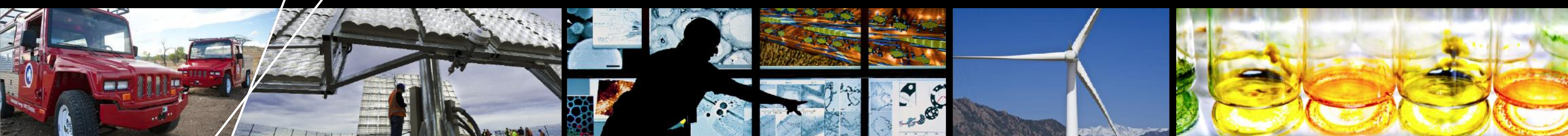
The Social Cost of Carbon and the Value of Wind



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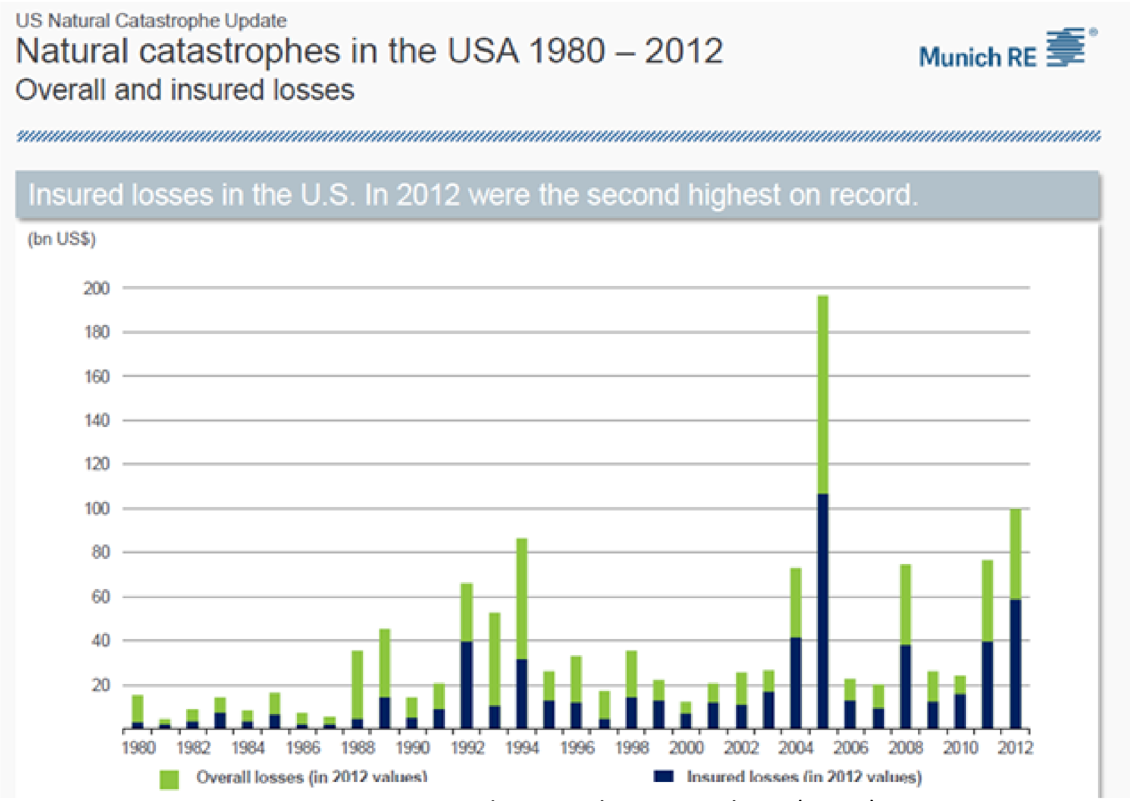
Overview

