The Energy Transition:
An Industrial Economics Approach

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Universidad Carlos III and CEPR

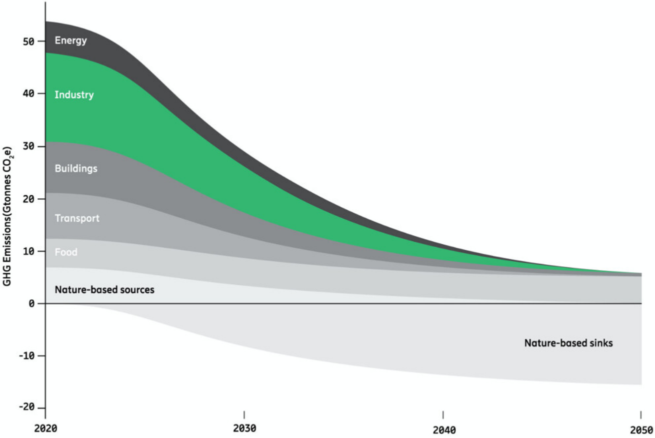
Paris Energy Economics Seminar (Virtual)

Introduction

How can we achieve the Energy Transition at least-cost?

Today's focus:

- Overview key regulatory challenges in the power sector



Key Regulatory Challenges

Key regulatory challenges to decarbonize power

1. **Market performance**:
   - How will firms compete in renewables-dominated markets?
   - Will the lower costs of renewables be passed on to consumers?

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   - And investments incentives?
   - And technology choices?

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2. **Market design**:
   - How will market design affect market performance?
   - And investments incentives?
   - And technology choices?
3. **Coping with renewables**:
   - **Renewables' intermittency** might create a mismatch btw demand/supply. How to cope with it?
     - Demand side: price signals for consumers?
     - Supply side: capacity, transmission, storage?

A team's work!

ERC project ELECTRIC CHALLENGES

1. **Market performance:**
   - "Auctions with privately known capacities: understanding competition among renewables" with Gerard Llobet
2. **Market design:**
   - "Market power and price exposure: learning from changes in renewables' regulation" with Imelda
   - "Technology-neutral versus technology-specific procurement" with Juan Pablo Montero
3. **Coping with renewables:**
   - "Estimating the Elasticity to Real Time Pricing: Evidence from the Spanish Electricity Market" with D. Rapson, M. Reguant and J. Wang (AER P&P)
   - "Storing power: market structure matters" with David Andres-Cerezo

Market Performance

Market performance

Will the lower costs of renewables be passed on to consumers?

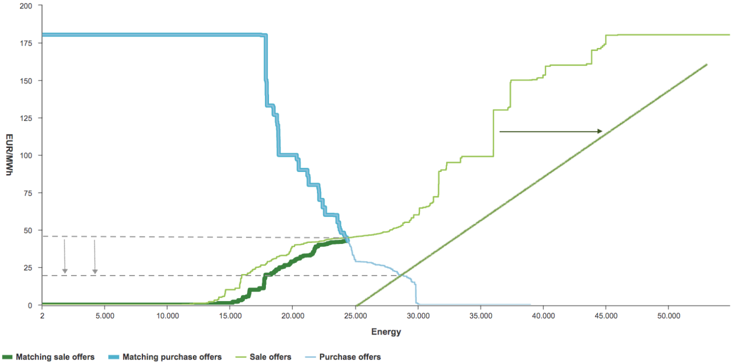

Figure: A (myopic) representation of the price depressing effect of renewables

Market performance

To understand the market impact of renewables, we **need to understand firms' optimal bidding behaviour** in this new context

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- Differences between conventional and renewable energy sources:
  - **Conventional plants**: known capacities, privately known costs
  - **Renewables**: privately known capacities, known (zero) marginal costs

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- Differences between conventional and renewable energy sources:
  - **Conventional plants**: known capacities, privately known costs
  - **Renewables**: privately known capacities, known (zero) marginal costs
- Renewables change **the nature of strategic interaction**:
  - Private information on costs $\rightarrow$ Private information on capacities

▸ Forecasts

A simple model

Understanding competition among renewables (Fabra and Llobet, 2020)

Firms and Demand:

- Ex-ante symmetric duopoly, $i = 1, 2$
- 100% renewables market, zero marginal costs
- Firms' available capacities k_i are private information
- Demand θ is known and price inelastic; price cap P

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Market Design:

- Uniform-price auction
- Renewables are paid at market prices ($+$ fixed premium)
- Firms bid a price-quantity pair $b_i(k_i) = (p_i(k_i), q_i(k_i))$ with $q_i \leq k_i$

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Equilibrium concept: Bayesian Nash equilibrium

