Empirical Methods for the Analysis of the Energy Transition: Day 3

CEMFI Summer School

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Today's outline

1) Environmental regulations in electricity markets
   - Cap-and-trade markets
   - Pass-through
   - Leakage
2) Case study: Leakage in the California electricity market
   - Overview of paper
   - Code

Introduction

Permit markets have been used in electricity to internalize pollution in several settings:

- **SO_2**: Acid Rain Program (EEUU)
- **NO_x**: Budget Trading Program, RECLAIM
- **CO_2**: ETS (Europe, Australia, New Zeland), RGGI, AB32 (EEUU)

Pollution permits interact with the existing institutional features of electricity markets (regulation, market power, technology mix, profitability).

Responses to pollution permits

Electricity firms can respond to pollutions costs in several ways:

- **Short-run:** shift production to cleaner inputs or different technologies
- **Medium-run:** perform plant refurbishing and install scrubbers
- **Long-run:** change investment plans to a cleaner mix

Depending on the pollutant, some abatement options are more feasible than others.

Today focus on *evidence of response* in the short and medium term.

Analyzing responses to pollution permits

Several empirical strategies have been used to identify the importance of pollution permits in market outcomes.

Some examples:

- Impacts on prices/short-run outcomes and compliance
  - Bushnell et al. (2013) (regression discontinuitiy), Fabra and Reguant (2014) (IV pass-through), Fowlie (2010) (random effects)
- Endowment effect
  - Fowlie and Perloff (2012), Reguant and Ellerman (2008)
- Counterfactual simulations
  - Fowlie, Reguant and Ryan (2014), Fowlie and Mueller (2013), Toyama (2020)

Bushnell, Chong and Mansur (2013)

Profiting from Regulation: Evidence from the European Carbon Market

By James B. Bushnell, Howard Chong, and Erin T. Mansur*

We investigate how cap-and-trade regulation affects profits. In late April 2006, the EU CO_2 allowance price dropped 50%, equating to a €28 billion reduction in the value of aggregate annual allowances. We examine daily returns for 552 stocks from the EUROSTOXX index. Despite reductions in environmental costs, we find that stock prices fell for firms in both carbon- and electricity-intensive industries, particularly for firms selling primarily within the EU. Our results imply that investors focus on product price impacts, rather than just compliance costs and the nominal value of pollution permits.

JEL: G14, Q50, H23, Q54, H22
Keywords: Climate Regulation, Incidence, Event Study

Summary of BCM (2013)

What does the paper do?

1) Explore the impacts of carbon prices on firms' stock value
2) Exploit an exogenous discontinuity in carbon prices due to information updating

What does the paper find?

- Responses of firms to the change in prices in line with predictions
- Cleaner firms suffered relatively more from the drop in carbon prices
- Importantly, firms can be *worse off* from reduced environmental compliance

Context and Data

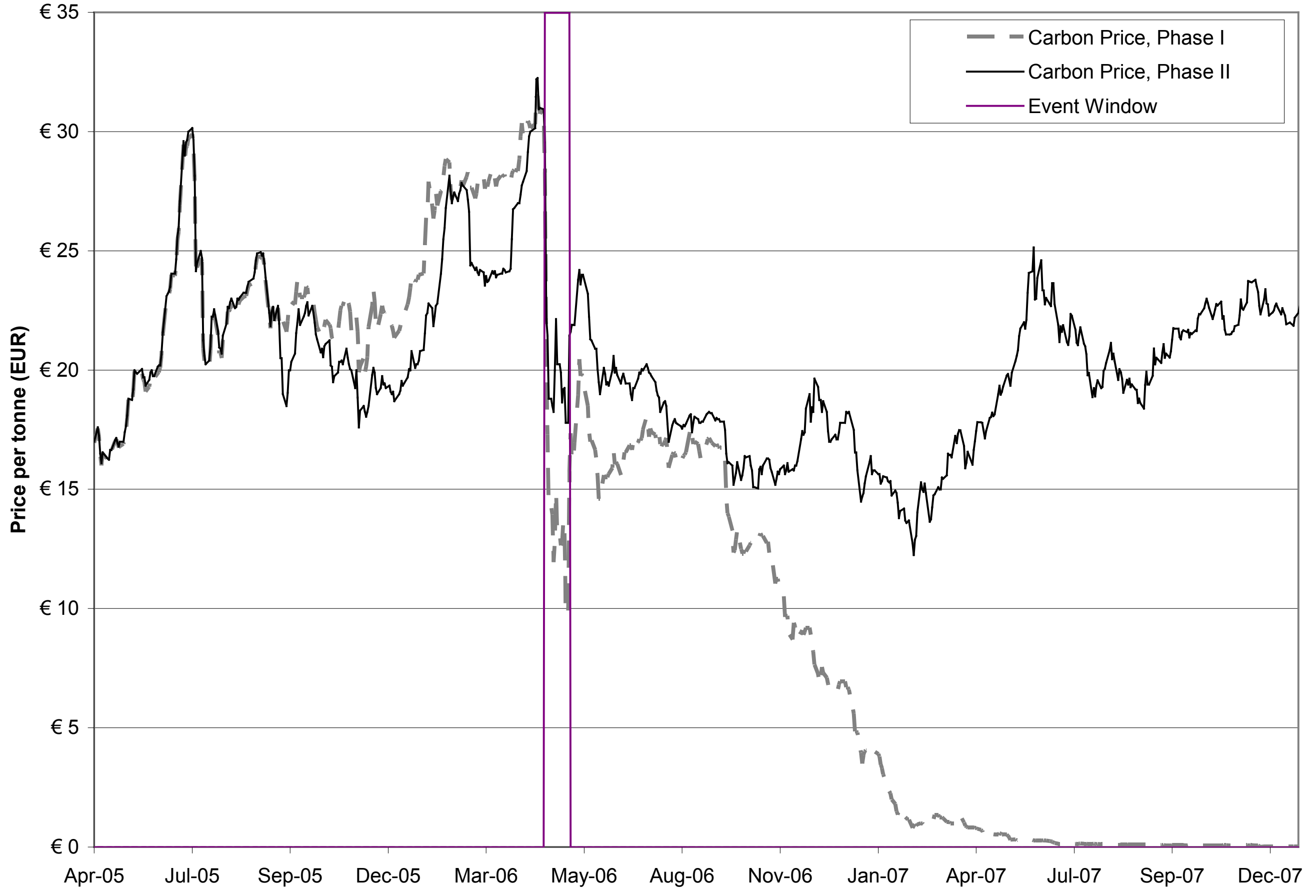
- Study effects of cap-and-trade regulation on firm profits during EU ETS trial period (2005-2007).
- Focus on sudden drop in prices in late April, 2006.
- Updated information in the stringency of the cap induced prices to collapse rapidly. Match firms to their publicly traded stocks and examine daily returns around price jump.
- Match some to their emissions.

Goal: Study market response to changes in regulatory costs.

EU Emissions Trading Scheme

- Cap-and-trade market for tons of CO_2
- Covers mostly static polluting installations in power generation and manufacturing
- First phase: 2005-2007, self-contained
- Emissions allowances given for free to most installations
- Firms can trade permits across countries/ industries:
  - Permits have an opportunity cost

Drop in ETS prices



Methodology

- Look at returns of firms affected by the regulation around the discontinuity.
- Stock market data (firm-level and Dow Jones).
- Emissions data from Community Independent Transaction Log (CITL).
- Basic event study regression:

$$S_{ijt} = \alpha_i + \beta_i M_t + \gamma_j EVENT_t + \epsilon_{ijt}$$

Event results

TABLE 1—STOCK MARKET THREE-BUSINESS DAY CUMULATIVE ABNORMAL RETURNS BY INDUSTRY

NACE	Industry Description	Observations	-44% Permit Price Drop April 26, 2006 Main Event		+16% Permit Price Rise January 13, 2006 Event	
10	Coal and lignite mining	2	-0.032	(0.021)	0.045	(0.034)
11	Crude petroleum extraction	20	-0.032	(0.017)*	0.038	(0.017)**
27	Basic metals	15	-0.031	(0.011)***	0.055	(0.027)**
90	Sewage and refuse	1	-0.027	(0.012)**	0.037	(0.033)
61	Water transport	2	-0.027	(0.020)	0.001	(0.023)
23	Refining and coke	2	-0.027	(0.015)*	0.037	(0.016)**
30	Computer manufacturing	2	-0.023	(0.007)***	-0.056	(0.055)
13	Metal ores mining	7	-0.023	(0.023)	0.096	(0.034)***
16	Tobacco manufacturing	3	-0.019	(0.005)***	0.019	(0.016)
40	Electricity and gas	26	-0.017	(0.014)	0.049	(0.026)*
70	Real estate	16	-0.016	(0.003)***	0.023	(0.010)**
41	Water	4	-0.016	(0.008)*	0.035	(0.027)

If regulation costs go down, how can profits go down?

Negative impact of price drop

Additional Effects

In the EU-ETS, and similar to other cap-and-trade programs, most permits were allocated for free.

Consider the profits of a firm:

$$\pi_i = P(q_i + q_{\neq i})q_i - C_i(q_i, \omega) + \tau A_i - \tau r_i(q_i, I_i)q_i - k(I_i)$$

ω: input costs

A_i: free allocation; τ : emissions price

r_i : emissions rate; I_i : abatement investments

Effect (local):

$$\frac{d\pi_i^*}{d\tau} = P' \frac{\partial q_{\neq i}^*}{\partial \tau} q_i^* + \left[P' \frac{\partial q_{\neq i}^*}{\partial \omega} q_i^* - \frac{\partial C}{\partial \omega} \right] \frac{\partial \omega}{\partial \tau} + [A_i - r_i q_i^*]$$

Revenue increase due to reduced output

Indirect impact on costs

Net position

Focus on Electricity Firms

- Exploit heterogeneity in technology mix.
- Cleaner firms have small effects on marginal costs, but benefit from high electricity market prices.
- Dirtier firms can have ambiguous effects:
  - Higher costs from higher carbon prices
  - Reduced revenues from permits if long
  - Reduced profits for clean share of mix

- Authors find that stock value decreased more for cleaner firms in response to lower carbon prices.