- Carbon emissions, climate change and the social cost of carbon (SCC)
- Recent estimates of the social cost of carbon by Interagency Working Group (IWG) (2010 and 2013)
- Types of uncertainty in the SCC – and its implications
    - Estimating future damage (limits of models, data, and knowledge about the future)
    - How to value future damages today (discount rates and discount factors)
- Use of scenario analysis with different SCCs
    - Value as difference in displaced fossil emissions (of system) x SCC (discounted)

Reducing carbon emissions may benefit society

- Mitigates impact of carbon dioxide emissions contributing to rising temperatures which may lead to e.g.,:
  - More frequent and extreme weather patterns such as: Heat waves, wildfires, floods, droughts
  - Rising water levels on coast line
  - Ocean acidification

Increasing number of natural catastrophes in last 40 years – though need to be careful (re: correlation vs. causation)



Source and copyright: Munich Re (2013)

Meaning of social cost of carbon and IAMs

- Integrated Assessment Models (IAMs) are being used to better link carbon emissions to their environmental and economic impact
- Recent Interagency Working Group (IWG) analysis used 3 IAMs – and equally weighted their results – to come up with recommendations for regulatory impact analysis (IWG (2010, 2013))

Socio-economic pathways (e.g., GDP, pop, CO_2e)
(5 pathways (550 to 889ppm CO_2e by 2100))

↓

Climate cycle model
(CO_2 => ΔT) (as a distribution)

↓

Damage functions
(ΔT => D/(GDP))

←

Perturb system by changing carbon emissions in given year t and estimate difference in discounted future* damages (D)
=> SCC

Repeat for different years

Source: IWG (2010, 2013). *Note: Relative to a baseline pathway. It varies by model but D are typically calculated on multi-century time horizons

Estimates of the social cost of carbon ($/metric ton) are highly uncertain

- May vary by:
  - Model used – even if future known (which it isn't)
  - Assumptions about future outcomes of the world/scenarios both related and unrelated to climate change (e.g., GDP, pop, CO_2 emissions)
  - Choice of discount rate in a given year
  - Interpretation of distribution: Whether or not using the "average" outcome understates the importance of rare but bad ('costly' or other) outcomes
  - Year of estimate – IWG recently revised estimates for all scenarios upwards significantly (e.g. SCC in 2020 at 3% discount rate increased from $26 to $43/ton in 2013 update)

  For these - and other reasons - estimating many of these factors is highly controversial
- For this reason IWG recommend the use of 4 cases
  - Expected value with 2.5%, 3% and 5% discount rate
  - Unlikely outcome (95th percentile) with 3% discount rate
- An alternative treatment for dealing with uncertainty in the discount rate that has been proposed is to use a declining discount rate (over time)

Note: SCC as used for these estimates refers to $ per metric ton of carbon dioxide (not carbon)