Symmetric Bayesian Nash equilibrium

Case $\overline{k} < \theta$

Proposition

If $\overline{k} \leq \theta$, at the unique symmetric Bayesian Nash equilibrium when capacities are privately known, each firm $i = 1, 2$ offers all its capacity, $q^*(k_i) = k_i$, at a price given by

$$b^*(k_i) = c + (P - c) \exp\left(-\omega(k_i)\right),$$

where

$$\omega(k_i) = \int_{\underline{k}}^{k_i} \frac{(2k - \theta)g(k)}{\int_{k}^{\overline{k}} (\theta - k_j) g(k_j) dk_j} dk.$$

Symmetric Bayesian Nash equilibrium

Case $\overline{k} < \theta$

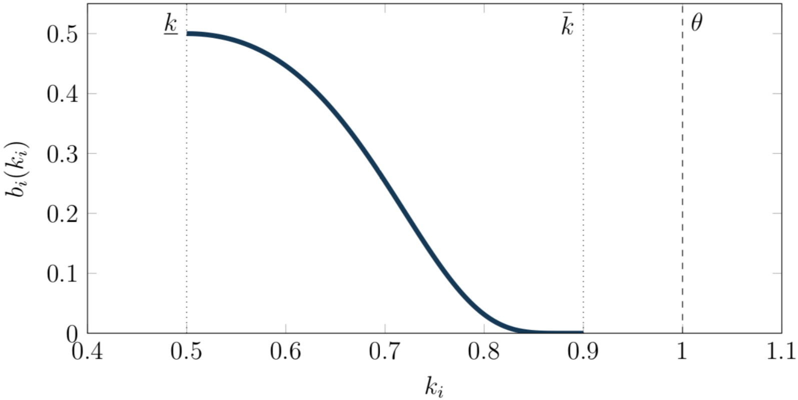


Figure: Equilibrium bids; $k_i \sim U[0.5, 0.9]$, $\theta = 1$, $c = 0$, and $P = 0.5$.

▸ Equilibrium

Symmetric Bayesian Nash equilibrium

Case $\overline{k} < \theta$

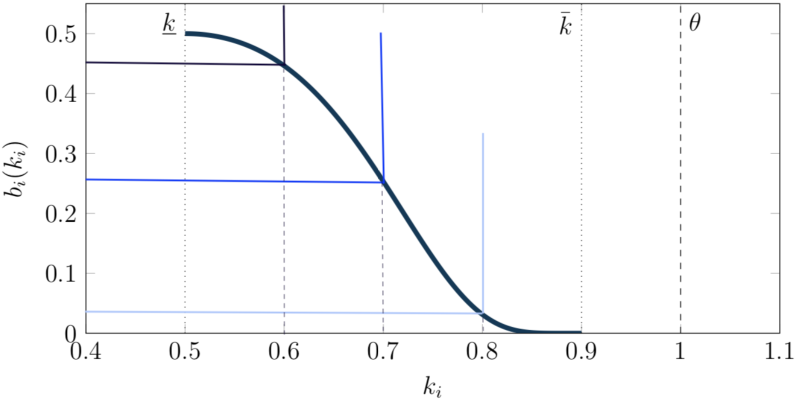
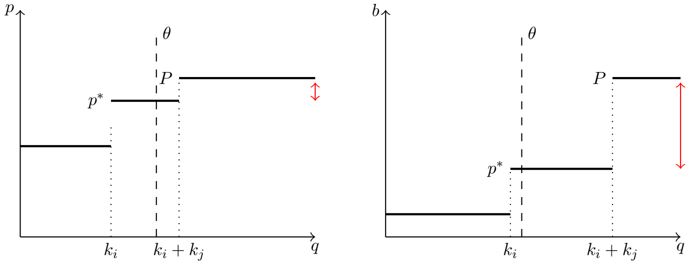


Figure: Equilibrium supply functions; $k_i \sim U[0.5, 0.9]$, $\theta = 1$, $c = 0$, and $P = 0.5$.

▸ Equilibrium

Implications for short-run market performance

Lower prices when realized capacities are large



(a) Small realized capacities (b) Large realized capacities

1. Market power mitigates the price-depressing effects of renewables
2. Market power gives rise to price volatility
3. Less market power than if capacities were known, but more market power than in the absence of private information

Implications for long-run market performance

Lower prices as installed capacity increases

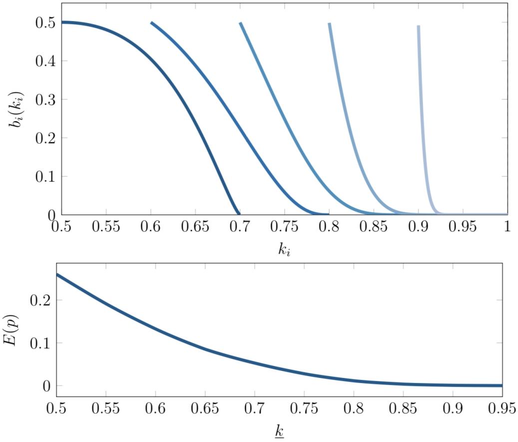


Figure: Equilibrium bids and expected prices as installed capacity increases; $\theta = 1$, $c = 0$, and $P = 0.5$