Results for electricity companies

Table 3—Stock Market Cumulative Abnormal Returns for Firms in the Electricity Sector

Stock name	Main event (1)		January counter event (2)		Carbon per MWh (3)	Carbon per equity (4)	Allowances per equity (5)	Net allowances per equity (6)
Fortum	−0.088	(0.075)	0.086	(0.060)	0.214	142.8	157.1	14.3
Verbundgesellschaft	−0.086	(0.061)	0.099	(0.063)	0.252	610.5	535.5	−75.0
British Energy Group	−0.071*	(0.043)	0.076**	(0.032)	0.108	1236.2	779.2	−457.0
EDF	−0.050*	(0.028)	0.093**	(0.044)	0.104	459.1	402.6	−56.4
RWE (XET)	−0.045**	(0.023)	0.054	(0.052)	0.909	3587.1	3436.8	−150.3
Vestas Wind	−0.026	(0.033)	0.086*	(0.049)				
A2A	−0.024***	(0.004)	0.066**	(0.027)	0.287	812.1	1029.8	217.8
Atel Holding ‘R’	−0.022	(0.015)	0.046*	(0.025)	718.1	821.6		
DRAX Group	−0.019	(0.047)	0.110***	(0.012)	1.046	4384.0	3071.8	−1312.2
United Utilities Group	−0.018***	(0.005)	0.030*	(0.016)	0.1	0.1		
EDP Energias de Portugal	−0.015	(0.011)	−0.018	(0.025)	0.712	1283.8	1221.2	−62.6
Solarworld	−0.013	(0.024)	0.077***	(0.026)				
International Power	−0.012**	(0.005)	0.091	(0.067)	0.611	1203.1	1098.4	−104.7
E.ON	−0.007	(0.015)	0.003	(0.028)	0.525	1196.0	1090.8	−105.2
Red Electrica de Espana	−0.005	(0.012)	0.055*	(0.03)				
Scot. & Southern Energy	−0.004	(0.010)	0.045*	(0.027)	0.819	1626.7	1178.7	−447.9
ENEL	−0.003	(0.006)	0.037	(0.037)	0.501	1320.2	1133.3	−186.8
National Grid	−0.001	(0.007)	0.022	(0.040)				
Terna	−0.001	(0.010)	0.021	(0.037)				
Sofina	−0.006	(0.013)	0.026*	(0.016)				
Union Fenosa	0.004	(0.005)	0.024	(0.015)	0.972	1740.3	1382.7	−357.6
Schneider Electric	0.011	(0.020)	0.003	(0.013)				
Iberdrola	0.015***	(0.002)	0.010	(0.013)	0.349	608.2	529.7	−78.6
Public Power	0.052***	(0.012)	0.014	(0.010)	0.982	11659.6	11550.4	−109.2
Coefficient estimates					0.071**	7.445***	7.175***	−5.937
					(0.033)	(1.924)	(2.098)	(31.510)

Conclusions

- Paper presents evidence that stock market responded to the event in the EU ETS.
- The stock market valuation captured the effects of carbon on firms' portfolios, not just compliance costs.
- Evidence is somewhat mixed in its quantification, unclear whether the impacts are as large as "theory would predict", or just suggestive.

Fabra and Reguant (2014)

Pass-Through of Emissions Costs in Electricity Markets†

By NATALIA FABRA AND MAR REGUANT*

We measure the pass-through of emissions costs to electricity prices. We perform both reduced-form and structural estimations based on optimal bidding in this market. Using rich micro-level data, we estimate the channels affecting pass-through in a flexible manner, with minimal functional form assumptions. Contrary to many studies in the general pass-through literature, we find that emissions costs are almost fully passed through to electricity prices. Since electricity is traded through high-frequency auctions for highly inelastic demand, firms have weak incentives to adjust markups after the cost shock. Furthermore, the costs of price adjustment are small. (*JEL* D44, L11, L94, L98, Q52, Q54)

Pass-through in economics

- Pass-through: price change after a cost shock.
  - Industrial Organization: merger assessment
  - International Economics: exchange rates
  - Public Economics: tax incidence

- Empirical measurement of pass-through, challenging.
  - Marginal costs non-observable and/or endogenous
  - Reliance on structural forms
  - Implications for pass-through?

This Paper

Pass-through of emissions costs to electricity prices

1. Measure pass-through
2. Decompose determinants of pass-through

Policy relevant topic:

- Cap&Trade programs for emissions control
- Efficiency vs distributional concerns
  - Cost internalization is necessary for efficiency
  - Distributional concerns of pass-through

Some advantages

- Electricity markets, unique setting for a pass-through analysis
  - Detailed bid data: supply and demand
  - Reliable cost data
  - Emissions costs well measured
  - Emissions costs relevant and heterogeneous
  - Plausibly exogenous to the firms in our market
  - Strategic behavior well understood

Literature

- Environmental/Electricity literature:
  - Zachmann and Hirschhausen (2008), Bushnell et al (2013)
  - Sjim et al. (2006), Fowlie (2010), Kosltad and Wolak (2008)

- Pass-through literature :
  - Theory: Fabinger and Weyl (2013)
  - Exchange-rates: Golberg and Hellerstein (2008, 2013), Golberg and Knetter, (1997) Golberg and Verboven (2010), Nakamura and Zerom (2010), etc.
  - Tax pass-through

Spanish Electricity Market

- Liberalized electricity market since 1998
- Relatively insulated from the rest of Europe
- Daily auctions to sell and buy electricity
- Production based on thermal plants (coal, gas), nuclear, hydro and renewables
- High concentration: 2 large+2 small firms
- Retail prices mostly regulated

Bid Data

- Market clearing prices and quantities
- Hourly bidding data at the wholesale electricity market (demand and supply)
  - Step-wise bids at the unit-level (generators) or demand-unit level (retailers, pumped storage, industrial customers)

This allows us to construct supply functions, demand functions, residual demand functions and to identify the price-setting unit

Cost Data

Marginal costs

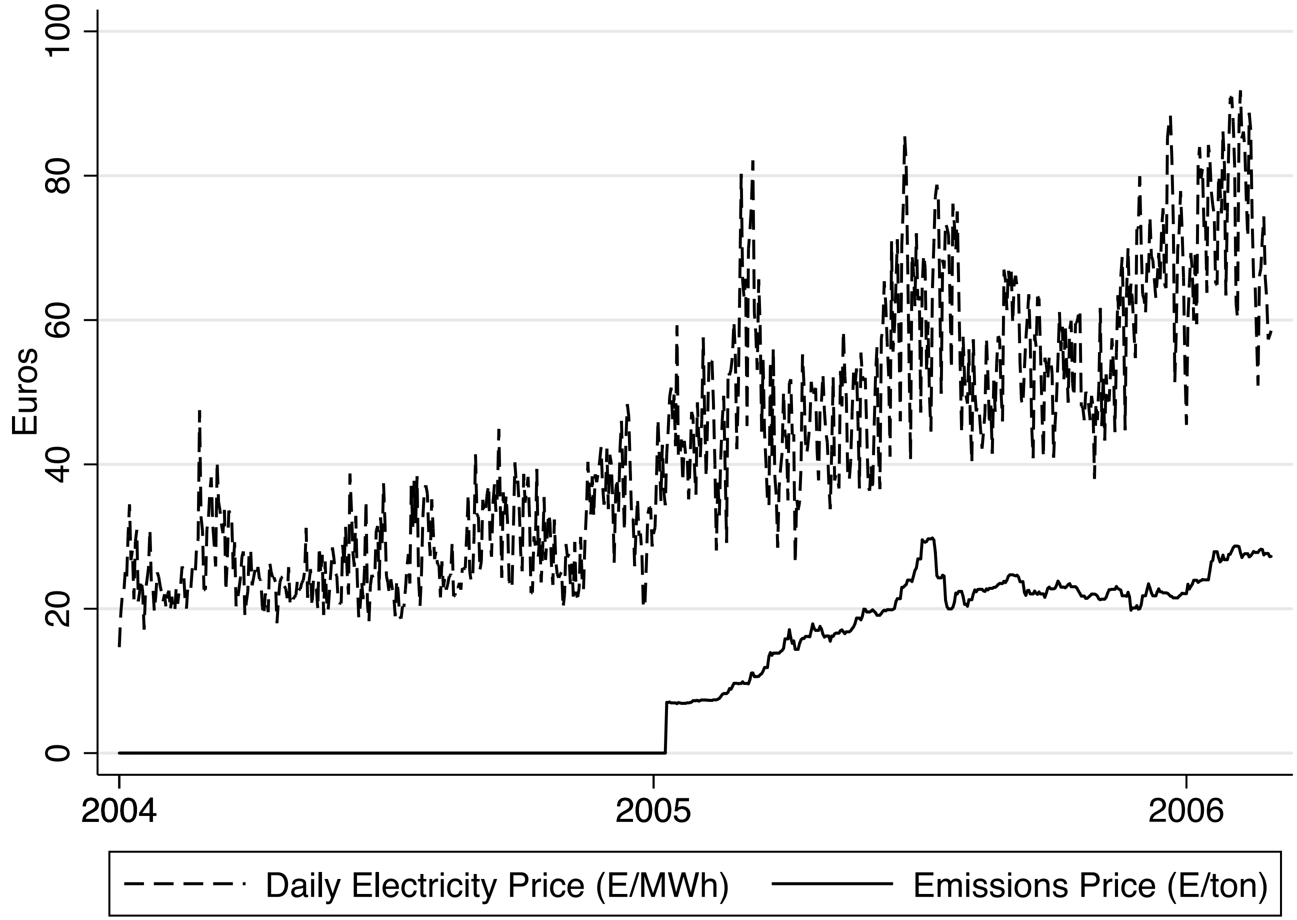
= input costs+ emissions costs

heat rates x
commodity prices
(coal, gas, oil)

emissions rate x
permit price

Information at the power plant level

Electricity and Carbon Prices



Measuring Pass-through

- Use reduced form representation of equilibrium prices:

