A simple formula for the social costs of carbon

Netwerk Groene Groei, 8 December 2015

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This research

- “Een eenvoudige formule voor de maatschappelijke kosten van CO_2”
  - rapport voor Ministerie van Infrastructuur en Milieu
- “A simple formula for the social cost of carbon”
  - Under review

Literature: IAM

- Social Cost of Carbon (SCC) = monetized damage from emitting one unit of CO_2 to the atmosphere
- Obtained from computational Integrated Assessment Models (IAMs), e.g. Global2100, DICE, MERGE, CETA, FUND, PAGE, MIND, DEMETER, … AR5-WG3-CH6
- Systematic assessments: Weyant, de la Chesnaye & Blanford, 2006; Hope, 2008; Nordhaus, 2008; Anthoff & Tol, 2013
  - Higher climate sensitivity, higher estimates of damages for given temperature change, and lower discount rates generally lead to higher SCC
- Fundamental problem: IAMs remain a black box / accepted or rejected on the basis of trust (Kelly & Kolstad, 1999a)

Literature: SCC formulas

- Analytical formula for SCC
- Golosov et al. (2014) derive an analytical formula for the SCC
  - based logarithmic utility, climate-change damages proportional to output and exponential in the atmospheric CO_2.
  - Barrage et al. (2014) sensitivity analysis of the assumptions
- Gerlagh and Liski (2012) add better climate system + time-inconsistent preferences.

This paper

- Present a ‘simple formula’ for the social costs of carbon
  - Based on balanced growth approximation
- More complicated vis-à-vis Golosov et al. (2014) & Gerlagh and Liski (2012)
  - Added: non-logarithmic utility, population growth, flexible damages
- Test formula

Purpose

- ‘simple’ derivation: education of SCC user
- simple rule: easy to test normative/descriptive choices

Educational purpose

Based on

- Fundamentals of climate change dynamics
- Fundamentals of economic analysis

Advantages:

- Provides precise insights in the relevant assumptions
  - positive (carbon cycle, temperature sensitivity, damages, discount rate)
  - normative (damages, discount rate)
- Explains the uncertainty in SCC estimates to the laymen
- Shows mechanisms for SCC growth over time

Tested

- The formula explains 99% of within-model SCC variation (DICE - Monte Carlo)

Testing the formula

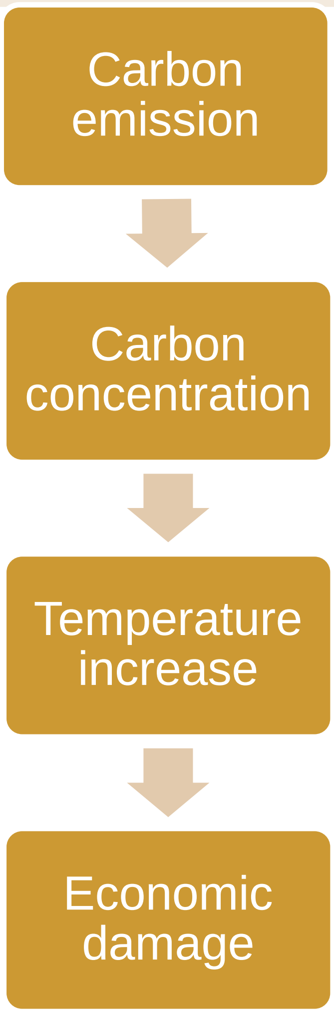
How much of the SCC variation is captured by the formula?

- The formula explains 99% of within-model SCC variation (DICE - Monte Carlo)

Where does the formula perform badly?

