The Energy Transition:
An Industrial Economics Perspective

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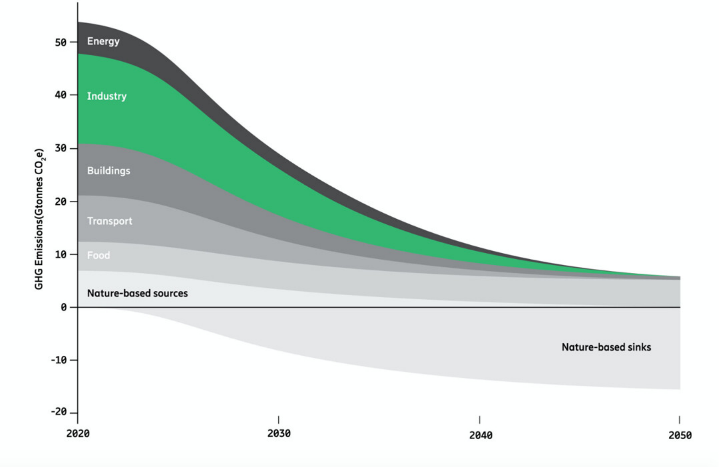
Keynote Lecture, EARIE Conference
August 2020

What is the Energy Transition?

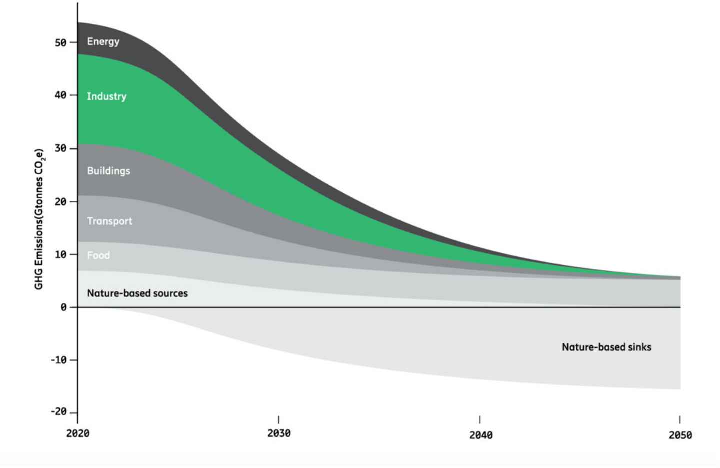
The **Energy Transition** is a pathway towards the transformation of the global energy sector from fossil-based to zero-carbon



What is the Energy Transition?

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

Today's focus: **power sector**



The Energy Transition is underway

- **Europe:**
  - **European Green Deal** (1Tn Euro): net-zero emissions by 2050
  - **Recovery Fund**: climate action is key for economic recovery

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- **United States:**
  - **California**: 90% carbon-free electricity by 2040
  - **Biden's Climate Plan** (3Tn USD):
    - net-zero emissions by 2050
    - 90% carbon-free electricity by 2035 ▸ 2035

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HOW?: Which policies to achieve these objectives?

Today's talk

Plan for today's talk:

- Overview key regulatory challenges to decarbonize power markets
- Describe some of our recent papers that address these challenges

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Objective: (Try to) convince you that research in this area provides exciting opportunities for IO economists

- Highly relevant
- Many issues at the heart of IO
- Large and detailed data sets
- Many questions remain unanswered and we need solutions fast!

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?
2. **Market design**:
   - How will competition depend on market design?
   - And investment 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 (on-going) work!

