Goldman Lecture in Economics, Wellesley College

Preparing for Our Common Future: Policy Choices and the Economics of Climate Change

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The Basic Science of Climate Change

- Growing emissions of greenhouse gases (GHGs) are accumulating in the atmosphere
- Mainly from fossil fuel use and land use
- Growing concentration of GHGs will change and warm the global climate
- Global climate change represents one of our most serious long-term risks
Numerous Greenhouse Gases from Diverse Sources

Percentage of Total GHGs (CO$_2$e, 2006)

- CO$_2$  84.80
- CH$_4$  7.90
- N$_2$O  5.20
- HFCs   1.80
- PFCs   0.09
- SF$_6$  0.25
- Total  ~100.00

Emissions by Sector, 2006*

- Transportation (28%)
- Industry (29%)
- Residential (17%)
- Commercial (17%)
- Agriculture (8%)
- U.S. Territories (1%)

*Approximately 33% of total GHG emissions are connected to electricity production.

Source: Data from EPA.
Virtually impossible to account for 20th-century changes in climate without attributing a significant but uncertain share to anthropogenic GHG emissions

Only about half of warming already set in motion has occurred to this point

Much more warming than that is likely, however

- Reducing emissions from current levels would still mean rising concentration
Historical and Projected Climate Change Under Various Scenarios

Global Surface Warming (°C)

- High Population Growth/Low Economic Growth
- Rapid Growth (Balanced energy sources)
- Service Info. Economy
- Constant Concentrations
- Intermediate Growth
- Rapid Growth (Fossil-fuel-intensive)
- Rapid Growth (Not fossil-fuel-intensive)

Source: IPCC (2007)
Projected change in global climate ranges from modest to very dramatic

- Likely temperature increase over next century:
  - 0.3 °C to 6.4 °C
- Potential decline in global GDP from 4 °C increase:
  - 1 percent to 5 percent
- Small chance of much larger damages
The Basic Science of Climate Change: Uncertainty in Outcomes

- Significant uncertainty in distribution of changes
  - Across seasons and regions
  - In ranges and extremes of temperature and precipitation
  - In the potential for abrupt shifts
  - In the effects on human and natural systems

- Possibility of nonlinearities in system

- Also, significant uncertainty in the economic valuation of damages and mitigation/adaptation costs
Some Potential Impacts as a Function of Different Changes in the Global Average Temperature

- **1 °C Increase**
  - Risk of extinction in up to 30 percent of all species
  - Grain production will tend to increase at higher latitudes and decrease at lower latitudes

- **2 °C Increase**
  - Likely increase in worldwide coastal flooding
  - Widespread mortality of coral

- **3 °C Increase**
  - Approximately 30 percent of global coastal wetlands lost
  - Substantial public health impacts due to malnutrition, altered development of infectious diseases, and increased natural disasters
Climate Change, Econ 101

- **Negative externality**
  - Uncertainty over effects
  - Effects occur over a long time span

- **Significant free-rider problem**
  - Effective response likely to require international collective action
Responding to Climate Change

- Three potential responses, not all mutually exclusive
  - Research: continued study of problem’s scope and mitigation/adaptation options
  - Mitigation: emission reductions and sequestration
  - Adaptation: adapt to warming that will occur

- For each response, optimal policy would balance expected marginal costs against expected future discounted marginal damages
  - Does one consider global costs/benefits or just domestic?
Assessment of what action should be taken today is sensitive to one’s choice of discount rate

- Opportunity cost of avoiding damages (or compensating future generations for damages) is the real risk-adjusted rate of return on long-term investments
- Adjustment for uncertainty about the future returns implies a lower implicit discount rate and more recommended mitigation today
Present Discounted Value of $1,000

- At 2 Percent
- At 3 Percent
- At 5 Percent
- At 7 Percent

Years in the Future

Dollars
Alternate view: Valuation of future benefits should be viewed primarily as a decision about equity rather than as a traditional investment decision.

