Pricing Climate Risk

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SCC under uncertainty

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What drives the risk premium? How large is it?

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We examine both approaches and relate them

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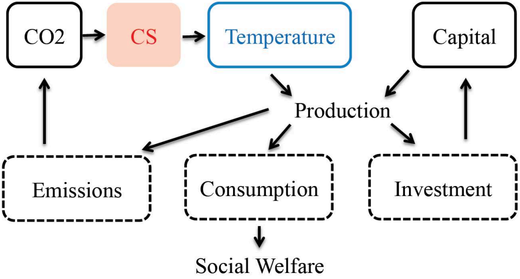
2. Explain the uncertainty premium channels
    - risk aversion, prudence, production damages (+ their interactions)
3. Quantify premium
    - without and with policy responsiveness
4. Match numeric DICE-based model for
    - Monte Carlo approach (no policy response)
    - Stochastic dynamic programming (responsive policy)

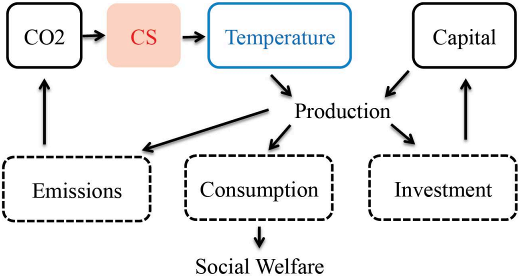
Social Cost of Carbon

DICE-style integrated assessment model



Social Cost of Carbon

What is the welfare cost of one additional ton emissions E_0?



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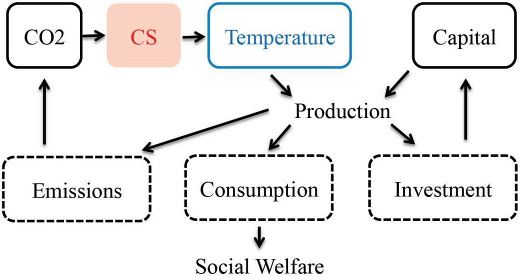

$$SCC_0 = -\frac{1}{u_0'(c_0)}\mathbf{E}_0 \sum_{t=1}^{\infty} \sum_{\tau=1}^{t} u_t'(c_t) \frac{\partial F_t}{\partial T_t} \frac{\partial T_t}{\partial CO_{2,\tau}} \frac{\partial CO_{2,\tau}}{\partial E_0}$$

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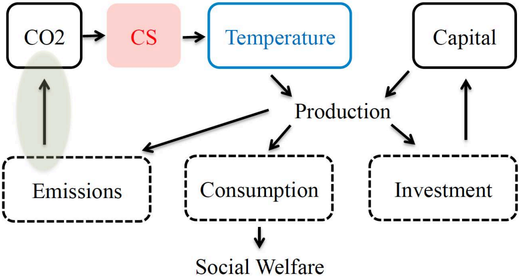

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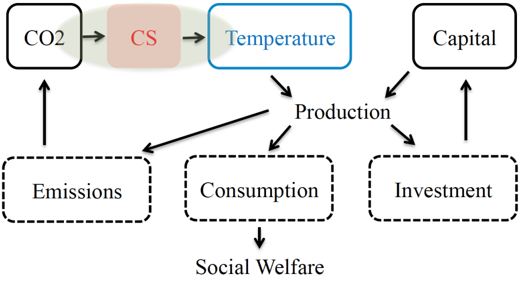

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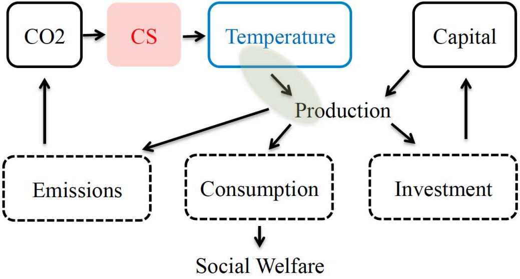

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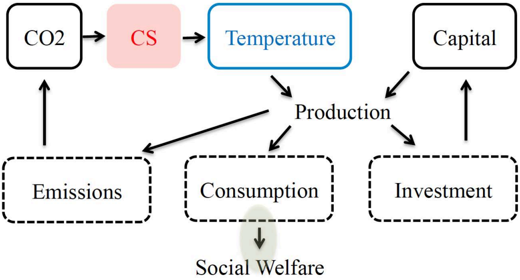

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Climate Risk Premium: Background

Why does risk generate a policy premium?

