Taxing Carbon in the Electric Power

Prof. Richard Sweeney

ECON3391.01, Boston College

Intro

- Review externalities
- Social cost of carbon
- Estimating the supply curve of CO2 emission reductions
  - Modeling
  - Reduced form (econometrics)
  - Event study (if we have time)

Externalities and Pigouvian taxes

- When externalities are present, the free market outcome will not be socially efficient
- The economist's solution is to set a Pigouvian tax equal to the marginal social cost of the externality
  - [graph MB = MC]

Calculating the social cost of carbon (SCC)

- In 2009 the United States formed an inter-agency working group (IAWG) to come up with a number for the social cost of carbon
  - Necessary for conducting mandatory RIAs
  - Differences in implicitly SCCs used across agencies at the time

Four steps in estimating the consequences of CO2 emissions

1. the future emissions of GHGs
2. the effect of past and future emissions on climate
3. the impact of changes in climate on the physical and biological environment
4. translation of those impacts into economic damages

(*For a review of the SCC calculation process see* Greenstone et. al. 2013)

Integrated assessment models (IAMs)

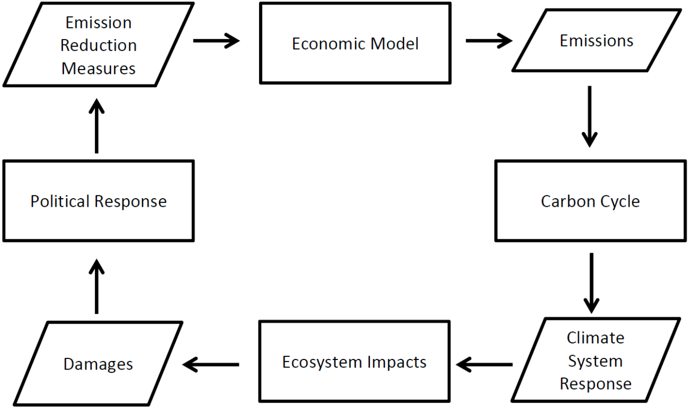


Figure 1. Integrated Assessment Model Schematic

- IAMS combine insights from science and economics
- Come at the cost of simplification

Three IAMs used by the US IAWG

- Dynamic Integrated model of Climate & the Economy (DICE)
    - William Nordhuas
- Climate Framework for Uncertainty, Negotiation and Distribution (FUND)
    - Richard Tol and David Antoff
- Policy Analysis of the Greenhouse Effect (PAGE)
    - Chris Hope

All three models:

- Emissions →GHG concentrations →Temperature →Economic Damages
- Baseline emissions based on projected socioeconomic paths (GDP, pop)
- Carbon cycle explicitly modeled
- Temp changes monetized with one or more "damage" functions

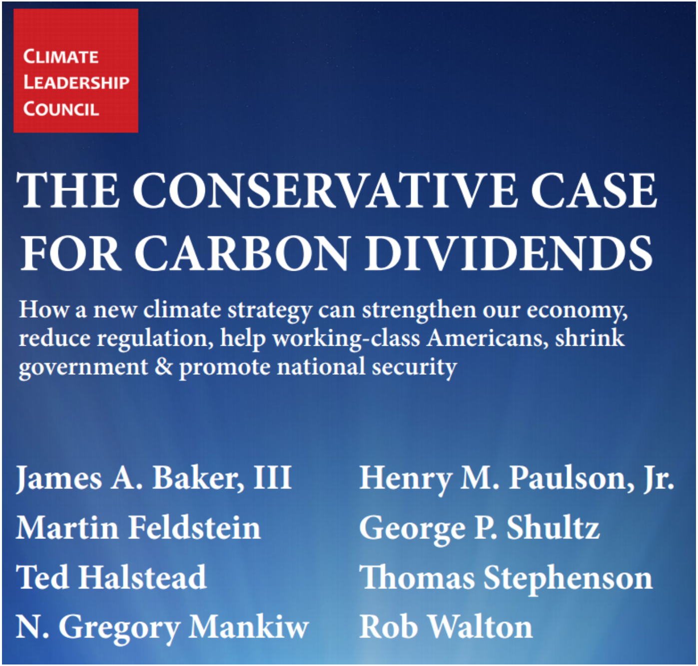
SCC estimates by discount rate

Model	Socioeconomic reference scenario	Discount rate			
		5% Mean	3% Mean	2.5% Mean	3% 95th percentile
DICE	IMAGE	10.8	35.8	54.2	70.8
	MERGE Optimistic	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 ppm average	8.2	24.9	37.4	50.8
PAGE	IMAGE	8.3	39.5	65.5	142.4
	MERGE Optimistic	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 ppm average	5.5	25.4	42.9	104.7
FUND	IMAGE	−1.3	8.2	19.3	39.7
	MERGE Optimistic	−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 ppm average	−2.7	−0.2	3.0	19.4