$$p^*_{th} = P_t(e_{th}\tau_t, X_{th}, X^S_{th}, X^D_{th})$$

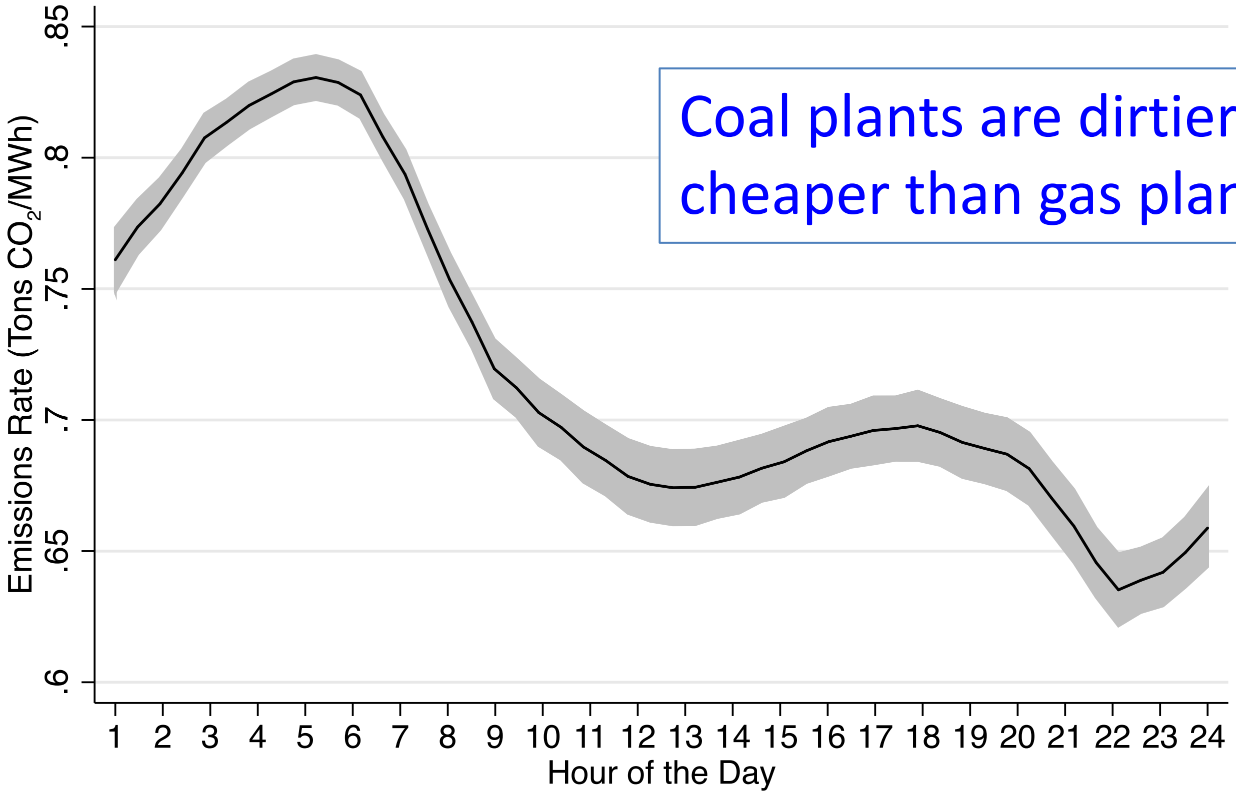
- Pass-through regression:

$$p_{th} = \boxed{\rho^c \tau_t e_{th}} + X_{th}\beta_0 + X^S_{th}\beta_1 + X^D_{th}\beta_2 + \omega_{th}\delta + \epsilon_{th}$$

Fabra & Reguant (2014)

Endogeneity of Emissions Costs

Figure 2.2: Average Marginal Emissions Rate across the Day



Coal plants are dirtier but cheaper than gas plants

Need to instrument marginal emissions rate with carbon price

Instrumental Variables Approach

- We use emissions prices at the European level as an instrument for emissions costs
- Supply side/structural model:
  - Emissions price freely traded across participating states, several sectors and many firms
- Demand side:
  - Emissions price could reflect macroeconomic trends
  - Within month variation, control for commodity prices and other demand shifters

Measuring Pass-through

	(1)	(2)	(3)	(4)	(5)
Mg. Emissions Costs (ρ)	0.862	0.860	0.835	0.829	0.848
	(0.181)	(0.182)	(0.173)	(0.172)	(0.168)
Temperature	-0.231		[illegible]		
	(0.060)				
Maximum Temperature	0.137				
	(0.050)		[illegible]		
Wind Speed	-2.086	-2.171	-2.089	-2.191	-2.238
	(0.354)	(0.361)	(0.333)	(0.337)	(0.329)
Wind Speed Squared	0.055	0.066	0.054	0.067	0.068
	(0.025)	(0.025)	(0.023)	(0.023)	(0.023)
Coal	57.477	45.548	57.496	45.469	
	(4.035)	(4.364)	(3.885)	(4.164)	
Gas	5.638	3.589	5.604	3.563	
	(0.407)	(0.405)	(0.391)	(0.387)	
Brent	-2.896	-1.685	-2.938	-1.778	
	(0.881)	(0.985)	(0.834)	(0.930)	

Estimates indicate 80% pass-through

Dynamic Effects: Peak vs Off-peak

	(1)	(2)	(3)	(4)	(5)
Mg. Emissions Costs - Peak	1.085	1.083	1.055	1.051	1.107
	(0.185)	(0.185)	(0.178)	(0.177)	(0.175)
Mg. Emissions Costs - Off Peak	0.635	0.633	0.608	0.603	0.496
	(0.170)	(0.170)	(0.164)	(0.163)	(0.164)
MonthXTemp,MaxTemp	N	Y	N	Y	Y
MonthXHour FE	N	N	Y	Y	Y
HourXInput	N	N	N	N	Y

Full pass-through at peak times

Lower pass-through when dynamic constrains present

Understanding Pass-through

- The finding of a complete pass-through is an exception in the broader pass-through literature
- Exchange-rate pass-through: <50% or less
- Main channels of pass-through incompleteness:
  - Mark-up adjustment
  - Non-traded costs (non affected by exchange rates)
  - Costs of price adjustment
  - [Mismatch between observed *vs.* actual costs]

Understanding Pass-through

Why pass-through so high?

Standard channels not at play?

Other channels?

- Demand, supply and markup adjustments
  - Measuring opportunity costs of permits
  - Incentives to adjust markups
- Functional form specification
- Price rigidities

Structural framework

- Profit maximization:

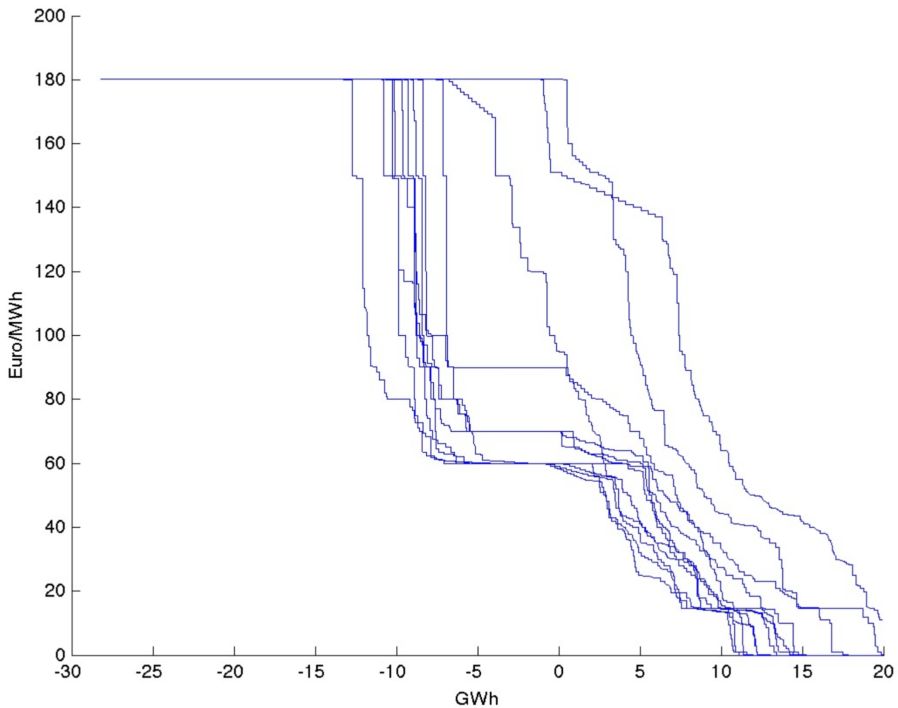
$$p = \underbrace{c_i + \tau e_i}_{\text{mg. cost}} + \underbrace{\left|\frac{\partial D_i^R}{\partial p}\right|^{-1} Q_i}_{\text{markup}}$$

- Empirical bidding equation:

$$b_{ijth} = \underbrace{\alpha_{ij} + \beta_i c_{jt} + \gamma_i \tau_t e_{ij}}_{\text{mg. cost}} + \underbrace{\theta_i \left|\frac{\partial \widehat{D^R}_{ijth}}{\partial p_{th}}\right|^{-1} Q_{ijth} + \epsilon_{ijth}}_{\text{markup}}$$

Constructing Markup Term

- Terms in FOC can be approximated thanks to the richness in the bidding data



Demand, supply and markups

- Profit maximization:

$$p = \underbrace{c_i + \tau e_i}_{\text{mg. cost}} + \underbrace{\left| \frac{\partial D_i^R}{\partial p} \right|^{-1} Q_i}_{\text{markup}}$$

- Empirical bidding equation:

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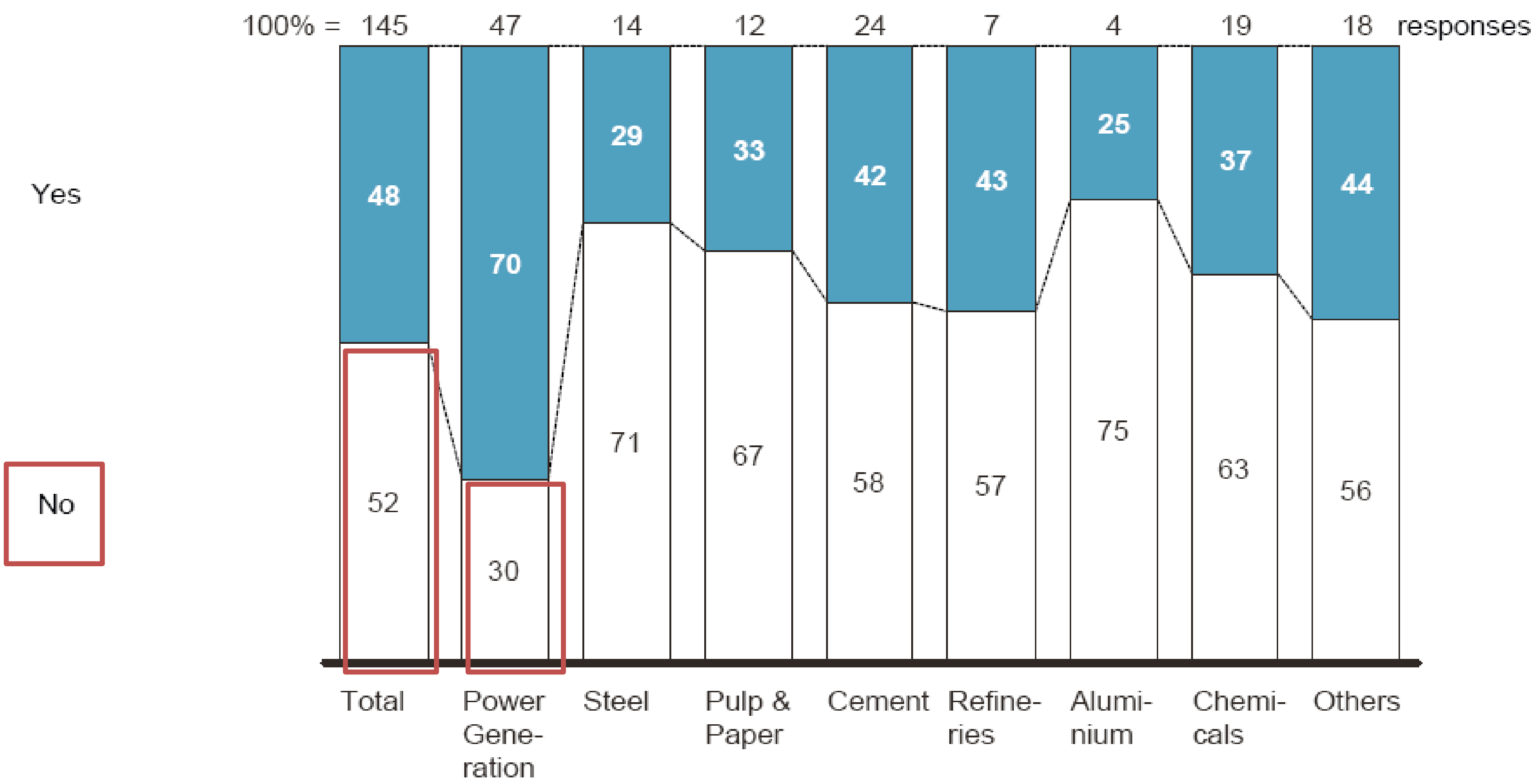
Which costs do firms internalize?

- Permits have an opportunity cost even if received for free, as they can be sold in the emissions market, but…
  - Are there transaction costs?
  - What if firms expect to receive more free allocations in the future if they increase their current emissions?
  - What if firms believe that permits cost nothing because they were free?

EU Survey (June-September 2005)

Are you already **now** "pricing in" the value of CO2 allowances into your daily operations?



Opportunity Costs: Emissions

	All	Firm 1	Firm 2	Firm 3	Firm 4
Emissions cost (γ)					
(1) No FE	0.939	0.925	0.998	1.117	0.806
	(0.070)	(0.039)	(0.032)	(0.039)	(0.073)
(2) Unit FE	0.971	0.947	0.963	1.062	0.803
	(0.034)	(0.031)	(0.039)	(0.046)	(0.102)
(3) Unit FE + Season	0.957	0.959	0.963	1.008	0.784
	(0.034)	(0.028)	(0.027)	(0.053)	(0.085)
(4) Spec.3 + Markup (IV)	0.959	1.036	0.962	1.013	0.834
	(0.062)	(0.058)	(0.024)	(0.197)	(0.101)

Estimates close to one, implying full internalization of permit prices

Opportunity Costs: Inputs

Input cost (β)					
(1) No FE	0.812	0.476	0.892	0.952	1.037
	(0.047)	(0.029)	(0.021)	(0.021)	(0.014)
(2) Unit FE	0.598	0.494	0.303	0.821	0.643
	(0.064)	(0.057)	(0.055)	(0.037)	(0.053)
(3) Unit FE + Season	0.601	0.497	0.348	0.769	0.640
	(0.058)	(0.047)	(0.039)	(0.043)	(0.027)
(4) Spec.3 + Markup (IV)	0.604	0.487	0.335	0.773	0.683
	(0.069)	(0.038)	(0.060)	(0.172)	(0.114)

More noisy estimates :
input costs not measured as
accurately as emissions prices

Fabra & Reguant (2014)

Measuring incentives to adjust markups

$$\Delta p = \underbrace{\underbrace{mc_i'(q_i) - mc_i(q_i)}_{\text{Direct cost shock}} + \underbrace{mc_i'(q_i') - mc_i'(q_i)}_{\text{Cost shift due to } q_i}}_{\text{Cost change}} + \underbrace{\underbrace{\left|\frac{\partial p'(q_i')}{\partial q_i'}\right|(\tilde{q}_i' - \tilde{q}_i)}_{\text{Markup change due to } \tilde{q}_i} + \underbrace{\left(\left|\frac{\partial p'(q_i')}{\partial q_i'}\right| - \left|\frac{\partial p(q_i)}{\partial q_i}\right|\right)\tilde{q}_i}_{\text{Markup change due to slope}}}_{\text{Markup change}}.$$

(labels above the terms: 1 = Direct cost shock, 2 = Cost shift due to q_i, 3 = Markup change due to $\tilde{q}_i$, 4 = Markup change due to slope)

Price changes decomposed in:

- **Cost changes:**
  1. Increase in permit price
  2. Quantity change
- **Mark-up changes:**
  3. Quantity change
  4. Change in slope of residual demand

First assume that mark-ups remain unchanged

Firms shift up their supply curves by emissions costs

Measuring incentives to adjust markups

	Mean	SD	P25	P50	P75
Changes in Quantity					
Aggregate Demand	-0.2%	0.3%	-0.2%	0.0%	0.0%
Firm 1	-0.3%	1.3%	0.0%	0.0%	0.0%
Firm 2	-0.2%	0.8%	0.0%	0.0%	0.0%
Firm 3	-0.3%	7.1%	0.0%	0.0%	0.0%
Firm 4	-0.3%	1.2%	0.0%	0.0%	0.0%

Little changes in total and firm-level output when firms shift up their supply curves by the emissions costs:
- Very inelastic demand
- High cost correlation across firms

Fabra & Reguant (2014)

Measuring incentives to adjust markups

Changes in Slope of Inverse Residual Demand					
Firm 1	1.1%	7.1%	-2.0%	0.8%	4.1%
Firm 2	0.3%	7.0%	-2.5%	0.2%	3.1%
Firm 3	0.9%	7.0%	-2.0%	0.6%	3.7%
Firm 4	0.8%	6.8%	-1.9%	0.5%	3.5%

Little changes in the slopes of residual demands:
- Little changes in quantity
- High cost correlation across firms

Measuring incentives to adjust markups

Changes in Markup					
Firm 1	-0.9%	9.6%	-4.5%	-1.0%	1.9%
Firm 2	0.1%	10.3%	-3.3%	-0.3%	2.5%
Firm 3	-0.7%	12.3%	-4.2%	-0.8%	1.9%
Firm 4	-0.6%	10.1%	-3.9%	-0.7%	1.9%

Weak incentives to adjust mark-ups
- Very inelastic residual demands before and after the cost shock
- Small changes in firms' output

Price Rigidities are small

	Previous Day Unit-Level	Previous Week Unit-Level	Previous Day Firm-Level
All days	0.375	0.710	0.795
Monday	0.490	0.705	0.907
Tuesday	0.304	0.691	0.774
Wednesday	0.276	0.682	0.719
Thursday	0.277	0.691	0.694
Friday	0.287	0.697	0.713
Saturday	0.605	0.739	0.932
Sunday	0.392	0.764	0.831

Costs of price adjustment relatively small:
- Firms change at least 1 bid 80% of the days
- Monday and Saturday effects (small costs of bid preparation)

Functional form: Linear vs. Log-log

- Measurement exercise as linear specification
- In pass-through literature, log-log specification is common
- Idea: multiplicative cost shock observed (e.g., exchange rate)
- Part not affected by exchange rate found to explain a large part of pass-through incompleteness

Leveraging engineering cost data

- Emissions costs enter linearly cost function
- In baseline, control for other costs while estimating cent-to-cent pass-through
- Exploit additional marginal cost data to estimate linear and log-log regression
- Emissions price still a valid instrument
- Intuitively, log-log is incomplete for emissions costs (small part of total costs)

Functional form assumptions

	Emissions Costs		Total Mg. Costs	
	Linear	Logs	Linear	Logs
Peak Pass-Through	1.045	0.146	0.893	0.799
	(0.174)	(0.038)	(0.120)	(0.156)
Off-Peak Pass-Through	0.453	0.094	0.218	0.268
	(0.162)	(0.036)	(0.089)	(0.124)

- Complete pass-through at peak hours using emissions or total costs
- Log-log differences help emphasize some advantages of having detailed data

Conclusions

- We explore impact of emissions costs on firms' decisions and market outcomes
- We find pass-through around 80-100%
- Firms fully internalize permit prices
- Institutional framework in electricity markets (frequent auctions for very inelastic demand):
  - Weak incentives to adjust markups
  - Small price rigidities

Auctions very efficient mechanism in inducing full pass-through

Fowlie (2010)

Emissions Trading, Electricity Restructuring, and Investment in Pollution Abatement

By MEREDITH FOWLIE*

This paper analyzes an emissions trading program that was introduced to reduce smog-causing pollution from large stationary sources. Using variation in state level electricity industry restructuring activity, I identify the effect of economic regulation on pollution permit market outcomes. There are two main findings. First, deregulated plants in restructured electricity markets were less likely to adopt more capital intensive environmental compliance options as compared to regulated or publicly owned plants. Second, as a consequence of heterogeneity in electricity market regulations, a larger share of the permitted pollution is being emitted in states where air quality problems tend to be more severe. (*JEL* L51, L94, L98, Q53, Q58)

NO_x Markets

- Large cap-and-trade program for NOx among eastern utilities---“NOx Budget Trading Program”
  - Began in 2003
- Cap-and-trade program for NOx in Southern California---“RECLAIM”
  - REgional CLean Air Incentives Market
  - Began in 1994
  - Also covers SO2
- **Important**: NO_x is a local pollutant.

