Methodology for the U.S Government's Social Cost of Carbon Estimates

Presentation on Behalf of the Interagency Working Group on the Social Cost of Carbon
to
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Outline

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- Overview of USG SCC Development
  - Interagency working group (IWG) process
  - Integrated Assessment Models
  - IWG modeling decisions
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What is the Social Cost of Carbon?

- The SCC provides a measure of the marginal damages from CO_2 emissions – and thus the *marginal benefit of abatement*
  - The SCC is the theoretically consistent value to compare with the marginal cost of abatement in benefit cost analysis
- Specifically, the SCC is the monetized value of future worldwide economic damages associated with a one-ton increase in CO_2 emissions in a particular year discounted to that year
  - This is identical to the avoided damages associated with a one-ton decrease
- It is intended to be a comprehensive measure of climate change damages, including (but not limited to):
  - changes in net agricultural productivity
  - net energy demand
  - human health
  - property damages from increased flood risk
  - the value of ecosystem services

SCC Interagency Working Group

- In 2009, the Obama Administration launched an interagency process to promote consistency in the SCC values used by agencies
  - Prior to 2008 the impacts of changes in CO_2 emissions were not valued
  - From 2008 to 2009 the SCC estimates used varied substantially across agencies
  - In 2009 "interim" USG SCC estimates were issued based on literature review
  - The final USG SCC estimates were issued in 2010
  - The estimates were updated in May 2013 to incorporate the latest versions of the models used in the peer-reviewed literature.
    - Minor technical corrections have been issued twice – in November 2013 and July 2015
  - The updated estimates have been used in 40+ regulatory actions published in Federal Register to date
- Workgroup members
  - Leads: CEA and OMB
  - Active participants: CEQ, NEC, OECC, OSTP, DOC, DOE, DOT, EPA, DOT, Treasury, USDA

Overview of SCC Analytic Process

- Estimating the SCC involves 4 steps:
  1. Translating GDP, population into CO_2 emissions
  2. Translating CO_2 emissions into changes in mean global temperature
  3. Estimating the impact of temperature on the physical and economic environment
  4. Discounting climate damages, expressed as a percent of GDP

- IWG modeling decisions:
  - Used 3 "integrated assessment models" (IAMs) – DICE, PAGE, and FUND
  - Applied a common set of assumptions in each model for:
    - Trajectories of future population, economic growth, and GHG emissions
    - Equilibrium climate sensitivity – a measure of the climate system's response to increased concentrations of GHGs in the atmosphere
    - Discount rates
  - All other features of the IAMs were left unchanged

Integrated Assessment Models (IAMs)

- IAMs combine climate processes, economic growth, and feedbacks between the two in a single modeling framework
  - IAMs contain highly simplified representations of the potential damages from climate change and are limited by the current state of research
  - Despite their inherent uncertainties and limitations, they are the best tools currently available for estimating the SCC

- DICE, PAGE, and FUND are by far the most widely used and cited IAMs that can link physical impacts to economic damages for the purposes of estimating the SCC (NAS 2010, Tol 2008)
  - Other IAMs generally do not include damage functions (e.g., MIT's IGSM and PNNL's GCAM used primarily for cost-effectiveness analysis)

Overview of IAMs used in USG SCC

	DICE (2010)	PAGE (2009)	FUND (v3.8)
Regions	1	8	16
Damage Categories	2: sea level rise (SLR); aggregate non-SLR	4: SLR, economic, non-economic, "discontinuity"	11 market and non-market sectors
Damage specification: SLR Non-SLR	- quadratic function of global SLR - quadratic function of global temperature	- power function of global SLR - power function of regional temperature	- based on internal model of optimal coastal adaptation - sector specific
Model treatment of uncertainty	Deterministic	Most parameters probabilistic	Most parameters probabilistic
Adaptation	Implicitly included in choice of some underlying studies	Generally included in specification of "tolerable" temp change	Explicitly included for some sectors
"Catastrophes"	Yes	Yes	No
GDP endogenous	Yes	No	Yes