Source: EPA SCC ; estimates for 2010 in 2007 dollars

How much lower would CO2 emissions be if we impose a tax equal to the social cost of carbon?

- Useful to understanding what we are buying with this tax and achieving CO2 targets
- Alternatively, can use cap-and-trade
- If we knew what the “supply curve” was of CO2 emissions reductions, we could answer these questions
- Politically, we are also interested in knowing how much electricity prices increase under the SCC tax


CLIMATE LEADERSHIP COUNCIL

THE CONSERVATIVE CASE FOR CARBON DIVIDENDS

How a new climate strategy can strengthen our economy, reduce regulation, help working-class Americans, shrink government & promote national security

James A. Baker, III
Martin Feldstein
Ted Halstead
N. Gregory Mankiw
Henry M. Paulson, Jr.
George P. Shultz
Thomas Stephenson
Rob Walton

Source: Climate Leadership Council

How would you go about coming up with this supply curve?

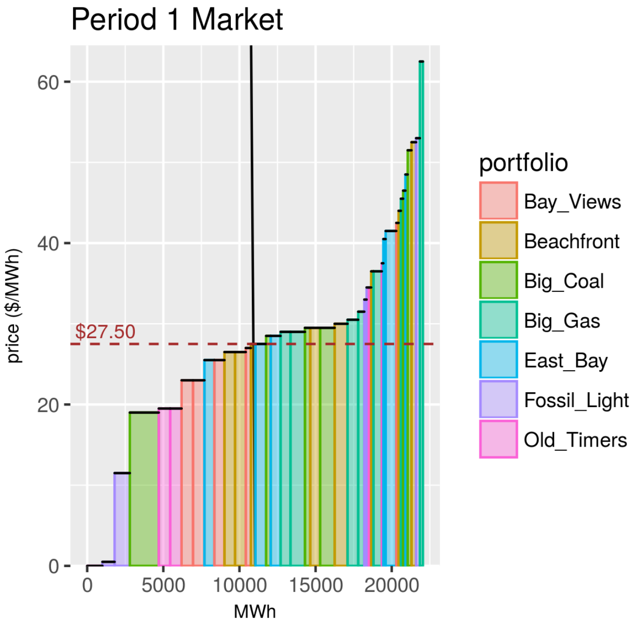
- Let's say we want to know how much lower CO2 emissions are under at $30/ton tax in the electricity sector.
- This works by requiring electricity generators to pay a tax equal to $30*(CO2/MWh) for every unit of power
- How would you predict how much lower CO2 emissions will be at this price?

Through what channels does a CO2 tax reduce emissions?

Through what channels does a CO2 tax reduce emissions?

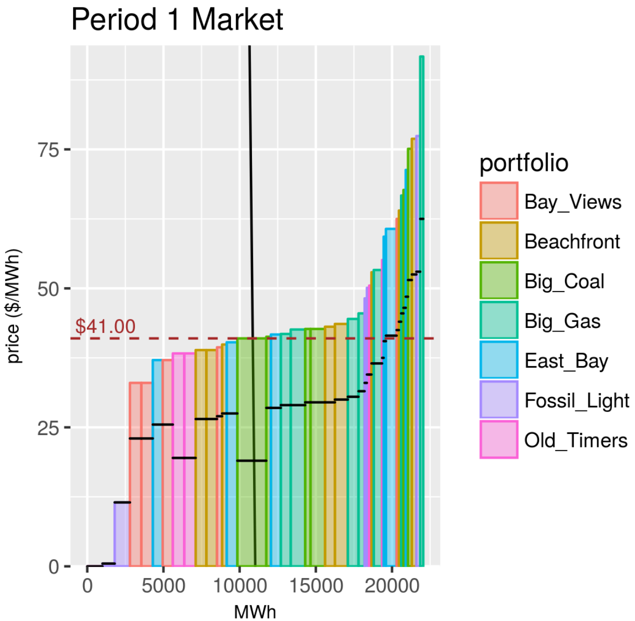
- Fuel switching
  - Coal may become more expensive than other low carbon sources
  - As coal becomes less competitive, it gets dispatched less often
- Demand response
  - If electricity prices increase, and consumers purchase less (short run)
  - If prices are expected to stay high, people may invest in energy efficiency (long run)
- Capacity entry / exit
  - The tax may reduce coal plant profits such that it is no longer profitable to stay online
  - When building new capacity to meet demand, investors may choose to build renewable or gas plants rather than coal or oil
- Innovation?