NO_x abatement options

- Selective Catalytic Reduction
  - Reduce NO_x emissions up to 90%
- Selective Non-Catalytic Reduction
  - Reduce NO_x emissions up to 35%
- Low NO_x burners (LNB) or combustion modifications (CM)
  - Reduce NO_x emissions up by 15-50%
- Produce less

Issues with cap-and-trade systems

- Many firms facing different incentives
  - In electricity: regulated v. independent power producers
- Market power
- Location, location, location
  - Marginal damage may differ depending on location
    - Exchange rates?
  - Wind patterns
  - Compliance methods may be correlated with demographics
- Transaction Costs
- Monitoring and Enforcement Problems

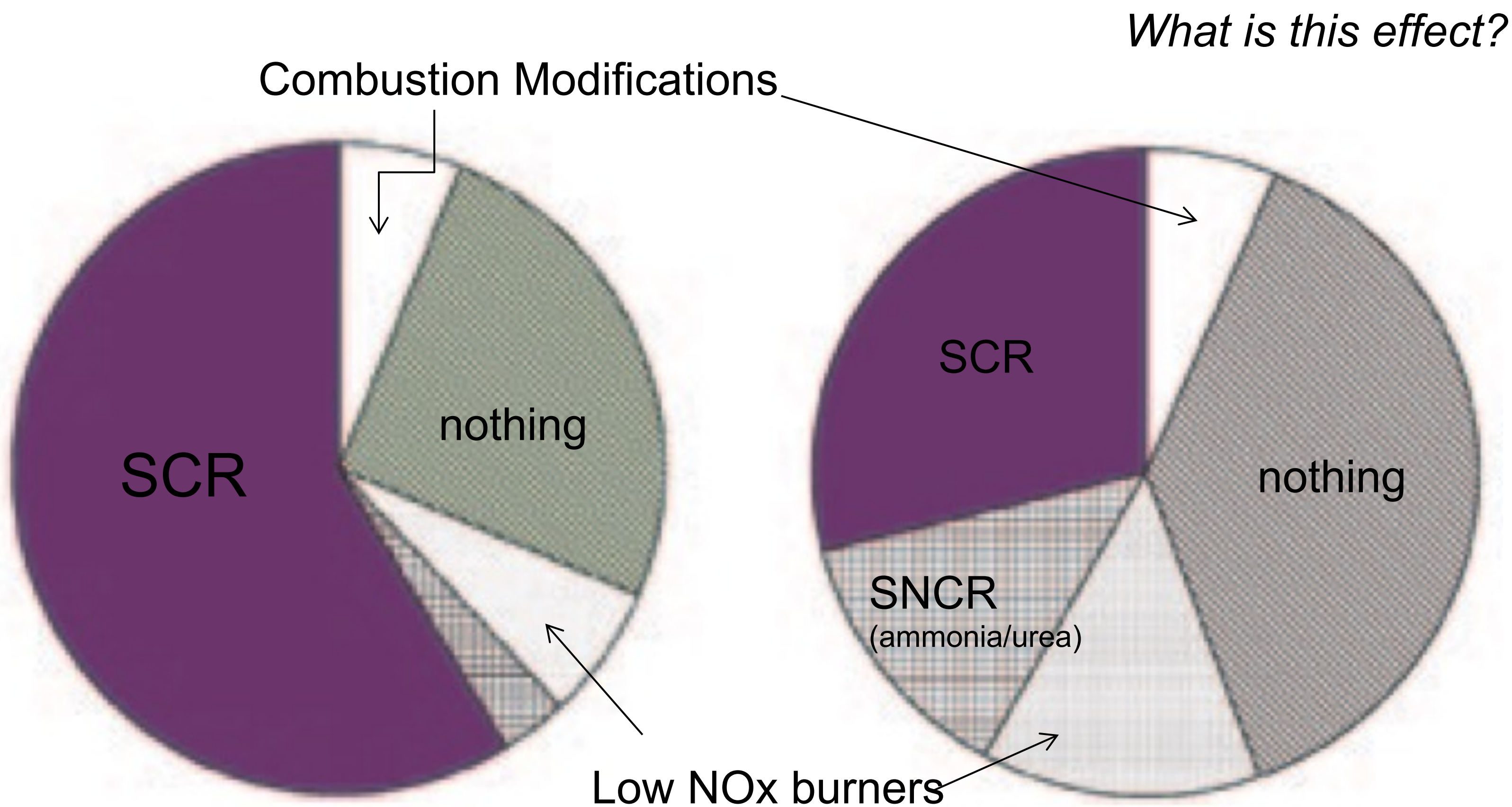
Firm incentives and cap-and-trade

- Basic model assumes all firms have equivalent incentives to reduce emissions costs
- Firms can face differing incentives
  - Regulatory treatment of firms
    - Rate of return regulation vs market
- Allocation mechanisms can distort incentives
  - The problem with endogenous allocations

This paper

- Develops a model of abatement choice (random coefficient logit).
- Shows that firms in deregulated vs. regulated states faced made very different choices.
- Damages ended up being larger due to this difference in compliance choices.

Does that SCR come in gold?



Compliance choices of regulated units

Compliance choices of unregulated units

Meredith Fowlie. “Emissions Trading, Electricity Industry Restructuring, and Investment in Pollution Control”. American Economic Review, 2010.

Market power in permits

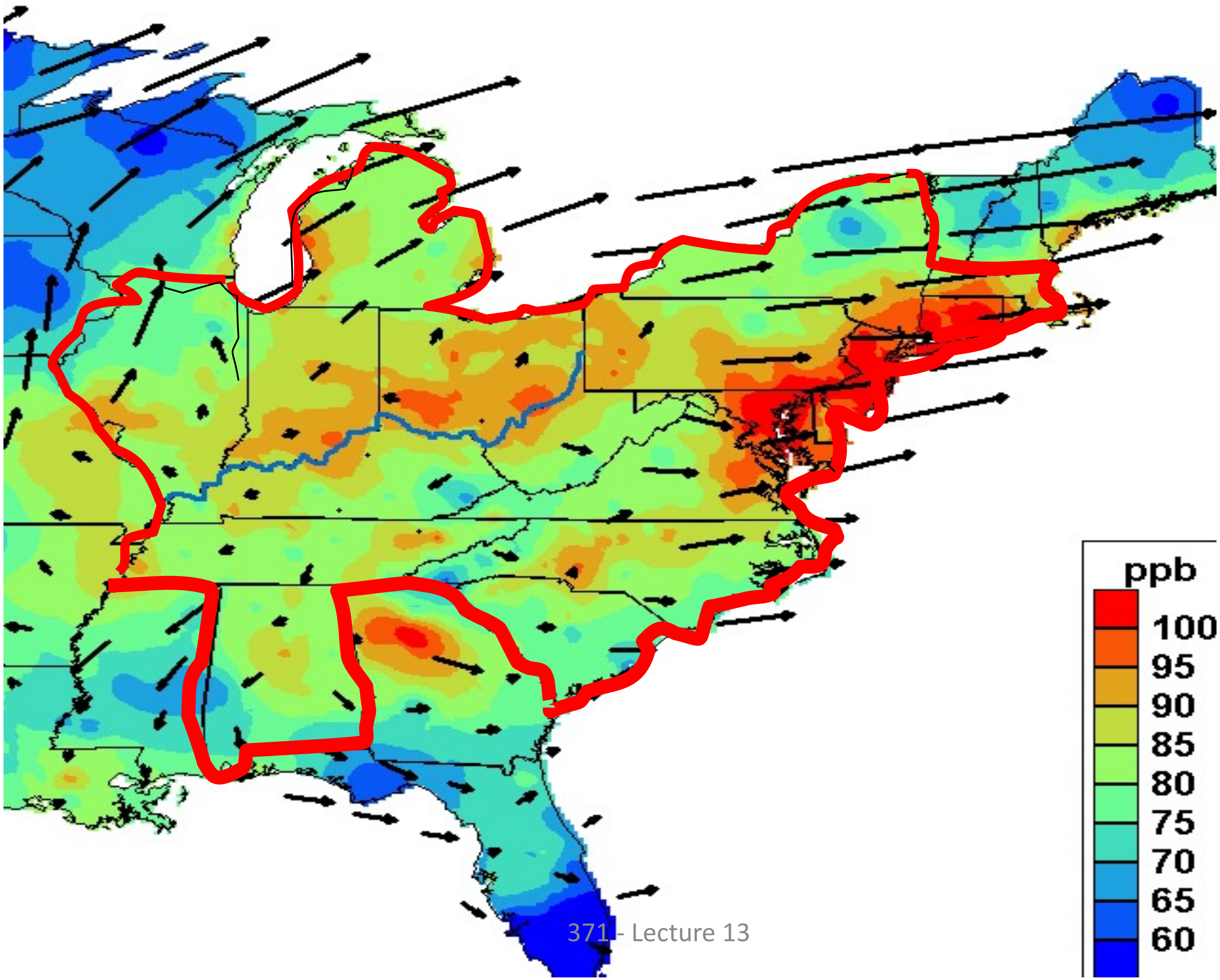
- Firms may have market power in permits
- This can feedback to profits in the electricity market
  - NOTICE: These are two different things
- If you have market power in the permit market, may want to raise permit prices by throwing away permits
- This can also increase your profits in the wholesale electricity market
  - Increasing your incentive to exercise permit market power
- Evidence of this in the RECLAIM market

Kolstad and Wolak. “Using Environmental Emissions Permits Prices to Raise Electricity Prices: Evidence from the California Electricity Market”

NOx and the location of emissions

- Local pollutants stay in the vicinity of where they get emitted.
  - E.g., NO_x, SO_2, PM2.5, etc.
- A centralized cap-and-trade market will not ensure a certain amount of emissions at a particular region.
- Additional constraints can be added to regulate regional emissions.
  - Regional caps, limits to trading

NOx flow patterns and concentrations



1997 8-hour standard80 ppb

Cap-and-Trade and Coverage Areas

- Regions must be “big” enough:
  – Induce liquidity in trades, take advantage of cost differences
  – Limit market power (RECLAIM problems)
  – Reduce leakage problems (GHG problems)
- Regions must not be too big:
  – Coverage should match damage or else “hot spots” can form (for local pollutants)
    - Pollution migrates up wind (or clean-up happens “downwind”)

Fowlie and Müller (2013)

Market-based emissions regulation when damages vary across sources: What are the gains from differentiation?