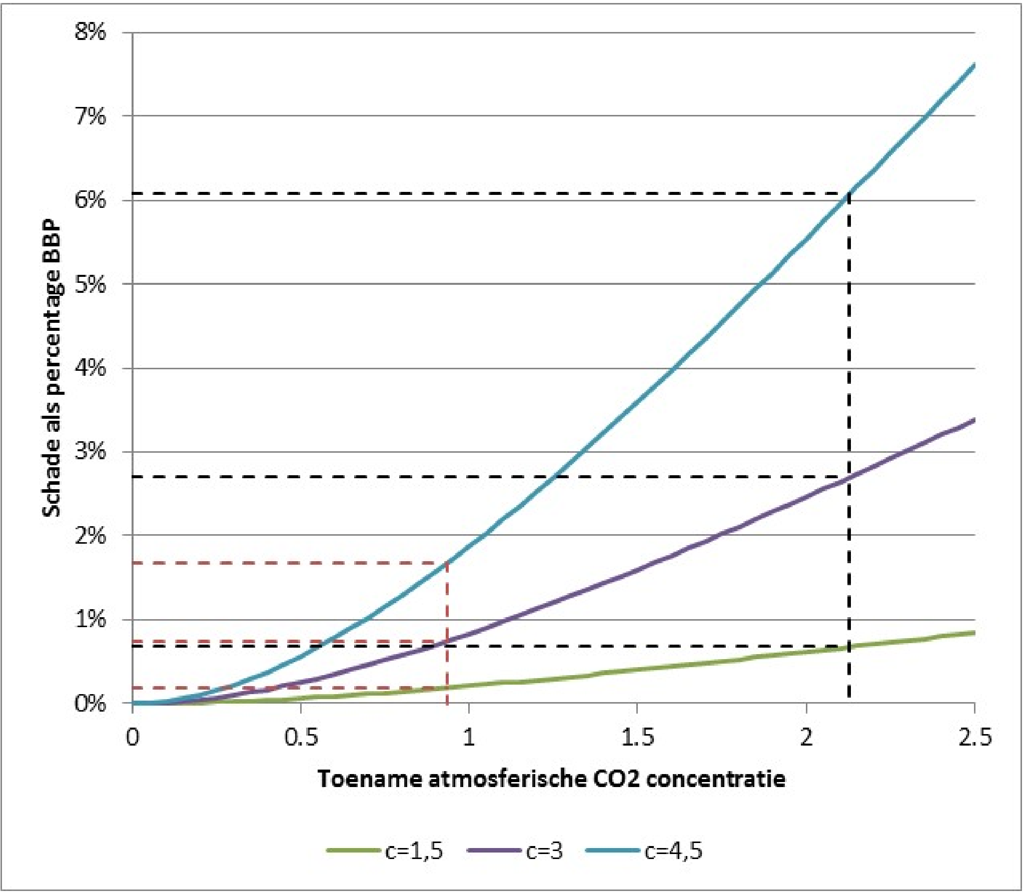
- Interaction between convexity of damages and discount rate is absent from formula

Deriving the formula: available on request in 30mins



1. Calculate damage per CO_2 when considering atmospheric CO2 without decay
2. Add CO2 decay
3. Add temperature lag
4. Determine effective discount rate

Step 1a: what if climate change was immediate?



