Empirical Methods for the Analysis of the Energy Transition

Slide Set 5

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Roadmap

I. Climate and Renewable Policies in Electricity Markets

a. Carrots
b. Sticks
c. Representing incentives

II. Empirical models

a. Regression evidence
b. Our simulation model

Climate policies in the electricity sector

- The electricity sector is among those with the most active climate policies.
- It is a sector "relatively easy" to decarbonize and it tends to be isolated (no competition concerns).
- Emphasis has been on both "carrots" and "sticks" strategies.

- Today we focus on **supply side** policies.
  - What are they?
  - Do they work?
- These policies also have impacts on the **demand side**, via price effects (but not explicitly engaging with demand agents, more about this next week).

Supply-side responses to climate policies

Electricity firms can respond to pollutions costs in several ways:

- **Short-run:** shift production to cleaner inputs or different technologies, aka "merit-order effects".
- **Medium-run:** perform plant refurbishing to improve efficiency or install filtering (limited with CO_2, more effective with NO_x or SO_2) .
- **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**, work on investment with a *simulation model*

A battery of policies

Carrots

- Renewable subsidies
- R&D subsidies (generation, batteries, transmission, etc.)
- Centralized tenders (auctions)

Sticks

- Carbon tax
- Cap-and-trade
- Renewable portfolio standards (carrot&stick)

a. Carrots

Example: Feed-In tariffs and premiums

- In Europe, subsidies to renewable power have been common.
- As a known fixed price (tariff).
- As an adder to the market price (premium)

- Advantages:
  - Predictable.
- Disadvantages:
  - Target quantity often unclear
  - Some experiences of "too much" entry (e.g., early solar investment in Spain and Portugal at high subsidy levels), now often include a cap.
  - They can lower electricity prices and incentivize consumption.
- Who pays for them? It depends on the market, but electricity price for consumers might be higher than the marginal wholesale price.

Example: Renewable Portfolio Standards

- Renewable portfolio standards (quantity) are quite popular in the US and Australia as they trigger investment at a lower tax threshold.
- States choose a certain goal for renewable energy penetration (in fuel standards: percent of ethanol in gasoline; in car standards: average km/100 l).
- Generators (or suppliers) need to show that they have enough "renewable energy credits" (RECs).
- Either produced by themselves or purchased in the market.

- Contested items: are they about renewables? Or about zero carbon (nuclear, hydro)?

Are carrots really needed?

- Current renewable policy focused on centralized procurement.
- Auctions to coordinate investment, but no longer at subsidized prices.
- Many potential benefits:
  - Cheaper than gas.
  - Can help ensure steady progress towards net-zero goals.
  - Can keep prices low if well designed.

- Remaining "carrots":
  - Subsidies or tax credits for more expensive technologies at the distributed level (rooftop solar) or less mature technologies (batteries).
  - (Implicit subsidy) Payment of the expansion of the grid (to enable new locations of solar and wind generation).

Uncertainty in the market and the need for support

- The prices in the market can be very volatile.
- Cannibalization effects and curtailment risk are also reducing the revenues from renewable producers (see day1).
- Despite large fluctuating natural gas prices in Europe, some auctions are still unsuccessful at attracting capital at the offered prices, or sometimes winning bids get undelivered.
- Fluctuations in prices also lead to contracting risk (see Fabra and Llobet, 2024).
- Entry in the market is driven by private PPA agreements or public procurement auctions that incentivize entry with more known terms.

What are the details of auctions in practice?

Auctions can be tailored to affect particular technologies or plants:

- Technology-specific: different instruments/levels of support depending on technology, scale, location, etc.
- Technology neutral: all technologies treated equally
- Hybrid schemes: corrected technology-neutral approaches
- Banding:
  - Bids of some technologies are deflated
  - Minimum quantities for certain technologies

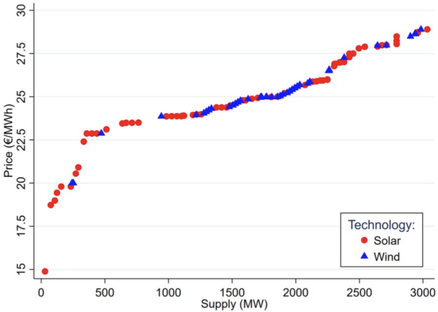
Overview of auction (many) characteristics