Reordering the dispatch curve: Baseline



Note: black marginal cost line assumes carbon price of $0.00

Reordering the dispatch curve: $40 Carbon tax



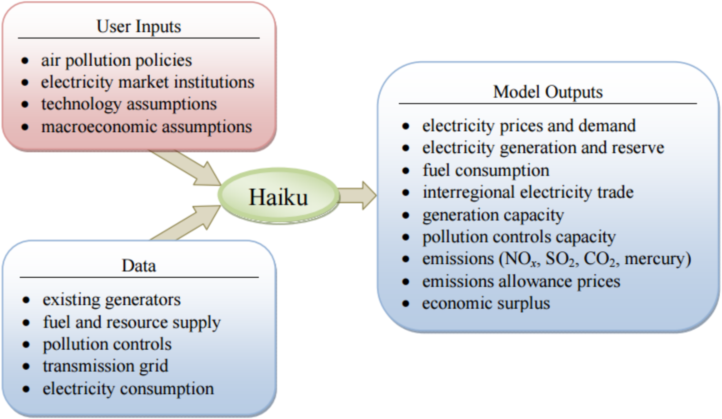
Note: black marginal cost line assumes carbon price of $0.00

The most common approach to estimating CO2 abatement cost curves is an "engineering" approach

- If we know the capacity, cost and carbon intensity of every generator, we can stack them up in ascending order to generate a supply curve
- Then if we know the quantity demanded at each location, we can figure out how much each generator will produce in a given time period
    - need to account for power flows across regions, transmission, etc
- We can do this under two scenarios, with and without the tax
- Sum up total emissions and take the difference to estimate reductions under the policy

This is the approach taken by Paul, Beasley and Palmer (2013)

