Pricing Carbon: Estimating The Social Cost of Carbon

Maureen Cropper
University of Maryland and Resources for the Future

V Congreso de Economía Colombiana
Bogota, September 29, 2016

What Is the Social Cost of Carbon?

- The dollar value of future net economic damages, worldwide, from emitting an additional ton of carbon
- Represents the marginal benefits of reducing carbon emissions
- Has been officially estimated by the US government since 2010 for use in regulatory impact analyses
- Also used by the Canadian government and the World Bank

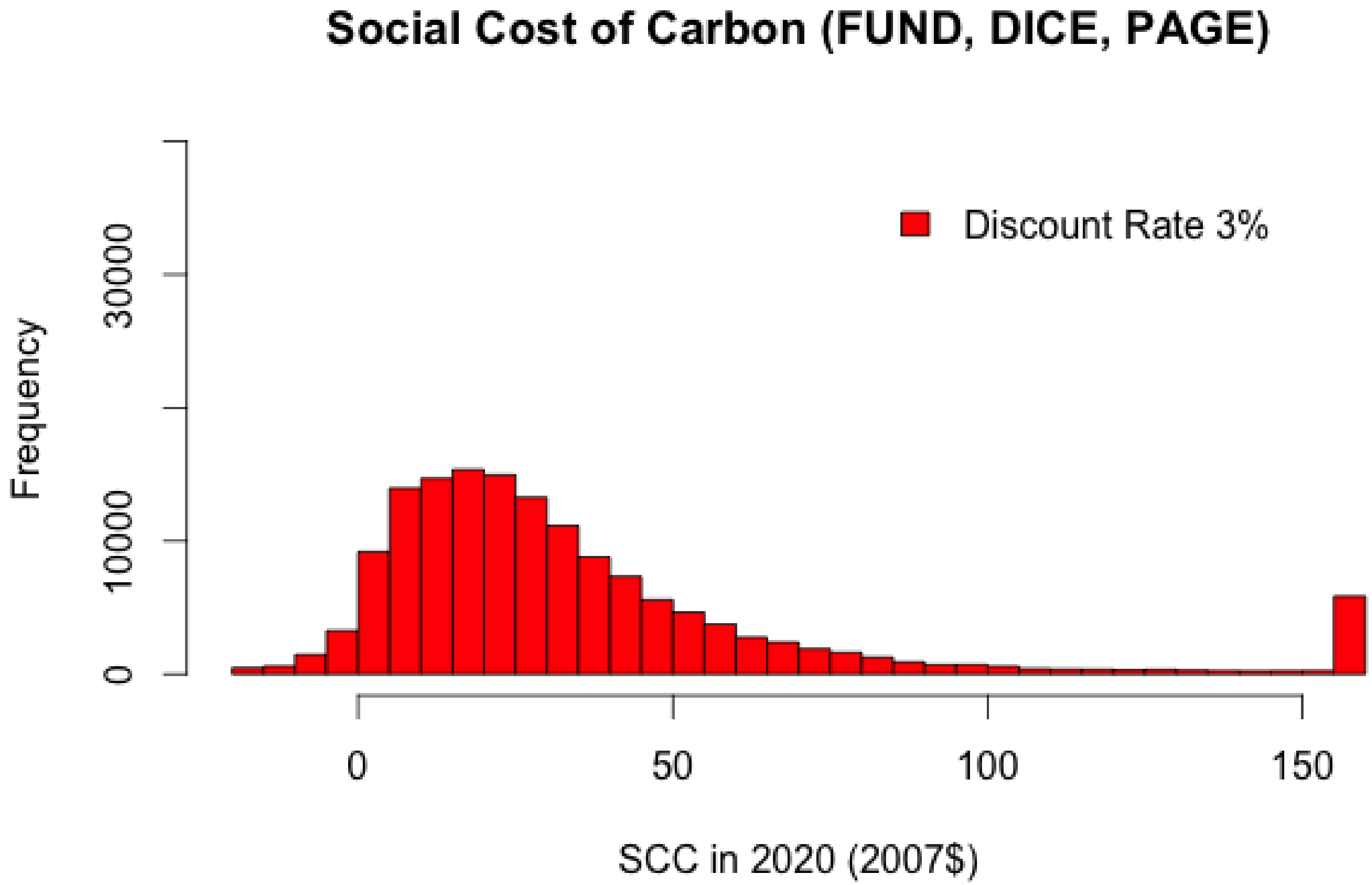
The US Social Cost of Carbon

- Based on 3 Integrated Assessment Models:
  - DICE (Norhaus)
  - FUND (Antoff and Tol)
  - PAGE (Hope)

