PROGRESS TOWARD A SOCIAL COST OF CARBON

Michael Greenstone

3M Professor of Environmental Economics

Massachusetts Institute of Technology

Improving the Assessment and Valuation of Climate Change Impacts for Policy and Regulatory Analysis

November 18, 2010

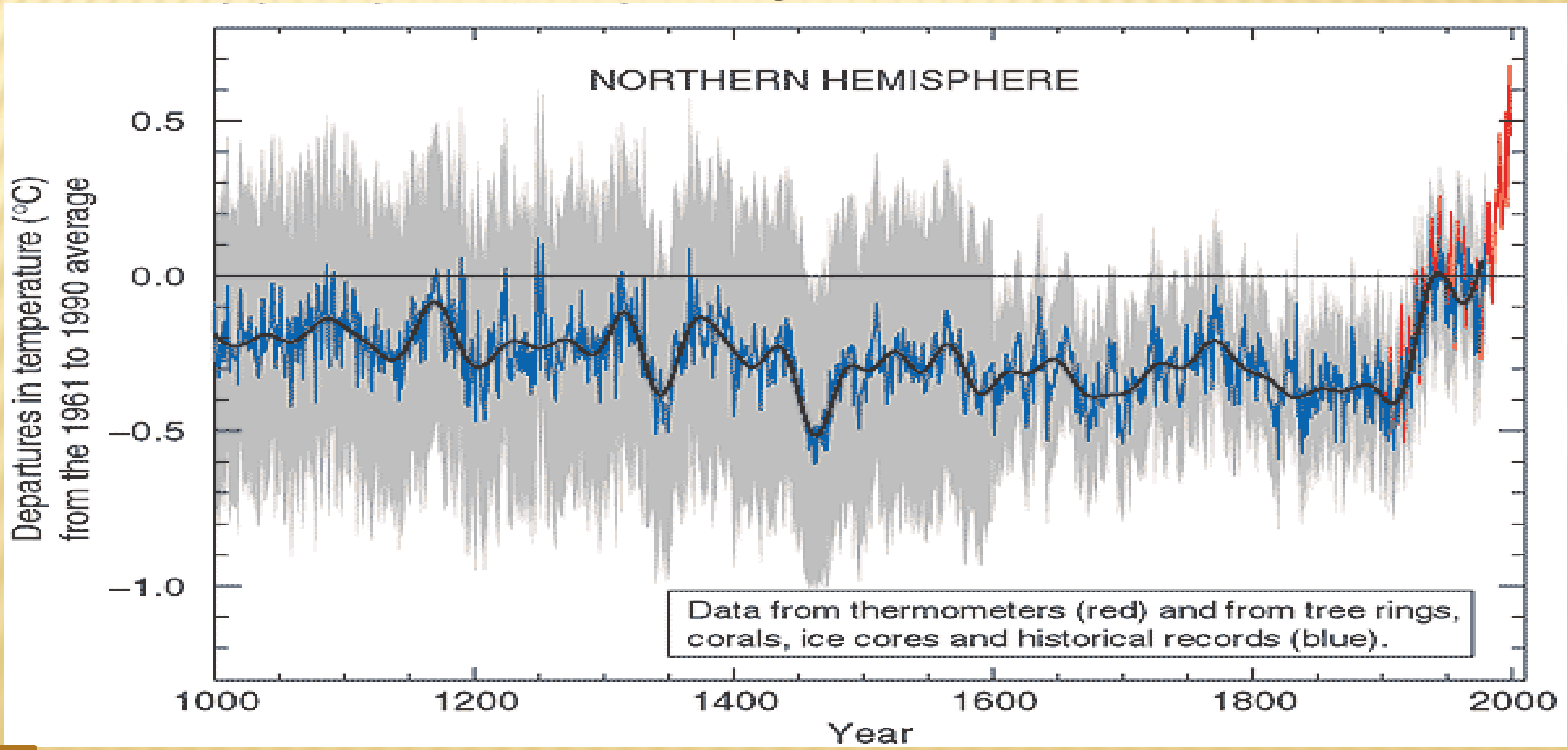
OUTLINE

I. Background & Motivation
II. Social Cost Of Carbon (SCC)
III. How is the SCC Calculated?
IV. Lifetime Damages of a Ton of CO_2 Emissions
V. Results
VI. Limitations
VII. Conclusions

