Topic 9

- Permit options
- Public good dynamics

Options Trading in Emission Permits

- Consider the decision by a power plant whether to invest in scrubbing technology

Representative Power Plant

Characteristic	Value	Units	Notes
power plant size	300	MW^e	
utilization	82%		capacity at which the plant operates on average
efficiency of plant	9,800 37%	Btu / kWh	Btus required to produce a kWh Using 1 kWh = 3,600 Btu, one can calculate the thermal efficiency (percent of thermal energy converted to electricity)
sulfur content of coal	4.10	lb SO_2 / mmBtu	

- 300,000 kWh $\times$ 365 $\times$ 24 hr/yr $\times$ 0.82 = 2,154,960,000 kW/yr
- 0.0098 mmBtu/kW $\times$ 4.10 lb SO_2/mmBtu = 0.04018 SO_2/kW
- 2,154,960,000 kW/yr $\times$ 0.04018 SO_2/kW = 86,586,293 lb SO_2/yr
- Source: Ellerman et al. (2000)

Sulfur Dioxide Emissions

Calculation	Value	Units	Notes
Electricity per year	2,154,960,000	kWh / yr	
SO_2 per kWh	0.04018	lb SO_2 / kWh	1,000,000 Btu = 1 mm Btu
SO_2 per year	86,586,293	lb SO_2 / yr	
	43,293	ton SO_2 / yr	

- Scrubbing efficiency 95%

Calculation	Value	Units
SO_2 abatement	41,128	ton SO_2 / yr
SO_2 after scrubbing	2,165	ton SO_2 / yr

Scrubbing Costs

Cost Item	Amount	Units	Notes
Fixed O&M	$616,927	per year	salaries
Variable O&M	$65	per ton SO_2 removed	power and sorbents
Total	$2,673,352	per year	

Scrubber Installation Cost		
lower end	$100,000	per MW^e of capacity
	$30,000,000	
upper end	$150,000	per MW^e of capacity
	$45,000,000	

U.S. Acid Rain Program

- Must buy permits to cover SO_2 emissions
- A market for permits exists, including options, futures, etc.

Key Insight

- Buy a scrubber?
  - ▷ Run the scrubber if permits are greater than \$65
  - ▷ Buy permits if permits are less than \$65
- Buy call options with a strike price of \$65?
  - ▷ Exercise the option if permits are greater than \$65
  - ▷ Buy permits if permits are less than \$65
- Installing a scrubber is equivalent to buying call options on SO_2 permits.

Scrubber Installation Decision

- Consider the decision of whether to install a scrubber with a five-year life and the ability to remove 41,128 tons of SO_2 per year

- The alternative is to purchase 41,128 emission permits for each of the five years

Five Year Cost of a Scrubber

- Assume $r = 0.03$
  - $\delta = 1/(1 + r) = 0.97$

$$\begin{aligned}
\text{PV} &= 30,000,000 + 616,927 + \delta 616,927 + \ldots + \delta^4 616,927 \\
&= 30,000,000 + (4.7088)(616,927) \\
&= 32,905,006
\end{aligned}$$

Cost of Call Options

- Cost of one year call options for 41,128 tons of SO_2 assuming that the spot price is $\$140$ and the interest rate is 3%.

$$\$76.9950 \cdot 41,128 = \$3,165,044$$

  - ▷ Note: The option is so far in the money that the one year option price is essentially $\$140$ minus the present value at 3% of $\$65$ received in the year of exercise; i.e., $140 - \delta^t 65$.

- For five years:

	Year				
	1	2	3	4	5
call option price	$77	$79	$82	$84	$86
cost for 41,128	$3,165,044	$3,255,719	$3,353,972	$3,452,950	$3,549,460
total cost	$16,777,146				

Summary

- Options can be a valuable tool for risk management

- In addition, thinking in terms of options can help you evaluate certain investment decisions

Voluntary Efforts to Reduce Pollution

- When can voluntary efforts to reduce pollution succeed?