Abstract

For much of the air pollution currently regulated under U.S. emissions trading programs, health and environmental damages depend on the location of the source. Existing policies ignore this fact. Differentiated policies can accommodate non-uniformly mixed pollution by using emissions penalties that vary with damages. Under perfect certainty, damage-based policy differentiation is welfare improving. With uncertainty about damages and abatement costs, differentiated policies may not dominate undifferentiated designs. Using data from a U.S. emissions trading program, we find that the extant undifferentiated policy dominates the differentiated counterfactual because ex post abatement costs exceeded expectations. A differentiated price-based policy welfare dominates the differentiated quantity-based alternative.

Summary of Fowlie and Müller (2013)

What does the paper do?

1) Present trade-off when regulating: complexity vs. simpler rules
2) Tailored rules are better ex-ante, but potentially not ex-post
3) Explore this situation for uniform vs. differentiated pollution policy

What does the paper find?

- US Trading program uniform policy was ex-post better than a differentiated one
- Main channel is through unexpected realization of abatement, which was uneven (shown in Fowlie, 2010)

Set-up

Consider the benefits of differentiation in cap-and-trade programs of local pollutants, i.e. when marginal damages of pollution (negative benefits) depend on each source.

$$TSC = \sum_{i=1}^{N} (D_i(e_i) + C_i(e_i))$$

Assume $D_i'(e_i) \equiv \delta_i$. Then,

$$-C_i'(e_i^*) = \delta_i \ \ \forall\ i.$$

Consider differentiated vs undifferentiated tax (price), differentiated (trading ratios) vs undifferentiated cap-and-trade (quantities).

Also consider the effect of uncertainty on damages and costs.

Main Theoretical Results

Extension of Weitzman (2014) to geographical heterogeneity of damages.

(R1) Accurate information on source-specific marginal costs is required to efficiently implement policies except for the differentiated tax

(R2) The extent to which differentiation reduces pollution damages and increases net welfare increases with heterogeneity in damages across sources.

(R3) The extent to which differentiation reduces pollution damages and increases net welfare decreases with the slope of the marginal abatement cost functions.

Main Results

(R4) For the case of emission taxes, the gains from differentiation are non-negative ex-post in the presence of cost uncertainty and certain damages.

What about for cap-and-trade?

Context and Data

- Same as Fowlie (2010): NOx Budget Program (NBP) 2003-2008.
- Focus on coal-fired generating units (94% of sources).
- Use a combination of ex-post data from the program, engineering cost and damage estimates.
- Very rich integration of data and models from different sources.

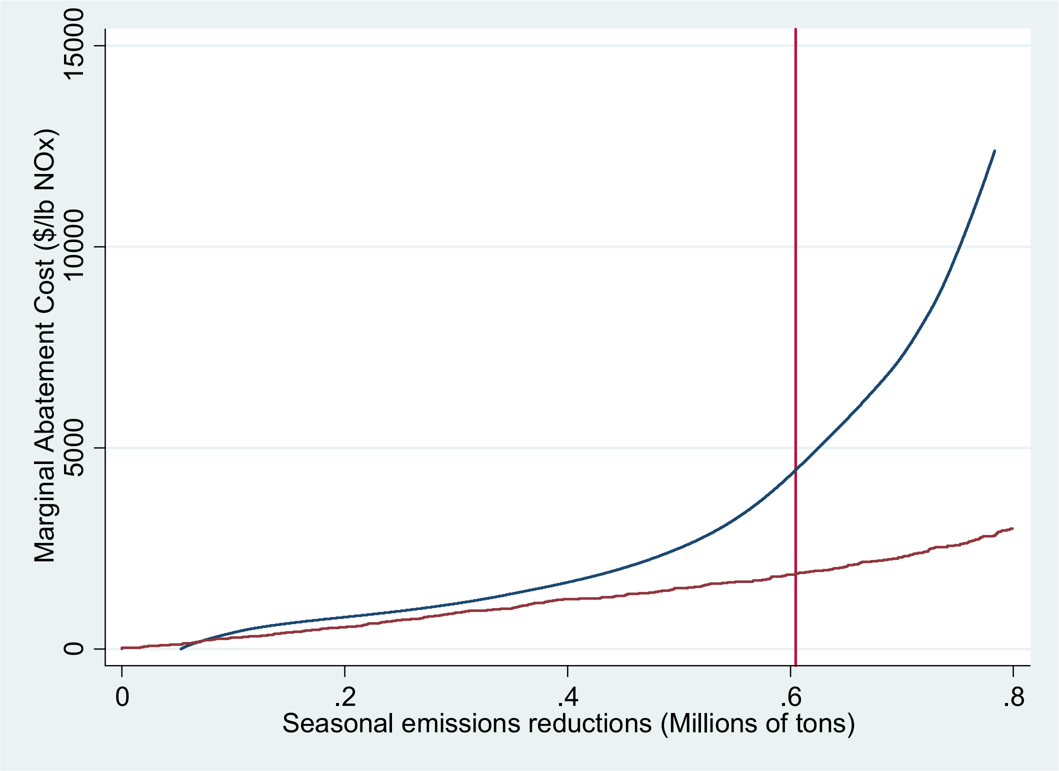
Goal: Compare net benefits across differentiated and undifferentiated policy designs in a real application.

Methodology

1. Estimate marginal damage parameters at each source (based on scientific model).
2. Construct source-specific marginal abatement costs (two different methods considered).
3. Use (1)-(2) to derive optimal ex-ante emissions cap and tax.
4. Simulate firms choices under each counterfactual.
5. Estimate total damages associated with simulated outcomes.
6. Estimate total abatement costs.
7. Compare total social cost for each case.

A key behind the results

Engineering estimates and econometric predictions are strikingly different.



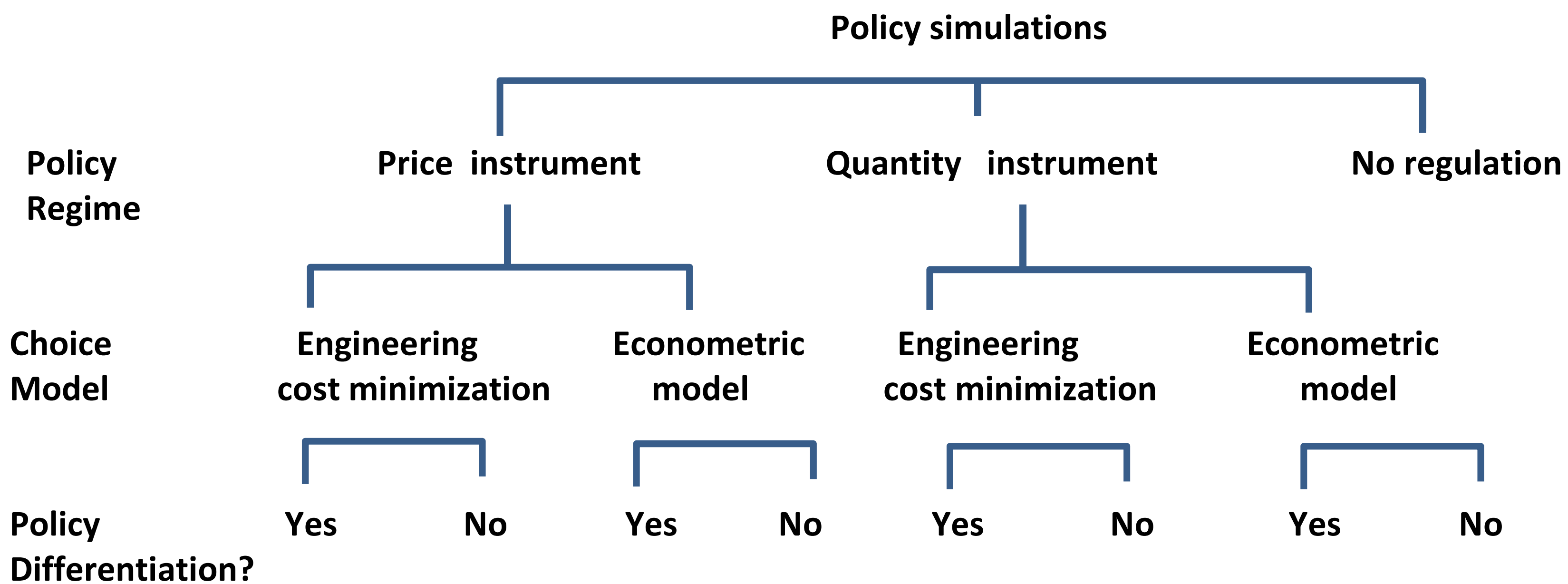
Ex-ante Engineering vs Ex-post Econometric Estimates

Table 2 : Observed, predicted, and correctly predicted compliance choices

Compliance choice	**SCR**	**SNCR**	**Low NOx burners**	**Combustion Modifications**	**No retrofit**	**Total**
Observed choices	187	42	53	58	292	632
Cost minimization model						
Predicted adoption rate	62	80	228	159	103	632
Correctly predicted	47	6	48	9	76	186 (29%)
Econometric model						
Predicted choices	179	15	35	21	382	632
Correctly predicted	166	7	22	18	284	497 (79%)

Notes: This table summarizes predicted and observed compliance choices for the 632 electricity generating units included in the study.