- Assume 3 Kelvin climate sensitivity

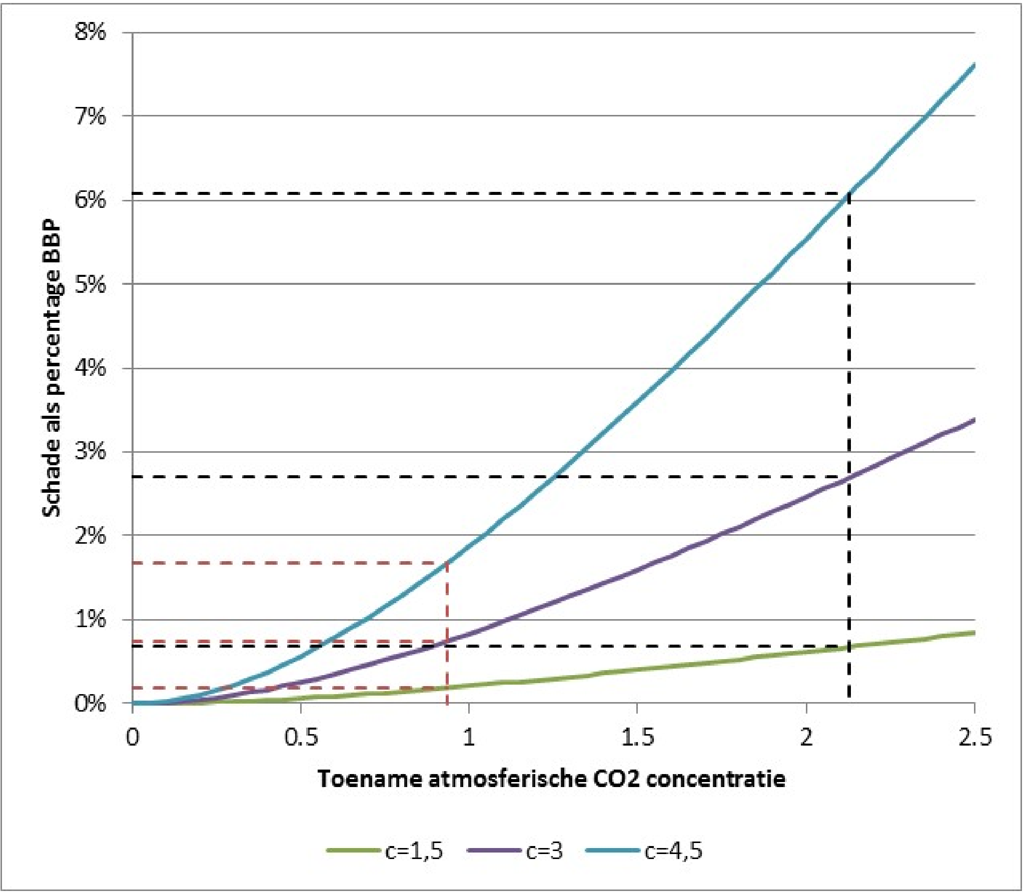
$$IMD = \frac{1.3\omega}{m} Y$$

The *Immediate Marginal Damage* depends on

- ω: Damage parameter [%GDP] at 3K
- m : natural atmospheric CO_2 [TtCO2]
- Y: Income [T€/yr]

$$IMD = \frac{1.3 \cdot 0.027}{2.1} 60 = 1 \text{ €/tCO}_2$$

Step 1b: what if climate change was immediate?



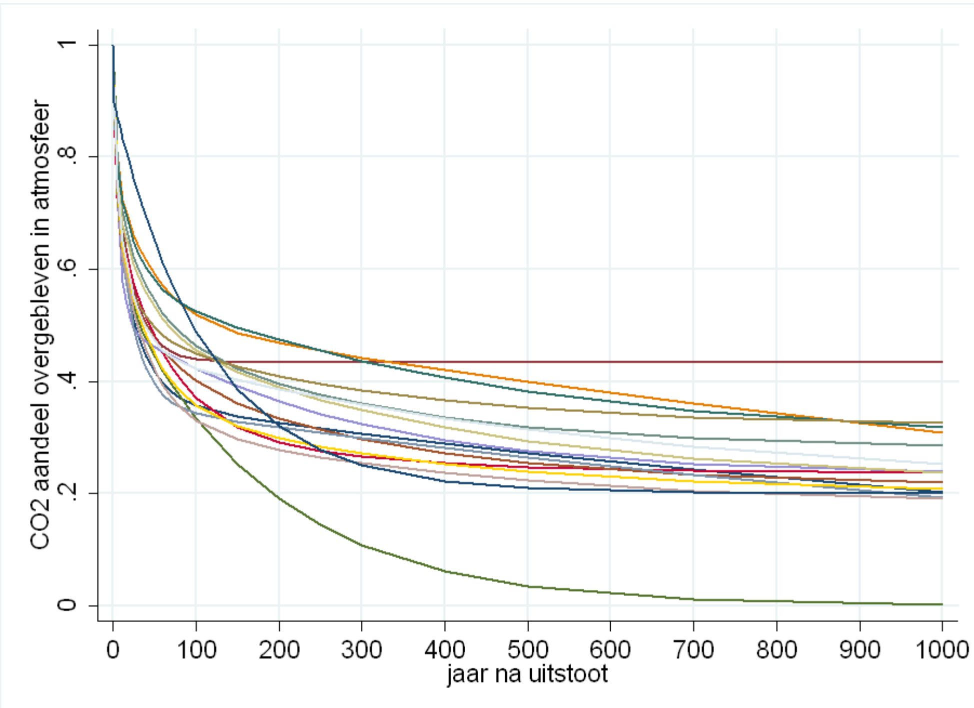
$$IMD = \frac{1.3\omega(c/3)^{\psi}}{m} Y$$

The *Immediate Marginal Damage* depends on

- ω: Damage parameter [%GDP] at 3K
- *c*: Temperature sensitivity [K] at doubling CO_2
- ψ: convexity of damages [.]
- m : natural atmospheric CO_2 [TtCO2]
- *Y*: Income [T€/yr]

