begin{aligned} & -\eta_z * 0 \\ & + \eta_K * [s_2 Q(t, \mu_2, g_2, K_2, T at_{i,2}, \overline{T at}_2) - \delta_K K_2] \\ & + \sum_j \eta_{R,j} * \left[\xi_j \frac{E(t, \mu_2, K_2)}{co2c} - \frac{1}{\tau_j \psi^0 \exp\left(\frac{iRRF_2^{100} + \Delta M_2 [c_{acc2} - \sum_j R_{j,2}] + \Delta T \cdot \sum_i T at_{i,2}}{\psi^1}\right)} R_{j,2} \right] \end{aligned}$$

$$\begin{aligned} & + \eta_{cacc} * \frac{E(t, \mu_2, K_2)}{co2c} \\ & + \eta_{F_{GHG}} * [\psi_1(1 - \mu_2)E_{GHG} - \psi_2 F_{GHG2}] \\ & + \sum_i \eta_{T,i} * \left[\frac{1}{\kappa_i} [F(R_{j,2}, F_{GHG2})(1 - 0 * g_2) \cdot \chi_i - T at_{i,2}] \right] \end{aligned}$$

$$+ \eta_{\overline{T at}} * \left[\bar{\chi} \cdot \left(\sum_i T at_{i,2} - \overline{T at}_2 \right) \right]$$

$$+ \zeta * [z_2 U \left((1 - s_2) Q(t, \mu_2, g_2, K_2, T at_{i,2}, \overline{T at}_2) / L \right)]$$

Define SCC and SCF

$$SCC_{E_{co2}} = -\frac{dC}{dE_{co2}} = -\frac{\partial V}{\partial E_{co2}} * \frac{1}{\lambda_K} = -\frac{1}{co2c} \cdot \frac{\sum_j (\lambda_{R_j} \cdot \xi_j) + \lambda_{Cacc}}{\lambda_K}$$

$$\text{where } E_{co2} = (1 - \mu)\sigma Y$$

$$SCC_{E_{GHG}} = -\frac{dC}{dE_{GHG}} = -\frac{\partial V}{\partial E_{GHG}} * \frac{1}{\lambda_K} = -\psi_1(1 - \mu_1) \frac{\lambda_{F_{GHG}}}{\lambda_K}$$

$$\text{where } F_{GHG_1}(t) = \psi_1(1 - \mu_1)E_{GHG} - \psi_2 F_{GHG_1}$$

$$SCF_{NF} = -\frac{dC}{dNF} = -\frac{\partial V}{\partial NF} * \frac{1}{\lambda_K} = -\frac{\sum_j (\lambda_{Tat_i} \cdot \frac{\chi_i}{\kappa_i})}{\lambda_K}$$

$$\text{where } NF = (1 - g)F(R_{j,1}, F_{GHG_1})$$

$$MAC_{E_{co2}}(\text{marginal abatement cost}) = \frac{dQ}{dE_{co2}} = \frac{dQ}{d\mu} \frac{d\mu}{dE_{co2}} = \frac{Y}{\sigma Y + E_{land}} \Lambda_\mu + \frac{\lambda_{F_{GHG}}}{\lambda_K} \cdot \frac{\psi_1 E_{GHG}}{\sigma Y + E_{land}}$$

$$MSC_{NF}(\text{marginal SRM cost}) = \frac{dQ}{dNF} = \frac{dQ}{dg} \frac{dg}{dNF} = \frac{\partial D_g}{\partial g_1} \frac{Y_1}{TF(R_{j,1}, F_{GHG_1})}$$

First Order Condition

$$\begin{cases} \frac{\partial \mathcal{H}}{\partial s_1} = 0 \\ \frac{\partial \mathcal{H}}{\partial s_2} = 0 \end{cases} \Rightarrow \begin{cases} \lambda_K = z_1 \frac{du(c_1)}{dc_1} \\ \eta_K = z_2 \frac{du(c_2)}{dc_2} \end{cases}$$

$$\begin{cases} \frac{\partial \mathcal{H}}{\partial \mu_1} = 0 \\ \frac{\partial \mathcal{H}}{\partial \mu_2} = 0 \end{cases} \Rightarrow \begin{cases} -\left(\sigma + \frac{E_{land}}{Y_1}\right) \left(\sum_j \lambda_{R,j} \xi_j \frac{1}{co2c} + \frac{\lambda_{Cacc}}{co2c}\right) = \frac{\lambda_{FGHG} \psi_1 E_{GHG}}{Y_1} + \lambda_K \frac{\partial \Lambda}{\partial \mu_1} \\ -\left(\sigma + \frac{E_{land}}{Y_2}\right) \left(\sum_j \eta_{R,j} \xi_j \frac{1}{co2c} + \frac{\eta_{Cacc}}{co2c}\right) = \frac{\eta_{FGHG} \psi_1 E_{GHG}}{Y_2} + \eta_K \frac{\partial \Lambda}{\partial \mu_2} \end{cases}$$

$$\begin{cases} \frac{\partial \mathcal{H}}{\partial g_1} = 0 \\ \frac{\partial \mathcal{H}}{\partial g_2} = 0 \end{cases} \Rightarrow \begin{cases} \sum_i \lambda_{T,i} \frac{\chi_i}{\kappa_i} F(R_{j,1}, F_{GHG_1}) = -\lambda_K \frac{\partial D_g}{\partial g_1} Y_1 \\ g_2 = 0 \end{cases}$$



$$\begin{cases} MAC_{E_{CO_2}} = SCC_{E_{CO_2}} & \text{(Stage 1)} \\ MAC_{E_{CO_2}} = SCC_{E_{CO_2}} & \text{(Stage 2)} \end{cases}$$

$$\begin{cases} MSC_{NF} = SCF_{NF} & \text{(Stage 1)} \\ g_2 = 0 & \text{(Stage 2)} \end{cases}$$



Relationship of abatement policy and SRM policy (Stage 1)

$$g^* = \frac{\theta_t^1 \theta_2}{2(\omega_c + \omega_d)} \frac{TF(R_j, F_{GHG}) \cdot SCF}{(\sigma Y + E_{land}) \cdot SCC_{E_{CO_2}} + E_{GHG} \cdot SCC_{E_{GHG}}} \mu^{*\theta_2 - 1}$$

$$TF(R_j, F_{GHG}) dg = \frac{\partial F}{\partial E_{CO_2}} (\sigma Y + E_{land}) d\mu + \frac{\partial F}{\partial E_{GHG}} E_{GHG} d\mu$$



the radiative forcing offset
by one unit of SRM



the radiative forcing reduction by reducing CO₂ and
non-CO₂ GHGs through emission cuts.