- Models are run using alternate GDP and emissions baselines, climate assumptions

- Results of 150,000 Monte Carlo runs (50,000 per model) are pooled to yield:

- Mean SCC for 2015 = $36/ton CO2 (2007$)
  - Assuming a 3% discount rate



Social Cost of Carbon (FUND, DICE, PAGE)
Discount Rate 3%
Frequency
0
10000
30000
0
50
100
150
SCC in 2020 (2007$)

Goal of My Talk

- To explain in simple terms, what drives estimates of the SCC
- van den Bijgaart, Gerlagh and Liski, *J. Environ Econ and Management* (2016) derive a simple formula for the SCC
    - Simple, one-sector growth model
    - Simplified model of the climate system
- Will present their analysis, including Monte Carlo runs that generate a distribution of the SCC

Social Cost of Carbon Simplified

$$SCC(0) = \sum_{t=0}^{\infty} \frac{\partial T(t)}{\partial E(0)} \frac{\partial D(t)}{\partial T(t)} (1+r)^{-t}$$

Where

- T = mean global temperature
- E = CO2 emissions
- D = monetized damages
- r = discount rate

$$\frac{\partial T(t)}{\partial E(0)}$$

Reflects impact of E on atmospheric CO2 concentrations (S) and impact of S on T via radiative forcing

Approximate SCC(0) Under Simple Assumptions

- One box model of the carbon cycle

$$\dot{S}(t) = E(t) - \delta_s S(t)$$

- Simple energy balance model of climate system

$$\dot{T}(t) = \varepsilon[\varphi(S(t)) - T(t)]$$

$\varphi(S) =$ equilibrium temperature corresponding to S

- Damages proportional to output
- Damages that are a power function of T
- Ramsey discounting