I. BACKGROUND & MOTIVATION

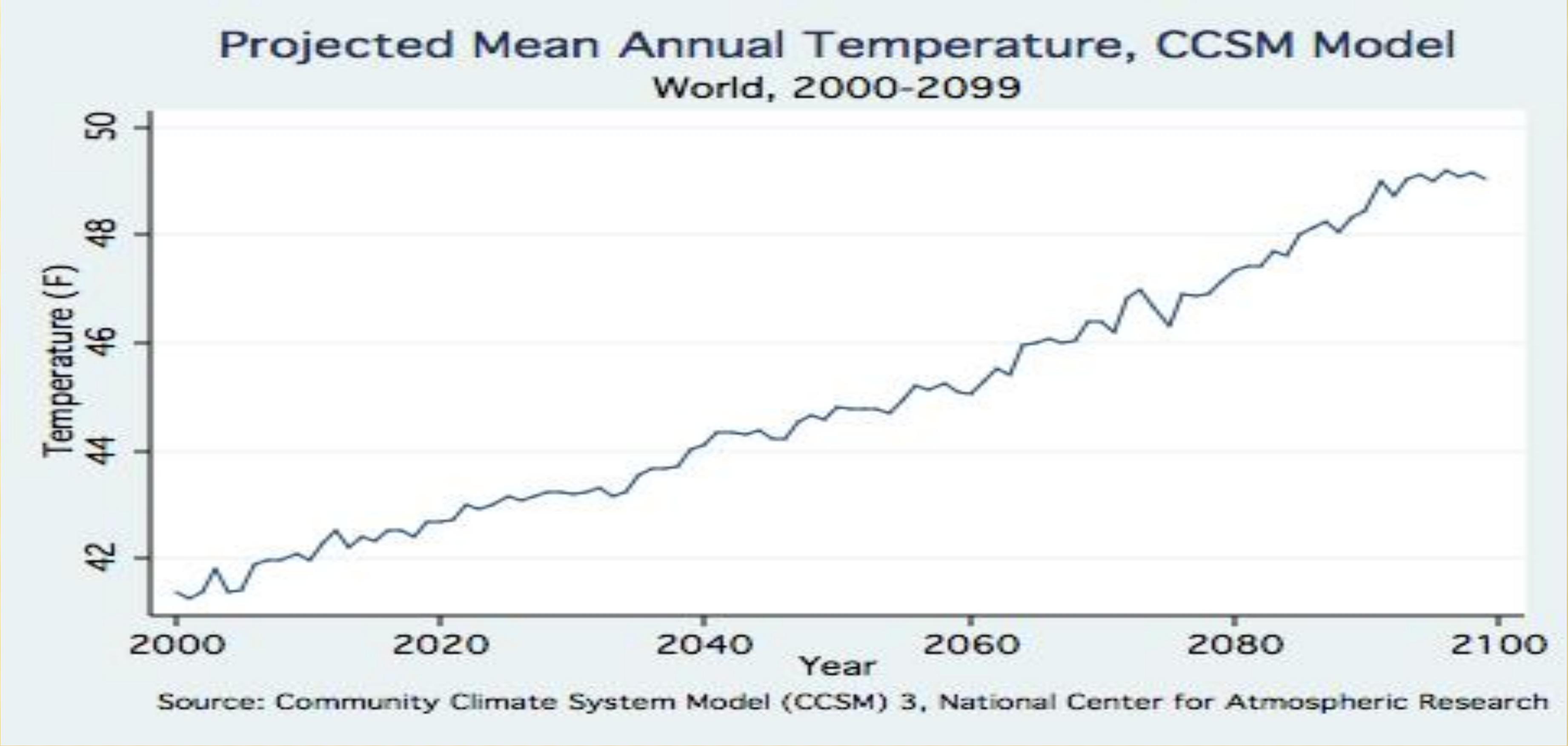
RISING TEMPERATURES

- Human-induced CO_2 emissions will likely cause temperature increases
- May have already begun