(Speculative, COVID-related) Empirical evidence

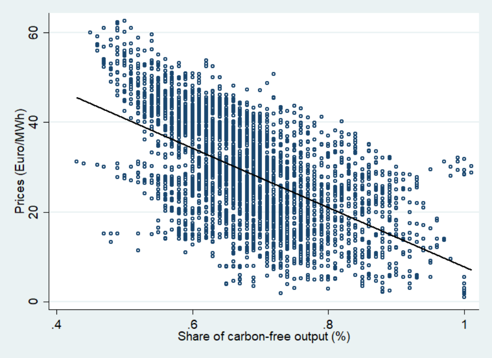


Figure: Market prices as a function of the share of carbon-free generation; Spanish electricity market, Feb-August 2020

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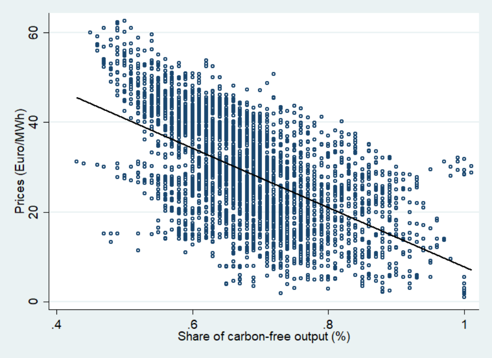

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Will future prices support today's investments?
Can this be improved through market design?

▸ Prices

Market Design

Market design

How should we procure and pay for renewables?

Policy choices:

- Expose producers to **volatile prices** or to **fixed prices**
- Use **price or quantity** instruments (auctions)
- Pay for **energy** or pay for **capacity**
- **Neutral** approach or **technology-specific** approach

Such choices have strong implications for...

- Market power in the energy market (as we show next)
- Financing costs
- Entry of new players
- Location of new investments
- Technology choices (as we show next)
- Payments by consumers (as we show next)

Market design and market performance

Pricing schemes for renewables:

- Market price + fixed premium (FiP)
- Fixed price set by regulator or through an auction (FiT)

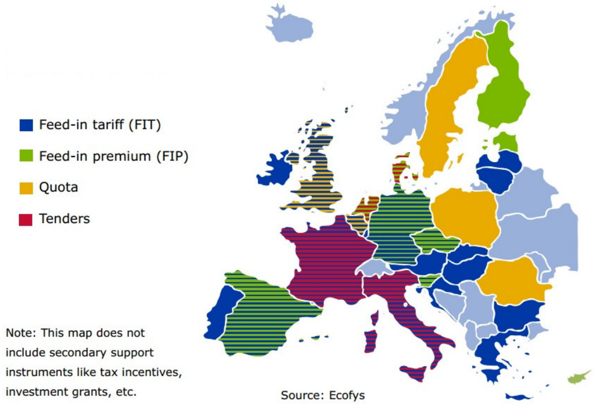

Figure: Renewable Support Instruments (source: Ecofys)

Impacts of fixed prices on market power

Market power and price exposure (Fabra and Imelda, 2020)

Theoretically:

1. act like **forward contracts** $\rightarrow$ mitigate market power
2. reduce price **arbitrage** $\rightarrow$ strengthen market power

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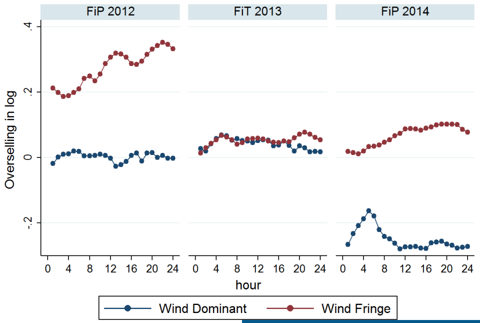
Empirically: ▸ Time Series

- Exogenous changes in the pricing schemes for wind in the Spanish electricity market help us identify the effects on market power



Taking the model to the data

- **From profit max.**, we can express the optimal price as:

$$p_t = p_{t+1} + \left| \frac{\partial DR_{it}}{\partial p_t} \right|^{-1} (q_{it} - I_t w_{it})$$

- w_t is wind, with fixed prices ($I_t = 1$) or market prices ($I_t = 0$)

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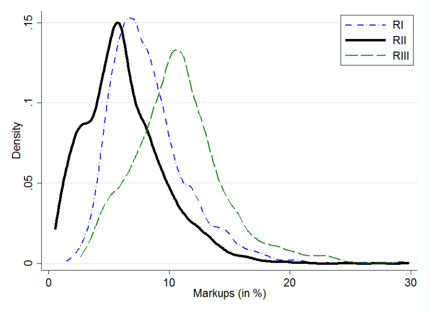

Figure: Distribution of estimated mark-ups when renewables receive fixed prices (RII) or market prices (RI and RIII) ▸ Table