- Metrics (MW or MWh)
- Timing (of auctions)
- Diversity (technology, as mentioned above)
- Participating conditions (e.g., local requirements)
- Remuneration type
- Remuneration form (FiT, PPA, FiP)
- Selection criteria (multiple or price only)
- Auction details (uniform vs. discriminatory, sealed vs dynamic, single product vs. complementarities)
- Existence of price ceilings, known or secret
- Time to delivery

See del Rio and Kiefer (2021) for a great review of these details and auction experiences.

Example: Spanish renewable auction

- It took place last January 26, 2021
- Technology Neutral Auction of 3000MW
- Minimum quantity of 1000MW for solar PV and Wind
- Pay-as-bid
- Contract duration: 12 years
  - Once the contract is over, investors are paid at market prices



b. Sticks

Cap and trade mechanisms

Permit markets have been used in electricity markets to internalize pollution in several settings, not just climate policy:

- **CO2:** ETS (Europe, Australia, New Zealand), RGGI, AB32 (EEUU)
- **SO2:** Acid Rain Program (EEUU)
- **NOx:** Budget Trading Program, RECLAIM

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

Cap and trade mechanisms, analogous to a tax

- Main goal: make emissions **more expensive**.
- In the electricity context, it has led to a lot of substitution: change in **merit order**.
  - $CO2$ prices and gas/coal ratio (substitution point) are interdependent.
- It has also increased the cost of electricity.
- It has contributed to making renewable technologies economical (Europe).

Responses to a carbon tax in the electricity sector

- **Short-run**: Less generation from emissions-intensive sources (merit-order switching), lowered demand from high prices
- **Medium-run**: Efficiency gains (power plants, demand) but no "easy" abatement technology (as opposed to SO2 or NOx)
- **Long-run**: Investment/divestment decisions (e.g., renewable entry), retirement of carbon-intensive power plants (coal, gas)

c. Representing incentives

Expressing policies as shifts to underlying fundamentals

- We want to understand how these different policies affect the underlying incentives of firms and households.
- To the extent that the carbon tax does not equal the social cost of carbon (SCC), all of them will not achieve the theoretical first best.
- Via prices or costs, each of them affects demand and/or supply.

Incentives: Tax

- Supply side instrument: Increase costs proportional to emissions rate.

$$\Delta C_i = e_i \tau.$$

- Demand side: response *along* the demand curve, via generally higher prices.

Incentives: Subsidy

- Supply side instrument: Decreases costs for selected technologies.

$$\Delta C_i = -s_i.$$

- Demand side: It depends!
  - If consumers don't pay a renewable charge: response *along* the demand curve, via cheaper prices.
  - If consumers pay a renewable charge: consumer price does not equal marginal price, *shift* in the demand curve for the purposes of computing equilibria.

Incentives: RPS

- Supply side instrument: Decreases costs for selected technologies.

$$\Delta C_i = \lambda(e_i - \overline{e})$$

- λ represents the shadow value/implicit cost of the policy.
- If a firm is cleaner than $\overline{e}$, it gets paid (negative cost).
- If a firm is dirtier than $\overline{e}$, it pays a fee (positive cost).

- Demand side: response *along* the demand curve, via *changing* prices.

- Important: consumers don't need to pay any additional money. The mechanism, by construction, ensures that the dirty power plants pay enough to subsidize the clean power plants.

Equations for equilibrium: Summary

Supply-side:

- Tax: $\Delta C_i = e_i \tau$
- Subsidy: $\Delta C_i = -s_i$
- RPS: $\Delta C_i = \lambda(e_i - \overline{e})$, where $\overline{e}$ is the target emissions rate.
  With target, $\Delta C_i = (1 - \textit{target})\lambda$ if i not renewable, $\Delta C_i = -\textit{target} * \lambda$ if i renewable.

Demand-side:

- Tax: Full carbon tax signal.
- Subsidy: It depends on whether interventions are priced or not into electricity.
- RPS: Medium price signal.