Step 2: Persistence

$$PF = \frac{1}{\delta_S + \sigma}$$



The *Persistence Factor* depends on

- δ_S: Carbon cycle deprecation [%/yr]
- σ: Effective discount rate [%/yr]

$$PF = \frac{1}{0.01/yr + 0.02/yr} = 33\ yr$$

Step 2: Delay

$$DF = \frac{\varepsilon}{\varepsilon + \sigma}$$

The *Persistence Factor* depends on

- σ: Effective discount rate [%/yr]
- ε: Temperature adjustment speed [%/yr]

$$DF = \frac{0.02/yr}{0.02/yr + 0.02/yr} = 0.5$$

A simple formula for the social costs of carbon

$$SCC = \frac{1.3\omega(c/3)^{\psi}}{m}\frac{1}{\delta_S + \sigma}\frac{\varepsilon}{\varepsilon + \sigma}Y$$

The SCC depends on

- ω: Damage parameter [%GDP] at 3K
- c: Temperature sensitivity [K] at doubling CO_2
- ψ: convexity of damages [.]
- δ_S: Carbon cycle deprecation [%/yr]
- σ: Effective discount rate [%/yr]
- ε: Temperature adjustment speed [%/yr]
- Y: Income [€/yr]

Everyone can calculate the SCC!

$$SCC = \frac{1.3\omega(c/3)^{\psi}}{m}\frac{1}{\delta_S + \sigma}\frac{\varepsilon}{\varepsilon + \sigma}Y$$

- Temperature sensitivity: 3K at 2.1 $TtCO_2$
- Damage parameter: 2.7% at 3K
- Damages quadratic: $\psi = 2$
- CO2 deprecation: 0.01 [./yr])
- Temperature adjustment speed 0.02 [./yr]
- Income: 60 [T€/yr]
- Effective discount rate: 0.02 [./yr]

- SCC: [1.3/2.1] [0.027] $[3/3]^2$ [1/0.03] [1/0.04] [60] = 17 [€/tCO_2]

You think the discount rate should be 1%?

$$SCC = \frac{1.3\omega(c/3)^{\psi}}{m}\frac{1}{\delta_S + \sigma}\frac{\varepsilon}{\varepsilon + \sigma}Y$$

- Damage parameter: 2.7% at 3K
- Temperature sensitivity: 3K at 2.1 $TtCO_2$
- Damages quadratic: $\psi = 2$
- CO2 deprecation: 0.01 [./yr])
- Effective discount rate: 0.01 [./yr]
- Temperature adjustment speed 0.02 [./yr]
- Income: 60 [T€/yr]

- SCC: [1.3/2.1] [0.027] $[3/3]^2$ [1/0.02] [1/0.03] [60] = 33 [€/tCO_2]

Feeling lucky: you think the climate is stable?

$$SCC = \frac{1.3\omega(c/3)^{\psi}}{m} \frac{1}{\delta_S + \sigma} \frac{\varepsilon}{\varepsilon + \sigma} Y$$

- Damage parameter: 2.7% at 3K
- Temperature sensitivity: 1K at 2.1 $TtCO_2$
- Damages quadratic: $\psi = 2$
- CO2 deprecation: 0.01 [./yr])
- Effective discount rate: 0.02 [./yr]
- Temperature adjustment speed 0.02 [./yr]
- Income: 60 [T€/yr]

- SCC: [1.3/2.1] [0.027] $[1/3]^2$ [1/0.03] [1/0.04] [60] = 1.9 [€/tCO_2]