Market design and investment

Using auctions to set renewables' prices

Auction choices for procuring renewable investments:
How, How much, How often, **Which technologies**

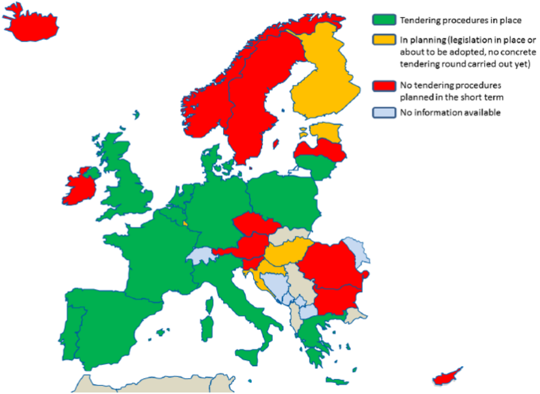

Figure: Use of renewables auctions across Europe (source: Ecofys)

Simple model

Technology-Neutral *vs* Technology-Specific Procurement (Fabra and Montero, 2021)

One good can be provided with **multiple technologies** (perfect or imperfect substitutes), with costs c_t subject to shocks (**cost uncertainty** σ and correlation ρ)

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Regulator cares about:

- Maximize **social benefits**
- Minimize **investment costs**
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Key insight: **rents-efficiency trade-off** (case of perfect substitutes)

- Technology-neutrality is good for **investment efficiency**
- But it leaves too **high rents** to suppliers
- **The technology-specific approach** allows to reduce rents by distorting quantities at the expense of efficiency

▸ Model ▸ Graphical representation

Taking the model to the data

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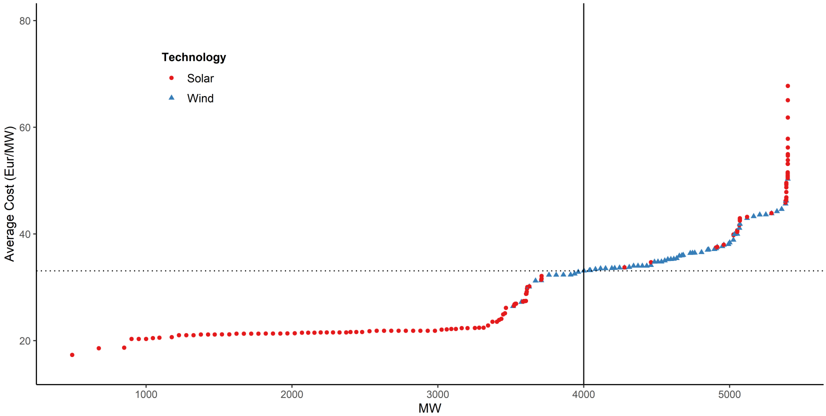

Figure: Average cost curve of solar and wind investments in the Spanish electricity market: Technology Neutral

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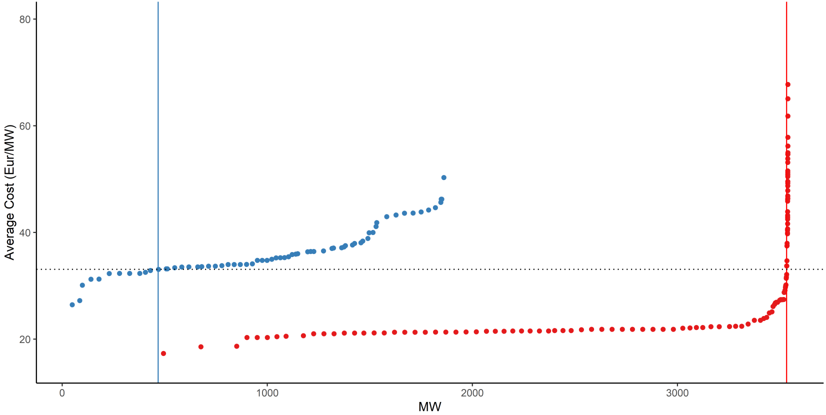

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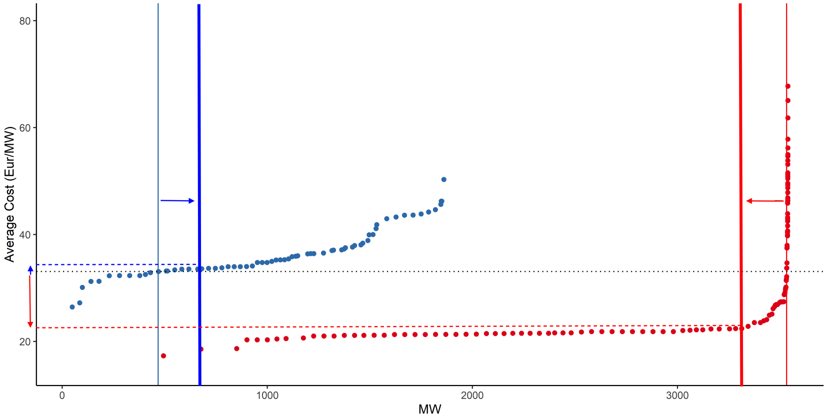

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When is technology-neutrality superior?