Key take-away: Policies look different institutionally but map into a small number of shifts in marginal costs and prices that allow us to represent them in a unified simulation model.

Comparison of policies

- Demand and supply effects can impact efficiency and distributional implications of policies.
- Pass-through of prices can be quite different depending on the design (as we will see in the practicum).
- Economists have tended to favor carbon taxes due to their higher efficiency in incentivizing demand reductions.
- However, this view is being revisited due to decarbonization needs, which rely on substitution towards electricity (e.g., heating applications), particularly if the alternative is mispriced.

Table 1: Large-scale renewable energy policies and its price impacts

Policy	**Wholesale prices**	**Retail impacts**	**Notes**
Carbon Tax	Tend to increase	Passed-through by design	A carbon tax is reflected at the margin at the wholesale level; at the retail level, it depends on how rates are set. Under real-time pricing, carbon taxes signal the pollution externality to both producers and consumers.
Feed-in tariff	Tend to decrease	Indetermined	Feed-in tariffs do not account for heterogeneity at the margin, and are not passed-through to retail prices explicitly.
Production subsidy	Tend to decrease	Indetermined	Production subsidies are a complement to wholesale prices, providing a market-value signal to renewable sources. Depending on cost recovery, they might not be directly passed-through to consumers.
RPS	Tend to decrease	Passed-through by design	Renewable sources see their effective opportunity cost reduced by the RPS price, acting as an implicit subsidy. Because retailers are responsible for acquiring credits, RPS costs will tend to be passed-through to final retail consumers. There might be heterogeneity on how such costs are charged.

Recent paper on differences between taxes and standards

- The paper suggests that a clean energy standard and a tax end up reaching similar levels of welfare if there is a clear target/pathway.
- The advantage of the standard is that it keeps electricity prices lower, which can make it more attractive to final consumers.
- This can be particularly relevant for states with very high electricity prices and low gas prices.

Carbon Pricing, Clean Electricity Standards, and Clean Electricity Subsidies on the Path to Zero Emissions

Severin Borenstein and Ryan Kellogg

PDF | PDF PLUS | Abstract | Full Text

Abstract

We categorize the primary incentive-based mechanisms under consideration for addressing greenhouse gas emissions from electricity generation—pricing carbon, setting intensity standards, and subsidizing clean electricity—and compare their market outcomes under similar expansions of clean electricity generation. Although pricing emissions gives strong incentives to first eliminate generation with the highest social cost, a clean electricity standard incentivizes earliest phaseout of the generation with the highest private cost. We show that the importance of this distinction depends on the correlation between private costs and emissions rates. We then estimate this correlation for US electricity generation and fuel prices as of 2019. The results indicate that the emissions difference between a carbon tax and clean electricity standard that phase out the fossil fuel generation over the same time frame may actually be quite small, though it depends on fossil-fuel prices during the phaseout. We also discuss how each of these policy options is likely to affect electricity prices, quantity demanded, government revenue, and economic efficiency. Large preexisting markups of retail electricity prices over marginal costs are likely to considerably weaken or even reverse the usual assumed efficiency advantage of carbon pricing policies over alternatives, including direct subsidization of clean electricity generation.

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Many studies examine impact of carbon taxes and subsidies on electricity markets

- Impacts on prices/short-run outcomes and compliance
  - Fowlie (2010) (random effects), Bushnell et al. (2013) (regression discontinuitiy), Fabra and Reguant (2014), Hintermann (2016), Kim (2021) [pass-through and competition impacts].
- Impacts on medium-run responses by demand
  - Responses to EU ETS using detailed manufacturing data such as Rottner (2023) [Germany], Colmer et al. (2025) [France].
- Subsidy effects
  - Abrell, Kosch and Rauch (2021) [price and welfare effects], Aldy and Sweeney (2021) [investment vs. production tax credit].
- Counterfactual simulations of alternative market regulations
  - Fowlie, Reguant and Ryan (2014), Fowlie and Mueller (2013) [design with different pollution impacts], Toyama (2020) [design with trading frictions in the permit market].