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Case1: myopic DM

Decision makers are not aware of the risk, but can optimize decisions after the shock happens

Case2: smart DM

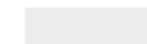
Decision makers are aware of risks and can optimize decisions before and after the shock happens

Results



Myopic Case

- Abatement Only
- Abatement +SRM (Expected path)
- Range of Uncertainty
- Abatement +SRM (Solution before shock)
- Abatement +SRM (Solution after shock)



- - - 50% percentile

- - - 75% percentile

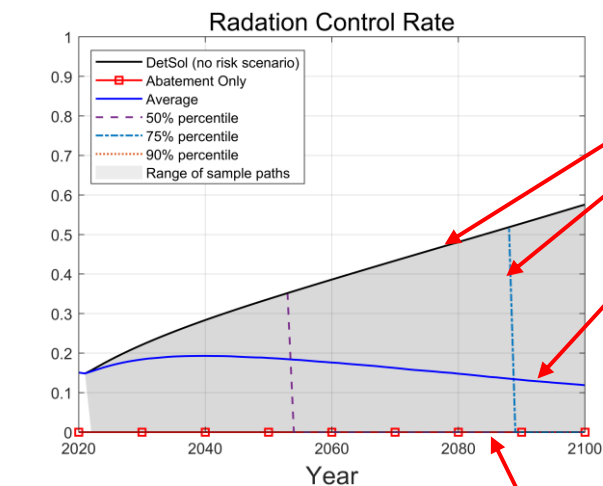
..... 90% percentile

Smart Case

Decision makers are aware of risks and can optimize decisions before the shock happens

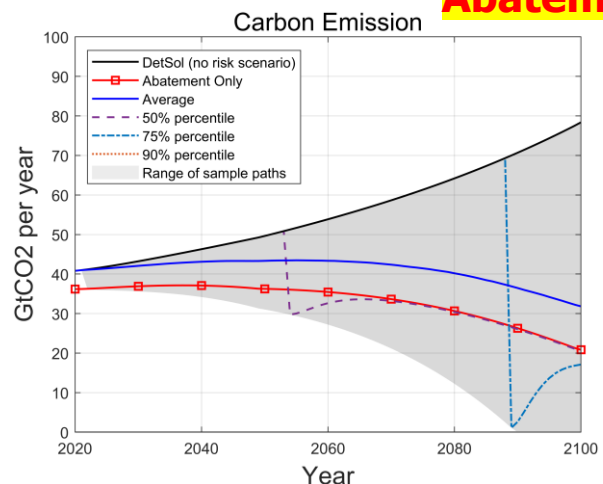
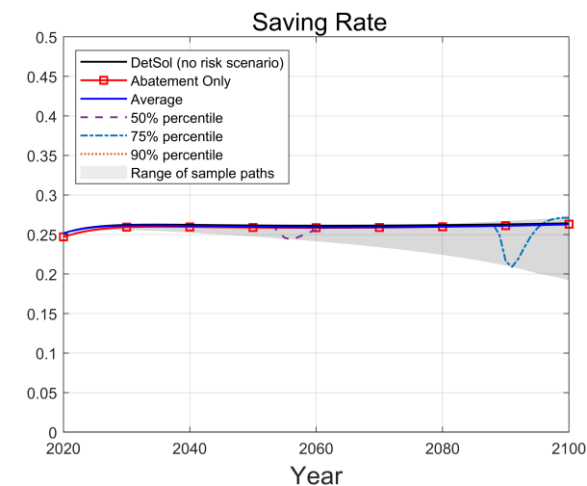
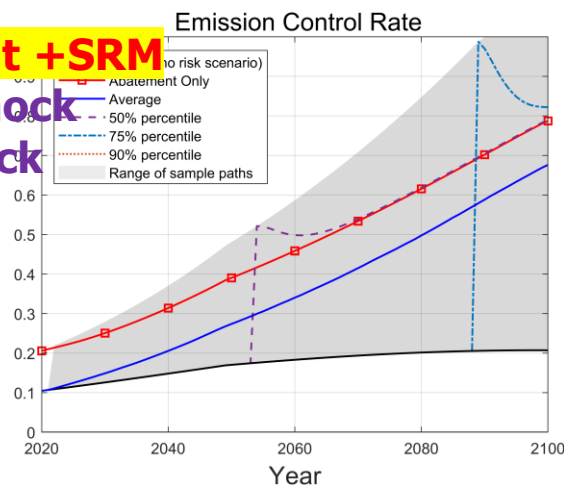
Baseline Scenario

Case1: myopic DM

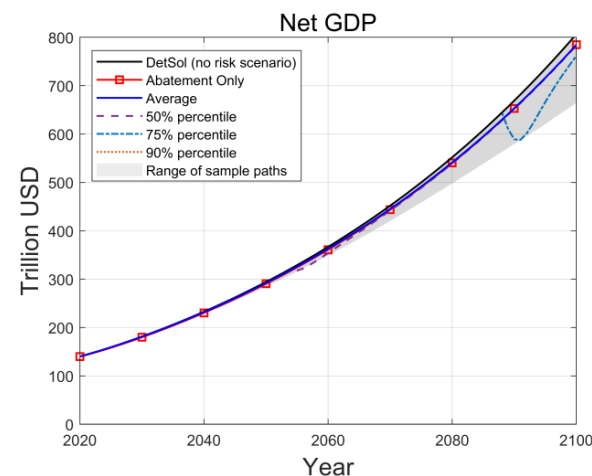
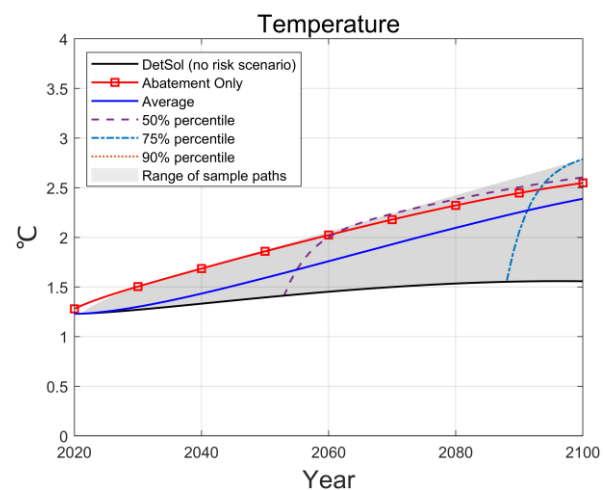


Abatement + SRM

- Before shock
- After shock
- Expected

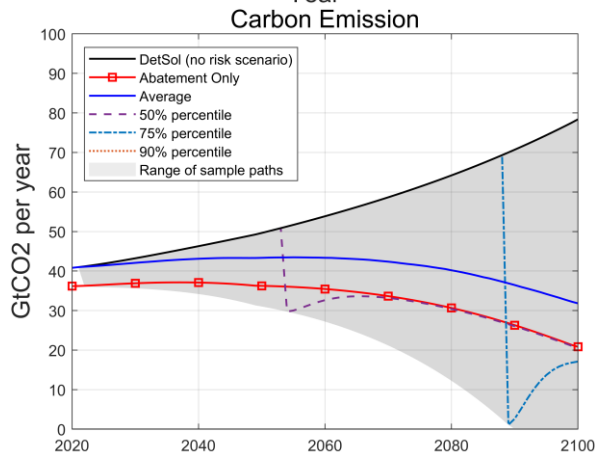
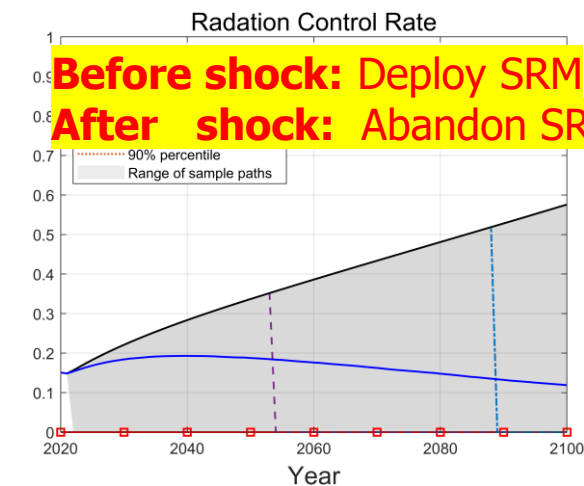