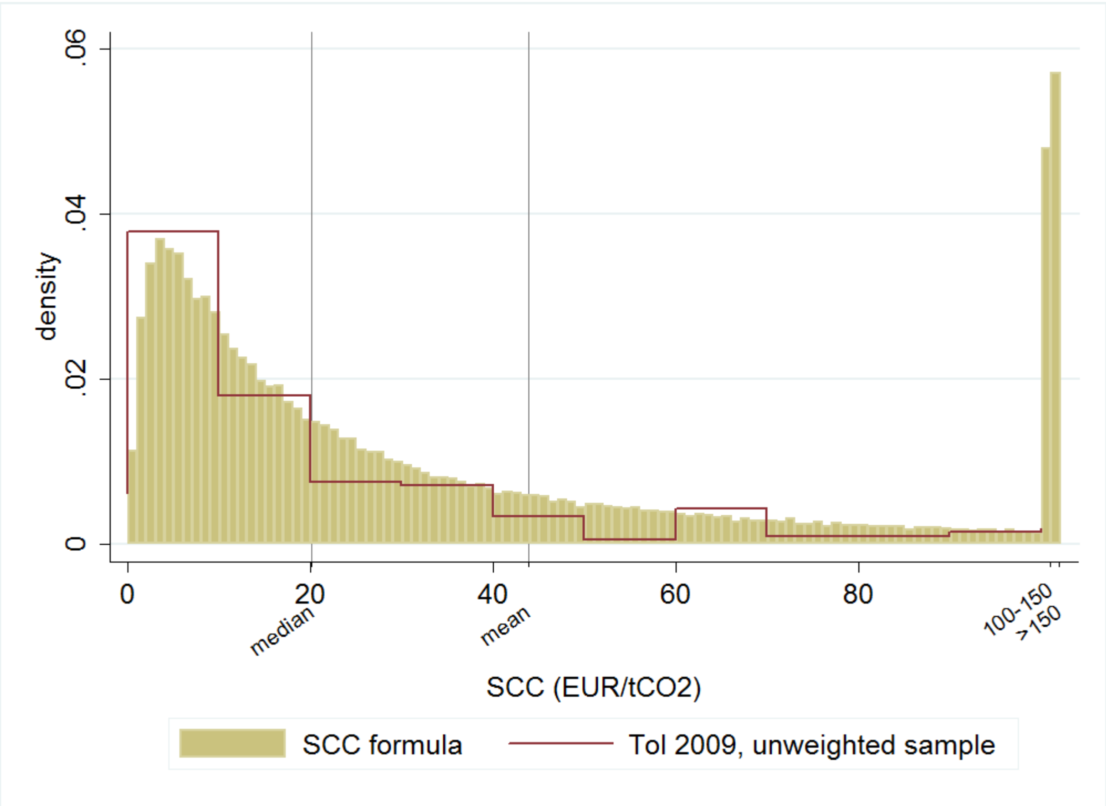
Pessimistic & responsible?

$$SCC = \frac{1.3\omega(c/3)^{\psi}}{m}\frac{1}{\delta_S + \sigma}\frac{\varepsilon}{\varepsilon + \sigma}Y$$

- Damage parameter: 2.7% at 3K
- Temperature sensitivity: 5K at 2.1 $TtCO_2$
- Damages quadratic: $\psi = 3$
- CO2 deprecation: 0.01 [./yr])
- Effective discount rate: 0.01 [./yr]
- Temperature adjustment speed 0.02 [./yr]
- Income: 60 [T€/yr]

- SCC: [1.3/2.1] [0.027] $[5/3]^3$ [1/0.02] [1/0.03] [60] = 155 [€/tCO_2]

You don't know?



- Taking the full range for all parameters gives:
- Nice fit of Tol (2009), and
- Median: 20 [€/tCO_2]
- Mean: 48 [€/tCO_2]
- No disagreement, but fundamental uncertainty: Very clear reason why the community can't agree on a unique SCC.