From empirical evidence to simulation models

What we learn from empirical work

- Identifies *causal short-run responses* to climate and renewable policies
- Measures pass-through, merit-order effects, and price impacts
- Typically focuses on one policy or one margin at a time

What empirical work cannot easily do

- Compare policies with very different institutional designs
- Study investment responses, capacity mix, and long-run equilibrium
- Trace distributional effects when costs are recovered through retail tariffs

Why simulation models

- Map policies into shifts in *costs, prices, and incentives*
- Run counterfactual comparisons across taxes, subsidies, and standards
- Make explicit who pays, who benefits, and why

Today

- Use a structural simulation model to study how *the way we pay for renewables* affects efficiency, emissions, and redistribution

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)

Fabra and Reguant (2014)

- Pass-through of emissions costs to electricity prices
  1. Measure pass-through
  2. Decompose determinants of pass-through

- Policy relevant topic:
  - Cap-and-trade programs for emissions control
  - Efficiency vs distributional concerns
    - Cost internalization is necessary for efficiency
    - Distributional concerns of pass-through

Some advantages of electricity markets

- 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

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.

Bid data

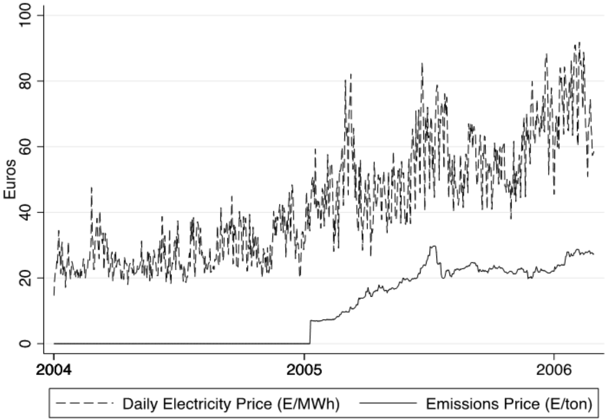
Information at the power plant level

Marginal cost
$=$ input cost $+$ emission cost

heat rates $\times$
commodity prices
(coal, gas, oil)

emissions rate
$\times$ permit price

Electricity and Carbon Prices



Measuring Pass-through

- Use reduced form representation of equilibrium prices:

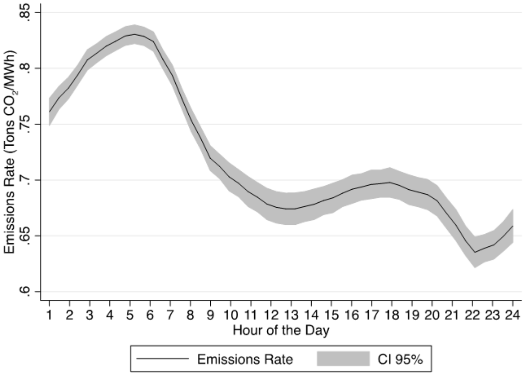
$$p^*_{th} = P_t(e_{th}\tau_t, X_{th}, X^S_{th}, X^D_{th})$$

- Pass-through regression:

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

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

Estimates indicate 80% 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		-0.204		
	(0.060)		(0.057)		
Maximum Temperature	0.137		0.112		
	(0.050)		(0.047)		
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)	

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.
  - Electricity markets exhibit very quick and perfect pass-through at the wholesale market.
- Exchange-rate pass-through: $< 50\%$ or less
- We also can test more directly if aggregate (time-series) pass-through is consistent with **individual firm behavior**.

Structural framework

- Profit maximization:

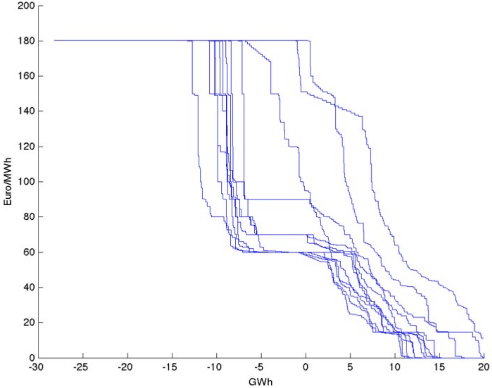
$$p = \underbrace{c_i + \tau e_i}_{\text{marginal cost}} + \underbrace{\left| \frac{\partial D_i^R}{\partial p} \right|^{-1} Q_i}_{\text{markup}}$$