Climate Damages and the Economy

- Let Y(t) denote output, excluding climate damages

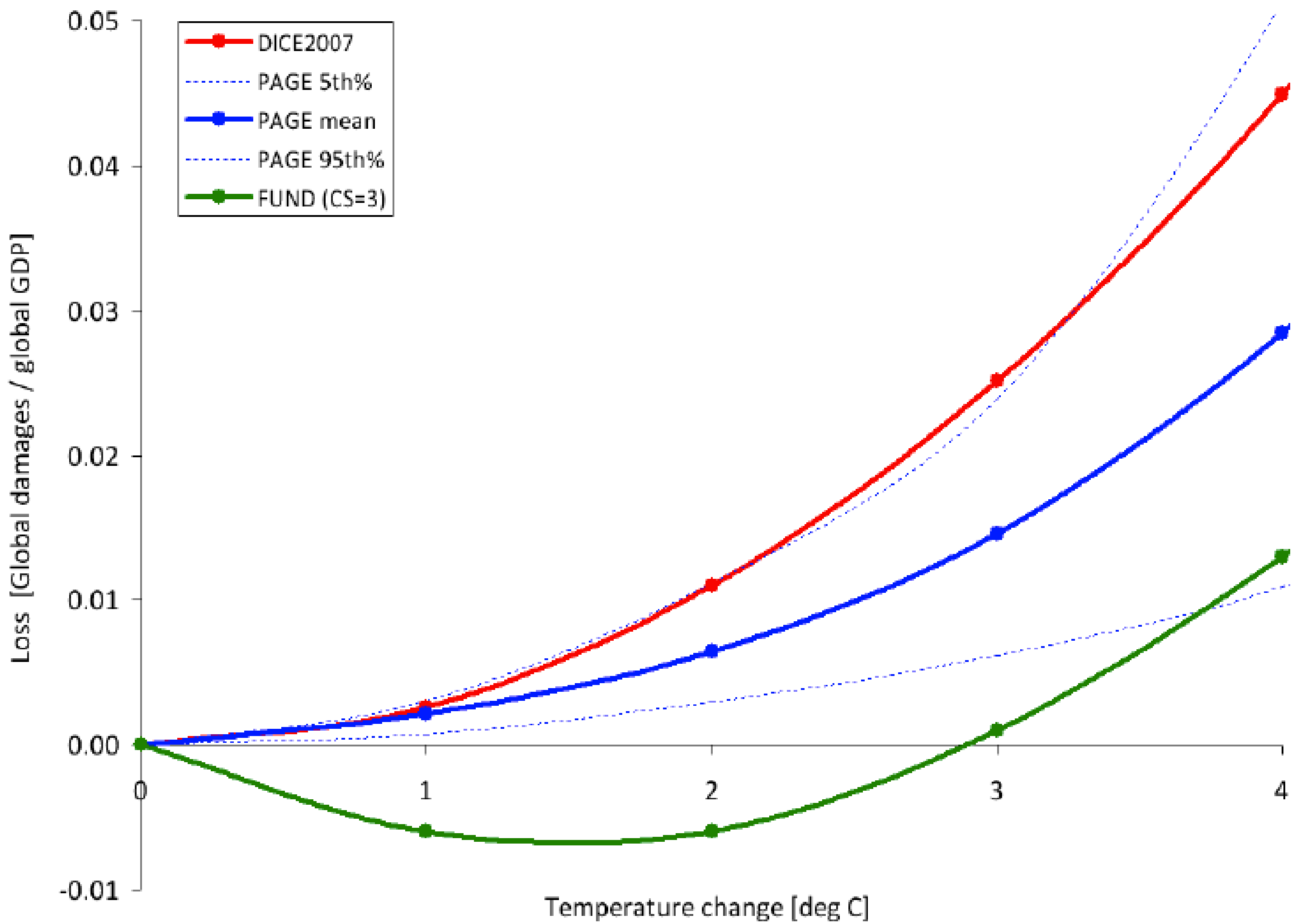
$$D(t) = wY(t)T(t)^{y}$$

w reflects damages as a proportion of Gross World Product at 3°C

y elasticity of damages w.r.t. temperature (= 2 in DICE)
(See next slide for examples)

- Assume constant savings rate (balanced growth path)
  - g = constant rate of growth per capita GWP
  - l = constant rate of population growth

Annual Percentage Loss in GDP as a Function of Temperature Change



Discounting Assumptions

- Ramsey discounting

$$r = r + hg$$

r = pure rate of time preference

h = (negative) elasticity of marginal utility w.r.t consumption

- Define the climate discount rate as

$$s \text{ º } r + hg - (g + l)$$

= Discount rate – (rate of growth in climate damages)

A Simple Formula for the SCC

In the neighborhood of equilibrium temperature ($\varphi(S)=T$) and S corresponding to 400ppm of CO2, SCC(0) can be approximated by

$$SCC(0) = awY(0)c^{\gamma} \frac{1}{d_s + s} \frac{e}{e+s}$$

c = Equilibrium Climate Sensitivity (T corresponding to a doubling of atmospheric CO2 from pre-industrial levels)

a = constant determined by S and climate system

What Drives the SCC?

