PRICING CO₂ EMISSIONS

Paul L. Joskow
Alfred P. Sloan Foundation
and
MIT
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The views reflected here are my own and not the responsibility of the Sloan Foundation or MIT
Climate change is an externality with a difference:

- Global
- Mitigation and associated costs must start now while benefits of avoiding significant adverse impacts of climate change occur (far) in the future
- Uncertainty over science, technology and economics
- Potentially catastrophic and irreversible costs of climate change (“fat tails”)
GLOBAL CO2 EMISSIONS

Source: Carbon Dioxide Information Analysis Center

<table>
<thead>
<tr>
<th></th>
<th>1990</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated Emissions</td>
<td>6,187.4</td>
<td>7,209.8</td>
<td>7,052.6</td>
</tr>
<tr>
<td>(Million Metric Tons CO₂e)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change from 1990</td>
<td>1,022.4</td>
<td>865.1</td>
<td></td>
</tr>
<tr>
<td>(Million Metric Tons CO₂e)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Percent)</td>
<td>16.5%</td>
<td>14.0%</td>
<td></td>
</tr>
<tr>
<td>Average Annual Change</td>
<td></td>
<td>0.9%</td>
<td>0.7%</td>
</tr>
<tr>
<td>from 1990 (Percent)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Change from 2007</td>
<td>-157.3</td>
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<tr>
<td>(Million Metric Tons CO₂e)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Percent)</td>
<td>-2.2%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: U.S. EIA
Figure 1. U.S. Greenhouse Gas Emissions by Gas, 2008

Energy-Related Carbon Dioxide* 5,735.5 (81.3%)

(Million Metric Tons Carbon Dioxide Equivalent)

2008 Total = 7,052.6

High-GWP Gases 175.6 (2.5%)
Nitrous Oxide 300.3 (4.3%)
Other Carbon Dioxide 103.8 (1.5%)
Methane 737.4 (10.5%)

Source: EIA estimates. *Adjusted.

Source: U.S. EIA
Figure 2. U.S. Energy-Related Carbon Dioxide Emissions by Major Fuel, 2008

2008 Total = 5,814.4 *

- Petroleum: 2,436.0 (41.9%)
- Coal: 2,125.2 (36.5%)
- Natural Gas: 1,241.8 (21.4%)

(Million Metric Tons Carbon Dioxide Equivalent)

*Includes small amounts of CO₂ from non-biogenic municipal solid waste and geothermal energy (0.2 percent of total).
Source: EIA estimates.
<table>
<thead>
<tr>
<th>World Energy-Related Carbon Dioxide Emissions, 1990, 2006, and 2030</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td>Estimated Emissions (Million Metric Tons)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Change from 1990 (Million Metric Tons)</td>
</tr>
<tr>
<td>(Percent)</td>
</tr>
<tr>
<td>Average Annual Change from 1990 (Percent)</td>
</tr>
<tr>
<td>Change from 2006 (Million Metric Tons)</td>
</tr>
<tr>
<td>(Percent)</td>
</tr>
</tbody>
</table>


Source: U.S. EIA
Figure 6. Regional Shares of World Carbon Dioxide Emissions, 1990, 2006, 2020, and 2030


Source: U.S. EIA
Atmospheric CO$_2$ at Mauna Loa Observatory

Scripps Institution of Oceanography
NOAA Earth System Research Laboratory

Source: NOAA
Figure 2. Total CO₂-eq (ppm on left-hand scale and metric tons on right-hand scale) from observed GHG mole fractions (oscillating colored lines), full 6-term equation (6) fit to the observations (oscillating black lines), and 3-term Legendre polynomial only fit to observations (smooth blue lines), for the “CO₂ Only”, “Kyoto Gases” and “IPCC Gases” cases. The “All Gases” case is only 0.2 ppm above the “IPCC-Gases” case and is not shown as it would be indistinguishable on the scale of the graph.

Figure 1.4  The link between greenhouse gases and climate change.