Paul et al (2013) use the RFF Haiku Electricity Model

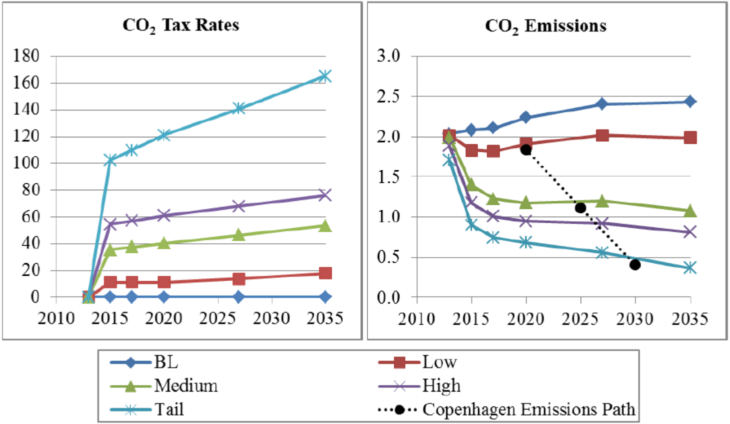


See the RFF Haiku documentation for more information

Paul et al (2013) use the RFF Haiku Electricity Model

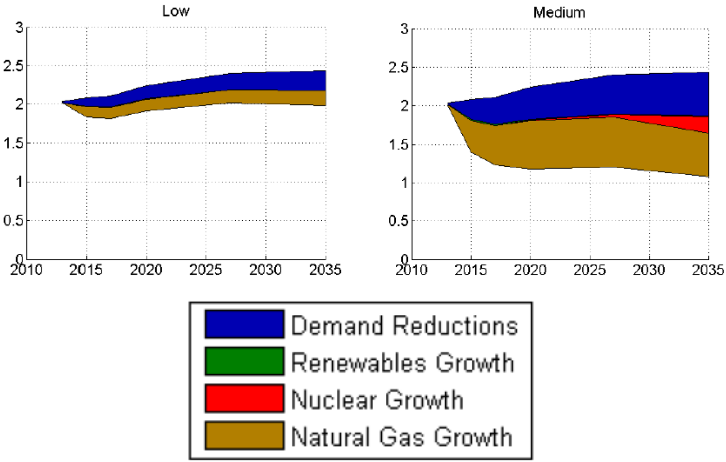
- Haiku solves for the spatially and inter-temporally linked minimum cost solution to meeting electricity demand
- Space: country aggregated into regions
- Time: model typically solved in 5 year increments out to 2025 or 2030
- Cost minimization: rules out market power
- There is no uncertainty in the model

Paul et al (2013) run Haiku for many different tax levels

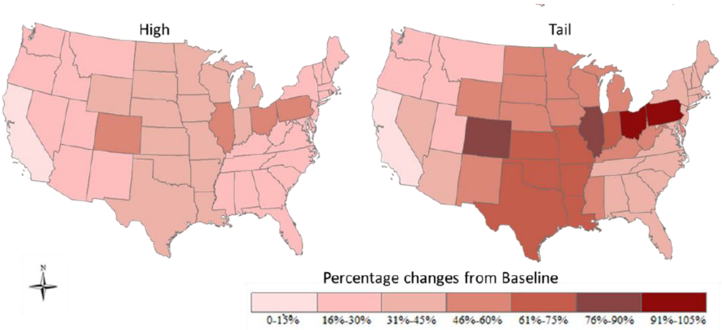


Able to clearly unpack the results to see what's going on

Figure 2. CO_2 Emissions Reductions Profile (B Short Tons)



Also able to estimate the impact on consumers by region



Pros and cons to the modeling approach

- Benefits:
  - very clear methodology, and easy to see assumptions
  - can model many different scenarios
  - can forecast well into the future
- Costs
  - model only only as good as the assumptions you give it
  - real world is much more complicated
  - uncertainty over future inputs probably first order

An alternative approach is to try to estimate the relationship between emissions and CO2 prices econometrically

- Don't currently have a nationwide tax on CO2 in the US
- There are some regional programs (RGGI, CA) and carbon prices have been implemented in other countries (EU, Australia)
- Power systems are idiosyncratic: how applicable those results?
- One option is the look for other things that affect electricity producers similarly to the way a carbon tax would
- Cullen and Mansur (2015)
  - Show that C02 prices and cheap natural gas affect the electricity sector the same way
  - Take advantage of the fracking revolution's impact on gas prices

Cullen and Mansur intuition

$$MC = VO\&M + HR * P_{fuel} + HR * \frac{CO_2}{btu} P_{co2}$$

- Fuel switching depends on the relative costs of available generators
  - if the marginal cost of gas is lower than coal, it will get dispatched first
- Put another way: if gas is cheaper than coal, $\frac{MC_{gas}}{MC_{coal}} < 1$
- Looking at equation above, for any CO2 price, there is an equivalent pair of fuel prices that generate the same cost ratios

The way we typically think about a CO2 supply curve ...

Table 1: Cost Ratios with Carbon Price

Carbon Price	Gas Cost					Coal Cost					Coal/Gas Cost Ratio
	Fuel	+	Carbon	=	Total	Fuel	+	Carbon	=	Total	
\$0	5.75	+	0.00	=	**\$5.75**	2.25	+	0.00	=	**\$2.25**	0.39
\$10	.	+	0.59	=	**\$6.34**	.	+	1.05	=	**\$3.30**	0.52
\$20	.	+	1.17	=	**\$6.92**	.	+	2.11	=	**\$4.36**	0.63
\$30	.	+	1.76	=	**\$7.51**	.	+	3.16	=	**\$5.41**	0.72
\$40	.	+	2.34	=	**\$8.09**	.	+	4.22	=	**\$6.47**	0.80
\$50	.	+	2.93	=	**\$8.68**	.	+	5.27	=	**\$7.52**	0.87
\$60	.	+	3.51	=	**\$9.26**	.	+	6.32	=	**\$8.57**	0.93
\$70	.	+	4.10	=	**\$9.85**	.	+	7.38	=	**\$9.63**	0.98
\$80	.	+	4.68	=	**\$10.43**	.	+	8.43	=	**\$10.68**	1.02
\$90	.	+	5.27	=	**\$11.02**	.	+	9.49	=	**\$11.74**	1.07
\$100	5.75	+	5.85	=	**\$11.60**	2.25	+	10.54	=	**\$12.79**	1.10

Notes: Fuel costs are in \$/mmBTU and carbon price is in \$/ton of CO_2.