- Empirical bidding equation:

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

Constructing Markup Term

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



Demand, supply and markups

- Profit maximization:

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

- Empirical bidding equation:

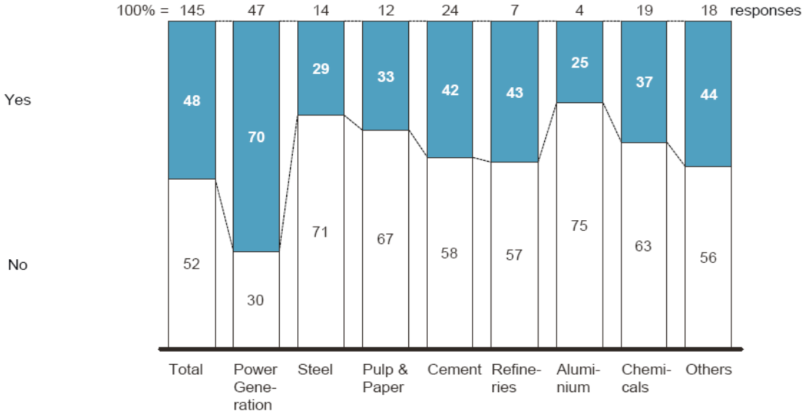
$$b_{ijth} = \underbrace{\alpha_{ij} + \beta_i c_{jt} + \gamma_i \tau_t e_{ij}}_{\text{marginal cost}} + \theta_i \underbrace{\left|\frac{\partial \widehat{D_{ijth}^R}}{\partial p_{th}}\right|^{-1} Q_{ijth}}_{\text{markup}} + \varepsilon_{ijth}$$

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

Estimates close to one, implying full internalization of permit prices

	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)

Opportunity Costs: Inputs

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

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)

Conclusions Fabra and Reguant (2014)

- 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

Day-ahead auctions very efficient mechanism in inducing full pass-through.
It also applies to cost of inputs, as we have seen.

Reguant (2019)

The Efficiency and Sectoral Distributional Impacts of Large-Scale Renewable Energy Policies

Mar Reguant

Abstract: Renewable energy policies have grown in popularity. Given that renewable energy costs are mostly nonmarginal, due to the large presence of fixed costs, there are many different ways to implement these policies in both the environmental design and retail pricing margins. I show that the efficiency and distributional implications of large-scale policies crucially depend not only on the design of wholesale policies to incentivize renewables but also on how the costs of such policies are passed-through to consumers. Using data from the California electricity market, I develop a model to illustrate the interaction between large-scale renewable energy policies (carbon taxes, feed-in tariffs, and renewable portfolio standards) and their pricing to final consumers under alternative retail pricing schemes (no pass-through, marginal fees, fixed flat tariffs, and Ramsey pricing). I focus on the trade-off between charging residential versus industrial consumers to highlight tensions between efficiency, distributional, and environmental goals.

JEL Codes: L51, Q42, Q58

Keywords: renewable policies, efficiency, distributional impacts

Motivation: how to pay for renewables?

- Renewable policies have grown in popularity across states in the US, and also worldwide.
- The costs and benefits from renewable policies are unevenly distributed across several margins.
  - Stakeholders.
  - Regional heterogeneity in resources (and correlation of resources with demand).
  - Heterogeneity across consumer types, e.g. residential vs commercial.
  - Heterogeneity in consumption, e.g., across income groups.

Goal: Quantify (some of) these distributional impacts under alternative policy assumptions, focusing on redistribution across sectors (customer classes). *Who to charge?*

- Carbon tax, feed-in tariff, production subsidy and renewable portfolio standards (RPS).
- We will do much more about distributional effects later in the course.