Land use change

Rising Atmospheric Greenhouse Gas Concentration (measured in CO₂ equivalent)

Emissions

Radiative Forcing (Change in energy balance)

Rising Atmospheric Temperatures

Rising Ocean Temperatures (Lagged)

Local and global feedbacks, for example: changes in the clouds, the water content of the atmosphere and the amount of sunlight reflected by sea ice (albedo)

Physical Changes in Climate

Rising Global Mean Surface Temperatures (GMT)

Rising Sea Levels

Changes in rainfall variability and seasonality

Changing Patterns of Natural Climate Variability

Melting of Ice Sheets, Sea Ice and Land Glaciers

Impacts on physical, biological and human systems

Feedbacks including a possible reduction in the efficiency of the land and oceans to absorb carbon dioxide emissions and increased natural releases of methane

Table 1.1  Temperature projections at stabilisation

Meinshausen (2006) used climate sensitivity estimates from eleven recent studies to estimate the range of equilibrium temperature changes expected at stabilisation. The table below gives the equilibrium temperature projections using the 5 – 95% climate sensitivity ranges based on the IPCC TAR (Wigley and Raper (2001)), Hadley Centre (Murphy et al. 2004) and the range over all eleven studies. Note that the temperature changes expected prior to equilibrium, for example in 2100, would be lower.

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<th>Temperature increase at equilibrium relative to pre-industrial (°C)</th>
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<tbody>
<tr>
<td></td>
<td>IPCC TAR 2001 (Wigley and Raper)</td>
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<tr>
<td>400</td>
<td>0.8 – 2.4</td>
</tr>
<tr>
<td>450</td>
<td>1.0 – 3.1</td>
</tr>
<tr>
<td>500</td>
<td>1.3 – 3.8</td>
</tr>
<tr>
<td>550</td>
<td>1.5 – 4.4</td>
</tr>
<tr>
<td>650</td>
<td>1.8 – 5.5</td>
</tr>
<tr>
<td>750</td>
<td>2.2 – 6.4</td>
</tr>
<tr>
<td>1000</td>
<td>2.8 – 8.3</td>
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</table>

Global Temperatures

Source: Hadley
<table>
<thead>
<tr>
<th>Global temperature change (relative to pre-industrial)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>0°C</strong></td>
</tr>
<tr>
<td><strong>1°C</strong></td>
</tr>
<tr>
<td><strong>2°C</strong></td>
</tr>
<tr>
<td><strong>3°C</strong></td>
</tr>
<tr>
<td><strong>4°C</strong></td>
</tr>
<tr>
<td><strong>5°C</strong></td>
</tr>
</tbody>
</table>

### Food
- **0°C**: Possible rising yields in some high latitude regions
- **1°C**: Falling crop yields in many areas, particularly developing regions
- **2°C**: Falling yields in many developed regions
- **3°C**: 
- **4°C**: 
- **5°C**: 

### Water
- **0°C**: Small mountain glaciers disappear – water supplies threatened in several areas
- **1°C**: Significant decreases in water availability in many areas, including Mediterranean and Southern Africa
- **2°C**: Sea level rise threatens major cities
- **3°C**: 
- **4°C**: 
- **5°C**: 

### Ecosystems
- **0°C**: Extensive Damage to Coral Reefs
- **1°C**: Rising number of species face extinction
- **2°C**: 
- **3°C**: 
- **4°C**: 
- **5°C**: 

### Extreme Weather Events
- **0°C**: Rising intensity of storms, forest fires, droughts, flooding and heat waves
- **1°C**: 
- **2°C**: 
- **3°C**: 
- **4°C**: 
- **5°C**: 

### Risk of Abrupt and Major Irreversible Changes
- **0°C**: 
- **1°C**: 
- **2°C**: 
- **3°C**: 
- **4°C**: 
- **5°C**: Increasing risk of dangerous feedbacks and abrupt, large-scale shifts in the climate system
Table 5.2  Summary costs of extreme weather events in developed countries with moderate climate change. Costs at higher temperatures could be substantially higher.

<table>
<thead>
<tr>
<th>Region</th>
<th>Event Type</th>
<th>Temperature</th>
<th>Costs as % GDP</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td>All extreme weather events</td>
<td>2°C</td>
<td>0.5 - 1.0% (0.1%)</td>
<td>Based on extrapolating and increasing current 2% rise in costs each year over and above changes in wealth</td>
</tr>
<tr>
<td>USA</td>
<td>Hurricane</td>
<td>3°C</td>
<td>1.3% (0.6%)</td>
<td>Assumes a doubling of carbon dioxide leads to a 6% increase in hurricane windspeed</td>
</tr>
<tr>
<td></td>
<td>Coastal Flood</td>
<td>1-m sea level rise</td>
<td>0.01 – 0.03%</td>
<td>Only costs of wetland loss and protection against permanent inundation</td>
</tr>
<tr>
<td>UK</td>
<td>Floods</td>
<td>3 – 4°C</td>
<td>0.2 – 0.4% (0.13%)</td>
<td>Infrastructure damage costs assuming no change in flood management to cope with rising risk</td>
</tr>
<tr>
<td>Europe</td>
<td>Coastal Flood</td>
<td>1-m sea level rise</td>
<td>0.01 - 0.02%</td>
<td>Only costs of wetland loss and protection against permanent inundation</td>
</tr>
</tbody>
</table>