Basic idea of *precautionary savings* motive:

- Risk aversion reduces *welfare*
- (Absolute) Risk aversion *falls* in income

$\hookrightarrow$ save more under uncertainty

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Captured by

- **Prudence**: Prud$= -\frac{u'''}{u''} * c$

which captures the *change in*

- Risk Aversion: RRA$= -\frac{u''}{u'} * c$

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Define

- Dam$_2$= $\frac{F''}{F'} * T$: *Damage convexity* in temperature,
- Dam$_3$= $\frac{F'''}{F''} * T$: Change of damage convexity in temperature; "*Economy prudence*."

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(Expect *interactions* between different contributions)

Analytic formula and channels

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$$X_t \equiv \underbrace{\text{RRA}\,\epsilon_{c,s}}_{\substack{\text{direct}\\\text{risk}\\\text{aversion}}}\Big[2+\underbrace{\text{Prud}\,\epsilon_{c,s}}_{\substack{\text{welfare}\\\text{prudence}}}+\underbrace{3\,\text{Dam}_2\,\epsilon_{T,s}}_{\substack{\text{welfare}\\\text{economy}\\\text{interaction}}}\Big]+\underbrace{\text{Dam}_2\,\epsilon_{T,s}}_{\substack{\text{direct}\\\text{damage}\\\text{convexity}}}\Big[2+\underbrace{\text{Dam}_3\,\epsilon_{T,s}}_{\substack{\text{economy}\\\text{prudence}}}\Big]$$

is greater than zero.

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Note: Under stochastic temperature risk rather than structural climate uncertainty, the “2 RRA” and “2 Dam_2” contributions disappear.

Analytic formula and channels

Quantifying the risk premium:

$$\Delta SCC_0 \approx \sum_{t=1}^{\infty} \sum_{\tau=1}^{t} \underbrace{\beta^t \frac{u_t'(c_t)}{u_0'(c_0)}}_{\substack{\text{consumption}\\ \text{discount}\\ \text{factor}}} \underbrace{\frac{\partial F_t}{\partial T_t} \frac{\partial T_t}{\partial M_\tau} \frac{\partial M_\tau}{\partial E_0}}_{\substack{\text{marginal}\\ \text{emission}\\ \text{damage}}} \underbrace{\frac{\mathbb{V}\text{ar}(s)}{2(\mathbf{E}s)^2}}_{\substack{\text{level of}\\ \text{uncertainty}\\ \text{(normalized)}}} X_t(\cdot) \ .$$

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Need: time paths for *one* model run under **certainty**.

Quantification w/o policy response

'Monte Carlo': Evaluate SCC w/o anticipating policy response

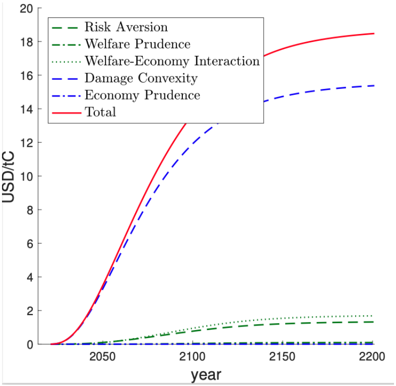


Figure: Today's SCC risk premium as function of time

$\Delta SCC_0 = \$19.1/tC$

- Damage convexity: dominates
- RRA: moderate contribution
- Prudence and 'Economy prudence': irrelevant

Policy responsiveness shows in **temperature elasticity** wrt climate sensitivity.