1. **Market performance:**
   - "Auctions with unknown capacities: understanding competition among renewables" with Gerard Llobet (CEMFi)
2. **Market design:**
   - "Market power and price discrimination: learning from changes in renewables' regulation" with Imelda (UC3M)
   - "Technology-neutral versus technology-specific procurement" with Juan Pablo Montero (PUC)
3. **Coping with renewables:**
   - "Real-time pricing for everyone" with David Rapson (UC Davis) and Mar Reguant (Northwestern)
   - "Storing power: market structure matters" with David Andres-Cerezo (EUI)

Market Performance

Market performance

The price depressing effect of renewables

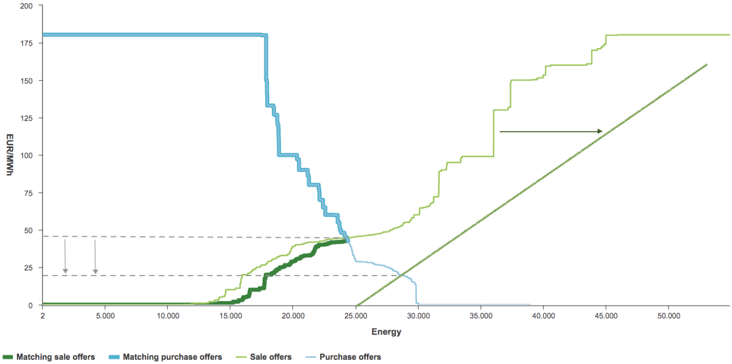

Figure: A (myopic) representation of the price depressing effect of renewables

Market performance

The price depressing effect of renewables

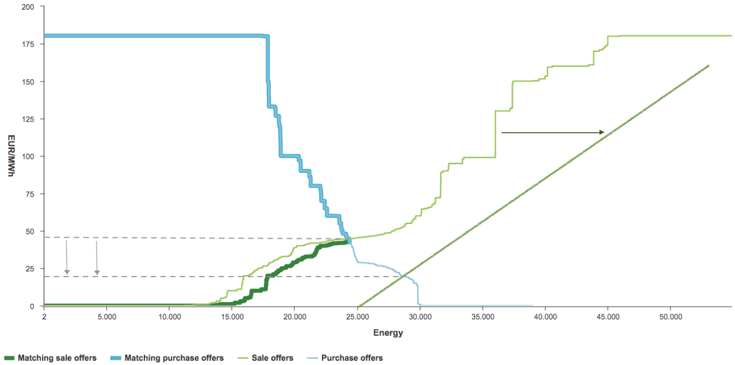

Figure: A (myopic) representation of the price depressing effect of renewables

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

Market performance

What is the new market game?

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

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Renewables change **the nature of strategic interaction**:
Private information on costs $\rightarrow$ Private information on capacities
(many other examples in IO)

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
- Cost of conventional suppliers 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 $\overline{k} < \theta$

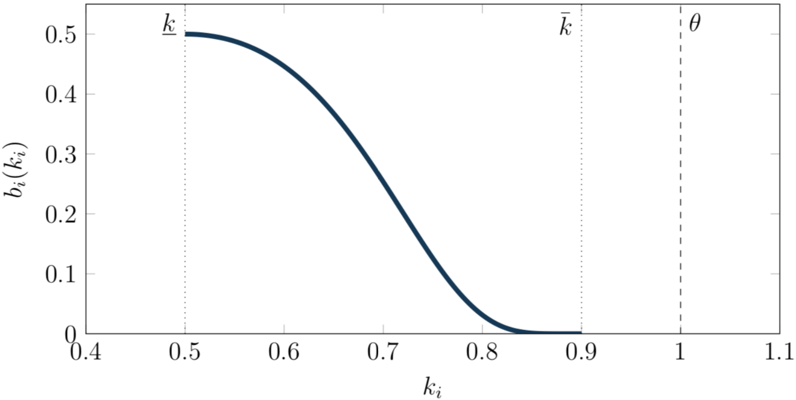

Figure: Equilibrium price offers; $k_i \sim U[0.5, 0.9]$, $\theta = 1$ and $P = 0.5$.