- References for this discussion:

  - ▷ "Dynamic Voluntary Contribution to a Public Project" by Leslie M. Marx and Steven A. Matthews (*Review of Economic Studies* 67, 327–358, 2000)

  - ▷ Great Lakes National Program Office at the EPA www.epa.gov/glnpo/glwqa/index.html

  - ▷ EPA scientist Paul Bertram

The Great Lakes

The Great Lakes account for 20% of the world's surface fresh water

Phosphorus

- Lake Erie can absorb 11,000 metric tons of phosphorous (maximum annual phosphorus loading)
- Where does phosphorus come from? *Sewage treatment plants*
  - ▷ A normal adult excretes 1.3–1.5 g of phosphorus per day.
  - ▷ Additional phosphorus from toothpaste, detergents, pharmaceuticals
  - ▷ Primary waste water treatment removes chunks, secondary reduces biologicals
  - ▷ Tertiary treatment required to remove phosphorus

- Other sources include runoff of fertilizers and pesticides

Great Lakes Water Quality Agreement of 1978

- Purpose: The Parties agree to make a maximum effort to develop programs, practices and technology necessary for a better understanding of the Great Lakes Basin Ecosystem and to eliminate or reduce to the maximum extent practicable the discharge of pollutants into the Great Lakes System.
  - ▷ Largely to control phosphorus (limiting substance of the time) particularly Ontario and Erie – algae was washing up and fouling beaches and creating oxygen deficits
- Force: Shall remain in force for a period of five years and thereafter until terminated upon twelve months' notice given in writing by one of the Parties to the other. No authority for penalties.

Great Lakes Water Quality Agreement of 1978

- Created the Great Lakes Office of the International Joint Commission
  - ▷ Collect data and issue water quality reports
  - ▷ Exchange of information: Each Party shall make available to the other at its request any data or other information in its control relating to water quality in the Great Lakes System.
- End Result
  - ▷ They did it – Investments of $8 billion made on upgrading water treatment to control phosphorus
  - ▷ Worked great until Zebra Mussels came 1988

Can a Voluntary Agreement Work?

- Consider the case of two polluters
- Need $8 billion in phosphorus reduction to put Lake Erie below its loading threshold
- Voluntary reduction reduces the threat of future onerous (costly to the firms) regulation

Can a Voluntary Agreement Work?

- An individual firm's benefit from investments in phosphorus reduction is slightly more than half of the total investment amount made by it and the other firm
  - ▷ Cost is direct
  - ▷ Benefit is indirect – reduced operating costs and reduced threat of future environmental regulation
  - ▷ Specifically, assume a firm receives benefit $\$\frac{5}{8}X$ billion if $\$X$ billion is invested (by itself and others) in phosphorus reduction
- If the total investment in reduction reaches $\$8$ billion, then there is an additional benefit of $\$1$ billion since at that point there is a significant reduction in the threat of environmental regulation
  - ▷ If total investment is $\$8$ billion, the benefit to each firm is $\frac{5}{8} \cdot 8 + 1 = 6$
- Will a single firm invest $\$8$ billion?

Sharing the Investment

- Suppose each firm agrees to invest $4 billion (investment are voluntary)
- Suppose investments are made simultaneously

Firm 2

Firm 1		invest 4	invest 0
	invest 4	$6-4,\ 6-4$	$\frac{5}{8}4-4,\ \frac{5}{8}4$
	invest 0	$\frac{5}{8}\cdot 4,\ \frac{5}{8}\cdot 4-4$	$0,\ 0$

- What type of game is this?
- What behavior do you expect from firms?

Sharing the Investment

- Suppose each firm agrees to invest \$4 billion (investment are voluntary)
- Suppose investments are made simultaneously

Firm 2

Firm 1		invest 4	invest 0
	invest 4	2, 2	-1.5, 2.5
	invest 0	2.5, -1.5	0, 0

- What type of game is this?
- What behavior do you expect from firms?