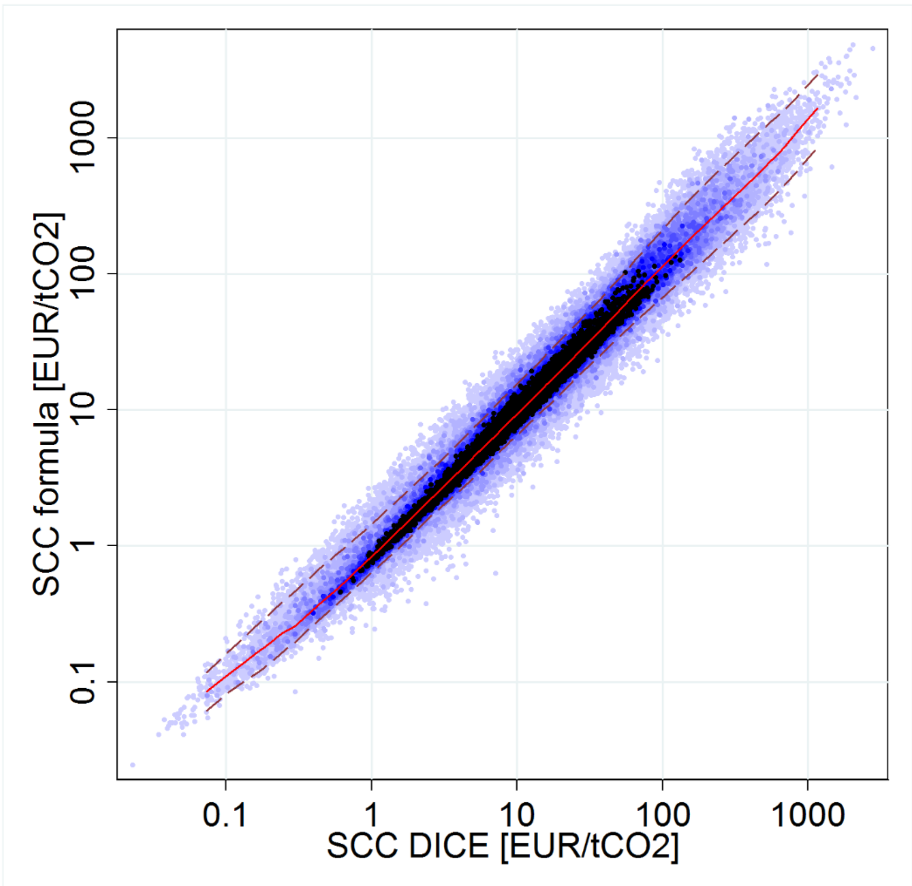
Discounting: extending the Ramsey rule

$$r = \rho + \eta g$$
$$\sigma = r - \xi g - l = \rho + (\eta - \xi) g - l.$$

- σ : climate effective discount rate
- r : real rate of return on investments
- ρ : pure rate of time preferences [0-0.03 /yr]
- η : elasticity of marginal utility [0.5-3]
- ξ : elasticity of damages to income [0-2]
- g: economic per capita growth: [0.015-0.03 /yr]
- l : population growth rate [0.008-0.015 /yr]

- σ = [0.02] + [2–1] [0.02] – [0.01] = 0.03 /yr

Testing the formula



- Take DICE++: ran 100000 Monte-Carlo simulations
- Vary 14 parameters over WIDE range
  - Including climate sensitivity, damage parameter, growth, EMU, price of backstops
- Calculate (implicit) formula parameters
- Calculate formula SCC and compare with DICE SCC
- R^2~0.99

Testing the formula

Table 1: Relative gap between formula and DICE SCC values: dependence on main parameters.