Comparing Welfare: (case of perfect substitutes)

$$W^N - W^S = \frac{1}{4C''}\left[2\sigma(1-\rho) - \frac{\lambda^2}{1+2\lambda}(\Delta c)^2\right] > 0$$

Rents-efficiency trade-off:

1. 1st term: efficiency gain under tech-neutrality (quantity adjustment)
2. 2nd term: excess rents left with the more efficient suppliers

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   - Perfectly correlated cost shocks: $\rho = 1$

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2. **Tech-neutrality always dominates if 2nd term=0**:
   - No concern for rents: $\lambda \to 0$
   - Symmetric ex-ante technologies: $\Delta c \approx 0$

Coping with renewables

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Renewables are intermittent: potential supply/demand mismatch.

Solutions to facilitate the integration of renewables:

- **Dynamic pricing:** charge consumers different prices over time, reflecting changes in the marginal costs of serving demand
- **Storage:** Pumped hydro, batteries, EVs...

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Further benefits:

- Reduce production costs
- Avoid investing in idle capacity
- Mitigate market power

Dynamic Pricing in Spain

Estimating the short-run elasticity to RTP (Fabra, Rapson, Reguant, Wang 2021)

- Since 2014, Spain is the only country so far in which households, by default, are charged Real-Time Prices (RTP) ▸ Figure
- We have hourly electricity consumption data at the household level for more than 2M Spanish households

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Empirical strategy to identify short-run price-elasticity:

- Main regression (household by household):

$$\ln q_{ith} = \beta \ln p_{ith} + \phi X_{ith} + \gamma_{th} + \epsilon_{ith}.$$

- Controls: temperature, time fixed effects, zip-code
- Wind generation as an IV for price changes

Dynamic Pricing in Spain

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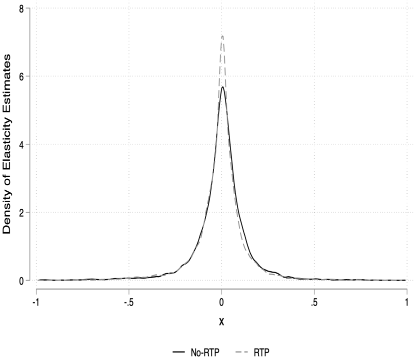

Figure: Distribution of household-level estimated elasticities

- Distribution centered around zero, median of no response
- Very similar for RTP and non-RTP customers

Storage

Storing power: market structure matters (Andres-Cerezo and Fabra, 2020)

Similar to demand response...

- Large price differences over time needed to make storage worth it

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Unlike demand response...

- Heavy investments in long-lived assets are needed
- Storage creates positive externalities beyond arbitrage profits
- Storage owners are not always price-takers:
  - Large storage owners, often vertically integrated with generators, internalize the price impacts of their storage decisions
- Potential distortions for storage use and investment

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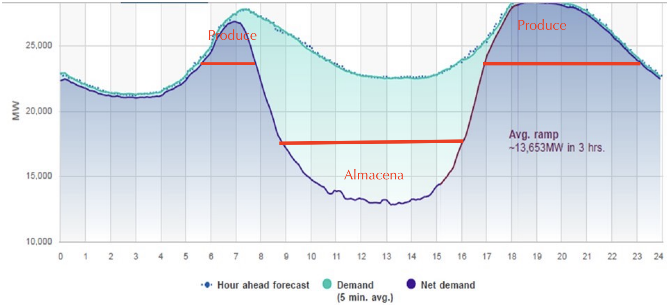
It matters **who owns and who operates** the storage facilities

Market power in storage and in generation give rise to underutilisation and underinvestment in storage

More on storage

Storage in a Competitive Market

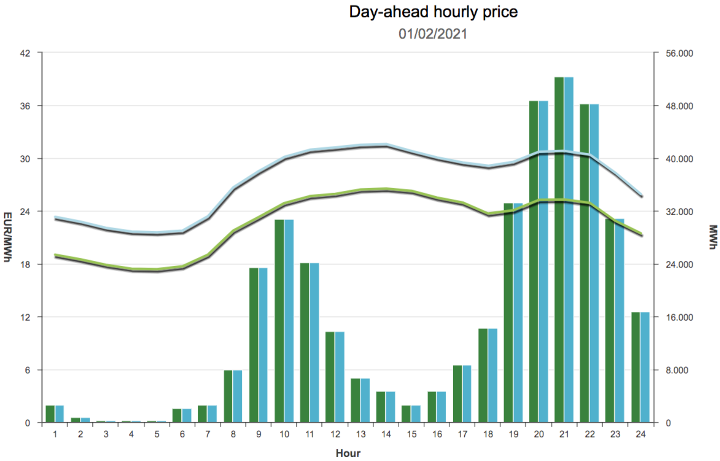
Store/release to **flatten demand/production** and invest in storage capacity so that the **marginal cost savings due to an extra unit of storage** equate the per-unit investment cost