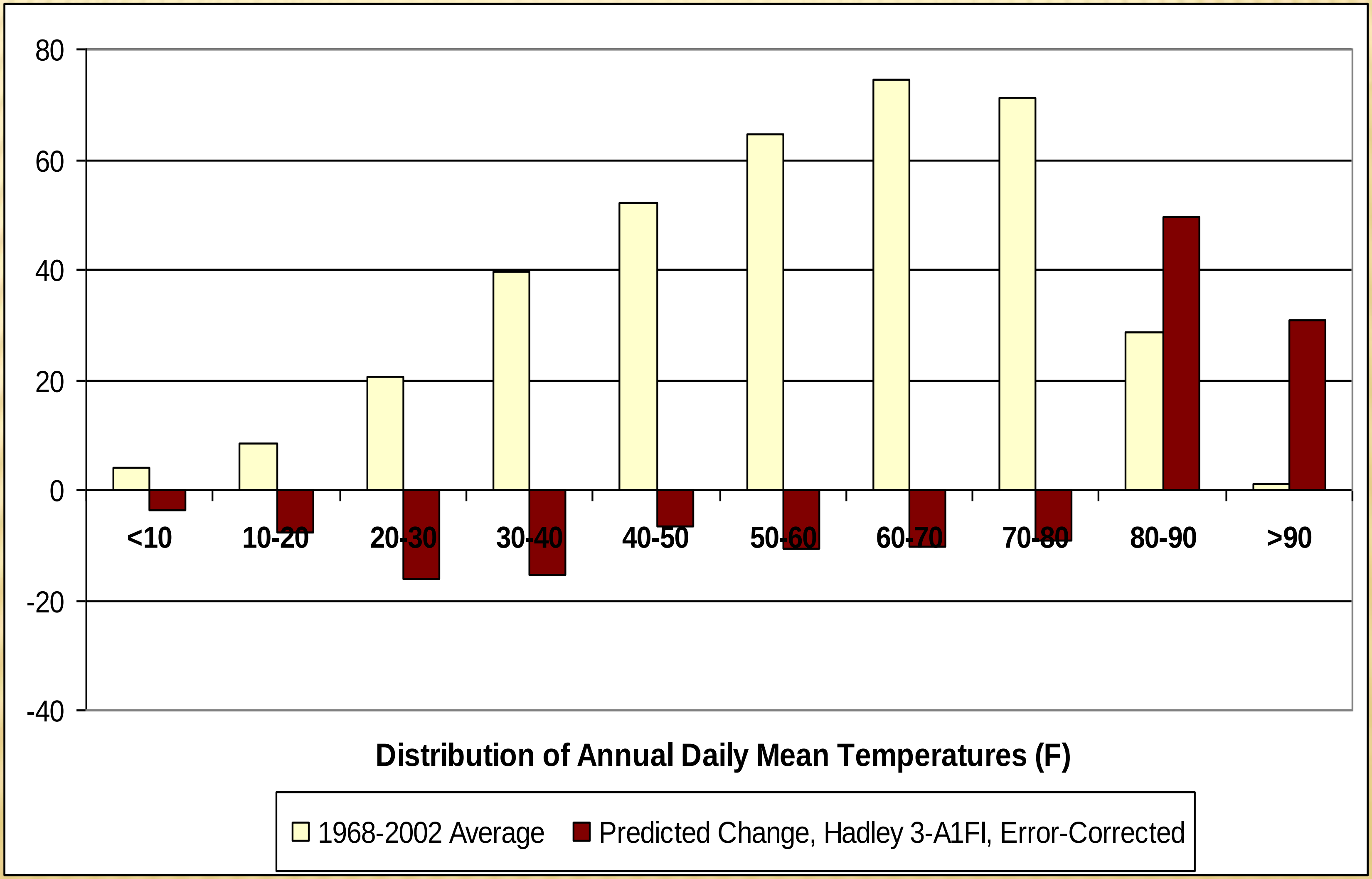


RISING TEMPERATURES

- Global temperatures projected to increase by 18% between 2000 and 2100



CURRENT AND PREDICTED CHANGE IN DISTRIBUTION OF TEMPERATURE FOR 2070-2099, UNITED STATES



U.S. LEGISLATION LANDSCAPE

- House passed Waxman-Markey cap-and-trade bill
- Senate declined to pursue legislation
- Best case in next several years:
  - Renewable electricity standards
  - More subsidies for nuclear power