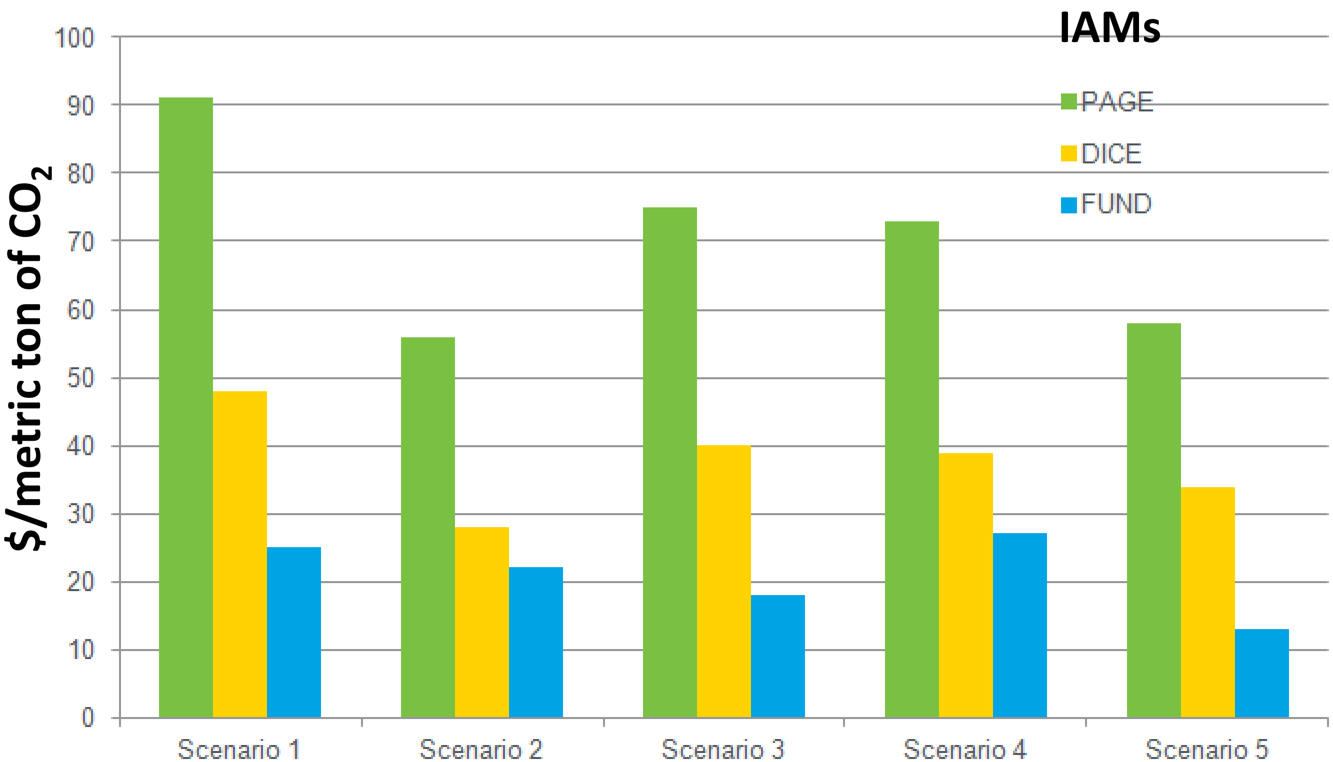
Sources of uncertainty: Models can lead to even greater variation than scenarios – which is worth reflecting on

Large differences in SCC depending on both model used and scenario chosen

- Different scenarios lead to different SCC
- However, the differences among the models for a given scenario are even greater (over 400% for some scenarios) – shown below for the 3% case

Overall range across all scenario for expected SCC in 2020: \$18 to \$91/metric ton

Average \$43/metric ton with standard deviation of \$23/metric ton)