Notes: Numbers in brackets show the costs in 2005. Temperatures are global relative to pre-industrial levels. The costs are likely to rise sharply as higher temperatures lead to even more intense extreme weather events and the risk of triggering abrupt and large-scale changes. Currently, there is little robust quantitative information for the costs at even higher temperatures (4 or 5°C), which are plausible if emissions continue to grow and feedbacks amplify the original warming effect (such as release of carbon dioxide from warming soils or release of methane from thawing permafrost).

Figure 9. Reference projections of global CO$_2$ Emissions under No Policy and concentration stabilization targets of 750, 650, 550, and 450ppm, as defined in Clarke et al. (2007).

Source: MIT Joint Program Report No. 165 11/08
METHODS TO REDUCE CO₂ EMISSIONS

• Reduce the rate of growth of demand for energy (energy efficiency) without significantly reducing economic growth and social welfare
  — End-use (e.g. vehicles and appliances)
  — Production (e.g. power plant efficiency)
• Substitute low-carbon for high carbon fuels in electricity generation and other industrial sectors (e.g. nuclear for coal, wind for fossil-fueled generation, biofuels for gasoline and diesel fuel)
• Capture and store CO₂ from fossil fuels and burn hydrogen-rich synthetic gas or pure hydrogen
• Adapt to climate change to reduce the costs of its impacts
• Geo-engineering to reduce the impacts of GHG emissions in the medium term (transition)
MECHANISMS TO INTERNALIZE GHG EXTERNALITIES

• An efficient GHG system should meet GHG emission stabilization targets at the lowest cost possible
  – Taking uncertainty and new information into account
  – Recognize that there is portfolio of options with uncertain attributes
  – Stimulate innovation and decentralized decisions
• Placing a price on GHG emissions is the best way
  • Emissions taxes
  • Property rights-based cap and trade systems (which also place a price on CO₂ emissions)
  • “prices vs. quantities”
• Regulations and subsidies
  • Emissions regulations
  • Direct subsidies/obligations for non/low-carbon sources of energy
  • Energy efficiency standards
  • R&D subsidies for low-carbon technologies
PLACING A PRICE ON CO$_2$ EMISSIONS IS THE BEST POLICY APPROACH

• Efficiently exploits diverse consumer and producer circumstances by stimulating decentralized “self-interested” decisions
• This is especially important when there is uncertainty about the costs of alternative mitigation options
• Makes low carbon supply technologies more profitable
• Increases energy prices making energy efficiency more profitable
• Increases the financial attractiveness of R&D focused on low-carbon technologies and energy efficiency
Table 1: Costs of Electric Generation Alternatives

<table>
<thead>
<tr>
<th></th>
<th>Overnight Cost</th>
<th>Fuel Cost</th>
<th>Levelized Cost of Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$/kW</td>
<td>$/MMBtu</td>
<td>¢/kWh</td>
</tr>
<tr>
<td>Nuclear</td>
<td>4,000</td>
<td>0.67</td>
<td>8.4</td>
</tr>
<tr>
<td>Coal (low)</td>
<td>2,300</td>
<td>1.60</td>
<td>5.2</td>
</tr>
<tr>
<td>Coal (moderate)</td>
<td>2,300</td>
<td>2.60</td>
<td>6.2</td>
</tr>
<tr>
<td>Coal (high)</td>
<td>2,300</td>
<td>3.60</td>
<td>7.2</td>
</tr>
<tr>
<td>Gas (low)</td>
<td>850</td>
<td>4.00</td>
<td>4.2</td>
</tr>
<tr>
<td>Gas (moderate)</td>
<td>850</td>
<td>7.00</td>
<td>6.5</td>
</tr>
<tr>
<td>Gas (high)</td>
<td>850</td>
<td>10.00</td>
<td>8.7</td>
</tr>
</tbody>
</table>

Notes: The low, moderate, and high fuel costs for coal correspond to a $40, $65, and $90/short ton delivered price of Central Appalachian coal (12,500 Btu), respectively. Costs are measured in 2007 dollars.