But viewed as an equity issue, inconsistencies arise relative to how other intergenerational trade-offs are analyzed.
- Developed countries have already contributed a very large share of historical emissions

  - Per capita incomes/emissions in developed countries (especially the United States) are much higher than those of most developing countries

  - The US has about 5 percent of the world’s population, but accounts for more than 20 percent of global GHG emissions (and also more than 20 percent of global GDP)
Range of Uncertainty in Cumulative CO\textsubscript{2} Emissions, Developed vs. Developing Countries

Billions of Metric Tons of Carbon

Developed Countries

Developing Countries
Developing countries’ per capita emissions are very low
  - But growing rapidly and will ultimately dominate in the aggregate
  - Many opportunities for low-cost reductions

Developing countries’ damages from climate change are likely to be larger, especially relative to income
Some conflict over distribution of costs between developed and developing nations is inevitable.

But to create a substantial impact on global emissions, the number of nations that need to coordinate is relatively small.
Cumulative CO₂ Emissions by Selected Countries, With and Without Land-Use Change, 1950 to 2000

- United States
- European Union
- Russian Federation
- China
- Brazil
- Indonesia

**MMtCO₂**

- Without Land-Use Change
- With Land-Use Change
Policy Responses to Climate Change: Mitigation

- Can influence behavior of consumers through creation of new social norms
- Can raise price or restrict quantity — and, in theory, reach the same outcome
  - Carbon tax
  - Cap and trade
Change in Energy Consumption and Behavioral Economics

Source: Schultz and others (2007).
Cap and Trade 101: What Is Cap and Trade?

- The basic contours of a cap-and-trade program are straightforward
  - A CAP limits the total amount of emissions. Allowances equal to that total amount are auctioned or otherwise allocated to emission sources
  - Emission sources may then TRADE allowances with other emission sources

- Emission sources must hold allowances (either allocated or purchased) equal to or greater than their emissions or else be subject to penalties
Cap and Trade 101: An Illustrative Example

- Two sources of emissions: Firm A and Firm B
- Under “business as usual” (BAU), each firm emits 4 units. The total emissions of the two firms thus equal 8 units.
- New Policy: A cap-and-trade system is instituted to reduce emissions by 50% from current levels
### Assumptions

- Two allowances are auctioned or allocated to each firm.
- Three times as costly for Firm B to reduce emissions as Firm A, such that

<table>
<thead>
<tr>
<th>Emissions</th>
<th>Total Cost</th>
<th>Marginal Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 (BAU)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>0</td>
<td>10</td>
<td>4</td>
</tr>
</tbody>
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<td>3</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>6</td>
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<td>1</td>
<td>18</td>
<td>9</td>
</tr>
<tr>
<td>0</td>
<td>30</td>
<td>12</td>
</tr>
</tbody>
</table>
If no trading was allowed, each firm would have two allowances, and each firm would emit two units.

**Total cost associated with 50% emission reduction**

- Firm A: $3
- Firm B: $9
- Total: $12
If trading is permitted, Firm A will sell one allowance to Firm B

- Firm A will hold 1 allowance and will emit 1 unit
- Firm B will hold 3 allowances and will emit 3 units

Total cost associated with 50% emission reduction

- Firm A: $6
- Firm B: $3
- Total: $9
Savings with trading: $3 ($12 without trading versus $9 with trading)

Emission sources will trade to point at which marginal costs of reducing emissions are equalized

Trading offers the lowest-cost means of achieving the environmental objective
Cap and Trade 101: Where Should the Cap Be Set?

- Economists’ answer: Cap should be set where the marginal cost equals the marginal benefit of emission reduction

- But ascertaining the marginal benefits of environmental improvement in dollar terms is a difficult task
The Clean Air Act Amendments of 1990 established a cap-and-trade program to reduce overall atmospheric levels of SO$_2$ and NO$_2$ to 50% of 1980 levels.