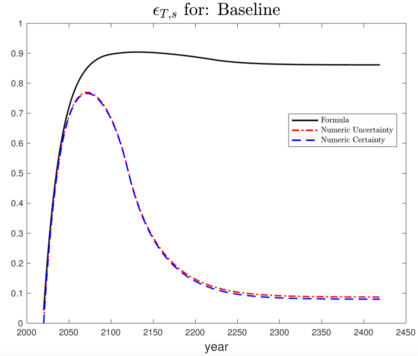


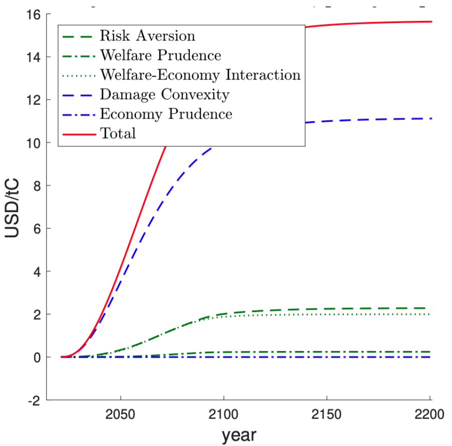
Figure: Analytic, unresponsive (black) vs numeric, responsive elasticity (color) $\epsilon_{T,s}$

- $\epsilon_{T,s}$ formula with non-responsive policy pretty far off
- Proxy:

  $\epsilon_{T,s}$ from deterministic model for $\epsilon_{T,s}$ from full stochastic model

Quantification with policy response

Using responsive elasticity $\epsilon_{T,s}$ from deterministic model:



$\Delta SCC_0 = \$16/tC$

- Reduction due to policy responsiveness: 16%
- Error in formula vs full recursive stochastic dynamic programming model: small

Quantification: Robustness

Risk premium and formula performance for different scenarios

	Analytic Formula Base	Analytic Formula Responsive	Stochastic Model	Stochastic Fraction	Fraction of Cert
RRA=2, $\rho = 1.5$, DICE13	19.1	16.0	15.8	1.6%	26%
RRA = 1.45	29.8	21.3	21.4	1.4%	21%
PRTP $\rho = 0.5$	34.3	22.6	23.0	2.1%	21%
Update PWT 2019 (RRA=3)	13.7	12.7	13.4	2.2%	28%
DICE 2007 Damages	16.0	13.4*	13.0	0.4%	21%
Howard & Sterner Damages	100	74.4*	80.9	6.7%	35%
Cubic Damages	70.8	46.8*	48.6	8.7%	76%
Cubic Damages, $\rho = 0.5$	122	71.2*	70.1	10.6%	63%
Epstein-Zin: $\eta = 2, RRA = 6$	26.4	21.8*	19.8	3.7%	32%
Epstein-Zin: $\eta = \frac{2}{3}, RRA = 6$	87.7	57.5*	51.3	5.7%	20%

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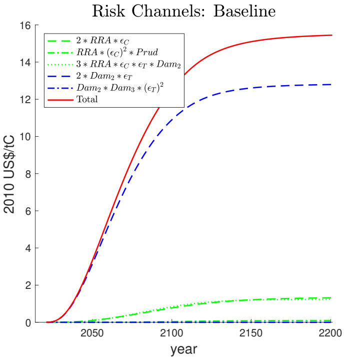
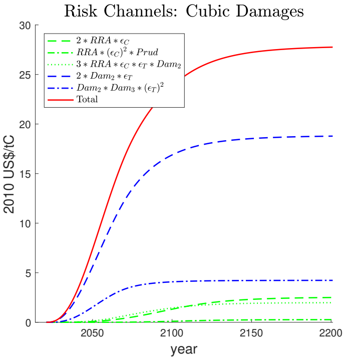
Risk premium is around 20-25% except for high damage level or convexity (then also policy responsiveness most relevant).

Climate Risk Premium: Characteristics

What are the important drivers? (responsive $\epsilon_{T,s}$)



$D(T) = 1 - 0.27T^2$ in % of output



$D(T) = 1 - 0.1068T^3$ in % of output

Summing up

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"Validate" formula against recursive stochastic DICE

- 20-25% risk premium in DICE.
- Exception: Cubic damages triple the risk premium