Table 2: Costs of Electric Generation Alternatives, Inclusive of Carbon Charge

<table>
<thead>
<tr>
<th></th>
<th>Overnight Cost</th>
<th>Fuel Cost</th>
<th>Levelized Cost of Electricity w/Carbon Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$/kW</td>
<td>$/MMBtu</td>
<td>$/kWh $/kWh</td>
</tr>
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<td>Nuclear</td>
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<tr>
<td>Gas (low)</td>
<td>850</td>
<td>4.00</td>
<td>5.1</td>
</tr>
<tr>
<td>Gas (moderate)</td>
<td>850</td>
<td>7.00</td>
<td>7.4</td>
</tr>
<tr>
<td>Gas (high)</td>
<td>850</td>
<td>10.00</td>
<td>9.6</td>
</tr>
</tbody>
</table>

McKinsey bottom-up approach

- ~27 Gton CO$_2$e below 40 EUR/ton (-46% vs. BAU)
- ~7 Gton of negative and zero cost opportunities
- Fragmentation of opportunities
Figure 9.5 Average cost of reducing fossil fuel emissions to 18 GtCO₂ in 2050*

*The red lines give uncertainty bounds around the central estimate. These have been calculated using Monte Carlo analysis. For each technology, the full range of possible costs (typically ± 30% for new technologies, ±20% for established ones) is specified. Similarly, future oil prices are specified as probability distributions ranging from $20 to over $80 per barrel, as are gas prices (£2-6/GJ), coal prices and future energy demands (to allow for the uncertain rate of uptake of energy efficiency). This produces a probability distribution that is the basis for the ranges given.

Figure 7. Alternative Technology Assumptions and Generation Choices: (a) 167_nuclear, (b) 167_ccs, (c) 167_wind_gas, (d) 167_wind_slow.

Source: MIT Joint Program Report No. 173  April 2009
FIRM LEVEL ABATEMENT

MCA_i

MCA_j

P_E^*

A_j^*

A_i^*

Firm i’s Abatement
CAP AND TRADE
PROPERTY-RIGHTS BASED MECHANISM

• Set cap at the optimal level/trajectory of aggregate pollution (E*)
• Issue E* tradeable emission permits for each year. These could be auctioned off by the government or allocated in some other way
• Require all sources to acquire enough permits to cover their emissions and allow a market for emissions permits to develop
• Allow banking and borrowing over reasonable time horizons to support flexibility in mitigation responses
• Emission permit trading will establish an emissions price $P_E$ and the economic effects are essentially the same as for a tax
EMISSION TAXES VS. CAP AND TRADE

• Are we more confident about getting the price trajectory or the quantity trajectory right?
• What are the costs of getting the price or the quantity trajectories wrong?
• Domestic Political Considerations
  – Use permit allocation to “buy” 60 Senate votes
  – Is the prefect the enemy of the good?
• Extensive U.S. experience with cap and trade
• International Linkage Considerations
• Cap and trade fits better with the way the science conceptualizes the problem
• Americans don’t like taxes compared to similar (often more costly) alternatives for controlling pollution
HYBRID SYSTEMS

• Create cap and trade system with emissions quantity targets and associated aggregate emissions permits
• Establish a “backstop” price or “safety valve” at which the government will sell additional permits to cap the marginal cost
• Adjust safety valve from time to time as more information about mitigation costs and damages resolves uncertainty
SHOULD WE WAIT FOR THE UNCERTAINTIES TO BE RESOLVED?

• Many of the uncertainties regarding the science, the costs of climate change and the costs of mitigation cannot be easily resolved now.

• But complete resolution is not necessary to make the case for embarking on mitigation policies now.

• We know enough to conclude that doing nothing is costly even with lower bound estimates.

• Irreversibilities further increase the costs of waiting.

• Waiting increases the likelihood of catastrophic consequences.
Figure 10. Global anthropogenic emissions over time. Shaded regions show the 50% (darker shading) and 90% (lighter shading) probability bounds on EPPA emissions in the no policy case. The red lines indicate the IPCC SRES marker scenarios, with scenario label to right of graph. The blue dashed lines indicate the Level 4 (750ppm) and Level 2 (550ppm) stabilization scenarios from Clarke et al. (2007).

Source: MIT Joint Program Report No. 165 11/08
Table 1.1  Temperature projections at stabilisation

Meinshausen (2006) used climate sensitivity estimates from eleven recent studies to estimate the range of equilibrium temperature changes expected at stabilisation. The table below gives the equilibrium temperature projections using the 5 – 95% climate sensitivity ranges based on the IPCC TAR (Wigley and Raper (2001)), Hadley Centre (Murphy et al. 2004) and the range over all eleven studies. Note that the temperature changes expected prior to equilibrium, for example in 2100, would be lower.