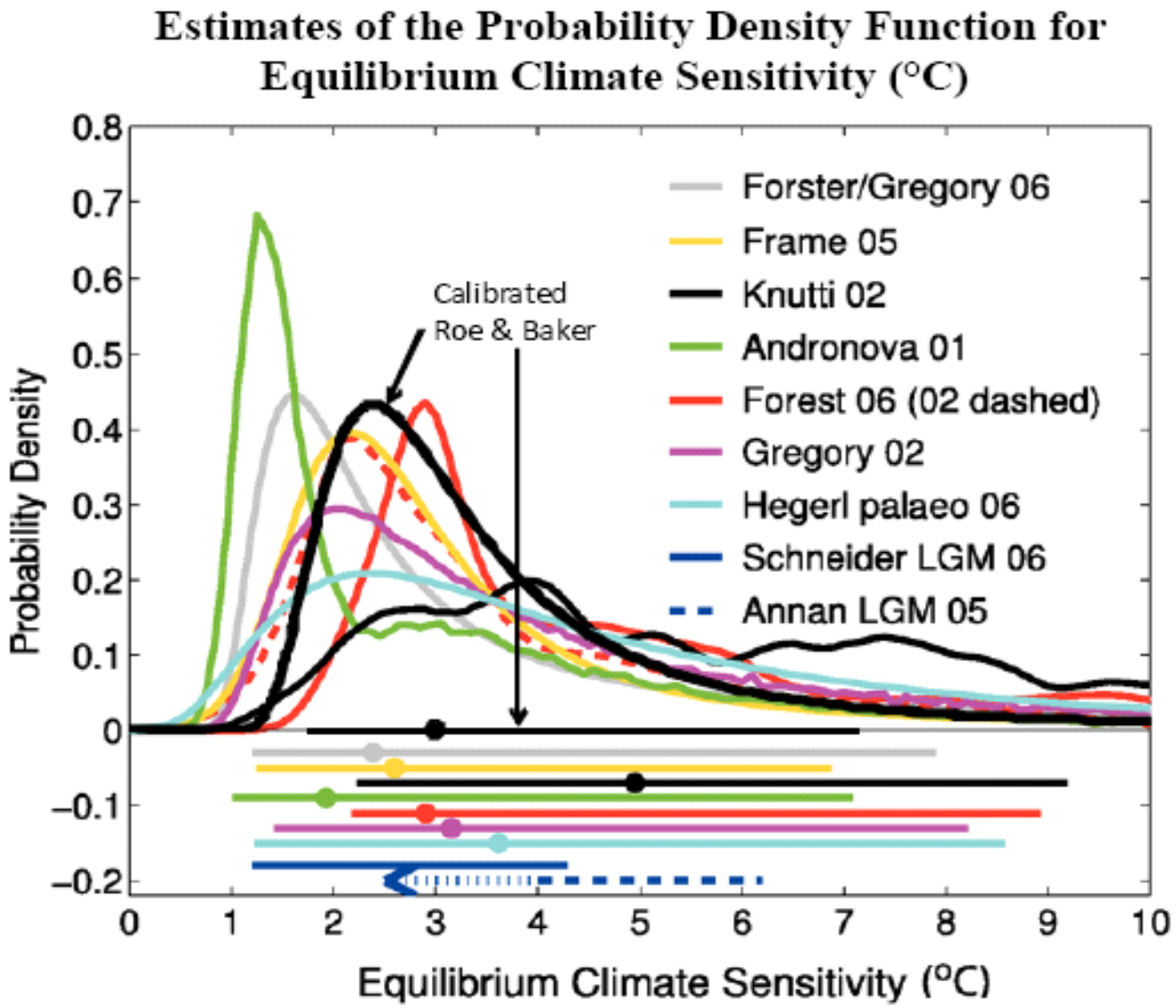
IWG Modeling Assumptions:
Socioeconomic & Emissions Trajectories

- Relied on Stanford Energy Modeling Forum Exercise 22 (EMF-22)
  - Uses well-recognized models that are peer-reviewed and published.
  - GDP, population, and emission trajectories are internally consistent.
  - Preferable to the IPCC SRES (developed in 1997) due to their age.
- Selected five reference trajectories:
  - 4 business-as-usual (BAU) paths that correspond to 2100 CO2 concentrations of 612 – 889 ppm, reflecting differences in assumptions about cost of low carbon energy sources
  - 1 lower-than-BAU path that achieves stabilization at 550 ppm CO2e in 2100, consistent with substantial action by countries to mitigate GHG emissions or what is potentially achievable when optimistic assumptions about technological advances are used in some models

IWG Modeling Assumptions:
Equilibrium Climate Sensitivity (ECS)

- ECS is the long term increase in annual global average surface temperature from a sustained doubling of atmospheric CO_2 concentration relative to pre-industrial levels
- IWG calibrated a probability distribution for ECS to fit the IPCC AR4 consensus statements
  - Likely (66% chance) to be in the range 2°C to 4.5°C
  - Most likely value is 3°C
  - Very likely (90% chance) to be larger than 1.5°C
  - Values substantially higher than 4.5°C cannot be excluded
- The Roe and Baker (2007) distribution was selected (out of 4 distributions considered):
  - Based on a theoretical understanding of climate system response to increased GHG concentrations
  - Most consistent with IPCC judgments regarding climate sensitivity in the tails of the distribution