$$SCC(0) = awY(0)c^{y} \frac{1}{d_s + s} \frac{e}{e + s}$$

$\frac{1}{d_s + s}$ = <u>Economic lifetime of CO2</u>

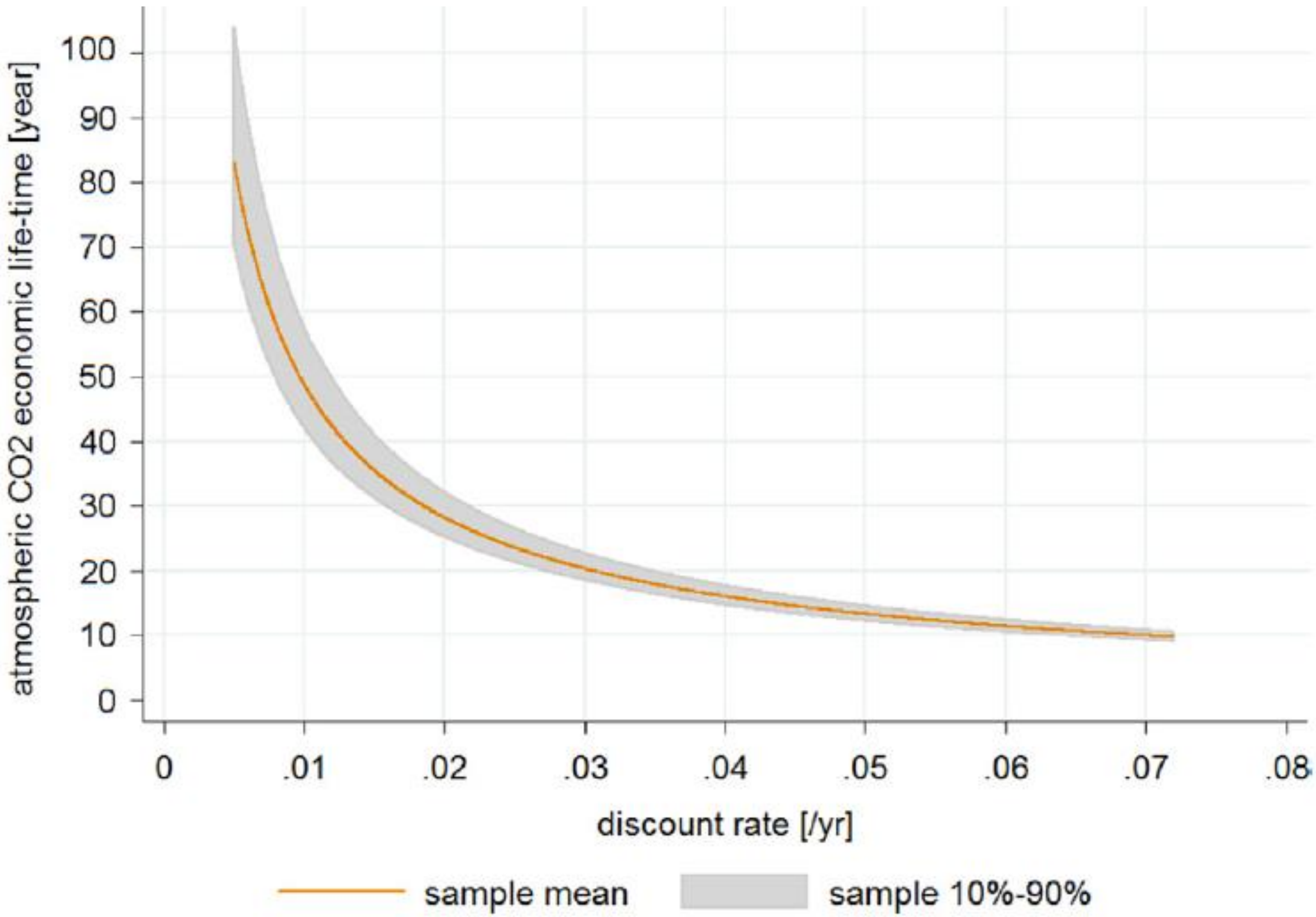
$$\frac{1}{d_s} » 50 - 100 yrs \qquad \frac{1}{d_s + s} » 25 - 33 yrs \, (s = 0.02)$$