Equilibrium

Symmetric Bayesian Nash equilibrium

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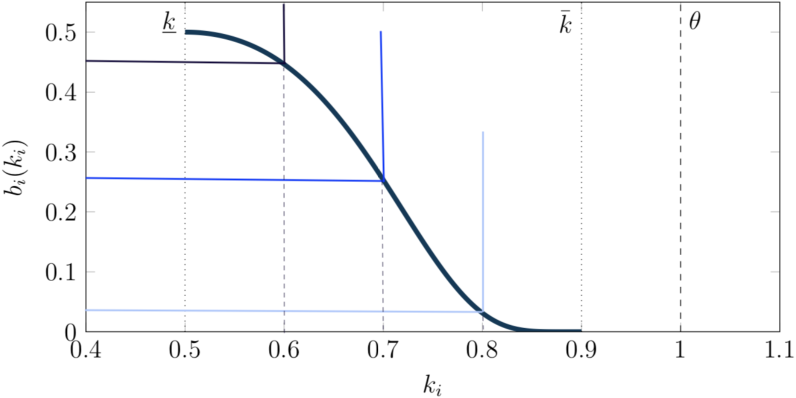
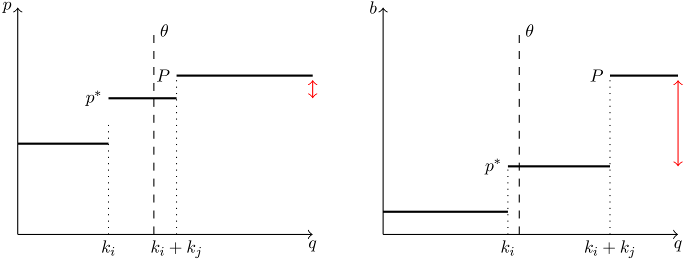


Figure: Equilibrium supply functions; $k_i \sim U[0.5, 0.9]$, $\theta = 1$ and $P = 0.5$.

Equilibrium

Implications for short-run market performance

Lower prices when realized capacities are large



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

Market power mitigates the price-depressing effects of renewables and gives rise to price volatility

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

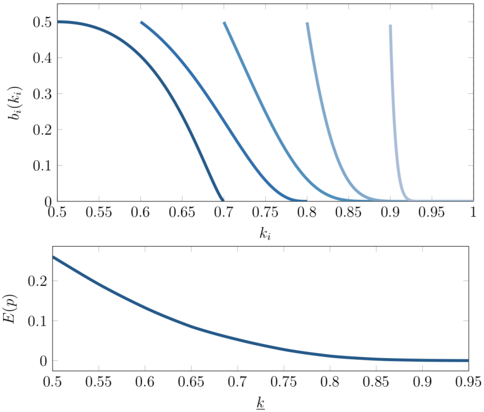


Figure: Equilibrium bids and expected prices as installed capacity increases

Market prices will go down towards renewables marginal costs

(Speculative, COVID-related) Empirical evidence

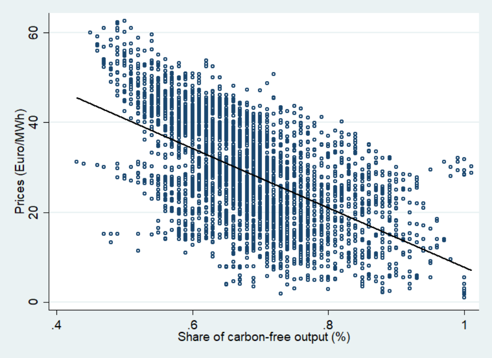


Figure: Market prices as a function of the share of carbon-free generation; Spanish electricity market, Feb-August 2020

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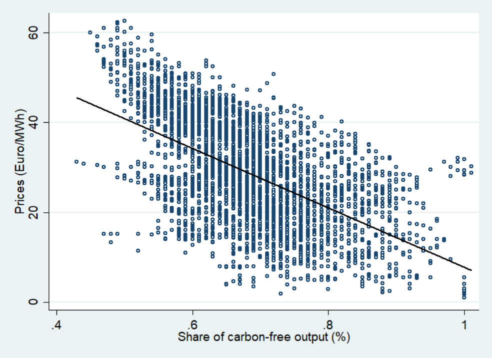

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Will future prices support today's investments?
Can this be improved through market design?