CLEAN AIR ACT

- EPA has finalized a "tailoring" rule for Greenhouse Gases (GHG) under the Clean Air Act to take effect in January 2011
  - Set Rules that Govern Behavior of 900 Largest Sources
  - Statute Requires Use of "Best Available Control Technology"
  - Likely to Be Numerous Court Cases

CLEAN AIR ACT

- Likely Impact of Clean Air Act Regulations
  - Reduce GHG Emissions by 5-12% in 2020, relative to 2005. President Promised 17% in Copenhagen

CLEAN AIR ACT

- Will these Regulations have Net Benefits?
  - A regulatory impact analysis (RIA) will be required and informs the public of the relative costs and benefits of this mandate
  - Analyses will use the “social cost of carbon” to monetize the benefits stemming from CO_2 reduction

II. SOCIAL COST OF CARBON

A. DEFINITION

- SCC: monetized damages associated with an incremental increase in carbon emissions in a given year

- It includes but is not limited to changes in:
  - Net agricultural productivity
  - Human health
  - Property damages from increased flood risk
  - The value of ecosystem services

B. SCC IN ACTION

- Up-front Technology Costs and Social Benefits of EPA/DOT GHG Emissions Standards for Light-Duty Trucks 2010-2050 (NPV 3% Discount Rate and 2007 Dollars)

	2007 $s	
Social Benefits	$277.5	
Costs	-$345.9	
Net Benefits, without SCC	-$68.4	
Social Benefits of CO2 Reductions (Central Value)		
Total Net Benefits		

B. SCC IN ACTION

- Up-front Technology Costs and Social Benefits of EPA/DOT GHG Emissions Standards for Light-Duty Trucks 2010-2050 (NPV 3% Discount Rate and 2007 Dollars)

	2007 $s	
Social Benefits	$277.5	
Costs	-$345.9	
Net Benefits, without SCC	-$68.4	
Social Benefits of CO2 Reductions (Central Value)	$176.7	
Total Net Benefits	$108.3	

III. HOW IS THE SOCIAL COST OF CARBON CALCULATED?

ESTIMATING SCC

- A USG interagency working group developed a transparent and economically rigorous way to estimate SCC

- Now will Summarize Some of the Key Decisions and Results. (USG Plans to Revisit as Science Advances)

III. HOW IS SOCIAL COST OF CARBON CALCULATED

A. INTEGRATED ASSESSMENT MODELS

A. INTEGRATED ASSESSMENT MODELS (IAMS)

- IAMs combine Climate Processes, Economic Growth, and Feedbacks between the Climate and the Global Economy into a single model

- Specifically, IAM translate changes in CO_2 emissions into economic damages

  1. Emissions
  [assumptions about GDP and population growth]

  2. Emissions → Atmospheric GHG Concentrations
  [based on carbon cycle]

  3. GHG Concentrations → Changes in Temperature
  [assumptions about climate model and climate sensitivity]

  4. Temperature → Economic Damages (market and non-market)
  [assumptions about damage functions]

A. INTEGRATED ASSESSMENT MODELS (IAMS)

- Benefit of these Models is that they Answer Everything

A. INTEGRATED ASSESSMENT MODELS (IAMS)

- Benefit of these Models is that they Answer Everything
- Cost of Models is that they Answer Everything