Abatement Only



Baseline Scenario

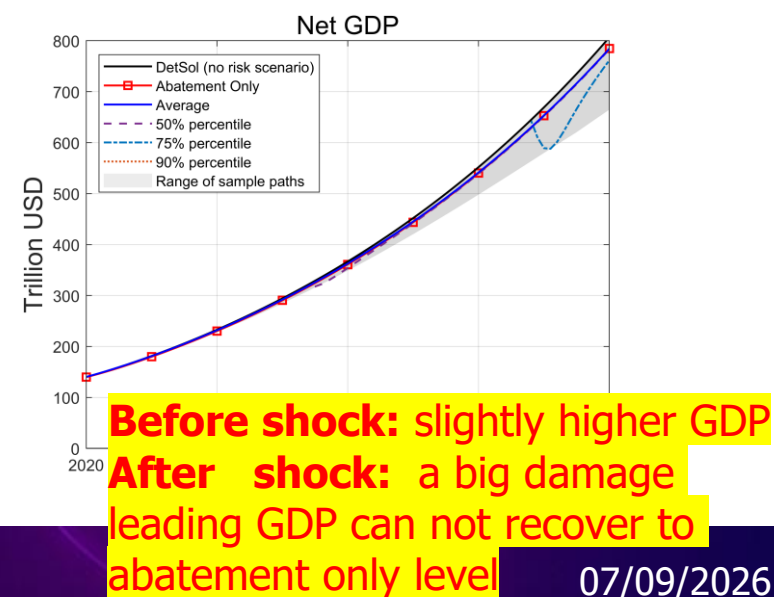
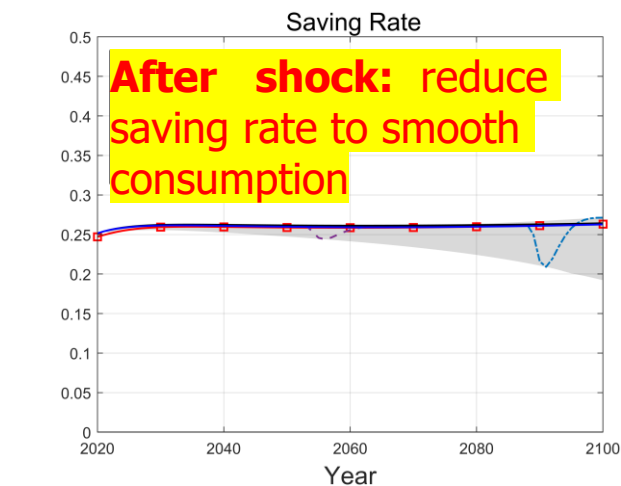
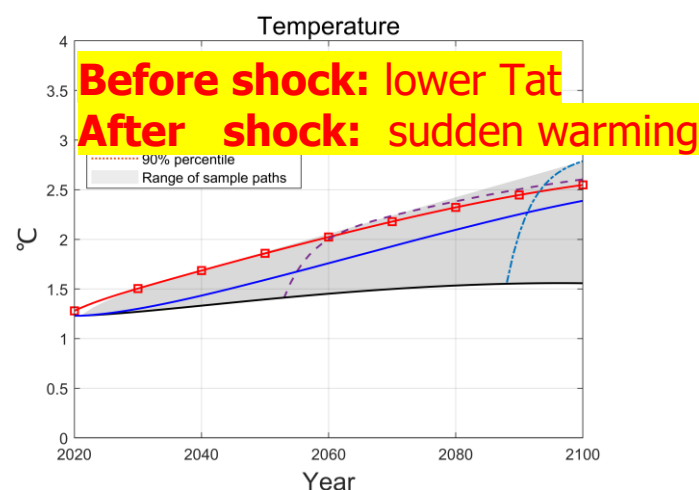
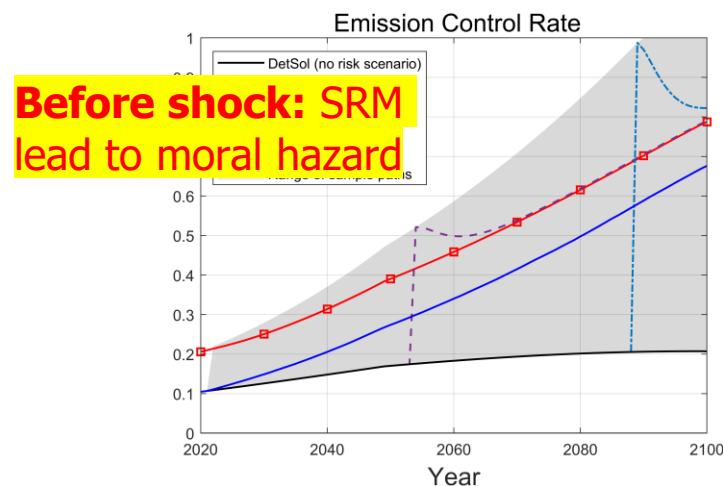
Case1: myopic DM