The Duck: CAISO Total Demand and Net (of Solar and Wind) Demand for Feb 7, 2019
(source: http://www.caiso.com/TodaysOutlook/Pages/default.aspx)

In the absence of market power, **prices allow firms to internalize the costs savings** associated with storage

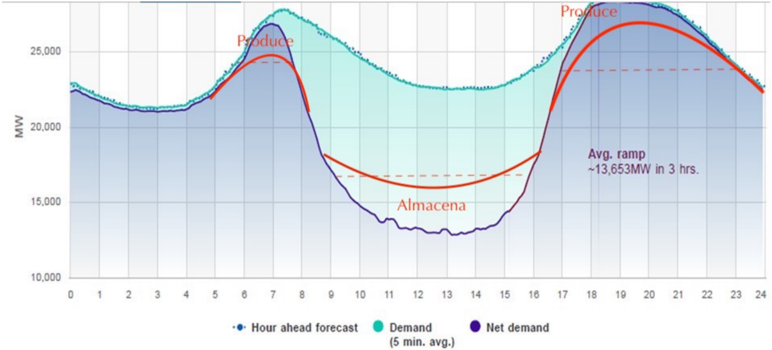
Price Arbitrage



Competitive firms make arbitrage profits by storing when prices are low are releasing when prices are high

Market Power in Storage

Large storage firms are no longer price-takers



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Market concentration in storage **distorts the optimal use of storage** and **weakens investment incentives**

Policy Implications

The Energy Transition is a key economic and social challenge

How we design it will be critical for its success

Key elements for its success:

- **Competition for the market** through auctions
- **Contracts** to be auctioned-off should **differ across technologies**
  - Fixed prices for energy (or limited price exposure) for renewables
  - Capacity payments with full price exposure for storage and back-up
- **Technology-neutrality** need not always be preferred
  - Concern over excessive rents
  - Different technologies provide different services and externalities
- **Market structure** matters
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Let's push the research frontier to contribute to this goal!

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Thank You!

Questions? Comments?

More info at nfabra.uc3m.es and energyecolab.uc3m.es

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Appendix

Private information reduces forecast errors

Predicting the hourly production of given wind plants using publicly available information only or also private information

Variables	(1)	(2)
Public information	0.582***	0.070***
	(0.035)	(0.021)
Private innformation		0.657***
		(0.008)
Observations	36,671	36,671
R-squared	0.520	0.826
Mean of the error	0	0
Standard deviation of the error	.18	.11

BACK

Symmetric equilibrium

Large installed capacities

Proposition

Assume $\overline{k} > \theta$*.*

(i) For $k_i \leq \theta$*, bidding is as in the small installed capacity case.*

(ii) For $k_i > \theta$*,* $b_i^*(k_i) = c$ *and firm* i *withholds output,* $q_i^*(k_i) = \theta$*.*

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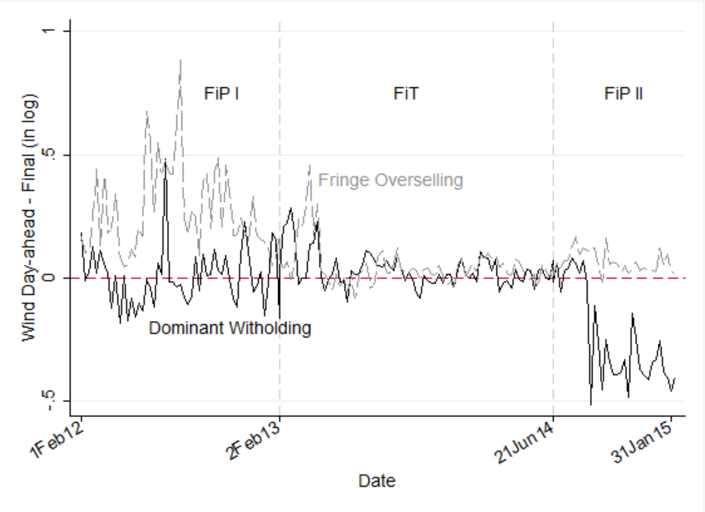
Overselling and withholding by wind producers



This figure shows day-ahead minus final commitments of wind producers.