A. INTEGRATED ASSESSMENT MODELS (IAMS)

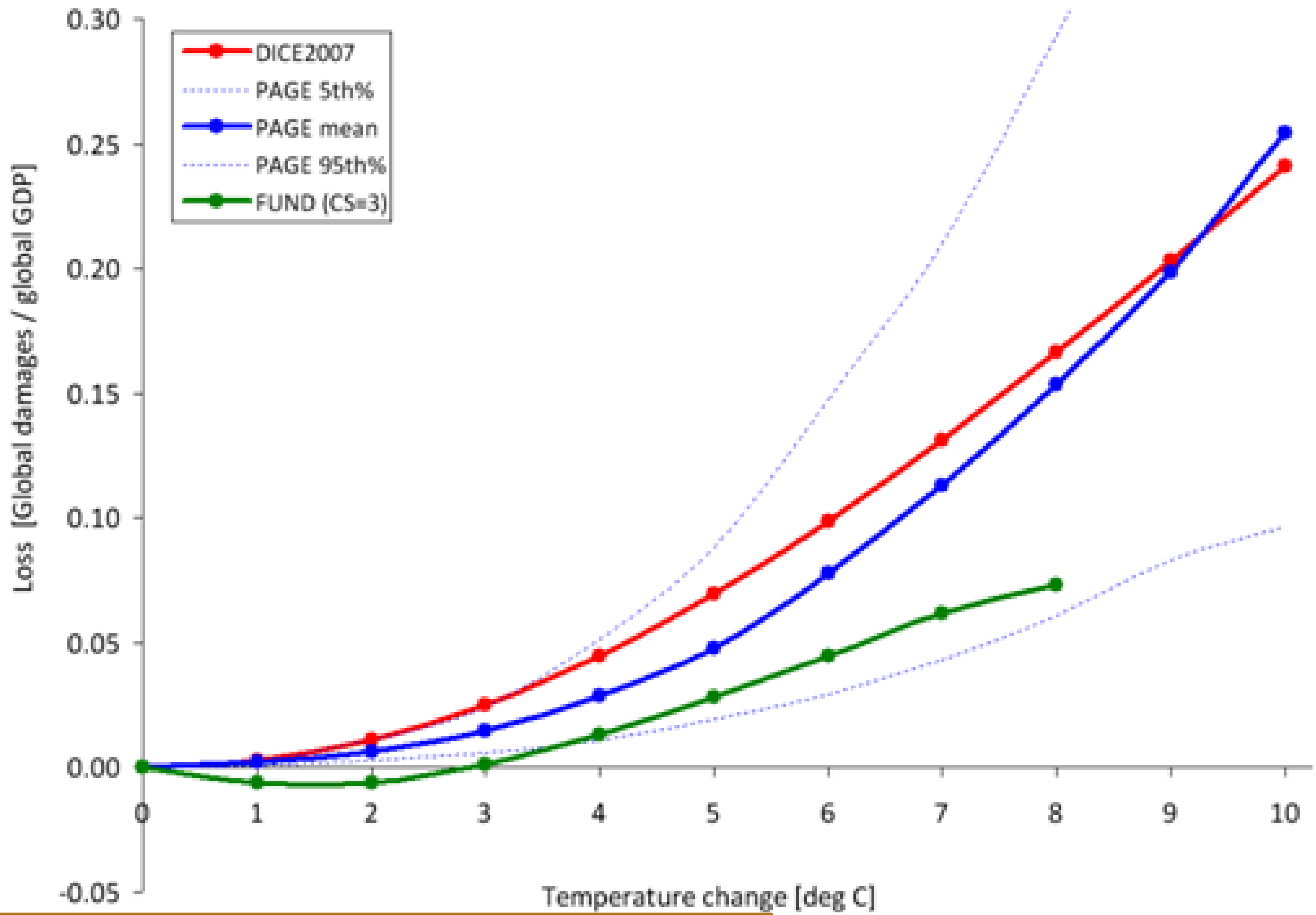
- Benefit of these Models is that they Answer Everything
- Cost of Models is that they Answer Everything
- Highly Dependent on Validity of Assumptions

A. INTEGRATED ASSESSMENT MODELS (IAMS)

- Relied on three commonly used IAM's to estimate SCC:
  - FUND (Richard Tol)
  - DICE (William Nordhaus)
  - PAGE (Chris Page)
- All 3 are frequently cited in the peer-reviewed literature and used in the IPCC assessment
- Each model is given equal weight to determine the SCC values

DAMAGE FUNCTIONS

Figure 1: Annual Consumption Loss as a Fraction of Global GDP in 2100 Due to an Increase in Annual Global Temperature in the DICE, FUND, and PAGE models



III. HOW IS THE SOCIAL COST OF CARBON CALCULATED?

B. ASSUMPTIONS

1. SOCIO-ECONOMIC & EMISSIONS TRAJECTORIES

- Socio-economic pathways are closely tied to climate damages
  - More and wealthier people tend to emit more GHG
  - Higher WTP to avoid climate disruptions
- For this reason, decisions necessary for several input parameters from present until 2100:
  - Global GDP
  - Global Population
  - Global CO_2 emissions