Before shock: Carbon emission increase

After shock: cut emission sharply

Expected: emits 6-10 GtCO₂ more than abatement only



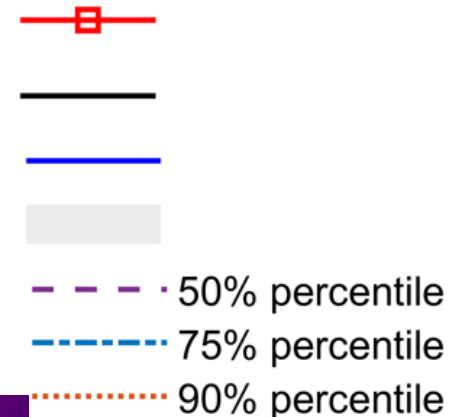
Results

Myopic Case

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- Abatement +SRM (Solution before shock)
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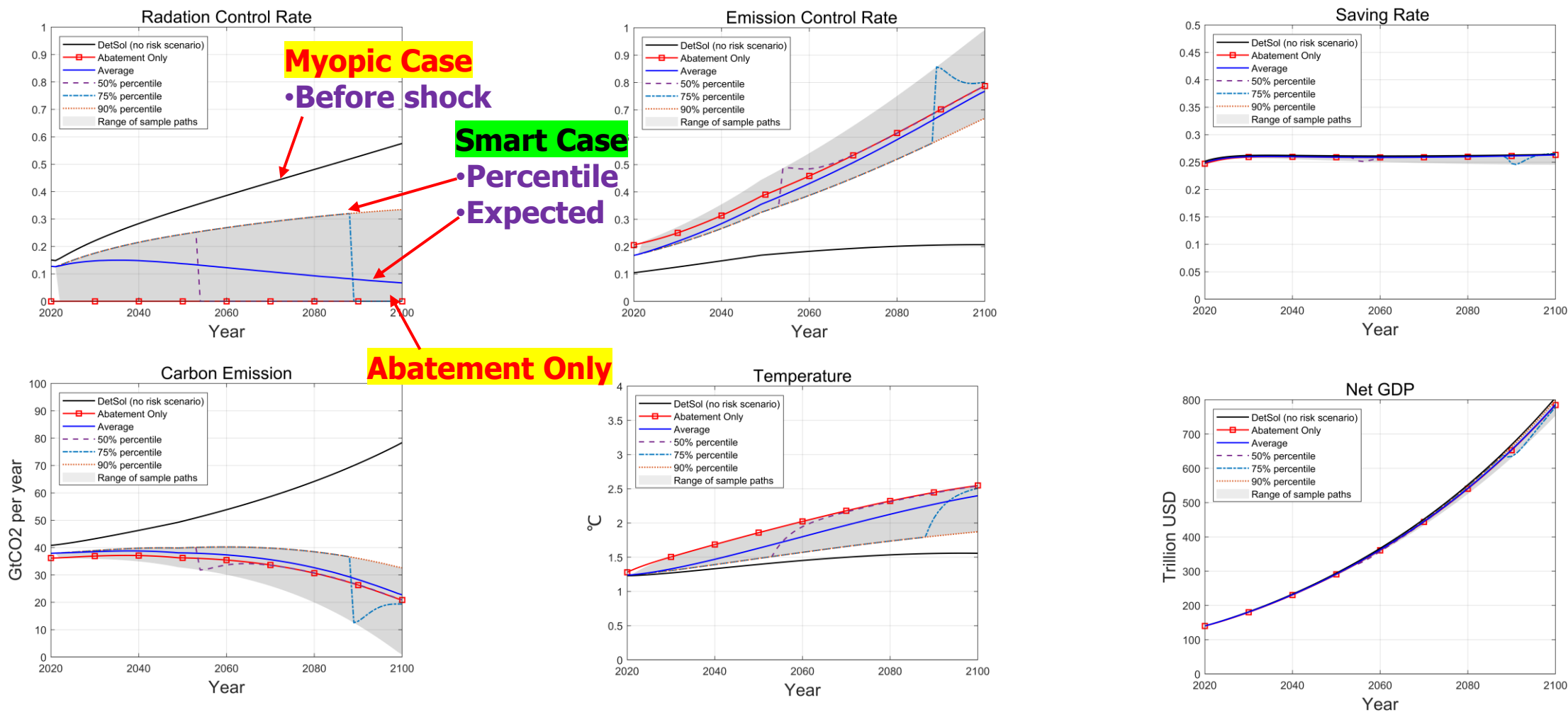
Smart Case

- Abatement Only
- **Myopic case (before shock)**
- Abatement +SRM (Expected path)
- Range of Uncertainty
- Abatement +SRM (Percentile-shock path)



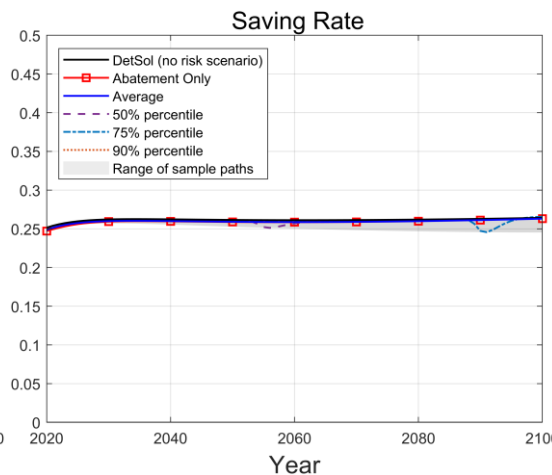
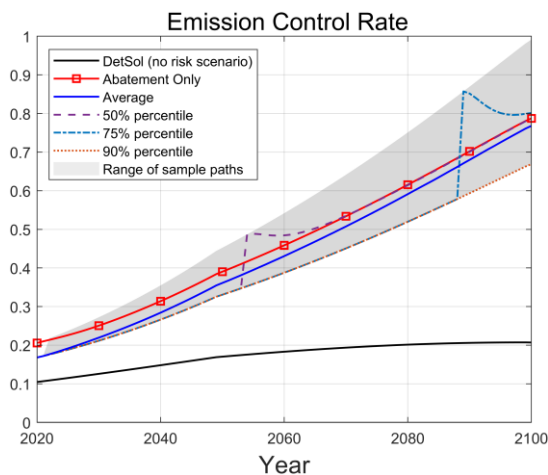
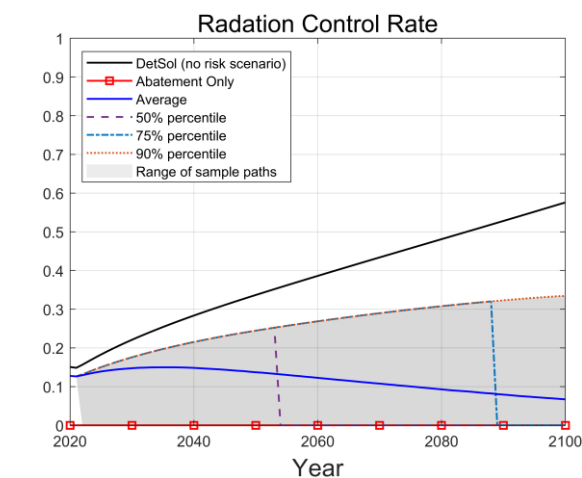
Baseline Scenario

Case2: smart DM



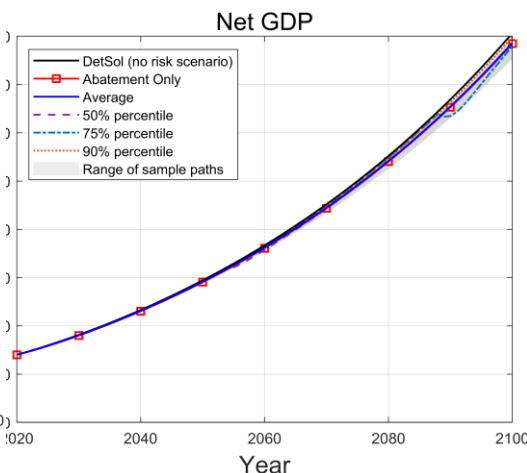
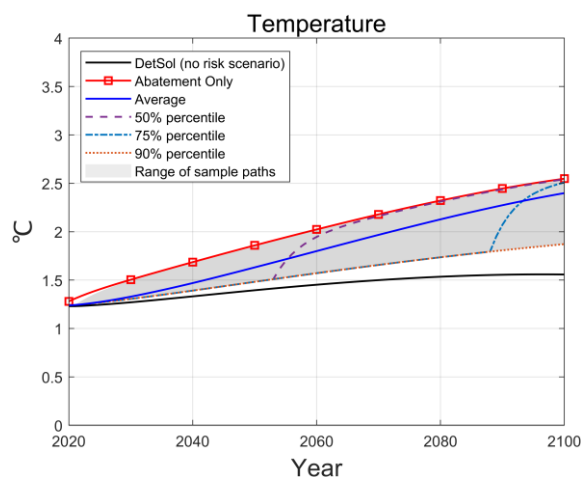
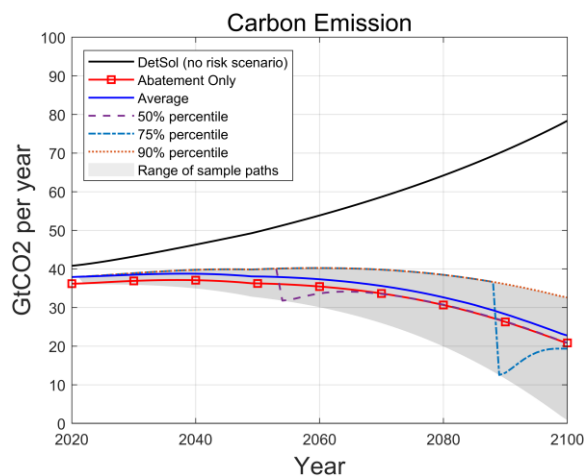
Baseline Scenario

Case2: smart DM



Before shock (Compare to Myopic):
Reduce SRM; increase abatement.