Spreading Out the Investment

- If we try to induce firms to make a single large investment, free riding is complete – no investment is made
- What if we ask firms to make smaller investments?
  - ▷ Year 1: Each firm invests $2 billion
    - ◇ Monitoring and reporting to confirm that all investments made
    - ◇ If investments not made, then discontinue agreement
    - ◇ If investments made, continue to year 2
  - ▷ Year 2: Each firm invests $2 billion
    - ◇ All payoffs occur in the second period (to make math simple)
- Principle for solving such games:
  - ▷ Reason backwards

Year-2 Incentives

- Suppose both firms invest $\$2$ billion in year 1 (sunk)
- What does the year 2 game look like?
  - ▷ Existing investment $= \$4$
  - ▷ Existing benefit $= \$\frac{5}{8} \cdot 4 = \$2.5$
  - ▷ Benefit if one firm invests $\$2$ billion more and other not $= \$\frac{5}{8} \cdot 6 = \$3.75$

Firm 2

		invest 2 more	invest 0 more
Firm 1	invest 2 more	$6-2$, $6-2$	$3.75-2$, 3.75
	invest 0 more	3.75, $3.75-2$	2.5, 2.5

Year-2 Incentives

- Suppose both firms invest $2 billion in year 1 (sunk)

- What does the year 2 game look like?

Firm 2

Firm 1		invest 2 more	invest 0 more
	invest 2 more	4, 4	1.75, 3.75
	invest 0 more	3.75, 1.75	2.5, 2.5

- If you think the other firm will invest $2 billion more, it is a best reply for you also to invest $2 billion more?

- Once you are closer to obtaining the benefit of $1 billion associated with reaching a total investment of $8 billion, firms *are* willing to invest

Year-1 Incentives

- What does the year-1 game look like?
- If either firm does not invest, then cooperation ends
- If both firms invest, get $4 in the second (in year 2 firms will both invest)
- If only one firm invests, cooperation ends and benefit is $\frac{5}{8} \cdot 2 = \$1.25$
- All payouts received in second year and discounted back to year 1 by δ

Firm 2

Firm 1		invest 2	invest 0
	invest 2	$\delta 4 - 2, \delta 4 - 2$	$\delta 1.25 - 2, \delta 1.25$
	invest 0	$\delta 1.25, \delta 1.25 - 2$	0, 0

- It is an equilibrium for both firms to invest in year 1

Summary

- When does this work:
  - ▷ players evaluate the public good similarly
  - ▷ there are enough periods
  - ▷ discounting is low or the period length small
- The only inefficiency is delay
- Dynamics can thus alleviate the well-known inefficiencies of one-shot contribution games

Mechanism Design

- This idea of modifying a game to achieve some policy objective is called mechanism design.
  - ▷ It is applied in many contexts. E.g., how to motivate employees to work efficiently.