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

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Such choices have strong implications for...

- Market power in the energy market
- Financing costs
- Entry of new players
- Location of new investments
- Technology choices
- Payments by consumers

Market design and market performance

Pricing schemes for renewables:

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

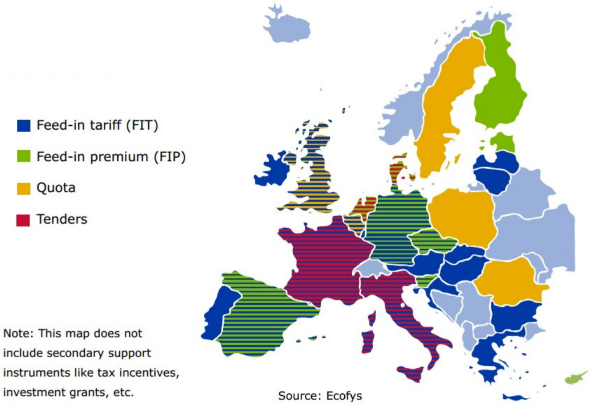

Figure: Renewable Support Instruments (source: Ecofys)

Impacts of fixed prices on market power

Renewables' price exposure and market power (Fabra and Imelda, 2020)

Theoretically: ▸ Figure

1. act like **forward contracts** → mitigate market power
2. mitigate **arbitrage** → strengthen market power

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Empirically:

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

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

where $I_t = 1$ with fixed prices and $I_t = 0$ with market prices.

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Mark-up

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Taking the model to the data

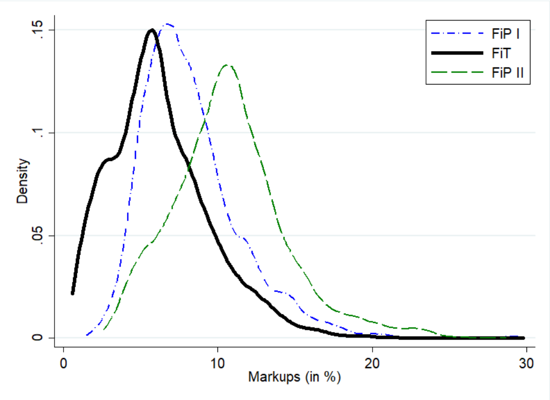

Figure: Distribution of estimated mark-ups when renewables receive fixed prices (FIT) or market prices (FIP) ▸ Table

Paying fixed prices to renewables mitigates firms' market power
(+ other benefits for investments: risk mitigation)

Market design and investment

Using auctions to set renewables' prices

Auction choices for procuring renewable investments:

How, How much, How often, **Which technologies**

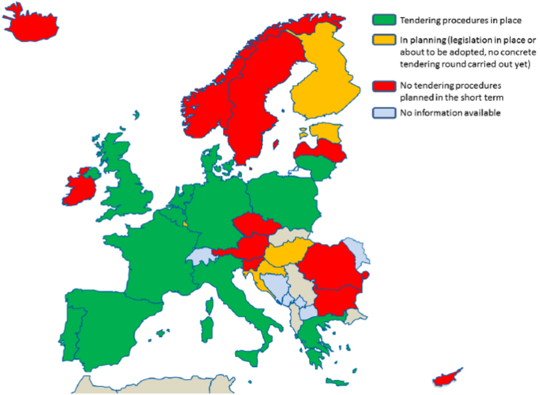

Figure: Use of renewables auctions across Europe (source: Ecofys)

Simple model

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

One good can be produced with multiple technologies: linear marginal costs; intercept c_t subject to shocks (variance σ; correlation ρ)