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Model Description

Technology-Neutral *vs* Technology-Specific Procurement (Fabra and Montero, 2020)

Firms and Technologies:

- One good can be produced with two technologies $t = 1, 2$
- Continuum of (risk-neutral) price-taking suppliers of each t

Costs:

- Unit costs $\sim U[\underline{c}_t, \bar{c}_t]$, with $\underline{c}_t = c_t + \theta_t$ and $\bar{c}_t = c_t + \theta_t + C''$...
- ...giving rise to an aggregate cost function, for $t = 1, 2$:

$$C_t\left(q_t\right) = \left(c_t + \theta_t\right) q_t + \frac{C''}{2} q_t^2$$

where $c_t \geq 0$ and $C'' > 0$

- Cost shocks: $E[\theta_t] = 0$, $E[\theta_t^2] = \sigma > 0$ and $E[\theta_1 \theta_2] = \rho\sigma \gtrless 0$

Social Benefits:

- $B\left(Q\right)$, where $Q = q_1 + q_2$, with $B' > 0$ and $B'' < 0$
- Ass.: Always optimal to procure units from both technologies

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The Planner's Problem

The planner maximizes (expected) **social welfare**:

$$\max W = E\left[B\left(Q\right) - \sum_{t=1,2} C_t\left(q_t\right) - \lambda T(q_1, q_2)\right]$$

where:

- λ: **shadow cost of public funds**
- $T(q_1, q_2)$: planner's total payment from procuring $Q = q_1 + q_2$

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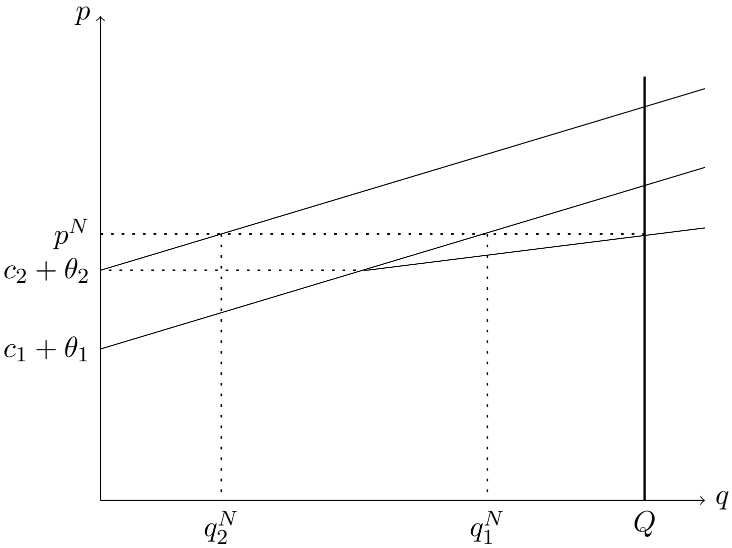
Graphical representation



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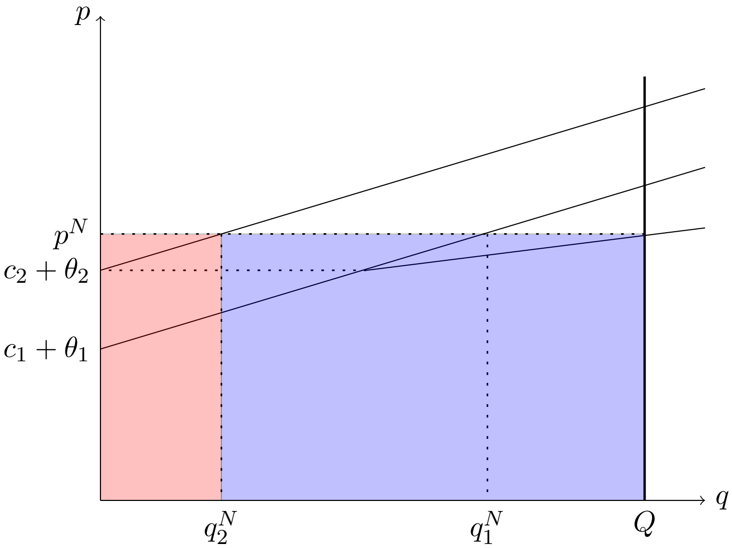

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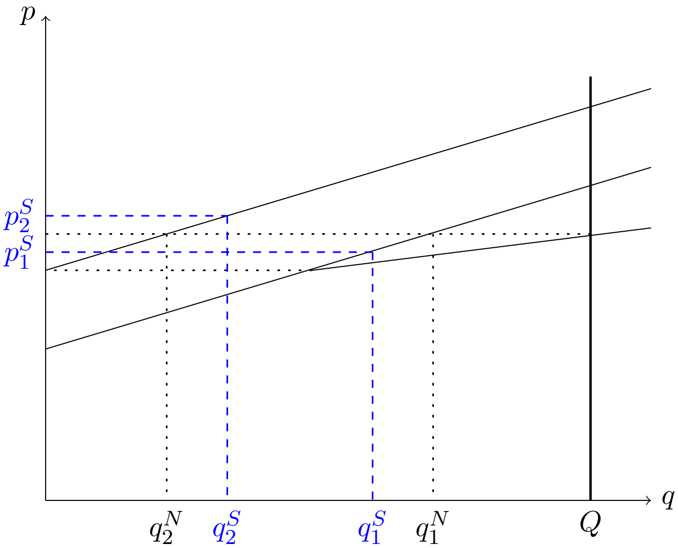
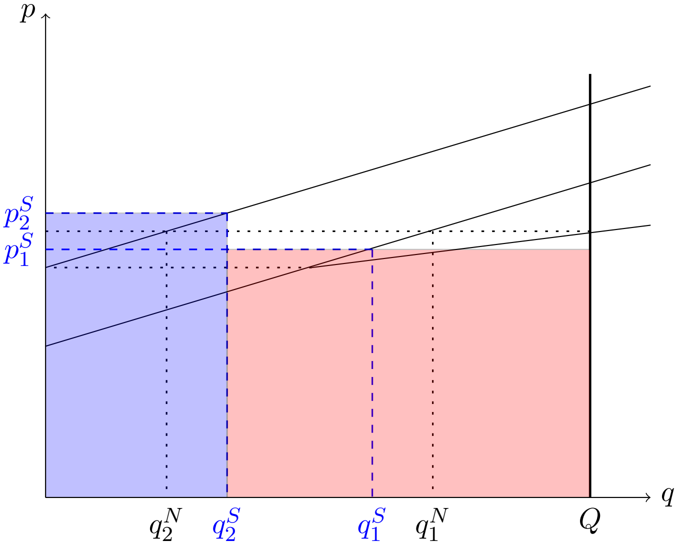