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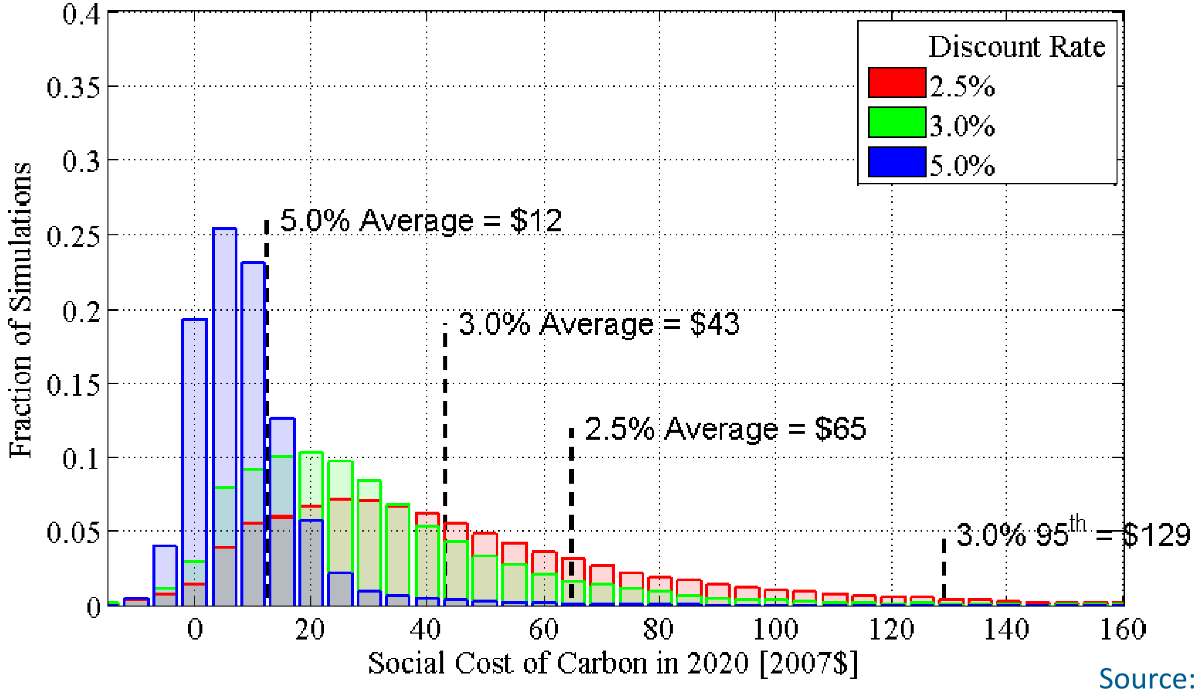
Source: Based on data from IWG (2013)

Note: PAGE, DICE and FUND are the IAMs used by IWG

IWG suggests the use of 4 discount rate related cases

- Expected social cost of carbon in 2020 varies widely based on discount rates
- Due to the shape of the SCC distribution, the expected (or average) value is significantly more costly than the 50:50 or most likely outcomes



Source: Figure from IWG (2013)

- Not clear "expected cost" fully reflects the impact of unlikely but plausible outcomes. The use of 95th percentile somewhat gets at this, though unclear how to mentally combine these cases. Note: Tail longer in low discount case

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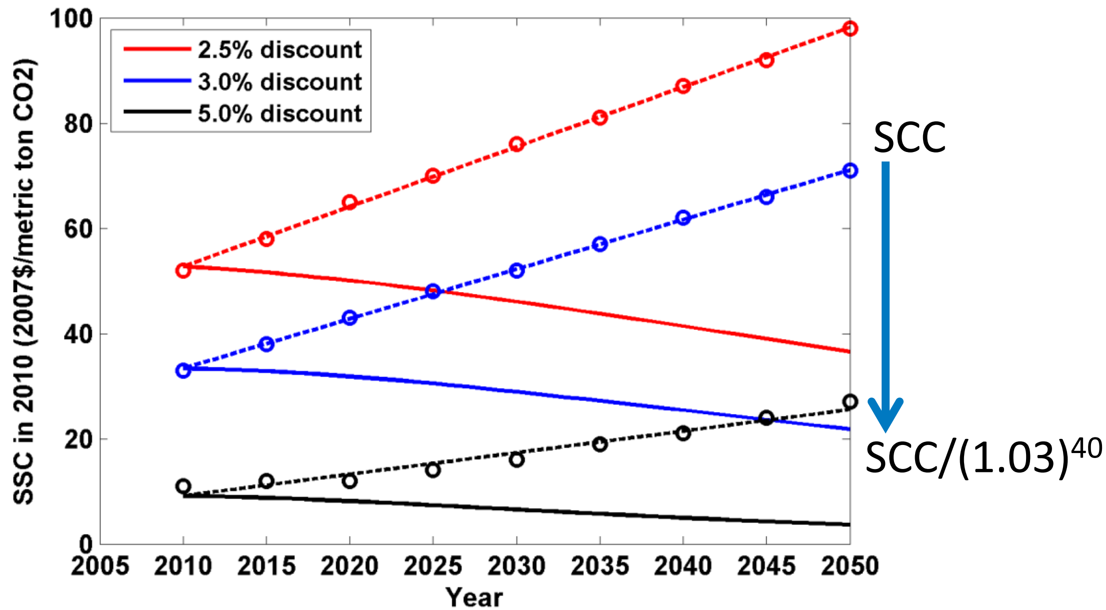
Increase in SCC over time more than offset by discounting