1. SOCIO-ECONOMIC & EMISSIONS TRAJECTORIES

- Relied on the Stanford Energy Modeling Forum exercise, EMF-22
  - Based on 4 of 10 models
  - Key advantage:
    - GDP, population and emission trajectories are internally consistent
  - Five trajectories selected:
    - 4 business-as-usual (BAU) paths
      - Correspond to 2100 concentrations of 612 – 889 ppm, reflecting differences in assumptions about cost of low carbon energy sources
    - 1 lower-than-BAU path
      - Achieves stabilization at 550 ppm in 2100

2. EQUILIBRIUM CLIMATE SENSITIVITY

- Equilibrium climate sensitivity (ECS): long-term increase in the annual global-average surface temperature due to a doubling of atmospheric CO_2 concentration relative to pre-industrial levels
  - Equivalent to the atmospheric CO_2 concentration stabilizing at about 550 parts per million (ppm)

2. EQUILIBRIUM CLIMATE SENSITIVITY

- According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC):

  *We conclude that the global mean equilibrium warming for doubling CO_2 ... is **likely to lie in the range 2°C to 4.5°C**, with a **most likely value of about 3 °C**. Equilibrium climate sensitivity is **very likely larger than 1.5 °C**.... For fundamental physical reasons as well as data limitations, **values substantially higher than 4.5 °C still cannot be excluded, but agreement with observations and proxy data is generally worse for those high values** than for values in the 2 °C to 4.5 °C range.*

2. EQUILIBRIUM CLIMATE SENSITIVITY

- Selected four candidate probability distributions and calibrated them to the IPCC statement:
  - Roe and Baker (2007)
  - Log-normal
  - Gamma
  - Weibull
- Calibration done by applying three constraints:
  - Median equal to 3°C
  - Two-thirds probability that ECS lies between 2 and 4.5°C
  - Zero probability that ECS is less than 0°C or greater than 10°C

2. EQUILIBRIUM CLIMATE SENSITIVITY

Table 1: Summary Statistics for Four Calibrated Climate Sensitivity Distributions

	Roe & Baker	**Log-normal**	**Gamma**	**Weibull**
Pr(ECS < 1.5°C)	0.013	0.050	0.070	0.102
Pr(2°C < ECS < 4.5°C)	0.667	0.667	0.667	0.667
5th percentile	1.72	1.49	1.37	1.13
Median	3.00	3.00	3.00	3.00
Mean	3.50	3.28	3.19	3.07
95th percentile	7.14	5.97	5.59	5.17

2. EQUILIBRIUM CLIMATE SENSITIVITY

- Selected the Roe and Baker distribution:
  - Only distribution based on a theoretical understanding of the response of the climate system to increased GHG concentrations
  - Most consistent with IPCC judgments regarding climate sensitivity:
    - "Values substantially higher than 4.5 °C still cannot be excluded"
    - ECS "is very likely larger than 1.5 °C"

3. GLOBAL OR DOMESTIC DAMAGES

- Current OMB guidance says Domestic Perspective is Mandatory and International Perspective is Optional

- Determined that a Global Measure of the Benefits from Reducing U.S. Emissions is Preferable:
  - Global Externality. Emissions in U.S. Cause Damages Around the World
  - The U.S. cannot mitigate climate change by itself
  - Decided against equity weighting that would place a greater weight on losses in poor countries
  - NB: Best available evidence is that US damages are 5-15% of global damges.

IV. LIFETIME DAMAGES OF A TON OF GHG EMISSIONS

A. LONG RUN DAMAGES

- Half Life of a Ton of CO_2 Emitted is 100 Years
- Ton of Emissions Today will Affect Temperatures and Damages for a Long Period
- Net Present Value of Damage due to Ton of Emissions Today Equals the Sum of the Discounted Value of the Damages Each Year Until It Has Disappeared from Atmosphere
  - The Choice of Discount Rate is a Key Factor

B. DISCOUNT RATES

- Choice of a discount rate, especially over long periods of time, raises difficult questions
- USG traditionally employs constant discount rates of both 3 percent and 7 percent