BACK

Graphical representation



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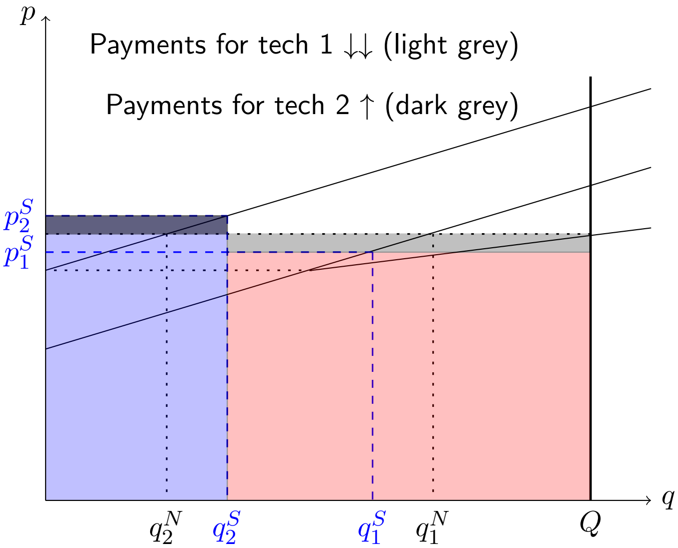

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Storage

Storing power: market structure matters (Andres-Cerezo and Fabra, 2020)

- **Research questions:**
  1. How is storage managed?
  2. What are the impacts of storage on wholesale prices and costs?
  3. What is the endogenous storage capacity?
  4. How does it all depend on the market structure?

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  1. How is storage managed?
  2. What are the impacts of storage on wholesale prices and costs?
  3. What is the endogenous storage capacity?
  4. How does it all depend on the market structure?
- We introduce **storage** in a model of wholesale market competition with different degrees of **market power in generation**
- We consider alternative **market structures for storage**:
  - Social planner
  - Competitive storage
  - Independent storage monopolist
  - Vertically integrated storage monopolist

Storage

Main results

Key ideas:

- Social gains: marginal cost savings from storing and releasing
- Private gains (competitive storage): marginal arbitrage profits
- Private gains (market power in storage): marginal returns

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2. Market power in generation $\rightarrow$ storage more valuable
3. Market power in storage $\rightarrow$ storage less valuable

Storage

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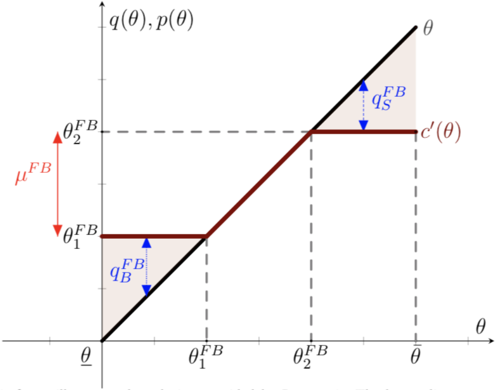
Main take-aways:

1. Never optimal to invest in storage capacty so as to fully flatten production (decreasing marginal gains)
2. Market power in generation → storage more valuable
3. Market power in storage → storage less valuable
   - Under competitive storage: **over-investment**
   - Under a storage monopolist: **under-investment**
   - Market power in generation → larger investment distortions

Storage under the first-best



Notes: This figure illustrates the solution provided by Lemma 1. The brown line represents market demand plus/minus storage decisions. The shaded area represents the amount of stored goods. The blue line gives prices at every demand level. As can be seen, demand and marginal costs are fully flattened. The marginal value of storage is found along the industry's marginal cost curve.

Figure: Optimal storage decisions under the first-best solution (energy market is perfectly competitive) ▸ Back