After shock (similar with myopic)
Abandon SRM; increase abatement



Compare to Myopic

Smaller uncertainty range
Less suddenly warming
Lower economic damage of the shock

Before shock:

2 carbon emission decrease over time

- Introduction
- Methods
- Theoretical analysis
- Numerical results
- **Sensitivity Analysis**
- Conclusion

Sensitivity Analysis

Sensitivity Analysis		Hazard rate	Long-term damage β_1	Short-term damage β_2
Shock Probability	0: baseline	2% constant	DICE para	1%
	1: higher hazard	3% constant	DICE para	1%
	2: increasing hazard	2%-3.5%	DICE para	1%
	3: decreasing hazard	2%-0.5%	DICE para	1%
Shock Damage	4a: low-low (baseline)	2% constant	DICE para	1%
	4b: high-low (baseline)	2% constant	3*baseline	1%
	4c: low-high (baseline)	2% constant	DICE para	2%
	4d: high-high (baseline)	2% constant	3*baseline	2%

Summary

Limited GDP recourse for
abatement after shock

Sensitivity Analysis	Myopic		Smart	
	Before shock	After shock	Before shock	After shock
Higher tipping probability	No impacts	No impacts	More abatement Less SRM	Less abatement
Higher Long-term damage	Less abatement More SRM	More abatement	More abatement More SRM	More abatement
Higher short-term damage	Little impacts	More abatement	More abatement Less SRM	More abatement

Moral hazard

Reduce damage of
post-shock period

Higher damage

Reduce shock
warming and damage

Reduce damage of
post-shock period

Summary

Sensitivity Analysis	Myopic		Smart	
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Reduce shock
warming and damage

Limited GDP resource (more
abatement before shock)

Summary

Sensitivity Analysis	Myopic		Smart	
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Moral hazard

Reduce damage of
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Higher overall
damage

Reduce shock
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Conclusion: Policy Implication

Myopic is dangerous

It will increase 6-10 GtCO₂ (the expected solution), and lead a big rapid warming within five years if the shock happens. (0.6 °C in 2050, 1.2 °C in 2100). After shock, The GDP could not recover to the abatement only level.

Decision maker should be "Smart"

Increase 2-3 GtCO₂ emission only. Taking the shock risk into account at an early stage can effectively reduce climate-economic uncertainty. After shock, The GDP could recover to the abatement only level.

Both "Myopic" and "Smart" DM should consider different impacts of short-term and long-term damage on SRM deployment (at an early stage).

Both high short-term damage (and high shock probability) will lead to a more cautious SRM deployment and more abatement efforts.

However, high long-term damage will lead to a more aggressive SRM deployment no matter whether the DM take the termination shock risk into account.

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14. Schrag, D. (2026). Sustainable development through multidisciplinary innovation: Linking technology, environment, and economic growth. *American Journal for Multidisciplinary Research, 1*(1).

Thanks for your attention.
Comments and suggestions are welcome.



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Appendixes

- Conclusion
- Numerical results (sensitivity analysis)
- Time horizon
- Short-term damage function

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Conclusion: Optimal responds to termination shock risk

Before shock

Myopic DM: increase carbon emissions significantly (compared to abatement only), because SRM is much cheaper.

Smart DM: increase carbon emissions slightly (compared to abatement only). But much less carbon emission and SRM compared to myopic one.

After shock

For both myopic and smart DM:

Give up SRM. And Reduce carbon emissions significantly.

Carbon emissions will be lower than the level of abatement only scenario.

The optimal savings rate falls abruptly to smoothing consumption and then rises to a level close to the abatement only scenario.

Conclusion: Climate- Economy Impacts of termination shock

Warming

If the termination shock occurs by 2050, global warming will rise rapidly about 0.4 °C -0.6 °C within five years, depending on whether policymakers take the risk into account.

If it occurs at 2100, the range rises to 0.6 °C -1.2 °C .

Carbon Emission

Myopic DM: The expected carbon emission is higher than that of abatement-only, increase 6-10 GtCO₂.

Smart DM: the emissions increase 2-3 GtCO₂ only.

GDP (Economic Output)

Myopic DM: Compared to abatement only, economic output increases slightly before tipping,
But a sudden damage when shock happens.

Then GDP rises gradually after tipping, leading GDP is lower than that of abatement only.

Smart DM: Reduces sudden economic damage and shrinks the output gap after shock.

GDP could recover to the abatement only level after shock

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Sensitivity Analysis

Shock
Probability
 $p_t = 1 - e^{-\nu t}$

Shock
Damage

$$D_t^L = \beta_1 (T_t^{at})^2$$

$$D_t^S = \beta_2 \left(\frac{T_t^{at} - \overline{T_{s,t}^{at}}}{\omega * S} \right)^2$$

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Summary

Limited GDP recourse for
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Moral hazard

Reduce damage of
post-shock period

Higher damage

Reduce shock
warming and damage

Reduce damage of
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Summary

Sensitivity Analysis	Myopic		Smart	
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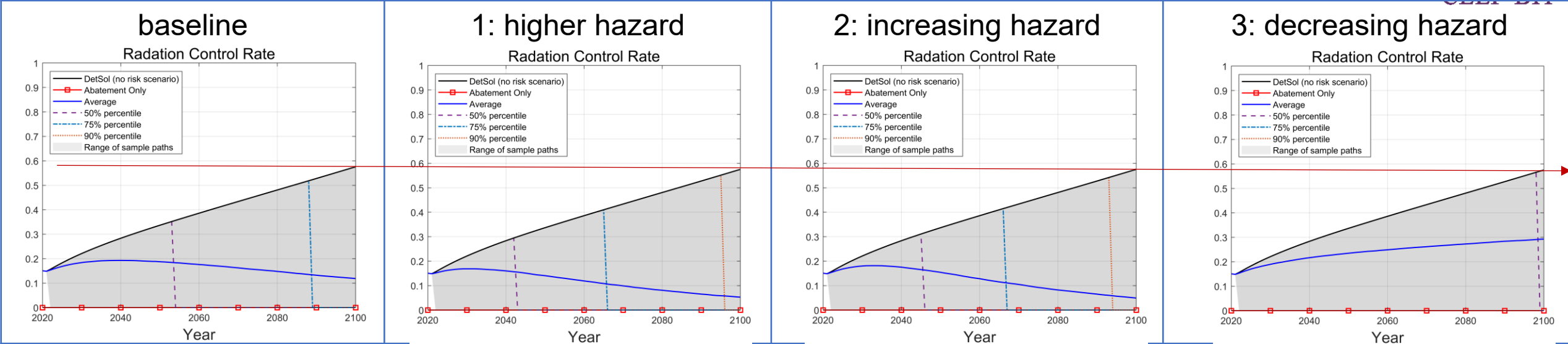
Reduce shock
warming and damage

Limited GDP resource (more
abatement before shock)