- Damages associated with the SCC increase over time as the incremental future damage associated with a metric ton of carbon dioxide also increases

- However this increase in SCC over time is more than offset – in all cases – by the impact of discounting the future

- Not surprisingly the net decline (on a percentage basis) in the present value of SCC increases with discount rate used



Source: Based on data from IWG (2013)

Discount rate (r) ⇨ $1/(1+r)^t$ Discount Factor

Note: Damage due to change in CO2 emitted in any given year – relative to a baseline pathway - are based on estimates (typically) for the next 200+ years* in IAM models (and discounted to that year). For each different year (t) - this estimate is estimated for 5 different pathways and 3 different models. *Approximate as end points of models differ.

Application of IWG methodology

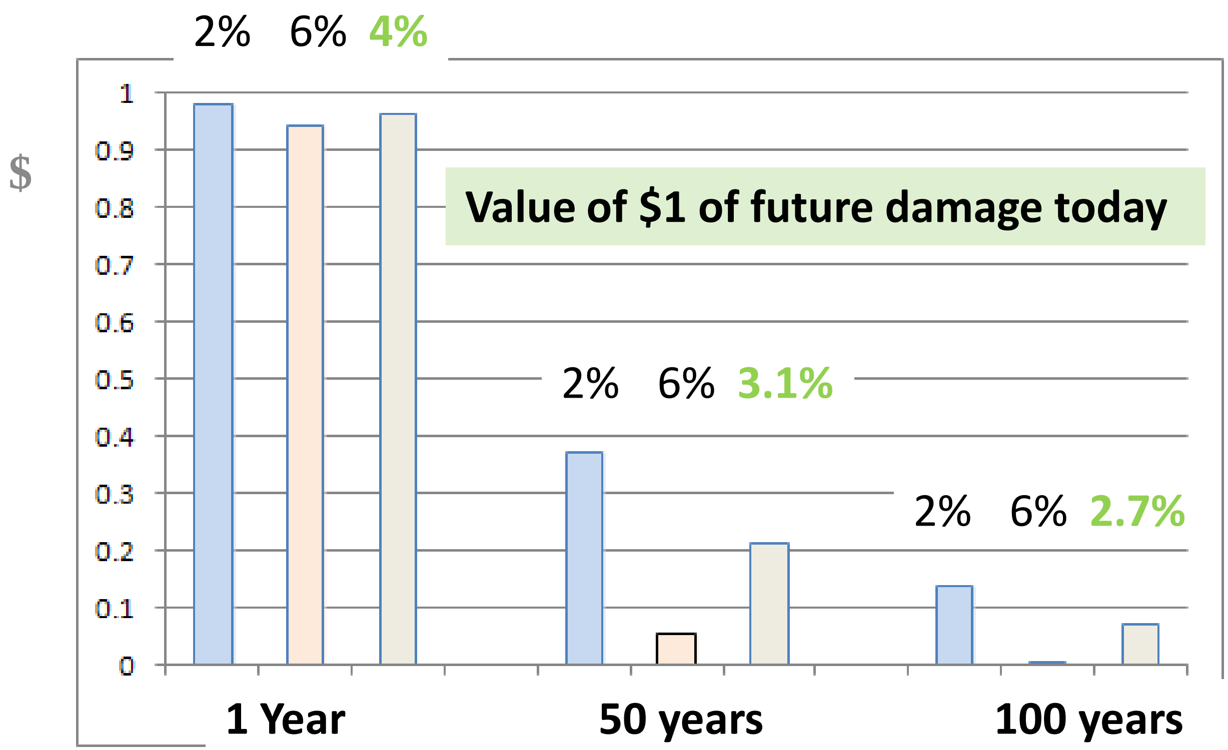
- Consider a “policy” or R&D program
- Estimate in any future year carbon emissions with and without policy
  - This is quite subtle and may include other effects (e.g. cost of energy changes) and may require system analysis to incorporate important effects associated with changes in dispatch and integration costs)
- For each scenario considered:
  - For each year
    - Multiply net metric tons of CO_2 emissions saved by SCC to get $ benefit
    - Discount all these “benefits” to current year
    - For example, the discounted value of SCC in 2050 today in the 3% case is $SCC/(1.03)^{37}$ = 0.34 x SCC (= 0.34 x $71/metric ton =$24/metric ton) (see figure on prior page)
  - and then sum for all years
- This provides and estimate of the carbon related “benefits” of policy or R&D associated with reduced carbon emissions
  - Provided emissions reduction is small enough that SCC estimate can be can be used
- SCC reflects inter-generational “damage” - unlike SOX/NOX or investment costs which is intra-generational
  - Raises question of how to incorporate SCC in traditional cost benefits analysis*