$\frac{e}{e + s}$ = <u>Reduction in damages due to Earth’s heat inertia</u>

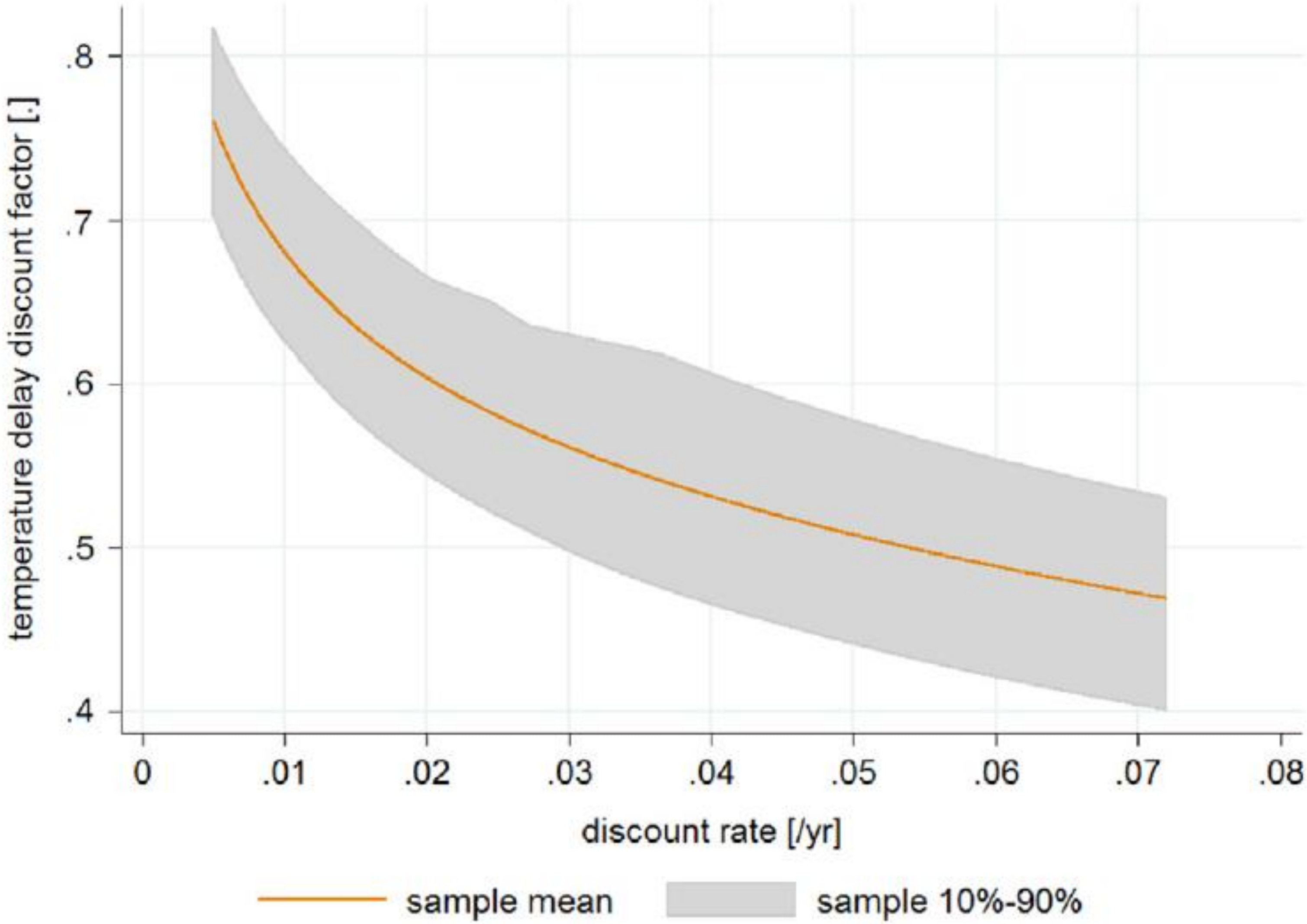
$$» 0.5 - 0.67 \; for \; s = 0.02$$

- van den Bijgaart et al. (2016) consider more sophisticated climate models based on Joos et al. (2013) and Caldeira and Myhrvold (2013)

Economic Lifetime of Atmospheric CO_2 as a Function of Climate Discount Rate



Discount Factor for Net Present Value of Damages Due to Delay in Temperature Adjustment



What Drives the SCC?

- Parameters that have the biggest impact are:
  - Equilibrium climate sensitivity ($\boldsymbol{c}$)
  - Parameters of the damage function ($\boldsymbol{\psi}$ and $\boldsymbol{\omega}$)
  - Climate discount rate ($\boldsymbol{\sigma}$)