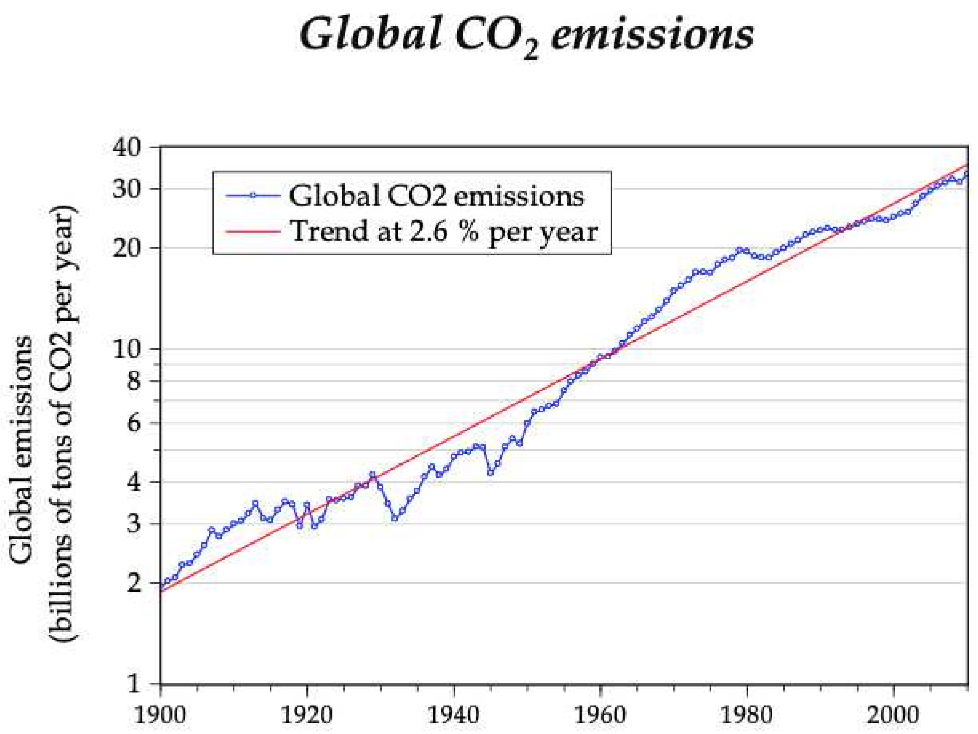
- Could mechanism design be applied to eliminate the global warming free rider problem?
  - ▷ Yes
  - ▷ William Nordhaus, Yale University, "National and International Policies for Slowing Global Warming," January 28, 2021, `bcf.princeton.edu/wp-content/uploads/2020/12/Combined-Slides-1.pdf`

- Next topic

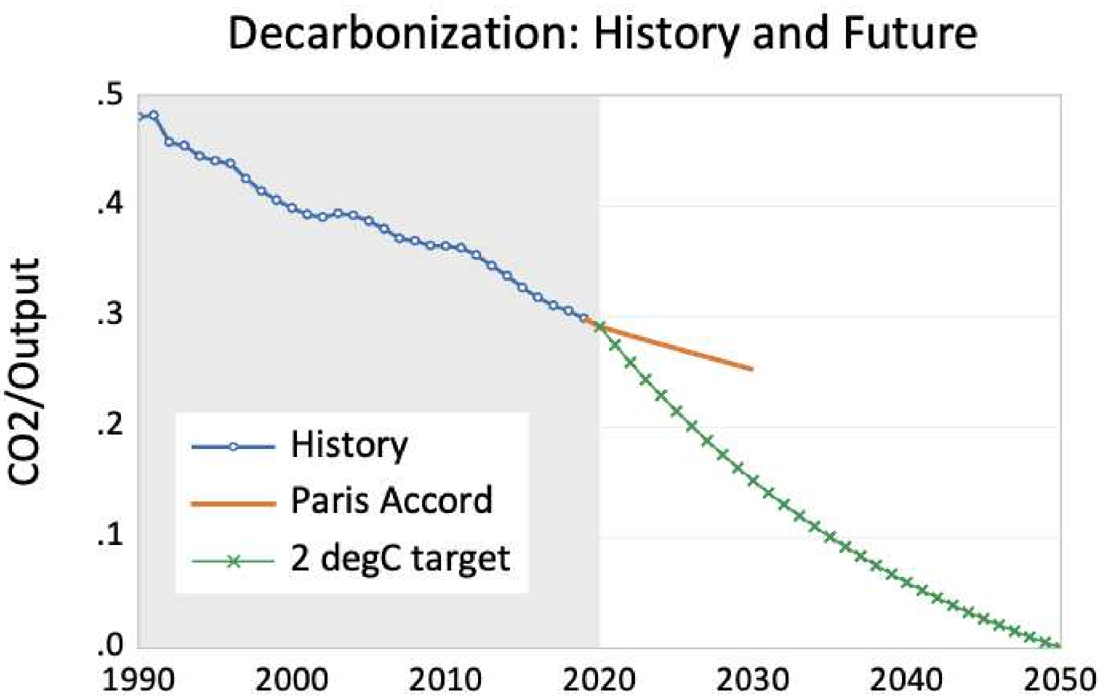
Four Key Issues

- Little progress in slowing emissions
- Small incentives for low-carbon technologies
- Important role of carbon pricing
- Need to combat international free riding with a climate compact