* A number of economists have raised concerns about the use of a different discount rate for different benefits – and suggest consideration of a declining discount rate (e.g. , Johnson and Hope (2012), Arrow et al 2013).

Uncertainty in social discount rate leads to declining discount factor

- Value of $1 of future damage today – with discount rate choice – and equivalent rate
- If 2% and 6% equally likely – we see effective “expected” discount rate declines out into the future towards the lower rate (from mid point 4% one year out to 2.7% 100 years out)

Discount rate (r) → $1/(1+r)^t$ Discount Factor



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Source: Figure closely follows approach discussed in Weitzman (2001) and Weitzman (2007)

Application of IWG methodology by EPA

Table 5-7. Pollution Damages ($/MWh) from Illustrative New Coal Unit *Relative to* New Natural Gas Combined Cycle Unit [44]

SCC Discount Rate	Damages from CO_2
5%	$3
3%	$11
2.5%	$18
3% (95th percentile)	$34

Mortality-Risk Study	Damages from SO_2 Only Discount Rate Applied to Health Co-Benefits 3% Discount Rate	7% Discount Rate
Pope (2002)	$6	$6
Laden (2006)	$16	$14

SCC Discount Rate	Combined Damages from CO_2 and SO_2 Discount Rate Applied to Health Co-Benefits 3% Discount Rate	7% Discount Rate
5%	$9 - $19	$9 - $17
3%	$17 - $27	$17 - $25
2.5%	$24 - $33	$24 - $32
3% (95th percentile)	$41 - $50	$40 - $48

Notes: Values in first two tables may not sum due to rounding.

In general cost benefit analysis of generation policy options needs to be done at the system level

Estimate system-wide difference in displaced carbon emissions in any given year – and discount appropriately

Source: EPA (2012): Note: These numbers are based on lower IWG 2010 SCC estimates.

A SCC of $43/metric ton in 2020 suggests a value of RE generation in place of natural gas CCGT at $15/MWh to $19/MWh (worth $12 to $15/MWh today) *

*Note: (1) Assumes 0.35 to 0.45ton/MWh. (2): Actual value and costs associated with RE would require system analysis (which would be location specific) including heat rates of generation under alternate scenario

Some key issues

- How to best represent uncertainty of (undiscounted) damages given
  - Differences in models and their ability to represent and estimate damage - including the effect of limited (and evolving) knowledge about the future
  - Difficulty to estimate certain impacts, such as tail events or “tipping points” – and implications for bias
- Choice of social discount rates, including potential use of declining discount rate
- Range of changes in carbon emissions over which SCC estimates are valid
- Primary vs. secondary impact