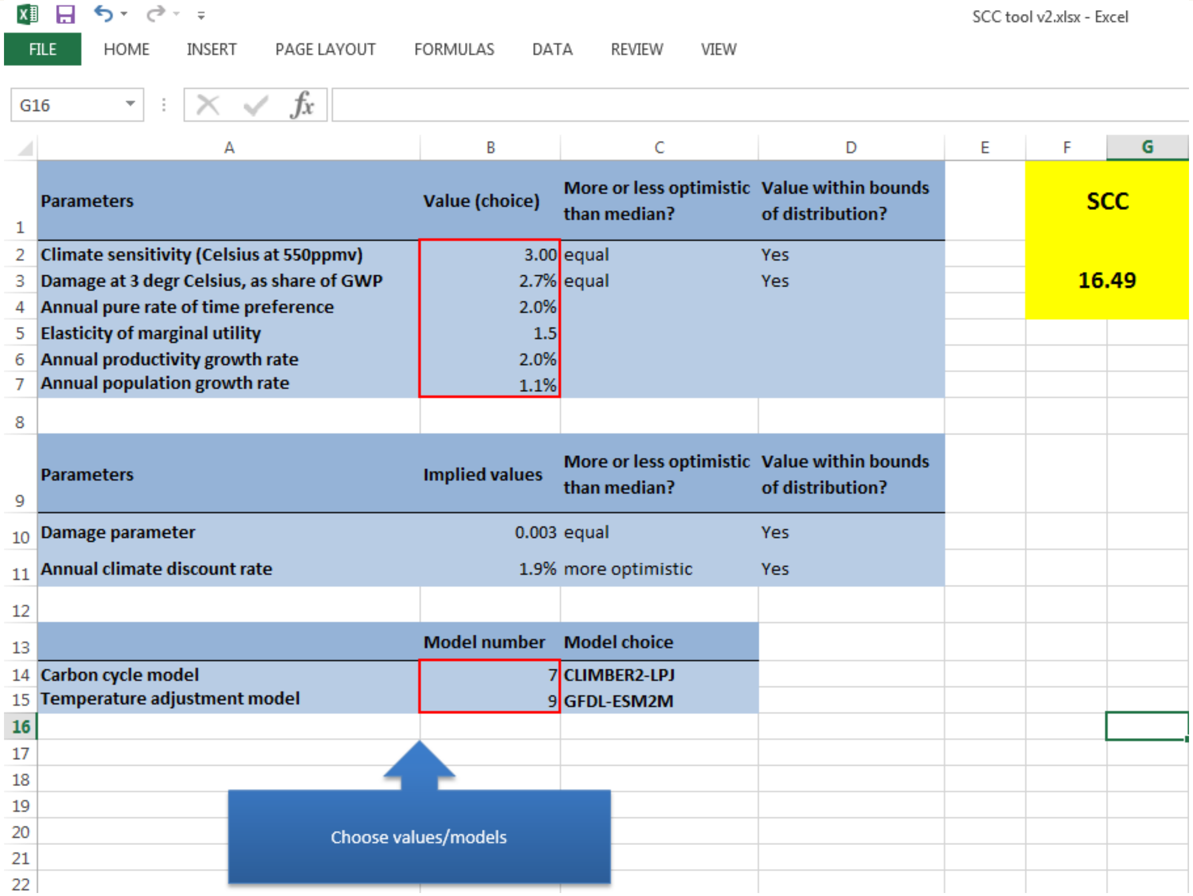
	OLS gap	OLS gap	OLS gap	OLS gap	within-sample spread	corner-center effect
	(1)	(2)	(3)	(4)	(5)	(6)
ln(c)	0.255	0.255	0.255	0.225	1.563	0.199
ln(ω)	0.043	0.044	0.044	0.045	3.219	0.072
ψ	-0.037	-0.037	-0.037	-0.038	2.900	0.055
ξ	0.202	0.202	0.202	0.226	1.263	0.143
ρ	1.733	1.692	1.693	1.093	0.075	0.041
η	-0.100	-0.100	-0.100	-0.103	2.478	0.127
g	-3.793	-3.825	-3.849	-3.313	0.109	0.032
l	10.13	9.894	9.886	10.39	0.005	0.029
ψ x ρ		9.279	9.278	9.803	0.142	**0.694**
ψ x η		0.192	0.192	0.194	4.582	**0.446**
Other linear var's	NO	NO	YES	YES		
Other interactions	NO	NO	NO	YES		
Nr independent vars	8	10	16	105		
Nr obs	100.000	100.000	100.000	100.000		
R2	**0.316**	**0.640**	0.642	0.815		

- Main error of formula: omission of convexity-discount rate interaction

Summary

- SCC can be understood through a simple formula
  - Useful to laymen, policy makers, researchers
- Skewed distribution:
  - Most chance of low SCC
  - But some chance of ‘high’ SCC
- Uncertainty of ‘true’ SCC value is clear from uncertainty of fundamental parameters (climate sensitivity)
- and subjective parameters (damage sensitivity, discount rate)

The Excel file



Parameters	Value (choice)	More or less optimistic than median?	Value within bounds of distribution?
Climate sensitivity (Celsius at 550ppmv)	3.00	equal	Yes
Damage at 3 degr Celsius, as share of GWP	2.7%	equal	Yes
Annual pure rate of time preference	2.0%		
Elasticity of marginal utility	1.5		
Annual productivity growth rate	2.0%		
Annual population growth rate	1.1%		

Parameters	Implied values	More or less optimistic than median?	Value within bounds of distribution?
Damage parameter	0.003	equal	Yes
Annual climate discount rate	1.9%	more optimistic	Yes

	Model number	Model choice
Carbon cycle model	7	CLIMBER2-LPJ
Temperature adjustment model	9	GFDL-ESM2M

SCC
16.49

- Put in the numbers
- Select the carbon- and temperature climate model
- SCC comes out.

Next steps (searching for funding from policy)

Extension to CH_4, major GHG gas for agricultural sector

- ‘short-lived’, thus needs thorough analysis of continuous versus discrete time
- Needs new IAM (most IAMs focus on CO_2)

“Common but differentiated responsibilities”

- Formula provides argument why high-income countries ‘should’ implement higher carbon prices

Kuznets curve

- Formula suggests higher carbon prices for higher income