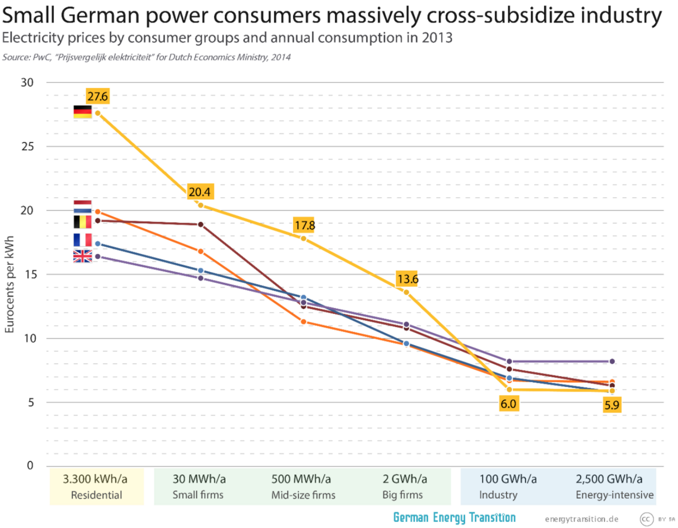
How to pay for renewables affects demand

- Subsidies to renewable can be considered a subsidy to consumers if they do not pay for them at the margin.
- Here, different experiences:
  - Europe: usually charged to residential/commercial consumers.
  - US: some of the subsidies are federal tax credits (FTCs), not reflected in price. State-initiatives usually as RPS (partially reflected).

Policy and Tariff Design

- Previous work on large-scale renewable policies tends to model wholesale demand for electricity (Fell 2013, Wibulpolprasert, 2014).
- Implementation of wholesale renewable policies can have impacts to electricity consumption also through its impacts on retail tariffs.
- Example:
  - If RPS, how do consumers pay for it through retail rates?
  - If production subsidies are used, how is the revenue raised?

Feed-in tariffs do not necessarily depress *all* prices



Source: energietransition.de

Also in the US

Table 4: RPS impact by retail sector

Effect of Renewable Portfolio Standards on Electricity Prices, by Sector

	Total (1)	Total (2)	Residential (3)	Commerical (4)	Industrial (5)
δ_1: 1(RPS)	0.714**				
	(0.298)				
$\delta_1 + 5\delta_3$		1.119**	1.499***	0.827	0.681
p-value		0.022	0.003	0.109	0.107
State FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
N	1224	1224	1224	1224	1224

Notes:
1) Coefficient estimates for states with data seven years before and five years after RPS effective date.
2) Standard errors clustered at the state level.
3) Asterisks denote significance at the 90% (*), 95% (**), and 99% (***) levels

Source: Greenstone and McDowell, 2016.

Proposed approach

- Integrate two elements:
  - Supply-side model with endogenous dispatch and capacity.
  - Demand-side model for residential, commercial and industry sectors, with tariff design.
- Use framework to simulate:
  - Carbon tax
  - Feed-in tariff/production subsidy
  - RPS/Standards

Key: Renewables mostly about fixed capital costs. How do we recover their costs?

$\rightarrow$ Affects *both* efficiency and distributional implications.

Stylized overview of the model

Demand

Demand Industrial:	$D^I_{rt}(P_{rt}, X_{rt}; \theta^I)$
Demand Commercial:	$D^C_{rt}(P_{rt}, X_{rt}; \theta^C)$
Demand Residential:	$D^R_{irt}(P_{irt}, X_{irt}; \theta^R)$

Supply

$$\min_{q,K} \quad \sum_g \left(F_g K_g + \sum_t C(q_{gt}, K_g, \tau) \right)$$

$$\text{s.t.} \quad \sum_g q_{gt} = \sum_r \left(D^I + D^C + \sum_i D^R \right)$$

Renewable policies considered

1. **Carbon tax:** Puts a price τ on carbon. Not necessarily about large-scale renewables.
2. **Feed-in tariff/subsidies:** Gives a flat rate per MWh of renewable production. Often technology specific. Also common to have subsidies at the margin, on top of the market price.
3. **Renewable Portfolio Standard:** Sets a percent goal in renewable generation, typically at the utility level. Trading of certificates to induce compliance and reveal market price. Similar in spirit to subsidies, but utilities are directly responsible to charge these costs.

Today: We will add subsidies. The key is how to pay for them.

Adding retail tariffs...