Simulations Considered



Main Results: Prices

Model of compliance choice	Cost minimization		Econometric	
Policy regime	**Undifferentiated**	**Differentiated**	**Undifferentiated**	**Differentiated**
Permit price ($/ton NOx)	$1630		$1630	
Ozone season emissions (thousand tons NOx)	723.6	746.6	868	881
% emissions occurring at high damage sources	40%	28%	38%	33%
Levelized annual costs ($M)	$361	$402	$259	$272
Avoided annual damages ($M)	$883 ($158, $2134)	$988 ($182, $2370)	$637 ($104, $1588)	$697 ($125, $1698)
Net benefits ($M)	$522 (-$203, $1773)	$586 ($-220, $1969)	$378 (-$155, $1329)	$426 (-$147, $1426)

Main Results: Quantities

Model of compliance choice	Cost minimization		Econometric	
Policy regime	Undifferentiated (1)	Differentiated (2)	Undifferentiated (3)	Differentiated (4)
Permit price ($/ton NOx)	$1630	$1732	$3008	$3937
Permits allocated (000)	726.3	642.2	726.3	642.2
Ozone season emissions (000 tons NOx)	726.3	746.6	726.2	698.2
% emissions occurring at high damage sources	40%	28%	38%	33%
Levelized annual costs ($M)	$361	$402	$521	$674
Avoided annual damages ($M)	$883 ($158, $2134)	$988 ($182, $2370)	$878 ($152, $2155)	$990 ($180, $2405)
Net benefits ($M)	$522 (-$203, $1773)	$586 ($-220, $1969)	$353 (-$373, $1629)	$316 (-$495, $1731)

Today's outline

1) Environmental regulations in electricity markets
   - Cap-and-trade markets
   - Pass-through
   - Leakage
2) Case study: Leakage in the California electricity market
   - Overview of paper
   - Code

Today’s application

- We will review a short paper examining the role of carbon border regulations to reduce ”leakage” and “resource shuffling”.

- **Concern**: electricity imports into California will claim that they are very clean and reduce the ambition and effectiveness of the policy.

Modeling: policy

- We consider several cases.

1. No regulation, tax is 0.
2. Uniform tax, every region.
3. CA tax only.
4. Tax of imports at default rate, with opt-out.
5. Tax of imports at default rate, no opt-out.

Main findings

- Mechanism to mitigate resource shuffling is not working if firms are allowed to chose their source (case 4).
- CA emissions in total are the same no matter the default rate.
- Observed outcomes a bit less negative but suggest high level of leakage.

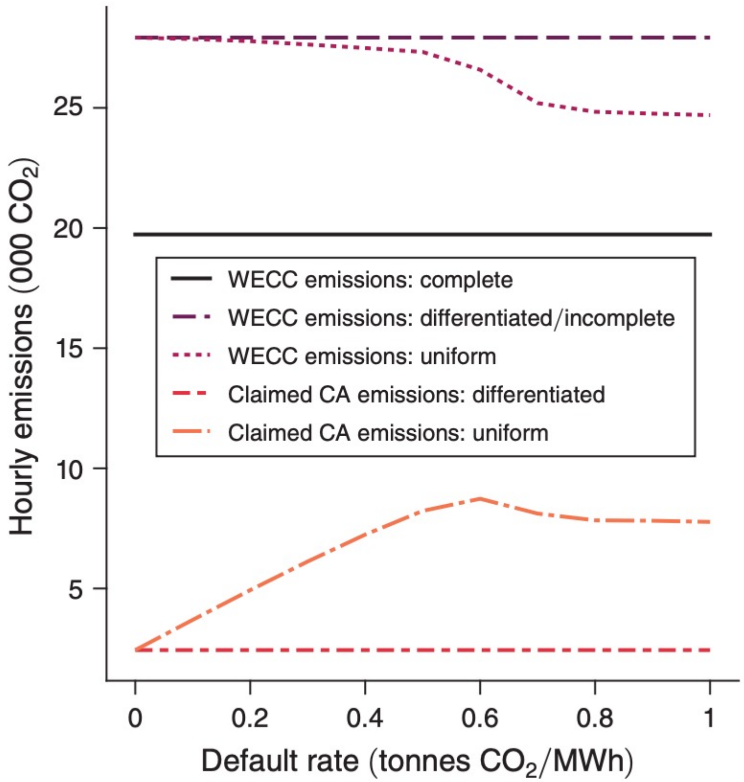


FIGURE 1. CLAIMED EMISSIONS VERSUS EMISSIONS IN CALIFORNIA

Modeling: the network

- Electric energy is injected into the grid by all generators and withdrawn by all end users
- To maintain frequency, the quantity injected must always equal the quantity withdrawn
- Contrast this with other commodity markets
- Power flows in inverse proportion to the resistance it faces (Kirchoff's laws), so that an injection or withdrawal anywhere affects the system everywhere else!

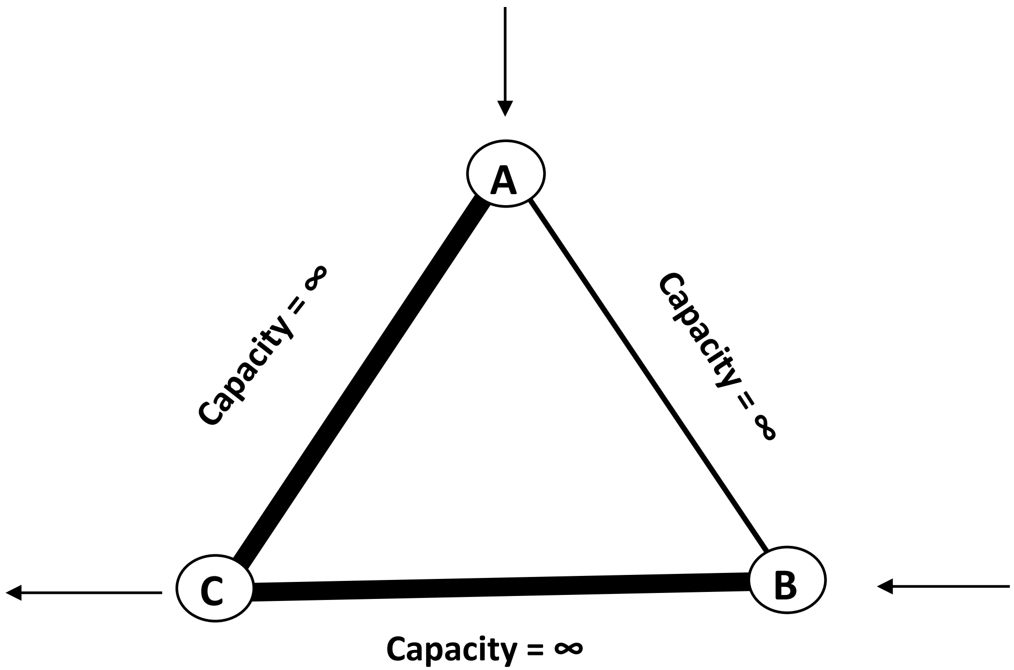
Electricity network externalities

- The key economic idea here is that there are *externalities* in electricity transmission networks.
  - Both positive and negative.
  - You are *hurt* if someone else’s actions cause congestion.
  - You are *helped* if someone else’s actions reduce congestion.

An *externality* is present whenever one agent’s actions impact the utility or production of another agent through a non-price mechanism.

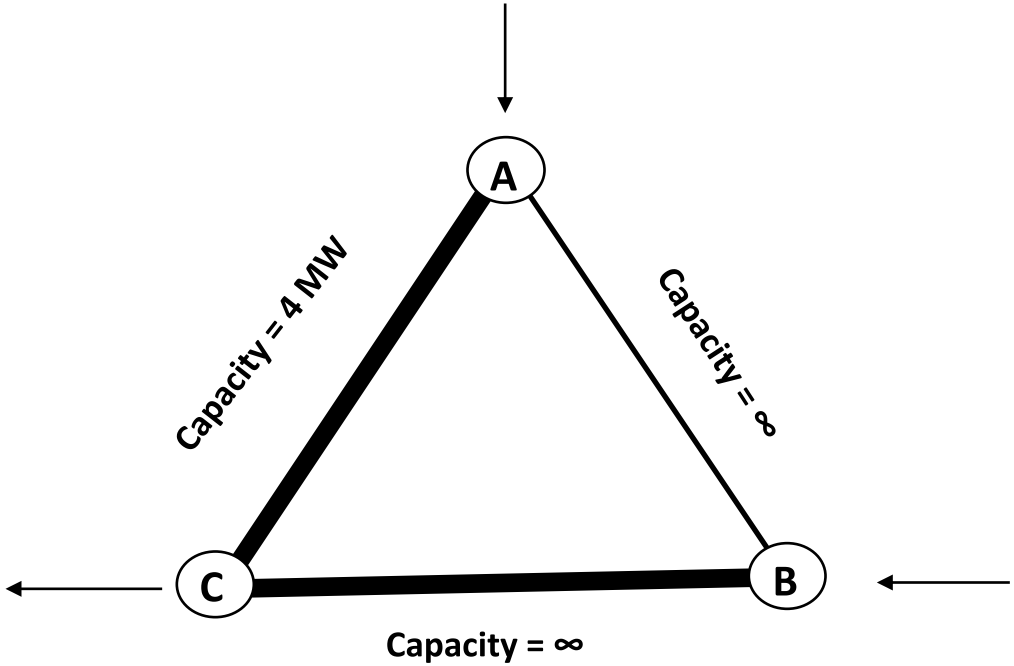
Loop flow example

- Consider this simple 3 node example.
- Nodes A and B are generators (supply only) and node C is a customer center (demand only)