C&M's insight is that the same ratios can be achieved by low gas prices

Table 2: Cost Ratios with Low Gas Price

Carbon Price	Gas Cost Fuel	Coal Cost Fuel	Coal/Gas Cost Ratio
\$0	\$5.75	\$2.25	0.39
\$0	\$4.33	.	0.52
\$0	\$3.57	.	0.63
\$0	\$3.13	.	0.72
\$0	\$2.81	.	0.80
\$0	\$2.59	.	0.87
\$0	\$2.42	.	0.93
\$0	\$2.30	.	0.98
\$0	\$2.21	.	1.02
\$0	\$2.10	.	1.07
\$0	\$2.05	\$2.25	1.10

Natural experiment: Fracking

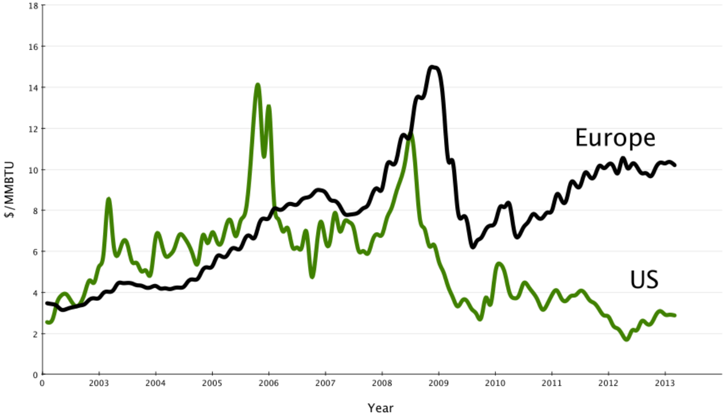
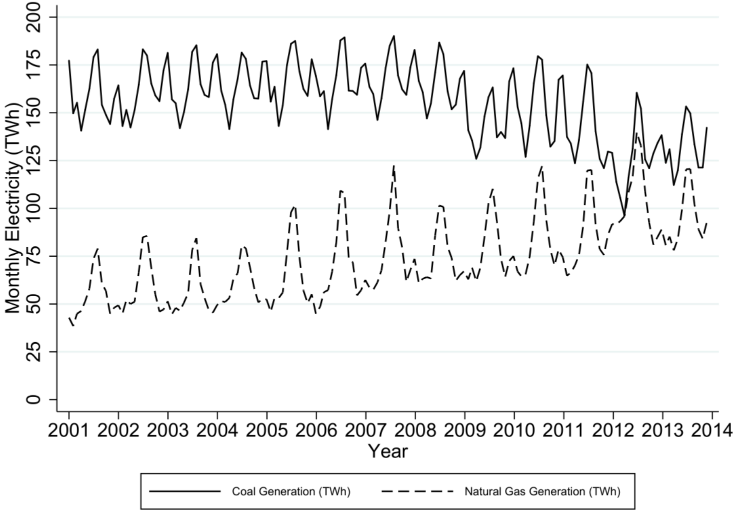
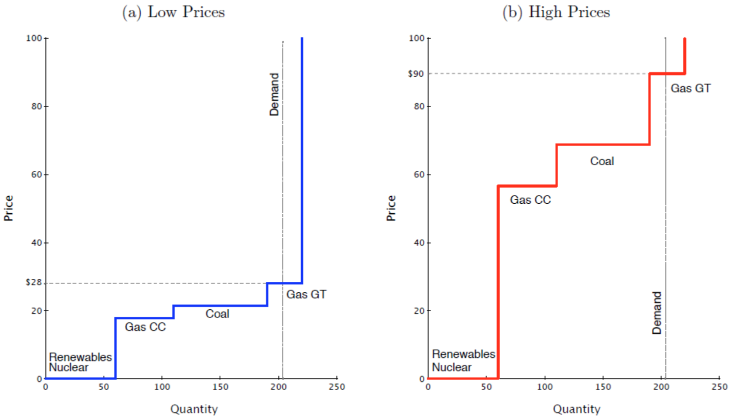