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<tr>
<td>1000</td>
<td>2.8 – 8.3</td>
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</table>
WHY IS EFFECTIVE POLICY RESPONSE SO HARD?

• Uncertainty about certain aspects of the science have used an excuse to do nothing
• Mitigation policies are costly and uncertain even if the best policies are put in place and the “avoided costs” are difficult to quantify
• The public has been educated poorly about the science and potential costly consequences of climate change. Activist scientists have created credibility problems of late.
• The most significant costs of climate change are far in the future while the mitigation costs are now. What is the right discount rate?
• Commitments by several major GHG emitting countries is needed
• Mitigation costs vary widely across countries, within countries, and across industries creating complex interest group politics created interest group politics challenges
• Ethical controversies between developed and developing countries
(c) Revised CO$_2$-e Price

Source: MIT Joint Program Report No. 173 April 2009
Figure C8. Energy Prices in H.R. 2454 with Medium Offsets (reference prices in blue, consumer prices in green, and producer prices in red).
Table C2. Cost per Household (in dollars) of H.R. 2454 with Different Offsets, Annual and Discounted to 2010 at 4%.

<table>
<thead>
<tr>
<th></th>
<th>H.R. 2454</th>
<th>Total Cost</th>
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<tbody>
<tr>
<td></td>
<td>Med Offsets</td>
<td>Full Offsets</td>
</tr>
<tr>
<td></td>
<td>Annual Discount to 2010</td>
<td>Annual Discount to 2010</td>
</tr>
<tr>
<td>2010</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2015</td>
<td>68</td>
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<td>2020</td>
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<td>2050</td>
<td>2695</td>
<td>561</td>
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<tr>
<td>Average</td>
<td>1223</td>
<td>404</td>
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</table>
Figure 6. Regional Electricity Generation by Fuel Source.
Table 6. Impacts on Fuel Prices Inclusive and Exclusive of GHG Charge (in %).

<table>
<thead>
<tr>
<th></th>
<th>Coal</th>
<th>Natural Gas</th>
<th>Refined Oil</th>
<th>Electricity</th>
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<td>exclusive</td>
<td>Inclusive</td>
<td>exclusive</td>
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<td>-4.6</td>
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<tr>
<td>US</td>
<td>72.9</td>
<td>-6.9</td>
<td>9.8</td>
<td>-2.9</td>
</tr>
</tbody>
</table>

Source: MIT Joint Program, Report # 182
Figure 3.5  Change in cereal production in developed and developing countries for a doubling of carbon dioxide levels (equivalent to around 3°C of warming in models used) simulated with three climate models (GISS, GFDL and UKMO Hadley Centre)

Source: Parry et al. (2005) analysing data from Rosenzweig and Parry (1994)

Note: Percent changes in production are relative to what they would be in a future with no climate change. Overall changes are relatively robust to different model outputs, but regional patterns differ depending on the model's rainfall patterns – more details in Fischer et al. (2005). The work assumed mostly farm-level adaptation in developing countries but some economy-wide adaptation in developed countries. The work also assumed a strong carbon fertilisation effect - 15 – 25% increase in yield for a doubling of carbon dioxide levels for responsive crops (wheat, rice, soybean) and a 5 – 10% increase for non-responsive crops (maize). These are about twice as high as the latest field-based studies suggest – see Box 3.4 for more detail.
PART II: The Impacts of Climate Change on Growth and Development

Figure 6.5a. Baseline-climate scenario, with market impacts and the risk of catastrophe.

Figure 6.5b. High-climate scenario, with market impacts and the risk of catastrophe.

Figure 6.5c. High-climate scenario, with market impacts, the risk of catastrophe and non-market impacts.

Figure 6.5d. Combined scenarios.