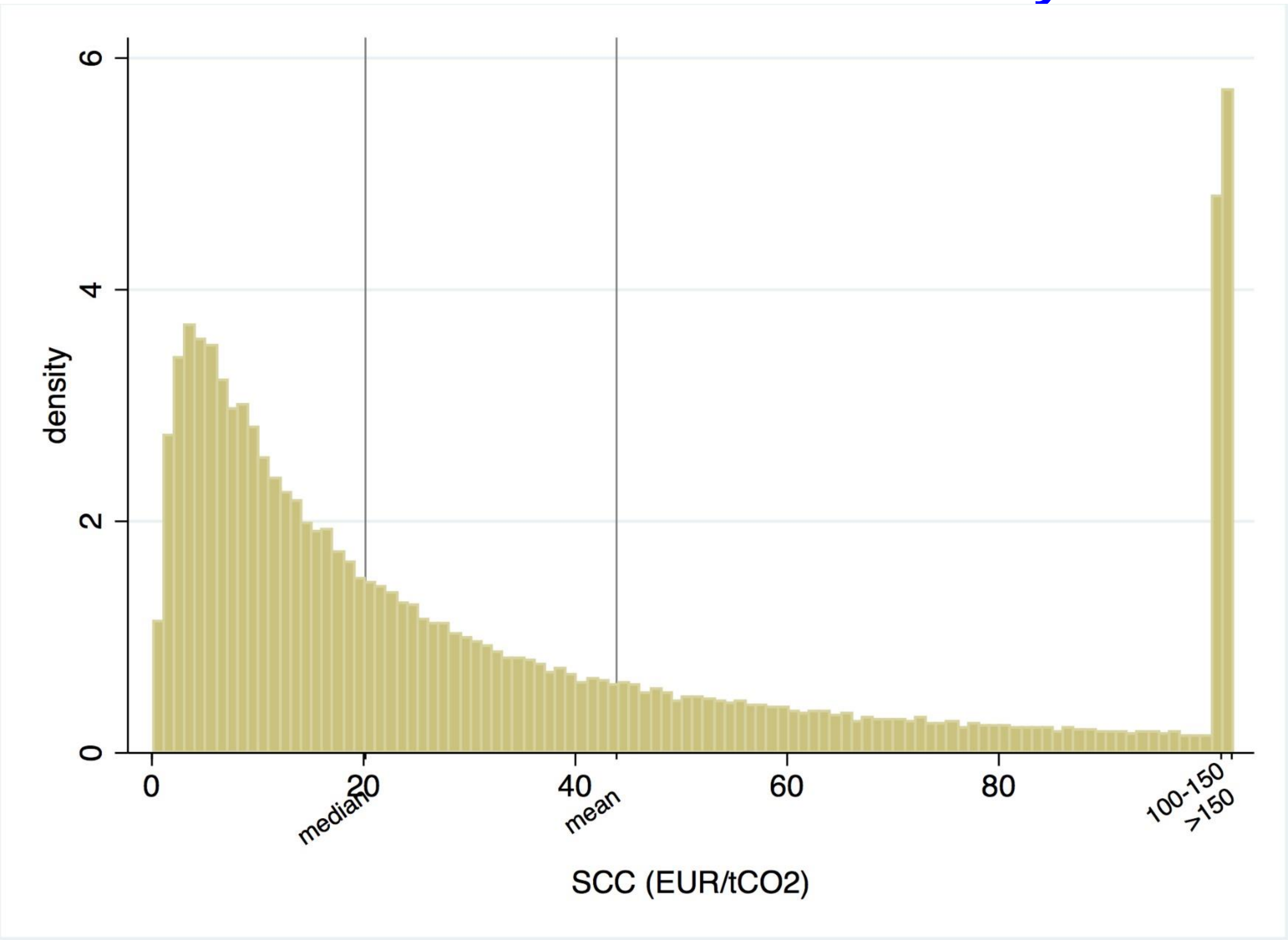
Suppose

- c = 3°C
- ψ = 2; ω = .027
- $\boldsymbol{\sigma}$ = .018 [ρ = .02; η = 1; l = 0.2%]
- SCC(2015) = 25€ (2010€) = $32 (2007$)

Consider Uncertainty in Key Parameters

- Three key parameters are all uncertain:
  - Equilibrium climate sensitivity ($\boldsymbol{c}$)
  - Parameters of the damage function ($\boldsymbol{\omega}$)
  - Climate discount rate ($\boldsymbol{\sigma}$)
- Allowing for log-normal distributions of each parameter will generate a skewed distribution of the SCC
- Setting ψ = 2 and using Y(2015) yields the distribution of SCC(2015) on the next slide
  - Based on 150,000 draws from the 3 lognormal distributions and draws from the models in Joos et al. (2013) and Caldeira and Myhrvold (2013)

Density Distribution of SCC Values Based on Monte Carlo Analysis



Impact of the Discount Rate

- Climate discount rate involves ethical parameters that we can adjust (ρ and η)
  - It differs from parameters of the climate system and damage functions, which are inherently uncertain
- What happens if we fix the discount rate?
  - Restrict uncertainty to the climate system and the damage function
- Next slide shows impact of fixing the discount rate and treating parameters of climate system and damages as uncertain

Discount Rate Sensitivity of the SCC

Climate Discount rate (%)	Median €/tCO2	Mean €/tCO2	Std.deviation €/tCO2
0.1	280	511	698
1	35.7	63.5	83.8
2	18.3	32.6	43.0
3	12.3	21.9	28.9

Note: Each row presents outcomes from the Monte Carlo experiment, where only the discount rate is fixed (Bijgaart, Gerlagh, and Liski 2016).

Conclusions and Caveats

What drives the SCC in simple IAMs are:

- Equilibrium climate sensitivity and speed with which temperature adjusts within the climate system
- How damages scale with output and temperature
- Climate discount rate

Understanding this helps to determine what to measure empirically to give the SCC good empirical grounding

But, simple IAMs ignore important types of damages—those that are sudden and/or irreversible (e.g., tipping points)

- And the impact of risk aversion on the SCC