Global CO2 Emissions



Carbon Emission Reduction



A Free Rider Problem

- Public return on innovation many times larger than private returns
- Worse, there is a double externality for low-carbon innovations
  - ▷ normal innovation externaltiy
  - ▷ climate impacts externality

  Policy requires
  - ▷ fix climate externality through carbon pricing
  - ▷ special incentives for low-carbon technologies
  - ▷ suggests that a punishment and reward mechanism design is required

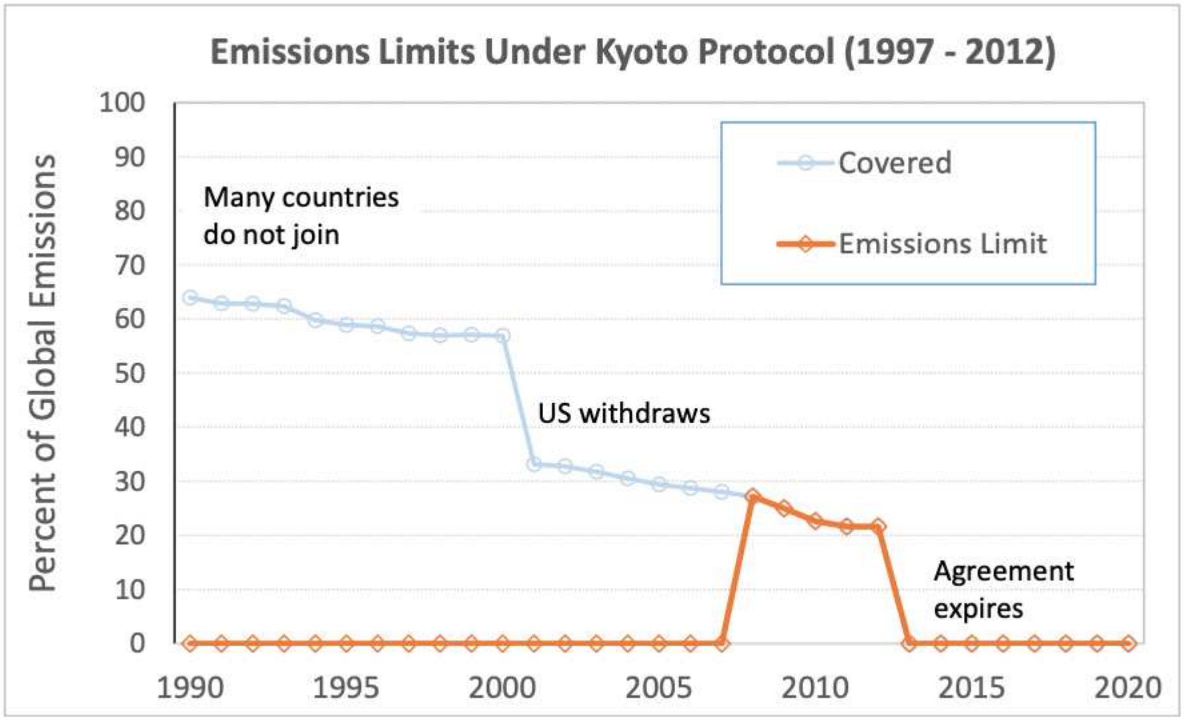
Low Carbon Taxes Around the World

The carbon price landscape, 2019

Region	*Percent of region covered by price*	*Carbon price ($/tCO2)*	*Effective price ($/tCO2)*	*% of global emissions*
Sweden	40	127	50.8	<1
Norway	60	59	35.4	<1
Switz	33	96	31.7	<1
BC	70	26	18.2	<1
France	33	50	16.5	1
Calif	85	16	13.6	2
ETS	43	25	10.8	8
Japan	70	3	2.1	5
Argentina	20	6	1.2	<1
Chinese cities	40	3	1.2	1
Northeast US	18	5	0.9	1
Mexico	45	1	0.5	1.5
Uncovered	100	0	0.0	80
Global average			**1.7**	