SELECTED DISCOUNT RATES

- In light of the above considerations, USG used three discount rates:
  - Low Value: 2.5 percent
    - Interest rates are highly uncertain over time
    - If climate investments are negatively correlated with market returns
    - Incorporates normative objections to rates of 3 percent or higher
  - Central Value: 3 percent
    - Consistent with estimates in the literature and OMB's guidelines for the consumption rate of interest
    - Roughly corresponds to the after-tax riskless rate
  - High Value: 5 percent
    - If climate investments are positively correlated with market returns
    - May be justified by the high interest rates many consumers use to smooth consumption
- Approach is largely descriptive and uses constant discount rates, but incorporates some key prescriptive concerns

C. PUTTING IT ALL TOGETHER

- Running the models produces 45 separate distributions of the SCC for a given year
  - (3 models) x (5 socioeconomic scenarios) x (1 climate sensitivity distribution) x (3 discount rates)
- The distributions from each of the models and scenarios are averaged together for each year
  - Produces three separate probability distributions for SCC in a given year, one for each discount rate

C. PUTTING IT ALL TOGETHER

For each IAM, here are steps for calculating the SCC:

1. Input the path of emissions, GDP, and population and calculate the temperature effects and (consumption-equivalent) damages in each year resulting from this baseline path of emissions.

2. Add an additional unit of carbon emissions in year *t* and recalculate the temperature effects and damages expected in all years beyond *t* resulting from this adjusted path of emissions.

3. Subtract the damages computed in step 1 from those in step 2 in each year.

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 damages.

V. RESULTS

OVERALL ESTIMATES

- USG selected four SCC estimates for use in regulatory analyses
  - In 2010, these estimates are $5, $21, $35 & $65 (in 2007 US$)
  - First three estimates are the average SCC across 3 models & 5 emissions scenarios for 3 distinct discount rates
  - The fourth value represents higher-than-expected impacts
    - Use the SCC value for the 95th percentile at a 3 percent discount rate
  - The $21 estimate associated with a 3% discount rate is the central value

HETEROGENEITY BY MODEL AND DISCOUNT RATE

Table 3: Disaggregated Social Cost of CO_2 Values by Model, Socio-Economic Trajectory, and Discount Rate for 2010 (in 2007 dollars)