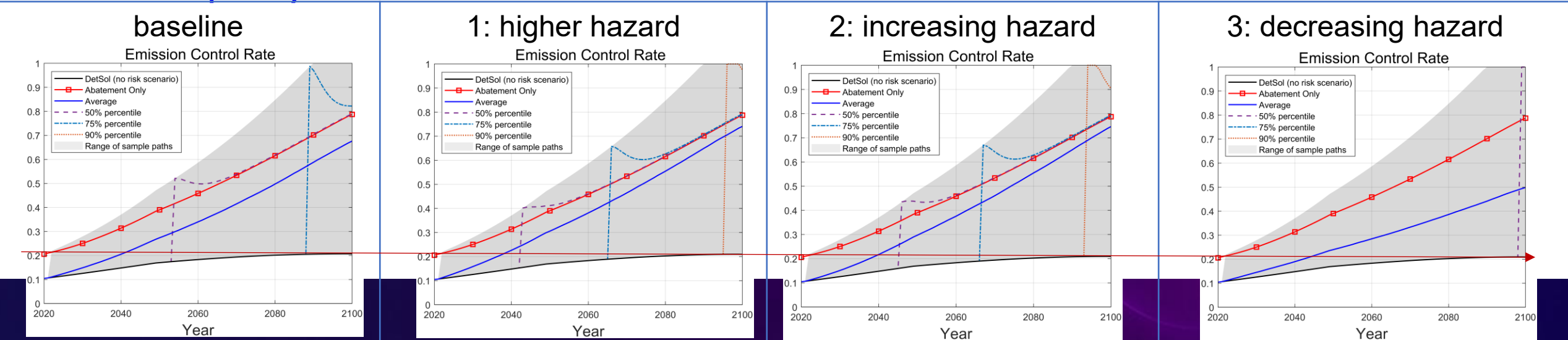
Shock Probability Case1: myopic DM

SRM policy

Before shock: No impacts
After shock: No impacts



Abatement policy



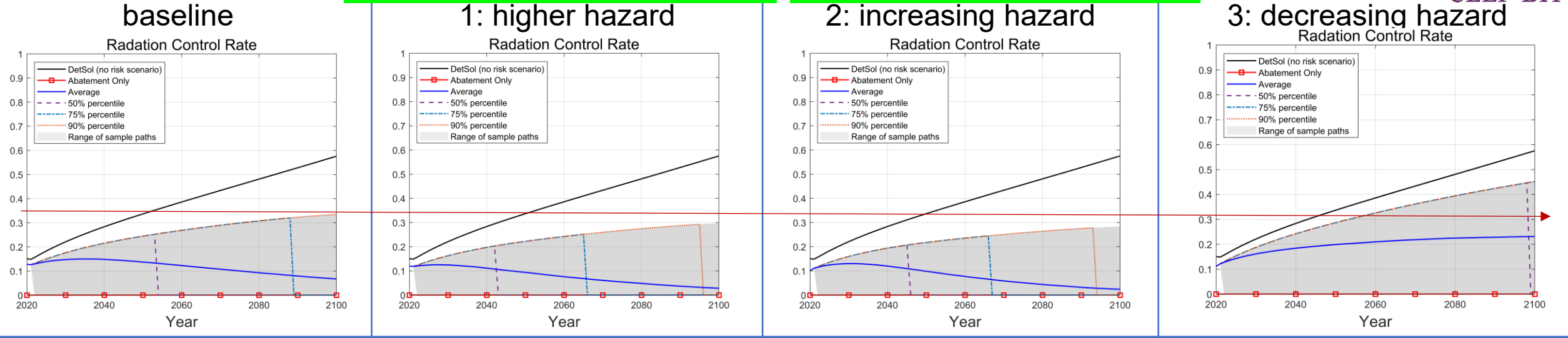
Shock Probability Case2: smart DM



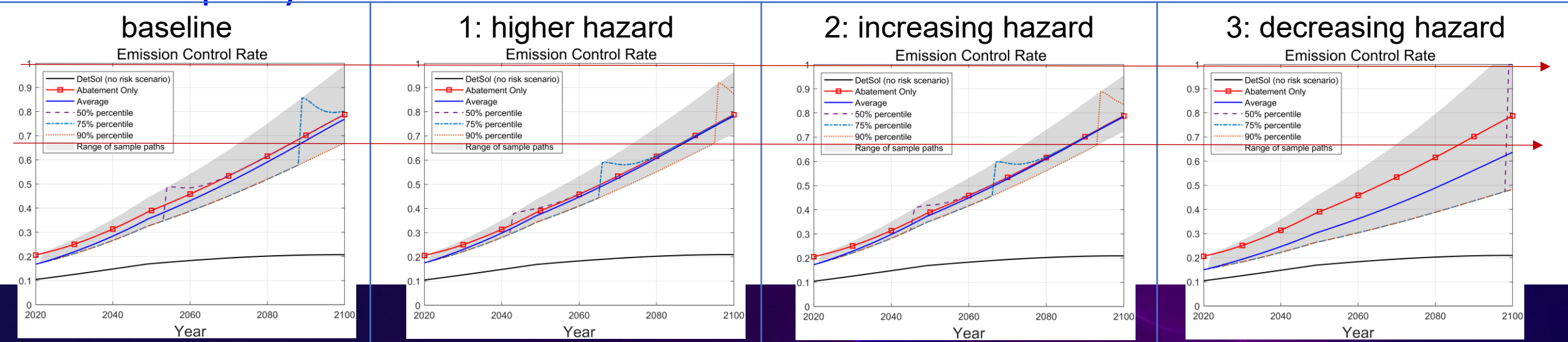
SRM policy

Before shock:
More abatement and Less SRM

After shock:
Zero SRM and Less Abatement

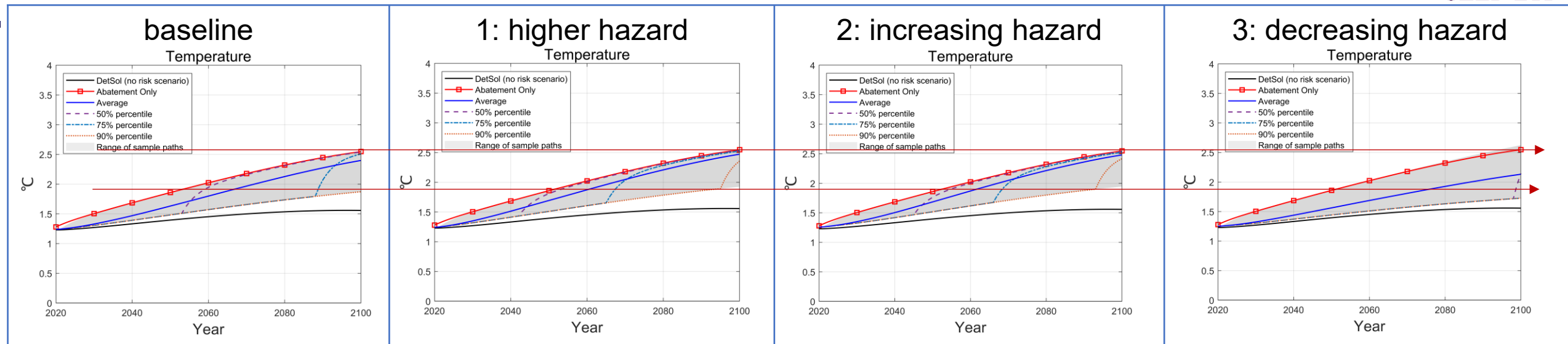


Abatement policy



Shock Probability Case2: smart DM

Warming



Before shock:

More abatement and Less SRM

After shock:

Zero SRM and Less Abatement

SRM determines the lower bound and the shadow range (more SRM corresponds to a low lower bound and big range)
Abatement determines the upper bound (more abatement corresponds to a low upper bound)