Figure 1. : US and European Natural Gas Prices

Natural experiment: Fracking



The key assumption is that demand is fixed



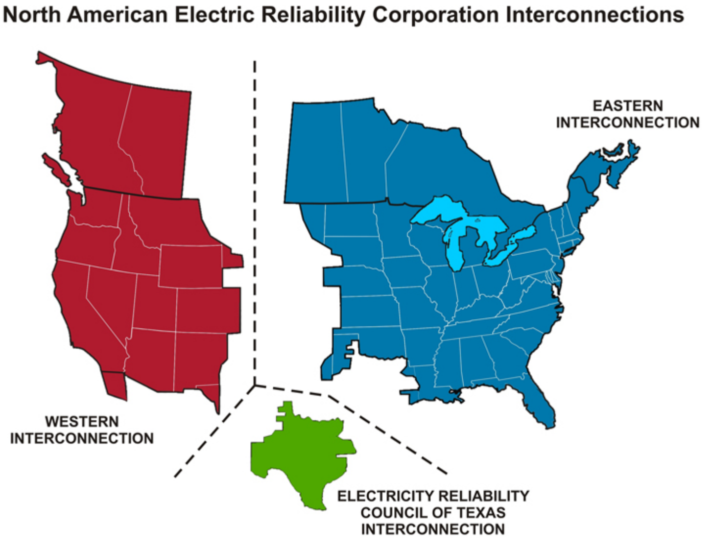
Then although the level of prices changes, the CO2 emissions from two scenarios are identical if they have the same cost ratios.

Cullen and Mansur data and methods

- Have detailed data on output by hour for every generator
- Construct regional input cost and demand variables
- Aggregate up to the interconnection level (East, West, Texas)

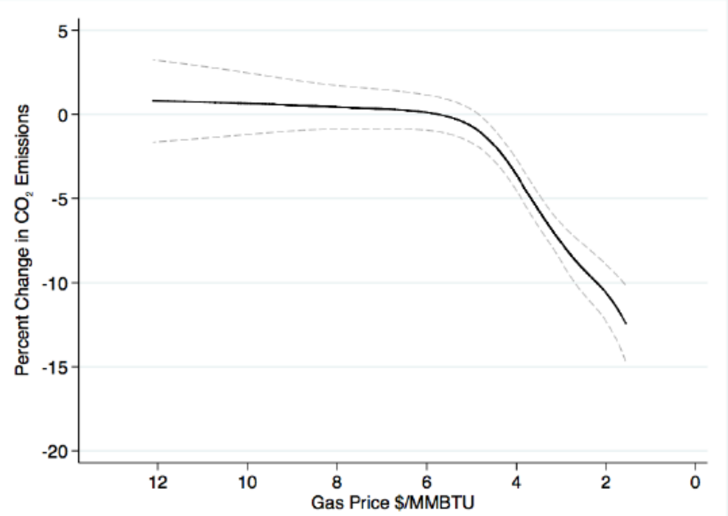
$$CO2_t = s(CR_t|\beta) + s(load_t|\theta) + s(tempt|\omega) + Xt\psi + D\gamma + \epsilon_t$$

Regressions run at the interconnection level



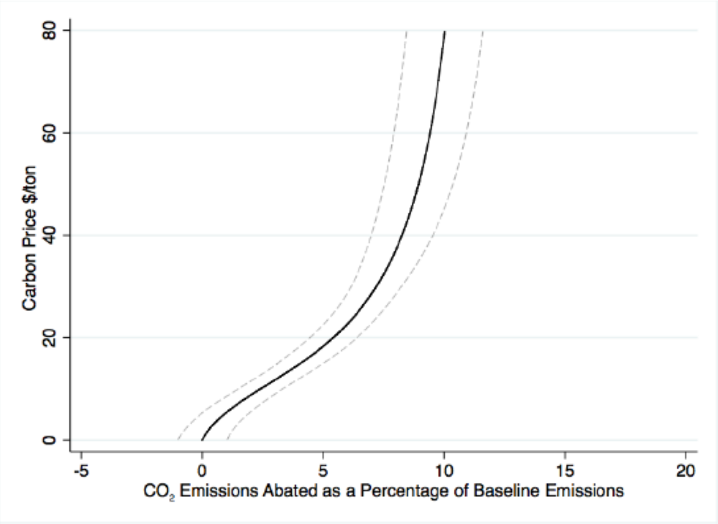
Regression results are complicated, but main point summarized graphically by region