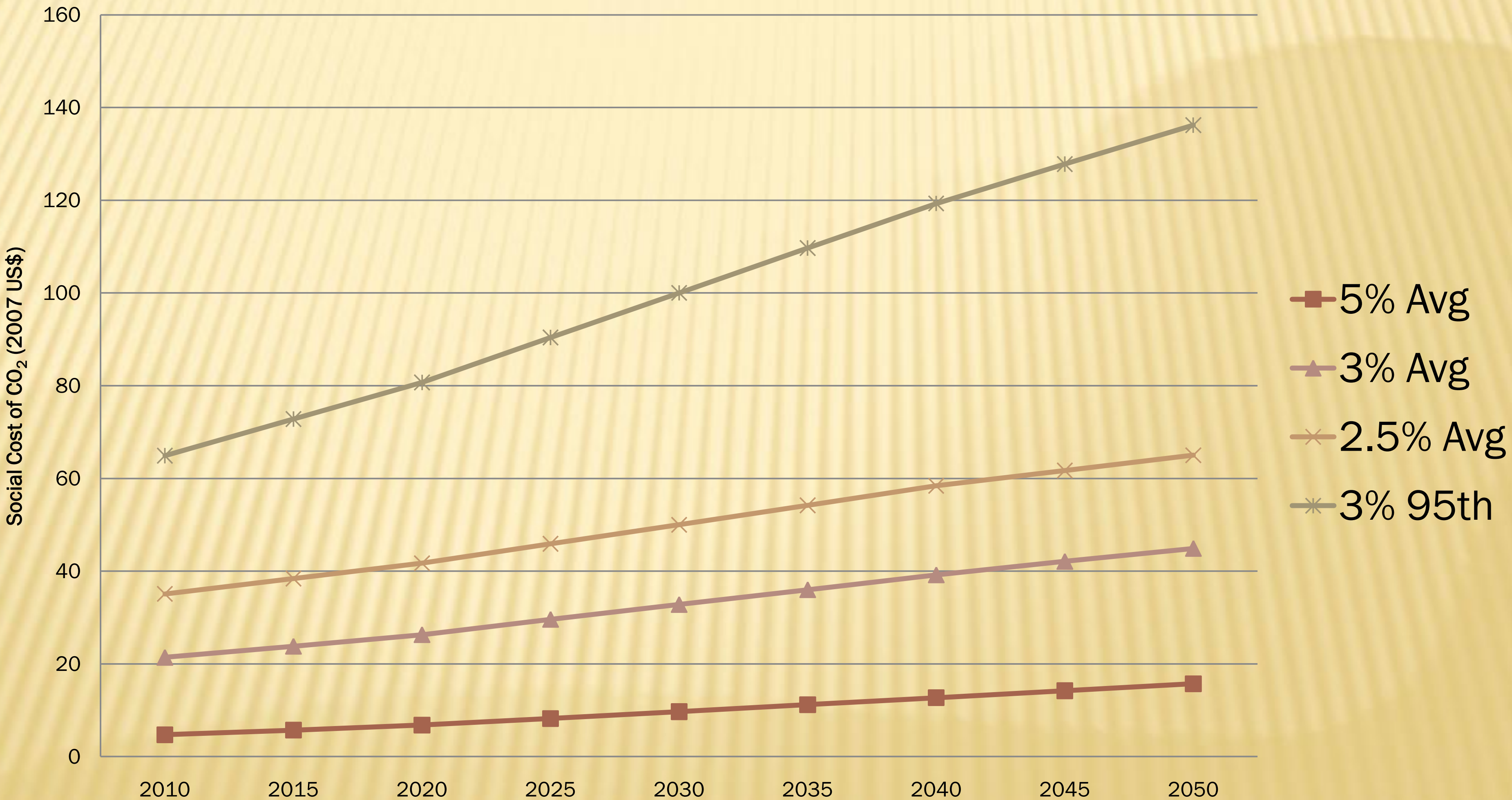
	Discount rate:	**5%**	**3%**	**2.5%**	**3%**
Model	*Scenario*	Avg	Avg	Avg	95th
DICE	IMAGE	10.8	35.8	54.2	70.8
	MERGE	7.5	22.0	31.6	42.1
	Message	9.8	29.8	43.5	58.6
	MiniCAM	8.6	28.8	44.4	57.9
	550 Average	8.2	24.9	37.4	50.8
PAGE	IMAGE	8.3	39.5	65.5	142.4
	MERGE	5.2	22.3	34.6	82.4
	Message	7.2	30.3	49.2	115.6
	MiniCAM	6.4	31.8	54.7	115.4
	550 Average	5.5	25.4	42.9	104.7
FUND	IMAGE	-1.3	8.2	19.3	39.7
	MERGE	-0.3	8.0	14.8	41.3
	Message	-1.9	3.6	8.8	32.1
	MiniCAM	-0.6	10.2	22.2	42.6
	550 Average	-2.7	-0.2	3.0	19.4

DISCUSSION

- Higher discount rates result in lower SCC values, and vice versa
- There are clear differences in the SCC estimated across the three main models
  - FUND produces the lowest estimates
  - PAGE produces the highest estimates
- Results match up fairly well with model estimates in the existing literature
- The SCC increases over time
  - Physical and economic systems will become more stressed

RESULTS OVER TIME

Figure 3: Social Cost of CO_2, 2010 – 2050 (in 2007 dollars)



VI. CONCLUSIONS & DIRECTIONS FOR UPDATING THE SCC

CONCLUSIONS

- The SCC offers a way to measure the economic value of emissions reductions
- The use of the SCC to guide GHG regulations under the Clean Air Act offers the possibility of achieving regulations where the benefits exceed the costs

DIRECTIONS FOR IMPROVEMENTS

- Key areas for future research and advances in calculation of SCC include:
  - Improvements in how IAM's capture catastrophic impacts
  - More attention to how predicted physical impacts translate into economic damages
  - Interactions between inter-sector and inter-regional impacts (e.g., conflict)
  - More complete treatment of adaptation and technological changes
  - Potential Incorporation of Risk Aversion
  - A methodology for valuing reductions in other GHG's