Figure 6.5a-d traces losses in income per capita due to climate change over the next 200 years, according to three of our main scenarios of climate change and economic impacts. The mean loss is shown in a colour matching the scenarios of Figure 6.4. The range of estimates from the 5th to the 95th percentile is shaded grey.
CURRENT POLICY MENU

• National Cap and Trade Policy
  – Start mostly with free allowance allocations based on historical emissions and adaptation burdens
  – Gradually auction more allowances
  – Use money to subsidize energy efficiency and low carbon supply technologies

• Emissions Taxes
  – Perhaps on petroleum and gas products at retail

• Renewable Electricity Portfolio Standards

• Tighter Auto and Appliance Efficiency Standards

• Tax subsidies and loan guarantees for low-carbon supply technologies and CCS

• Overlapping state and regional portfolios of all of the above (CA, RGGI). Federal Pre-emption?
CONCLUSIONS

• GHG Stabilization at 550ppm requires significant global reductions in GHG emissions from BAU
• There are no silver bullets and the cost of mitigation is significant but are not “catastrophic” (1-2% of real GDP forever) if the most efficient mitigation mechanism are used and we believe that the cost of climate change is even higher
• Many current policies lead to inefficient mitigation responses (CA ~ $600/ton for PV program)
• Placing a significant price on GHG emissions provides decentralized incentives to adopt the least cost mix of supply and demand-side mitigation and incentives for innovation
• Cap and trade was thought to a be politically more attractive than emissions taxes to establish a CO2 price and easier to link with programs in other countries
• Cap and trade has gotten a bum rap and very inefficient mitigation policies are being implemented instead
• We need to get on a better long-run policy path to keep the costs of mitigation as low as possible
BACKUP
EMISSIONS TAXES

• An emissions tax (or “fee”) system requires defining the appropriate fee level that properly “prices” the external effects of the pollution

• This fee level $P_E$ is defined as the level that equates marginal damages of additional emissions with the marginal cost of additional abatement (both are very uncertain)

• Producers must now pay a fee on any GHG that they (or perhaps their customers) emit and will have the incentive to reduce emissions up to the point where the marginal costs of abatement are equal to the fee

\[
\text{Firm's pollution costs} = P_E(E-A) + C_A(A)
\]

Cost minimization $\Rightarrow C_A'(A) = MC(A) = P_E$
Cap and Trade Systems Fix the Quantity of Pollution But Create Uncertainty Over the Cost

Source: Stern Review, Part IV, p. 313
Emissions Taxes Fix the Price and Marginal Cost of Pollution Abatement But Leave the Quantities and Marginal Damages Uncertain

This contrast between short-term and long-term marginal cost and marginal benefit curves gives rise to the problem of how to combine a tax-like regime in the short term with a quantitative constraint in the long term. A rule is needed for updating the tax in the light of new information about costs over the long term and the ex post quantity of emissions.

Source: Stern Review, Part IV, p. 314
1990 PROGRAM TO CONTROL SO$_2$ EMISSIONS

- Relies on cap-and-trade program to control SO$_2$ emissions from power plants (70% of SO$_2$ emissions)
- Sets national cap on SO$_2$ emissions of 9 million tons per year (or about a 50% reduction from 1985 levels)
- Cap met in two phases
  - 1995-1999 control emissions on dirtiest 263 power plants
  - 2000 forward 9 million ton cap applies to all power plants
- Most permits were allocated to existing sources and some are auctioned annually
  - All sources must have continuous emissions monitoring equipment
  - Unused permits available for a year may be “banked” for future years if they are not used
Annual Mean Ambient SO₂ Concentration

1989-1991

2006-2008

Notes:
• For maps depicting these trends for the entire continental United States, visit <www.epa.gov/castnet>.
• Dots on all maps represent monitoring sites. Lack of shading for southern Florida indicates lack of monitoring coverage in the 1989-1991 period.

Sources: CASTNET, 2009
Annual Mean Wet Sulfate Deposition

1989-1991

2006-2008

Source: NADP, 2009
Annual Mean Ambient Total Nitrate Concentration

Notes:
- For maps depicting these trends for the entire continental United States, visit www.epa.gov/castnet.
- Dots on all maps represent monitoring sites. Lack of shading for southern Florida indicates lack of monitoring coverage in the 1989-1991 period.

Source: CASTNET, 2009

Source: CantorCO2e Market Price Index, 2009
EU ETS

• First international cap and trade system involving all 27 EU countries
• Two phases:
  – 2005-2007 (trial period)
  – 2008-2012 (Kyoto Commitment period)
• Covers industrial and electricity generation sources (not transport) accounting for less than 40% of EU emissions
• Linkage to developing countries through CDM and to other annex 1 countries through trading credits
• Individual countries have additional mechanisms in place (e.g. subsidies for wind generation)
• Each country assigned target emissions reduction goals (burden sharing to reflect different rates of economic growth)
• 95+% of allowances in Phase one were allocated for free
• Program designed and implemented very quickly
EU ETS PERIOD 1 CO2 EMISSIONS PRICES (euros/ton)

MIT CEEPR (2007)