Calibrated Roe and Baker Distribution for ECS



IWG Modeling Assumptions:
Discount Rate

- Federal regulatory analyses typically employ constant discount rates of both 3% and 7% for intra-generational impacts per OMB Circular A-4 guidance

- In light of disagreement in the literature on what to use in inter-generational context, the interagency group used 3 constant discount rates to span a plausible range
  - 2.5%: incorporates concern that interest rates are highly uncertain over time
  - 3% : consistent with economics literature and OMB Circular A-4 guidance for the consumption rate of interest
  - 5%: represents the possibility climate damages are positively correlated with market returns

For Each Model, the Steps for Calculating the SCC are:

1. Input the path of emissions, GDP, population and calculate the resulting path of temperature effects and per capita consumption in each year.

2. Add an additional unit of carbon emissions in year *t* and recalculate the paths of temperature and per capita consumption in all years beyond *t* resulting from this adjusted path of emissions.

3. Compute the marginal damages in each year as the difference between the per capita consumption computed in step 1 from those in step 2.

4. Discount the resulting path of marginal damages back to the year of emissions using the agreed upon fixed discount rates and calculate the SCC as the net present value of the discounted path of marginal damages.

Putting It All Together

- The model runs produced 45 separate SCC distributions (10,000 observations per distribution) for a given emissions year

(3 models) x (5 socioeconomic scenarios) x (1 ECS distribution) x (3 discount rates)

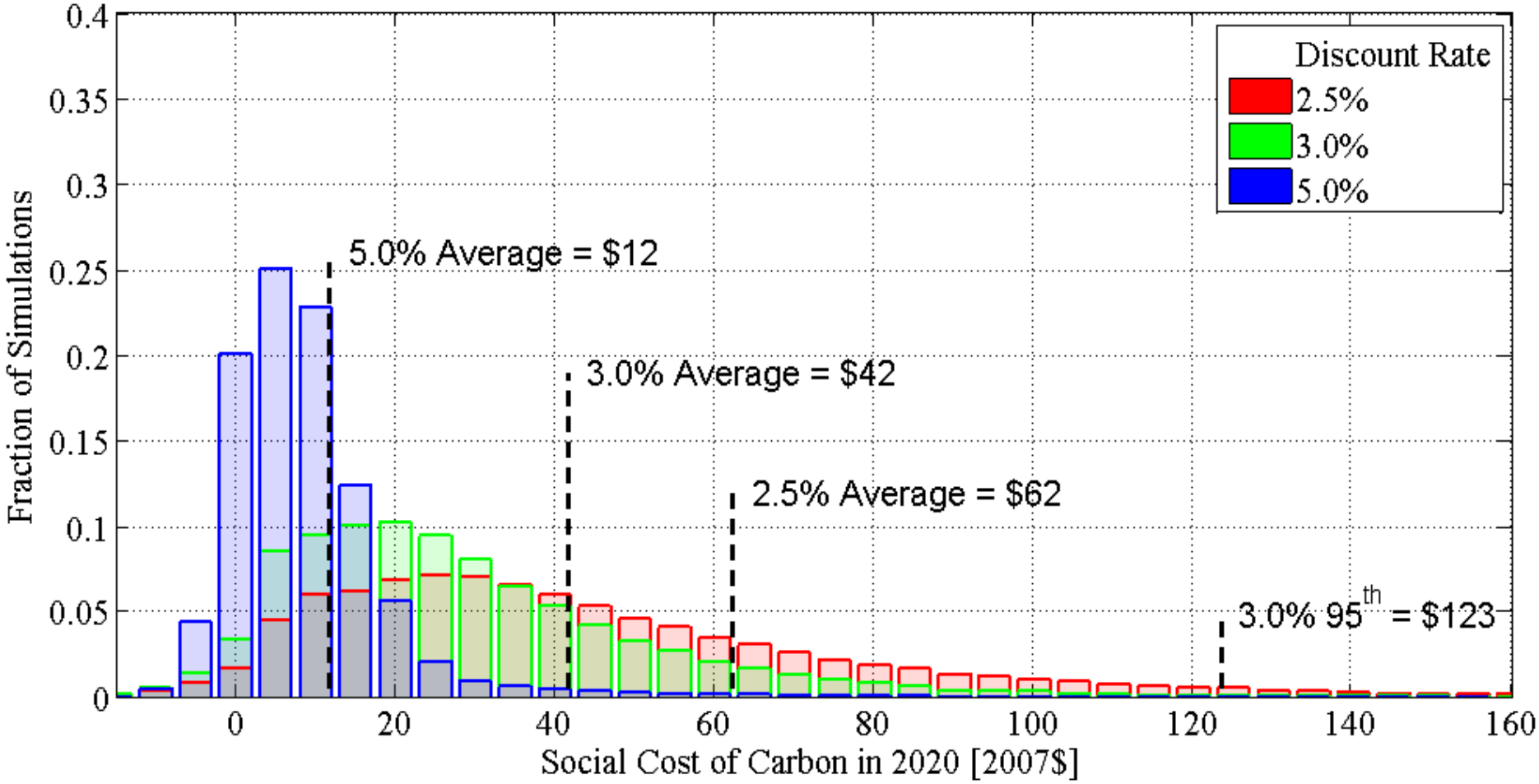
  - In FUND and PAGE uncertain parameters beyond ECS were allowed to vary based on models' default distributions