- Some of these policies generate revenues or policy costs that are not accounted for by the model.
- Typical partial equilibrium assumption is to treat them as lump-sum transfers, maybe with a multiplier (large body of work looking at how they might impact general equilibrium).
- In practice, some of them might be priced directly into electricity consumption, e.g., with environmental charges to the price of electricity.

- Two extreme cases:
  - lump-sum charges, no multiplier
  - full cost recovery at the margin within the electricity sector –¿ Need to solve for it in equilibrium as demand responds

Solution approach to find renewable charge in the code

- We will use a **loop** to search for the right level of renewable charge added to the electricity price.
- These solutions can also be implemented as "raising the water level" algorithms, as it is very clear that the solution will cross the optimal point at some point (also with carbon tax to get a certain level of emissions).
    - If renewable charge collects too little money, increase.
    - If renewable charge collects too much money, decrease.

Retail tariffs considered in the paper

1. **Flat or real-time plus lump-sum:** assumed to be allocated equally across sectors.
2. **Flat or real-time plus marginal fee:** assumed to be allocated equally across sectors.
3. **Ramsey:** potential reallocation of costs across sectors (only for environmental fixed costs).

Can Ramsey prices justify shifting the burden on residential consumers vs. industrial consumers?

Theory detour on Ramsey prices

Typical Ramsey formula:

$$\frac{p_s - c}{p_s} = \frac{\lambda}{1+\lambda}\frac{1}{\epsilon_s},$$

- Given that industrial consumers are more elastic, serves as a justification for the type of pricing that we see.
- Burdensome on consumers, but potentially still efficient.
- Importantly, these are optimal Ramsey prices ignoring the presence of an externality.

Theory detour on Ramsey prices

Adding externality to the Ramsey formula:

$$\frac{p_s - c}{p_s} = \frac{\lambda}{1+\lambda}\frac{1}{\epsilon_s} + \frac{1}{1+\lambda}\frac{e_s \times \text{SCC}}{p_s},$$

- No longer as clear whether Ramsey formula is optimal or prescriptive in its standard form.
- Can depend substantially on marginal emissions rate, e_s.
- If consumers see to low prices due to renewable subsidies, possible to justify charging more to the *more* elastic.
- As long as they are also elastic *in terms of emissions*, i.e. no leakage.

Ramsey prices considered

1. **Ramsey:** Ramsey prices that recover costs of renewables and maximize welfare (ignoring externality).
2. **Ramsey enviro:** Ramsey prices that recover renewables costs and consider externalities.
3. **Ramsey enviro + leak:** Ramsey prices when emissions reductions in the industrial sector leak (decoupling between electricity response and emissions response).

Note: For all of them, additional markups exactly cover renewable costs. Of course, in practice, there are many other reasons why retail prices are above marginal cost.

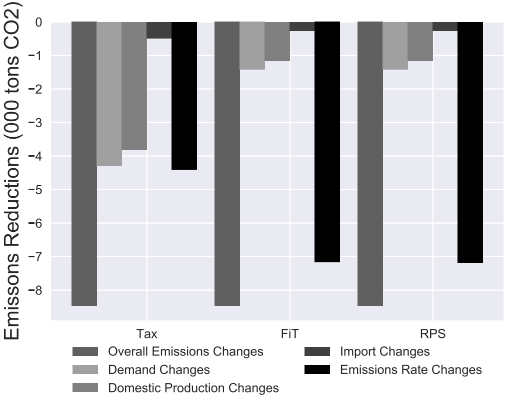
Efficiency and Distributional implications

- Do policies induce the right investment?
- How is this reflected in abatement?
- Who are the winners and losers?
- How much does it all change as the cost of renewables is passed through to consumers?