Source: World Bank

Collapse of Kyoto Protocol



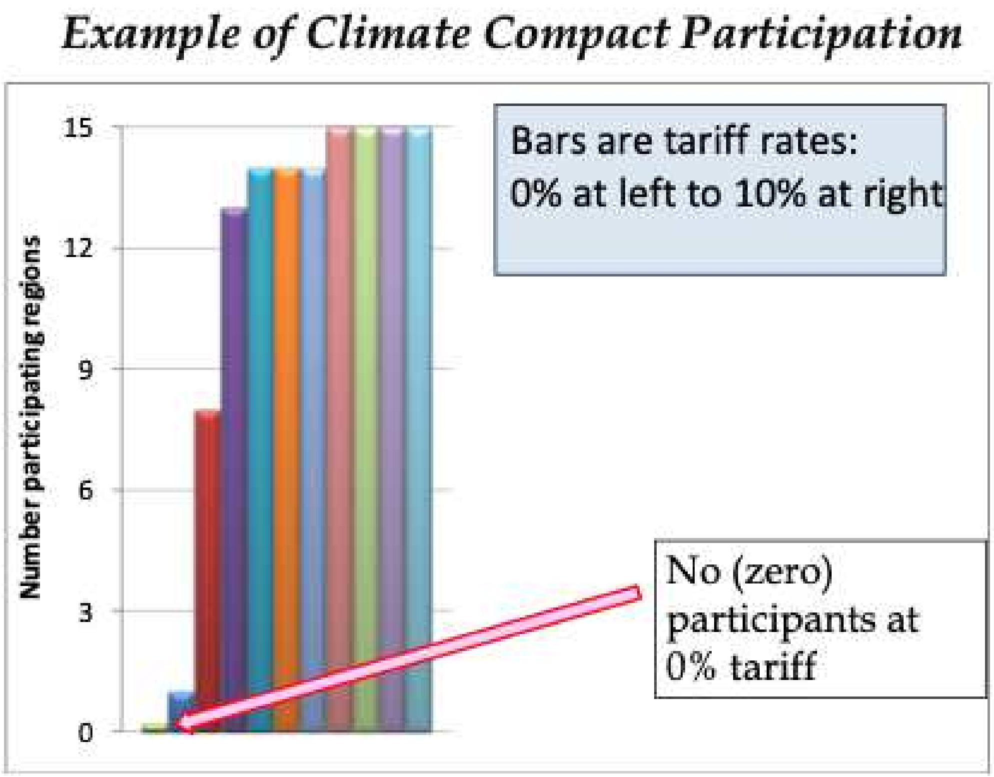
The Global Free Rider Problem

- International climate policy is at a dead end
- Why? Climate change policy is hampered by the free rider problem:
  - ▷ The agreements are voluntary
  - ▷ Compliance is costly
  - ▷ So there are no penalties for noncompliance
- Evidence:
  - ▷ Low carbon prices around the world
  - ▷ Collapse of Kyoto Protocol

Nordhaus's Proposed Mechanism

- Carbon price of \$50 per ton of CO_2
- Penalty tariff of 3% on non-participants
- Modeling of this mechanism, next slide

Predicted Effect of Possible Mechanisms



Example for $50/ton minimum carbon price.

Summary

- Little progress on slowing warming
- Low-carbon technologies plagued by double externality
- Central goal is high and harmonized carbon taxes
- Effective international policies require climate compact structure with punishments and rewards