- The distributions from each model and scenario were equally weighted and combined to produce three separate probability distributions for SCC in a given emissions year, one for each of the three discount rates

- From the 3 distributions, the interagency group selected 4 values:
  - The average SCC at each discount rate: 2.5%, 3%, and 5%
  - The 95th percentile at a 3% discount rate, representing higher than expected economic impacts further out in the tails of the distribution

Distribution of USG SCC Estimates for 2020

- For 2020, the SCC values are: $12, $42, $62, & $123 (2007$/metric ton CO_2)*



* Includes July 2015 technical correction.

USG SCC Estimates, 2010-2050

- The values increase over time, as determined within each model, because future emissions are expected to produce larger incremental damages as the economy grows and physical and economic systems become more stressed in response to greater climatic change

USG SCC (2007$/metric ton CO_2)*, based on year of emission reductions

Discount Rate	5.0%	3.0%	2.5%	3.0%
Year	Mean	Mean	Mean	95th
2010	10	31	50	86
2015	11	36	56	105
2020	12	42	62	123
2025	14	46	68	138
2030	16	50	73	152
2035	18	55	78	168
2040	21	60	84	183
2045	23	64	89	197
2050	26	69	95	212

* Includes July 2015 technical correction. .

Limitations of the Analysis

- Any SCC estimate must be taken as provisional and subject to further refinement in accordance with evolving scientific, economic, and ethical understandings

- Estimates remain conservative in number of respects, e.g.,
  - SCC estimates do not include some damages categories (e.g. ocean acidification)
  - Many categories of direct impacts in the models remain incomplete and rely on science that lags behind the most recent research (e.g., agriculture)
  - A number of potentially significant damage categories remain exceedingly difficult to monetize (e.g., biodiversity loss)
  - Damages from most large scale earth system feedback effects (e.g., Arctic sea ice loss, melting permafrost, large scale forest dieback, changing ocean circulation patterns) are not included in one model, and imperfectly captured in others
  - The SCC is a partial equilibrium measure of mitigation benefits

- Also limited in representation of some complexities, e.g.,
  - extrapolation of damages to high temperatures, treatment of adaptation, technological change, and inter-sectoral and inter-regional interactions

Characterization of Uncertainty in Modeling

- Inputs harmonized across models:
  - ECS uncertainty is represented by a probability distribution and is common to all models
    - Probabilistic treatment of ECS directly affects all damages through the change in temperature (and through the rate of change in temperature in FUND)
  - Socio-economic and emissions inputs are represented by 5 scenarios, each given equal weight in the aggregated distribution
    - No formal modeling of uncertainty in GDP, population and emissions
  - Influence of discount rate is examined through sensitivity analysis using a range of constant rates
    - No formal modeling of uncertainty in components of the discount rate

Characterization of Uncertainty in Modeling

- Physical science components and damage functions:
  - Ensemble of three models cover a range of potential outcomes as expressed in the literature
    - E.g., the three models collectively span a range of carbon cycle and climate change responsiveness that reflects the uncertainty in the literature.
  - Probability distributions specified for over 100 parameters in PAGE and FUND; many related to damage functions can be regionally specified

Presentation of Uncertainty

- Final range includes 4 values:
  - First three show influence of discount rate assumption (5%, 3%, and 2.5%)
  - 4th value (the 95% value of the 3% discount rate scenario) in part captures uncertainty in tails of the distribution
- Technical Support Document (TSD) presents:
  - Full distribution of SCC estimates: 1st-99th percentiles of the 2020 SCC estimates from each model-scenario-discount rate combination
  - Additional summary statistics for 2020 estimates by model and discount rate (mean, variance, skewness, kurtosis)
- Regulatory analyses include:
  - Use of all four estimates, discussion of limitations of the SCC analysis and sources of uncertainty based on TSD

References

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