The program has met (and even exceeded) its goals:

- Emissions have declined 40% since 1990; acid rain levels have declined 65% since 1976.
- Prior to the program’s launch, the expected market price for SO$_2$ allowances was between $579-$1,935 per ton; the actual market price as of March 2008 was $380 per ton.
SO₂ Emissions Under the Acid Rain Program

Source: Data from EPA.

SO₂ Cap-and-Trade Program Begins

Source: Data from EPA.
The Acid Rain Program: Baseline Acid Rain Concentrations, 1989 to 1991 Average
The Acid Rain Program: Acid Rain Concentrations After Cap and Trade, 2000 to 2002 Average
Other Examples of Cap and Trade: European Union Emission Trading System (EU-ETS)

- World’s first CO$_2$ cap-and-trade program
- EU-ETS began with a three-year trial period (2005–2007); will be used to meet binding requirements of the Kyoto Protocol beginning with the second trading period (2008–2012) and beyond
- Early Difficulties
  - High price volatility
  - Overallocation of allowances (and lack of banking) leads to collapse of the allowance price in first period
EU-ETS: Allowance Prices in Period One and Period Two, 2005–2007

€ per tCO$_2$e

Working Examples of Cap and Trade: Regional Greenhouse Gas Initiative (RGGI)

- RGGI involves 10 Northeastern states, from Maryland to Maine
- Starting date is January 1, 2009
- Covers emissions for all fossil-fuel-fired electricity-generating plants 25MW and larger
- Cap will “stabilize” emissions until 2014 (188 million allowances) and then reduce emissions 10% by 2018 (169 million allowances)
Cap and Trade: Two Key Decisions About Policy Design

- **Degree of flexibility in annual caps**
  - Include a floor and/or a ceiling for the price of an allowance?
  - Allow firms to bank and/or borrow allowances?

- **Allowance allocation**
  - How to set initial number of allowances?
  - Sell the allowances or give them away?
  - Who gets free allowances or auction revenues?
Cap and trade sets limit on emissions; price of emissions is uncertain

Meeting strict annual targets can add significantly to total cost, with little offsetting benefit

- Cost of meeting an annual cap is likely to vary significantly from year to year
- In terms of climate effects, annual fluctuations in emissions matter little compared with multiyear trends
- Inflexible caps would require too few reductions in low-cost years (when meeting the cap is easy) and too many reductions in high-cost years
Flexible Cap Designs Could Lower the Cost of Meeting Long-Run Targets

- Price floors and ceilings could provide timing flexibility and more certainty about allowance prices
  - Floor would tighten cap in low-cost years; ceiling would loosen cap in high-cost years
  - Floor and ceiling could be adjusted periodically to ensure that emissions are on track to achieve long-term targets
Banking and borrowing allow firms to shift emission reductions across years

- Banking would allow firms to exceed required reductions in low-cost years and save the allowances for use in future years.
- Borrowing would allow firms to use future allowances in current year if allowance prices were high.
Illustrative Comparison of Various Policies to Reduce CO₂ Emissions Under Different Cost Conditions in 2018

<table>
<thead>
<tr>
<th>Emission Reductions (Millions of metric tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Costs Equal Anticipated Costs</td>
</tr>
<tr>
<td><img src="image1" alt="Graph" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Costs (Billions of dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Costs Equal Anticipated Costs</td>
</tr>
<tr>
<td><img src="image2" alt="Graph" /></td>
</tr>
</tbody>
</table>

- Cap That Reduces Emissions by 869 Million Metric Tons
- Cap That Reduces Emissions by 869 Million Metric Tons with Safety-Valve Price Equal to $45 per Metric Ton
- Cap That Reduces Emissions by 869 Million Metric Tons with Price Floor Equal to $19
Illustrative Comparison of Total Emission Reductions and Total Costs and After One High-Cost and One Low-Cost Year