Summary

Sensitivity Analysis	Myopic		Smart	
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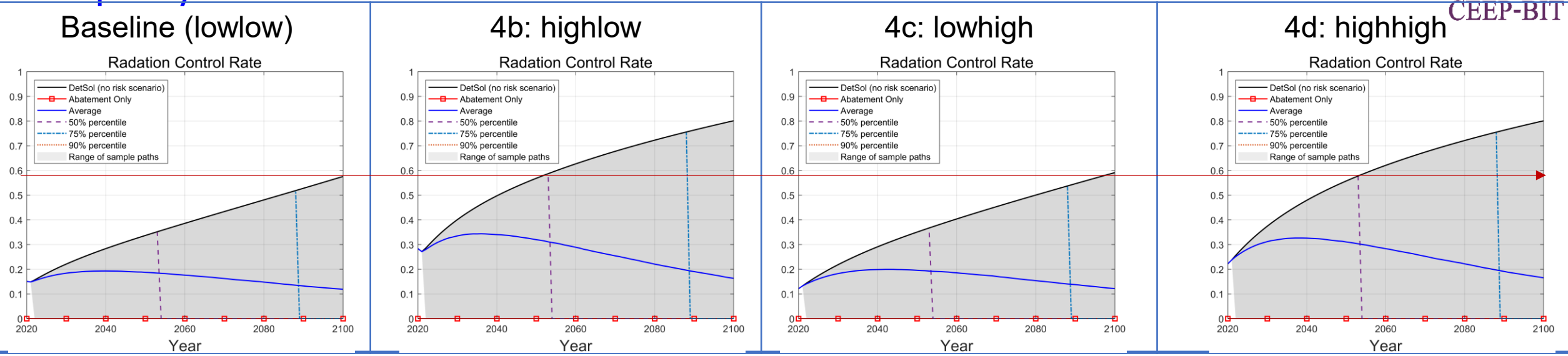
Moral hazard

Reduce damage of
post-shock period

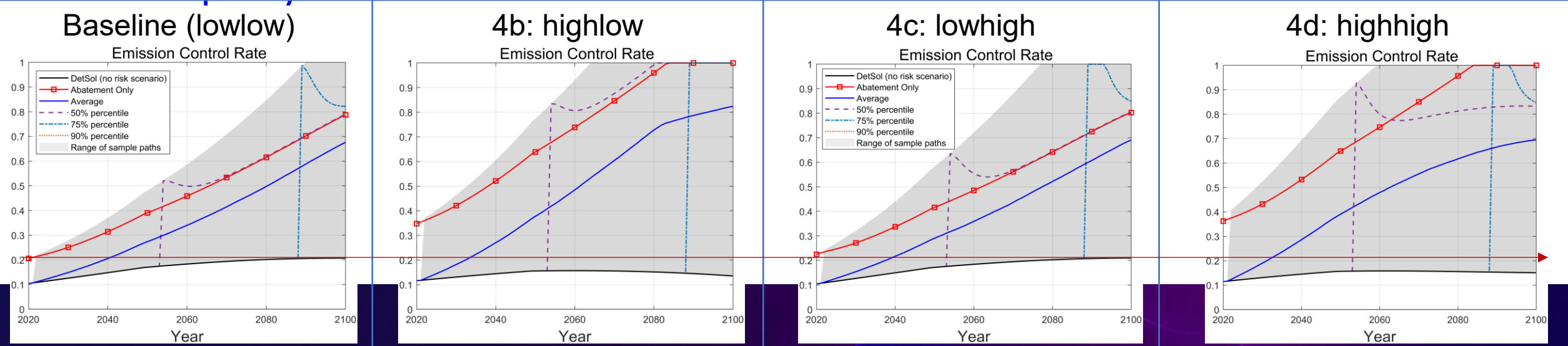
Shock Damage Case1: myopic DM

SRM policy

Before shock: Less abatement; More SRM (β_{Long})
Little impacts (β_{Short})
After shock: More abatement; No SRM (β_{Long})
More abatement; No SRM (β_{Short})



Abatement policy



Summary

Sensitivity Analysis	Myopic		Smart	
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After shock:
Zero SRM and Less Abatement

Higher overall
damage

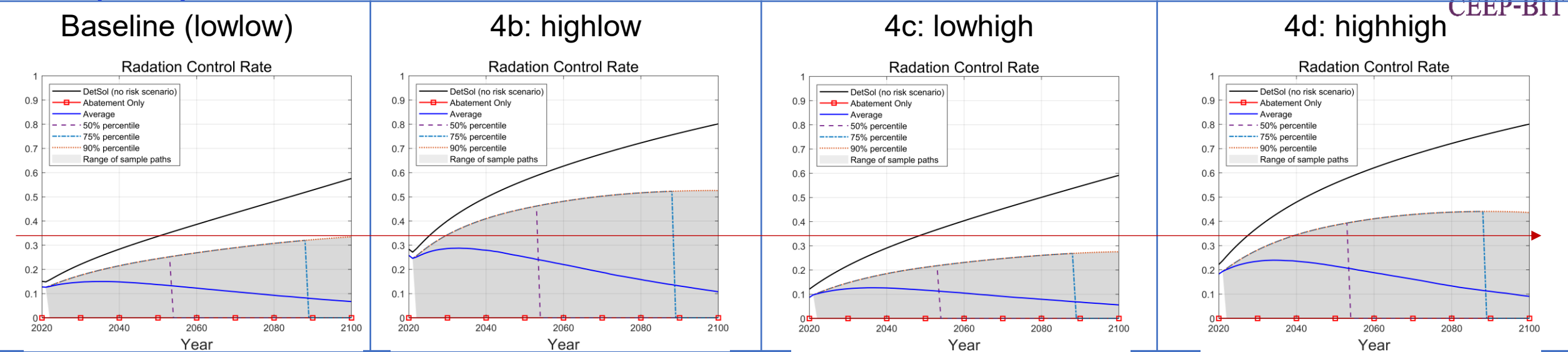
Reduce shock
warming and damage

Reduce damage of
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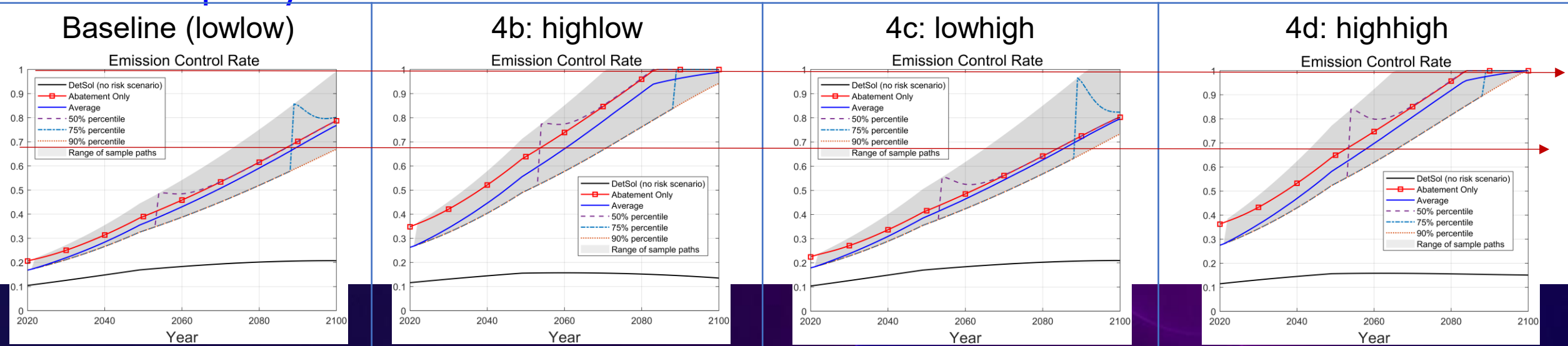
Shock Damage Case2: smart DM