Reference and sources

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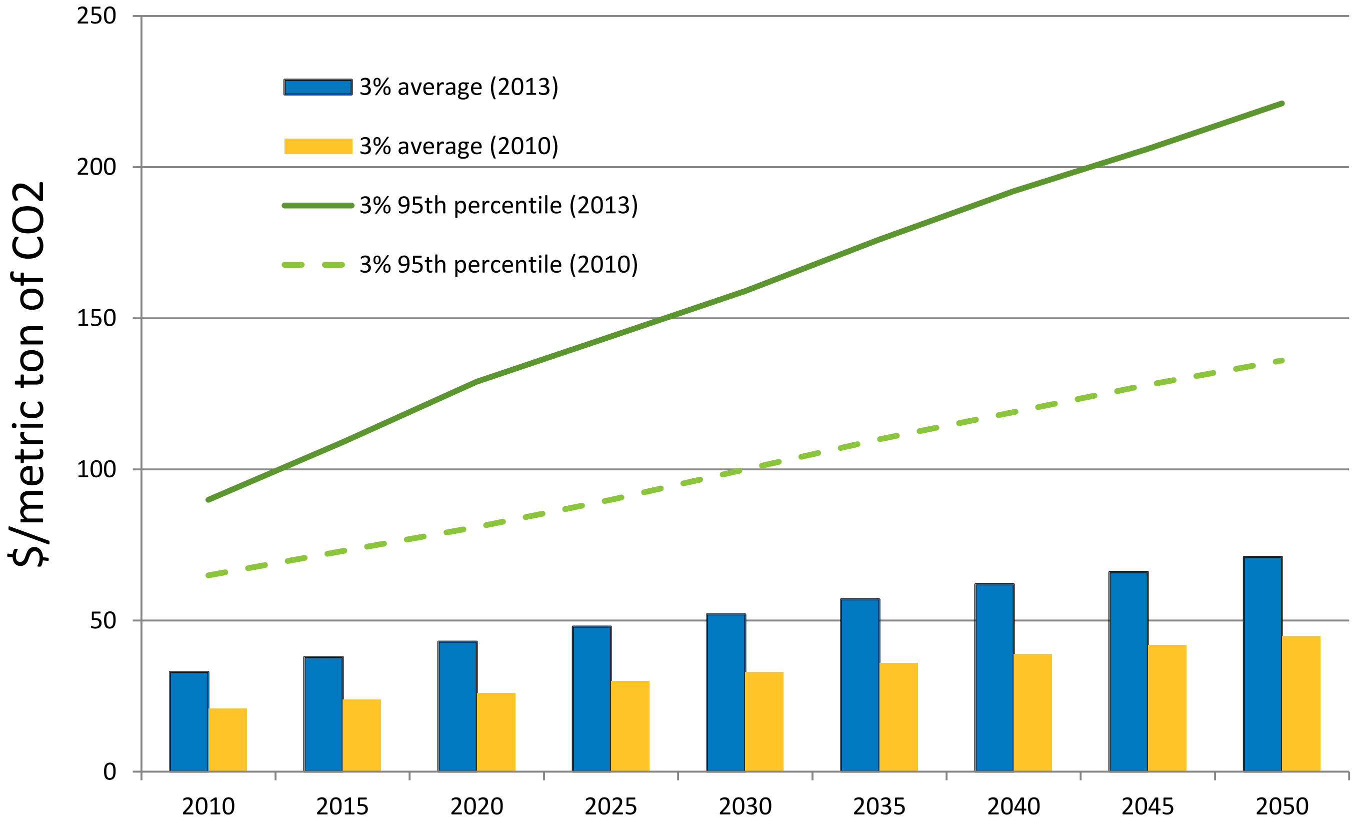
Appendix

Sources of uncertainty: “Improvements” in modeling approaches over time

Update of models and analysis by IWG in 2013 – including broader and better ability to capture impact – led to 50%+ increase in the SCC vs. 2010