(a) Eastern Interconnection



Can convert this into an emission reduction supply curve

(a) Eastern Interconnection



Combining the three regions yields a national supply curve

Table 5: Predicted Emissions (and Percentage Abatement)

Tax	East		ERCOT		West		All	
0	51.7	(0.0%)	5.7	(0.0%)	8.7	(0.0%)	66.2	(0.0%)
10	50.5	(2.4%)	5.6	(2.6%)	8.7	(0.6%)	64.8	(2.2%)
20	49.0	(5.4%)	5.5	(4.2%)	8.5	(2.1%)	63.0	(4.9%)
30	48.0	(7.2%)	5.5	(4.7%)	8.3	(4.7%)	61.8	(6.7%)
40	47.5	(8.3%)	5.4	(5.3%)	8.1	(7.2%)	61.0	(7.9%)
50	47.1	(8.9%)	5.4	(6.2%)	7.9	(9.5%)	60.4	(8.8%)
60	46.9	(9.4%)	5.3	(7.1%)	7.7	(11.5%)	59.9	(9.5%)
70	46.7	(9.8%)	5.3	(7.9%)	7.6	(13.1%)	59.5	(10.0%)
80	46.6	(10.0%)	5.2	(8.6%)	7.5	(13.6%)	59.3	(10.4%)

Notes: Prediction emissions are in 100,000 tons/day.

Pros and cons of this approach

- Benefits
  - do not need to model complicated electricity sector
  - do not need to know costs, who can supply which markets, etc
  - observed behavior encompasses market power or other objective functions
- Cons
  - Short run only
    - Assumes no investment / exit

Comparison with other engineering studies

TABLE 5

ESTIMATES OF EMISSIONS REDUCTIONS FROM A NATIONAL CARBON PRICE

Study	Tax rate in 2015 (\$/metric ton CO_2e)	Annual increase in tax rate	Emissions reductions in 2030 (vs baseline)
McKibben et al. (2012)	\$17.76	4.0%	11%
Paltsev et al. (2007)	\$21.16	4.0%	31%
Rausch & Reilly (2012)	\$21.63	4.0%	19%
Shapiro et al. (2008)	\$27.27	\$1.80	30%
Rausch et al. (2010)	\$28.99	4.0%	25%

Source: Adapted from Morris and Mathur (2014).

Another approach to estimating the impact of some policy on industry is an event study

- A company's stock price is equal to the present value of expected future profits $marketcap = \sum_t^{\infty} \frac{profit_t}{(1+r)^t}$
- If a new regulation is suddenly imposed, its stock price should immediately adjust to reflect the expected impact on profits
- If we can estimate the profit function, can translate this into changes in marginal cost
- Example: Lange and Linn (2008) use this to estimate the impact of New Source Review
  - Al Gore was expected to have a much broader interpretation of this rule
  - L&L look at what happened to the stock prices of affected companies when the Supreme Court halted the recount of votes in FL, which gave the presidency to Bush

Meng (2015) uses this approach to estimate marginal costs of cap-and-trade

- In 2009, a nation-wide cap-and-trade program (Waxman-Markey) passed in the House, but subsequently died in the Senate
- Under this bill, some regulated firms received free permits, which, in expectation, are worth the value of marginal abatement costs
- Meng looks at the relationship between these firms' stock prices and prediction markets on the probability of WM becoming law
- He estimates that the marginal abatement cost of CO2 is between $5 and $18

Summary

- Intro to different ways to estimate the cost of policy
  - Each approach has pros and cons
  - The latter two might be feasible strategies for your term paper
- More generally, discussed current estimates of the cost of climate policy
  - All three approaches suggest the world is not going to end...
  - The discussion also highlights the key drivers of climate policy costs:
    - demand response
    - fuel switching
    - investment
  - We now know a decent amount about the first two, but very little about the long run stuff