SRM policy

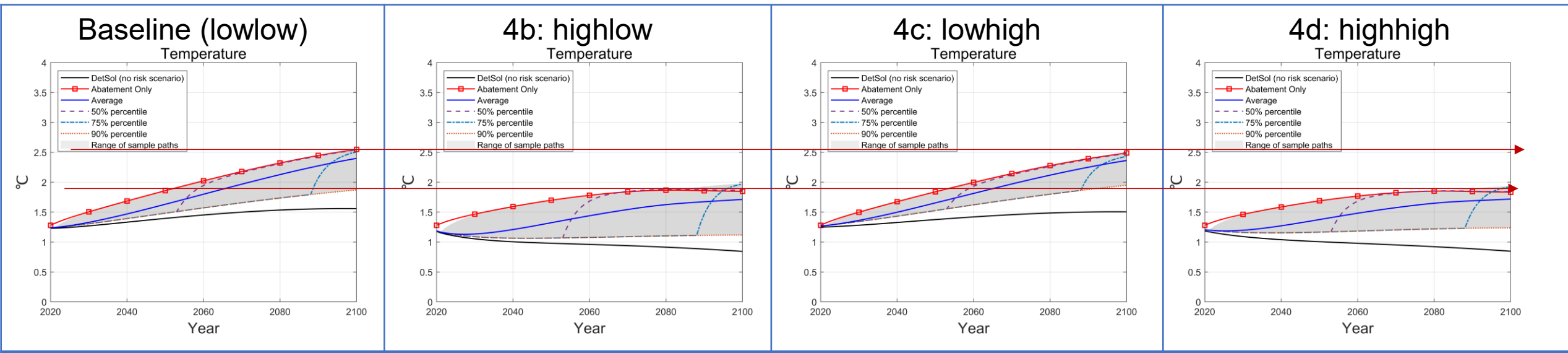
Before shock: More abatement; More SRM (β_{Long})
More abatement; Less SRM (β_{Short})
After shock: More abatement; No SRM (β_{Long})
More abatement; No SRM (β_{Short})



Abatement policy



Warming



Before shock: More abatement; More SRM (β_{Long}) More abatement; Less SRM (β_{Short})
After shock: More abatement; No SRM (β_{Long}) More abatement; No SRM (β_{Short})

SRM determines the lower bound and the shadow range (more SRM corresponds to a low lower bound and big range)
Abatement determines the upper bound (more abatement corresponds to a low upper bound)

- Conclusion
- Numerical results (sensitivity analysis)
- **Time horizon**
- Short-term damage function

Time horizon

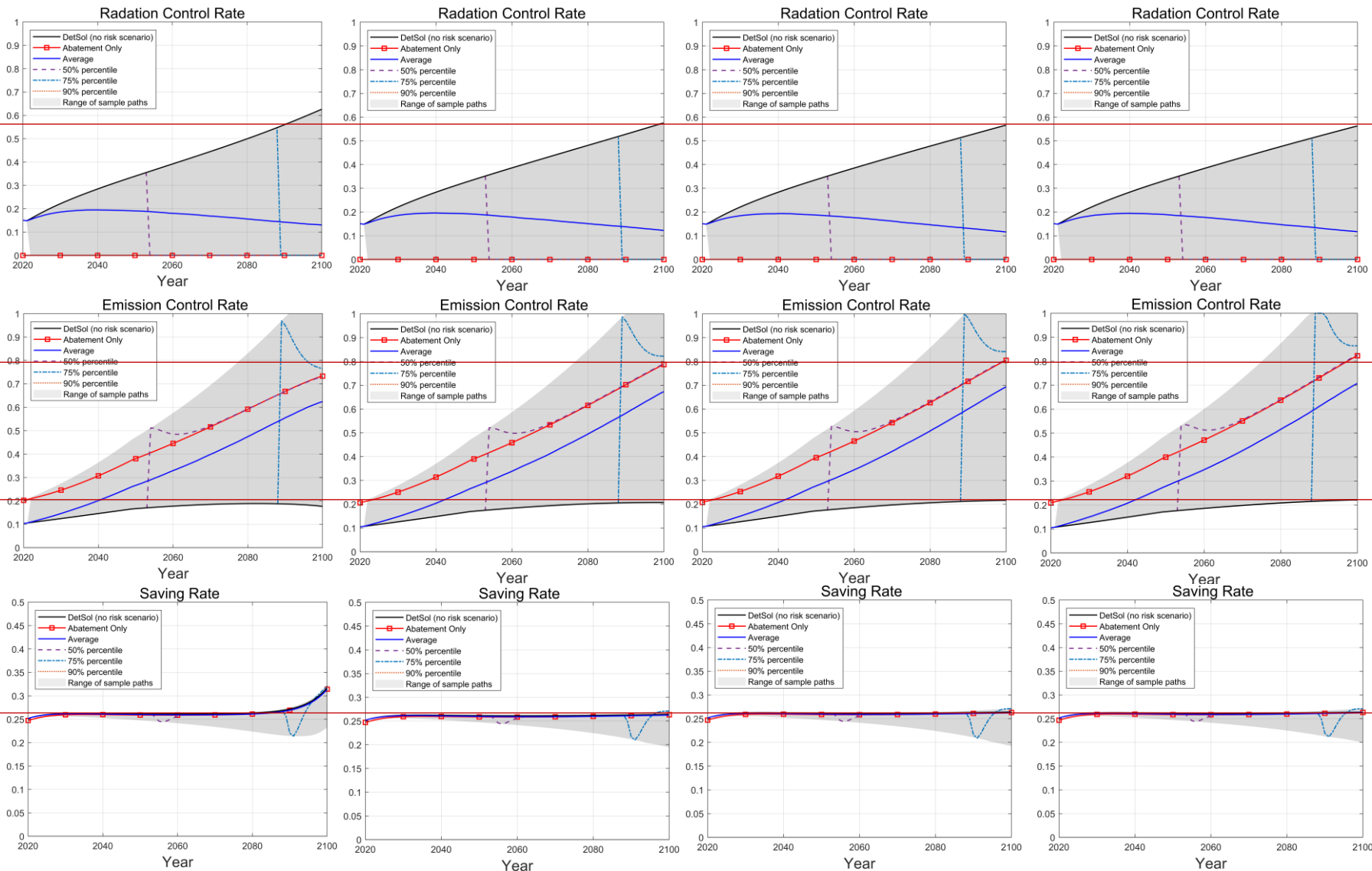
Case1:
myopic DM

T=100

T=130

T=150

T=170



- Conclusion
- Numerical results (sensitivity analysis)
- Time horizon
- **Short-term damage function**
- Theoretical model (SCC, SCF)

Short-term damage function

$$D_t^S = \beta_2 \left(\frac{T_t^{at} - \overline{T_{s,t}^{at}}}{\omega * s} \right)^2$$

$\omega = 0.02$ # 0.2 per 10 years from RCP2.6

$\omega = 0.05$ # 0.5 per 10 years from RCP8.5

$s = 5$ # last 5 years

$\overline{T_{s,t}^{at}}$ # the average warming of last 5 years

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