Loop flow example

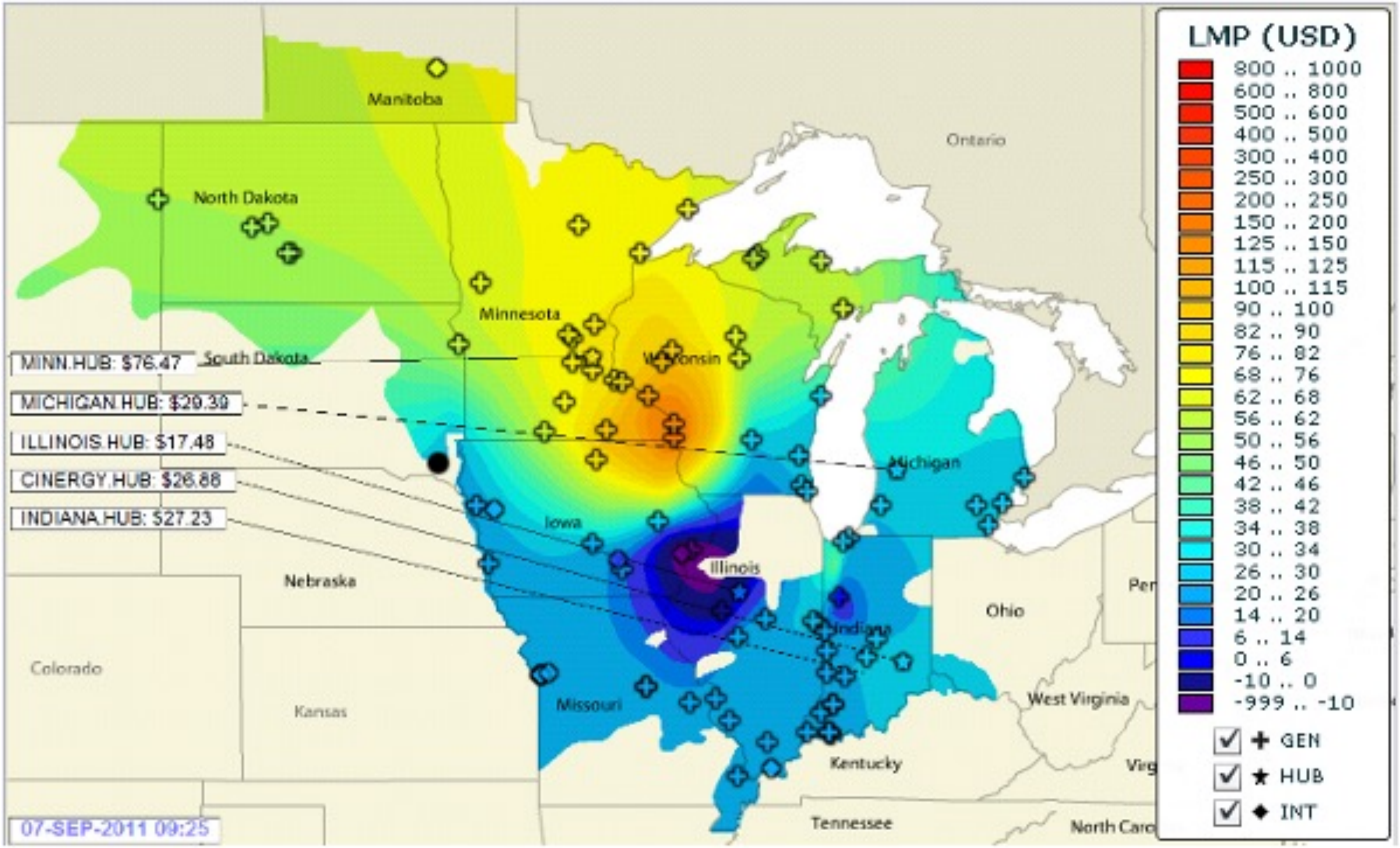
- Now suppose capacity A->C is only 4MW.
- Let total demand in C be equal to 10MW.
- Can A produce all 10MW? Can B?
- How much can each produce?



Loop flow example

Nodal prices in markets are complicated!

Midwest ISO real-time LMP, 9/7/2011, 9:25 a.m.



Simplifying networks in electricity models

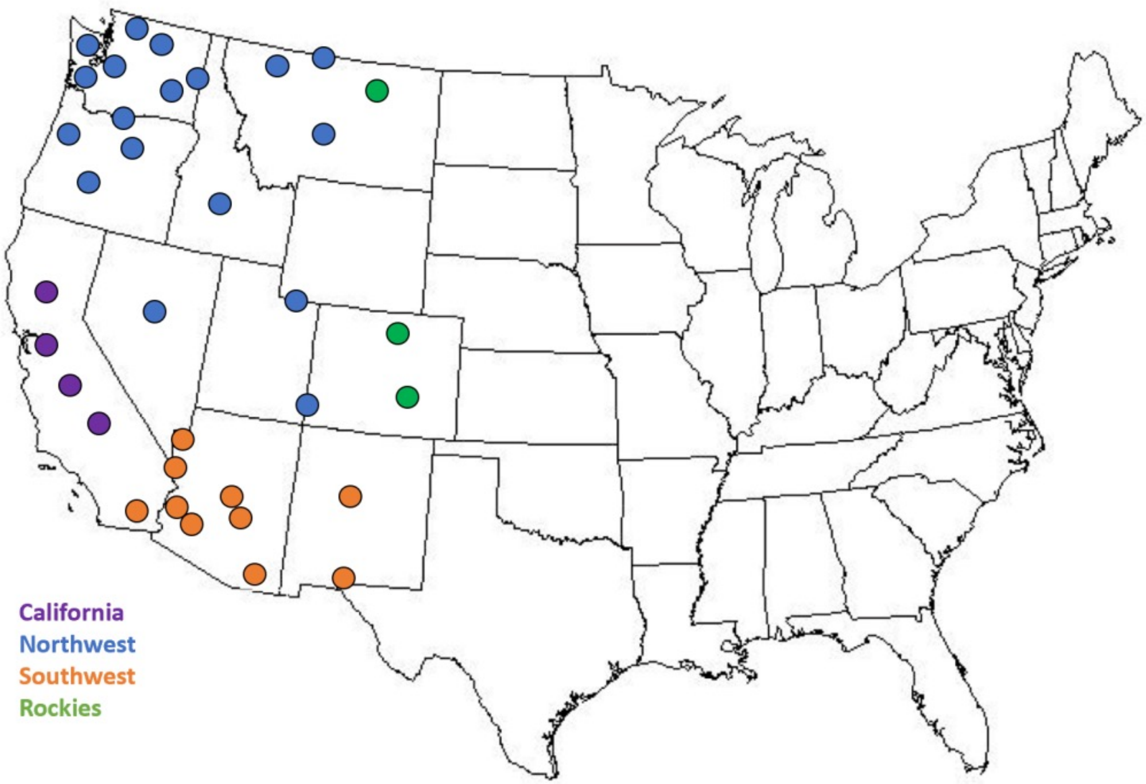
- Electricity networks are a non-linear object that depends on the topological features as well as voltage, resistance, reactive power.
- An active research area in electrical engineering looks for formulations of the grid that are good enough but linear.
- Optimal power flow (OPF) models tend to work with a linearized direct current (DC) version of the grid.
- In Economics, we tend to use the simplest possible models.

In our application

- We take a very simplified version of the network from Bushnell et al., 2017, that separates the Western interconnection in 4 areas.
- In practice, machine learning tools can be used to decide how narrow the network can be (see Mercadal, 2021).
  - Combination of k-means clustering with market fit to tune the number of clusters.
- **Intuition**: areas that are not congested should exhibit highly similar prices.

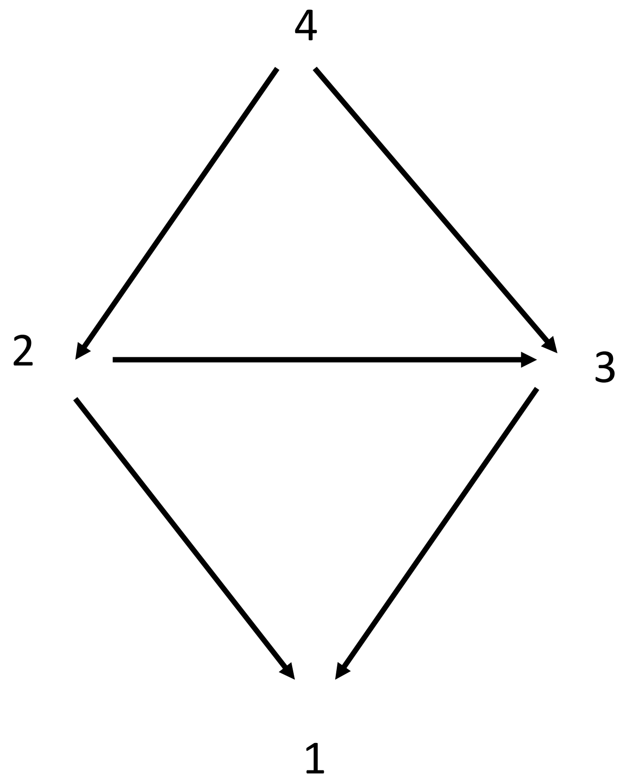
The flows can be expressed as constraints

Figure A.1: Illustration of balancing authority regional designations



The line conditions

- Two inputs:
  - Line size
  - Flow factors



The line conditions: factors

factors

region	12	13	42	43	23
2	0.623	0.378	-0.144	0.144	0.234
3	0.378	0.623	0.144	-0.144	-0.234
4	0.5	0.5	0.5	0.5	0

The flows can be expressed as constraints

- Flows are part of the market clearing condition:
  - Demand = Production in-state + incoming flows
- Lines are limited by their capacity and the flows which circulate according to the factors:

$$-lines_l \leq \sum_{r \notin CA} fct_l * yflow_{rt} \leq \text{lines}_l$$

Next class

- Demand I.
  - How do consumers respond to feedback in the residential market?
  - What does the experimental data say?
  - Can we test behavior in a non-experimental setting?

References

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