Efficiency decomposition

- Reduction of emissions held fixed across policies.
- Decompose source of reductions between:
  - Demand/supply changes
  - Emissions rate becoming cleaner
- Two sets of results:
  - Carbon tax, subsidies, and RPS
  - Carbon tax with marginal rebate, subsidies charged at the margin, and RPS

Efficiency implications: Subsidy matters depending on payment

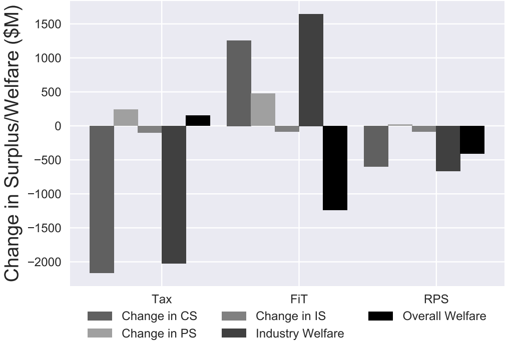


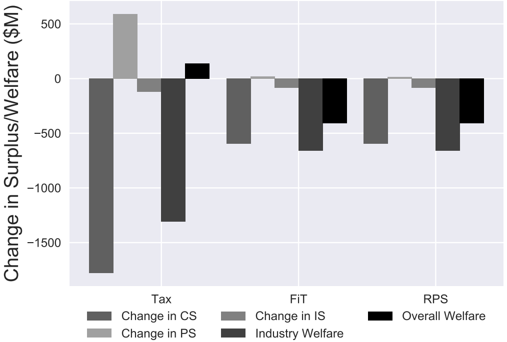
Distributional implications

- Who are the winners and losers?
- How does it depend on retail pass-through?

- For now, look at producers vs consumers:
  - Consumer surplus
  - Producers surplus
  - Import surplus

Distributional impacts: Welfare, winners, losers also change





Getting at sectoral redistribution

- I consider three different Ramsey scenarios:
  1. Standard Ramsey formula (ignores externality).
  2. Optimal Ramsey taking into account externality for welfare.
  3. Optimal Ramsey when industrial emissions leak.

- Also important to consider different levels of renewables subsidies.
- Helps consider situations far from first best, as Ramsey pricing can be used as corrective tool.

Results for Ramsey pricing

Low renewable target – FiT $107

	Prices			Δ Surplus			
	Res.	Com.	Ind.	Res.	Com.	Ind.	Δ W
Flat	40.84	40.84	40.84	-0.05	-0.09	-0.14	-1028.86
Ramsey	45.19	38.72	36.92	-0.08	-0.06	-0.05	-1047.02
Ramsey Enviro	39.51	41.14	43.14	-0.04	-0.09	-0.19	-1026.54
Ramsey Enviro Leak	40.86	43.14	34.65	-0.05	-0.12	-0.00	-1044.23

Ramsey prices are not welfare improving

High renewable target – FiT $148

	Prices			Δ Surplus			
	Res.	Com.	Ind.	Res.	Com.	Ind.	Δ W
Flat	59.19	59.19	59.19	-0.18	-0.33	-0.51	-3702.68
Ramsey	76.48	47.50	47.19	-0.29	-0.18	-0.28	-3641.29
Ramsey Enviro	69.78	52.42	47.80	-0.25	-0.25	-0.29	-3611.35
Ramsey Enviro Leak	72.36	52.47	41.73	-0.26	-0.25	-0.16	-3622.08

Results for Ramsey pricing

Low renewable target – FiT $107

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Ramsey prices with externality reverse!

High renewable target – FiT $148

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Subject to no leakage assumption

High renewable target – FiT $148

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If prices above first best, then traditional qualitative result holds

Getting at sectoral redistribution - insights

- Ramsey pricing can be detrimental to the extent that it prevents reductions from most elastic sectors.
- Ramsey pricing accounting for externalities prescribes prices that are closer together (if renewable goal large enough), or even reversed in the presence of too modest targets (increase reductions of electricity instead of avoiding them).
- All of this crucially depends on whether elasticity of electricity is correlated with elasticity of emissions:
  - If electricity-elastic sectors are not truly reducing emissions, then a further motive to strengthen Ramsey result.

Conclusions

- Paper builds a model to understand the trade-offs between charging different types of customers.
- I find it is key to understand whether elasticity is for electricity or for emissions.
  - If elasticity is for emissions, Ramsey undoes potential environmental goal.
- Model is silent about distributed generation as it doesn't have household granularity, but also a big part of the discussions on equity.

Next class

- **Supply II**
  - Adding transmission and leakage.