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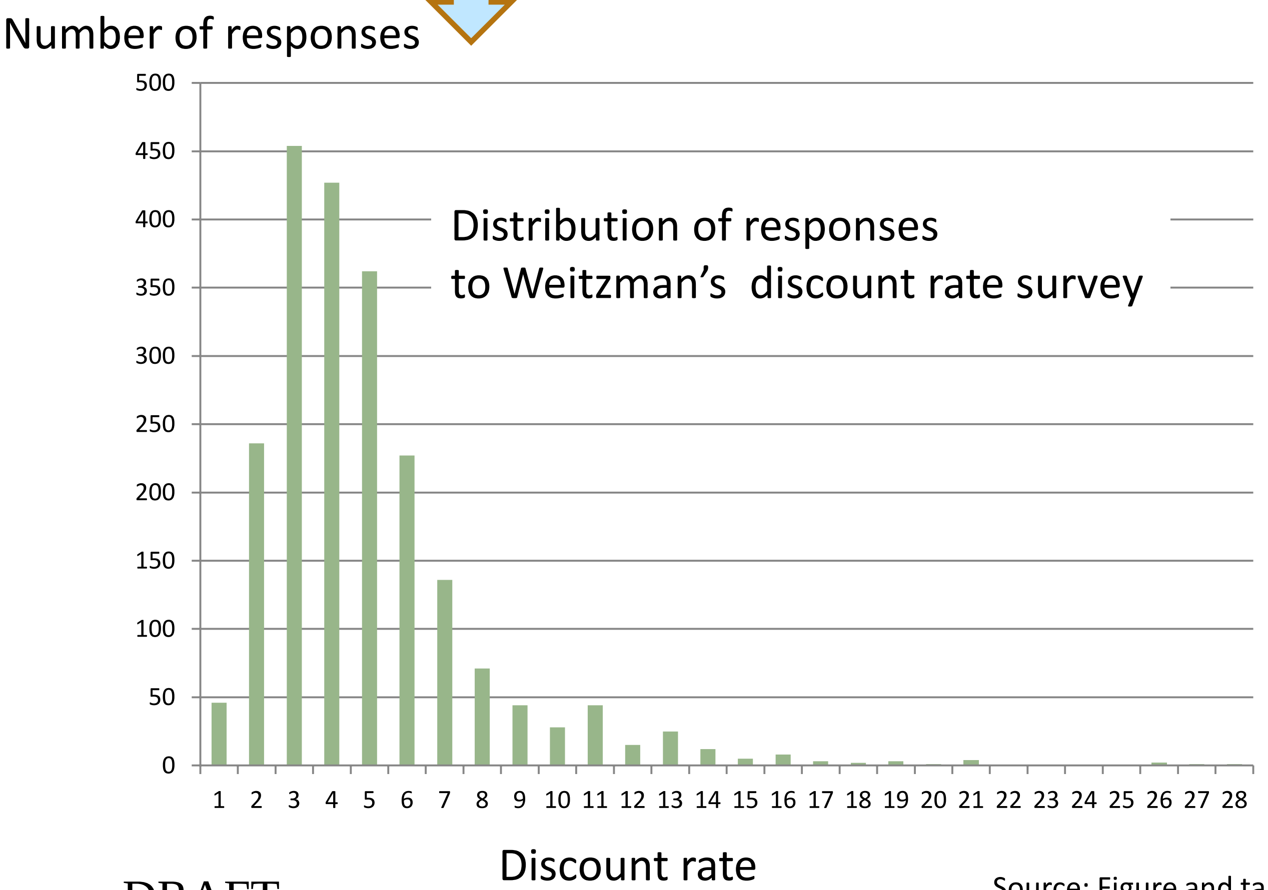
Source: Based on IWG data (2010, 2013)

Uncertainty in social discount rate leads to declining discount factor (Weitzman 2001)

Discount rate (r) → $1/(1+r)^t$ Discount Factor



Marginal discount rate

1 to 5 years	4%
6 to 25 years	3%
26 to 75 years	2%
76 to 300 years	1%
300 years+	0%

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Source: Figure and table come directly from data and analysis in Weitzman (2001). No original work or ideas added by presenter