<table>
<thead>
<tr>
<th>Billions of Metric Tons</th>
<th>Billions of 2006 Dollars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflexible Cap</td>
<td>Safety Valve Only</td>
</tr>
<tr>
<td>Price Floor Only</td>
<td>Safety Valve and Price Floor</td>
</tr>
</tbody>
</table>

The diagram shows the comparison of total emission reductions and total costs for different policies over a high-cost and a low-cost year. The policies include an inflexible cap, safety valve only, price floor only, and safety valve and price floor.
Allocation Matters: Amount of the Allowance Value (Income) Transferred Likely to Be Large

Approximate Value of SO₂ Allowances in 2005

Approximate Value of GHG Allowances in 2020 Under Legislative Proposals

Billions of 2006 dollars
Allocation Matters: How to Allocate the Allowances?

- **Someone will receive the value of the allowances**
  - Determined by policymakers’ decisions

- **Someone will pay for the allowances**
  - Determined by market forces
“If I’m going to have buy those permits from the government, I’m going to have to turn around and charge the customers a lot more than I would if I just had those allowances allocated for free.”

— Bruce Braine, American Electric Power

Cost of holding an allowances would become a part of doing business

Market forces would determine who bears the allowance cost

- Primarily borne by consumers in form of price increases
  - Disproportionate burden on low-income households
- Workers and shareholders could experience transitional costs
**Illustrative Example Showing Increase in Average Household Costs from a 15 Percent Decrease in Carbon Emissions**

<table>
<thead>
<tr>
<th>Average for Income Quintile</th>
<th>Lowest</th>
<th>Second</th>
<th>Middle</th>
<th>Fourth</th>
<th>Highest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Increase in 2006 Dollars</td>
<td>680</td>
<td>880</td>
<td>1,160</td>
<td>1,500</td>
<td>2,180</td>
</tr>
<tr>
<td>Cost Increase as a Percentage of Income</td>
<td>3.3</td>
<td>2.9</td>
<td>2.8</td>
<td>2.7</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Efficiency Cost of a 15 Percent Cut in CO$_2$ Emissions, with Revenues Used in Different Ways

-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3

Percentage of GDP

Revenues from Allowance Sales Used to Provide Equal Lump-Sum Rebates to Households
Revenues from Allowance Sales Used to Cut Corporate Taxes
Allowances Given Away

-0.5
-0.2
-0.5
Effects of a 15 Percent Cut in CO₂ Emissions on Average After-Tax Real Household Income

Percentage Change

- Allowances Sold and Revenues Used to Provide Equal Lump-Sum Rebates to Households
  - Lowest Quintile: 1.8
  - Second Quintile: 0.7
  - Middle Quintile: -0.1
  - Fourth Quintile: -0.6
  - Highest Quintile: -0.7

- Allowances Sold and Revenues Used to Cut Corporate Taxes
  - Lowest Quintile: -3.0
  - Second Quintile: -1.9
  - Middle Quintile: -1.7
  - Fourth Quintile: -1.5
  - Highest Quintile: 1.6

- Allowances Given Away
  - Lowest Quintile: -2.0
  - Second Quintile: -1.6
  - Middle Quintile: -1.7
  - Fourth Quintile: -1.7
  - Highest Quintile: 1.4
Conclusions: Timing Flexibility Matters

- Requiring that firms meet an inflexible cap could substantially increase cost while providing little additional benefit.

- Design features can allow timing flexibility:
  - Banking and borrowing could help in some situations, though borrowing typically limited because of enforcement concerns.
  - Price floor and ceiling could address wide array of situations and be adjusted over time to keep emissions on track to meet long-run cap.
Conclusions: Allocation Matters

- Value of allowances likely to be large
  - Policymakers determine who receives their value
  - Market forces determine who bears their cost

- Selling allowances would allow policymakers to capture their value, which could help to lower overall economic costs and offset costs to low-income households
Conclusions: Allocation Matters (continued)

- Freely allocating allowances would be equivalent to selling them and distributing the revenues to producers
  - Free allocations would not prevent price increases
  - Free allocations to producers could create windfall profits