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Key insight: rents-efficiency trade-off

- 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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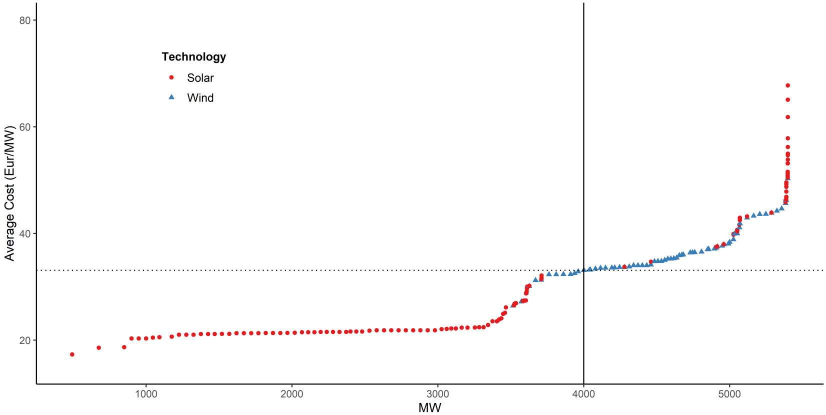

Figure: Average cost curve of solar and wind investments in the Spanish electricity market: Technology Neutral

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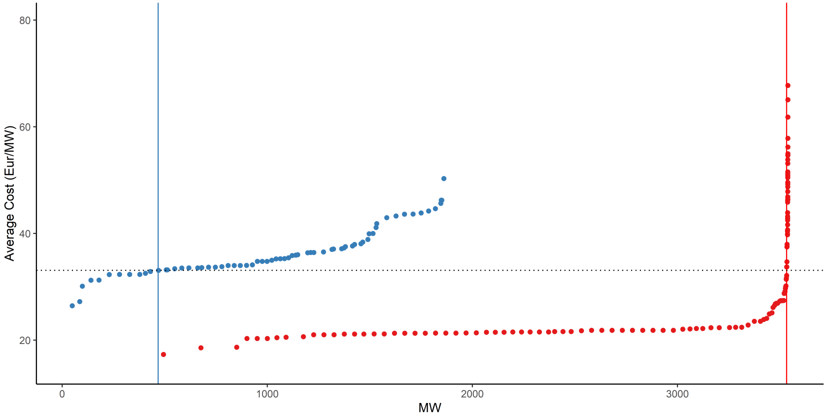

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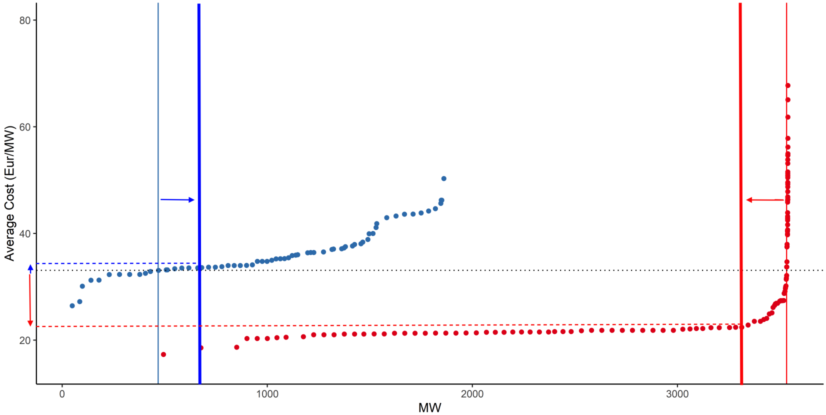

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Is technology-neutrality always preferred?

Comparing Welfare under the two approaches:

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

Rents-efficiency trade-off:

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

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Technology neutrality is not always optimal: whether to adopt a tech-neutral or specific approach should be assessed case-by-case

Coping with renewables

Coping with renewables

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

Storage: an illustration

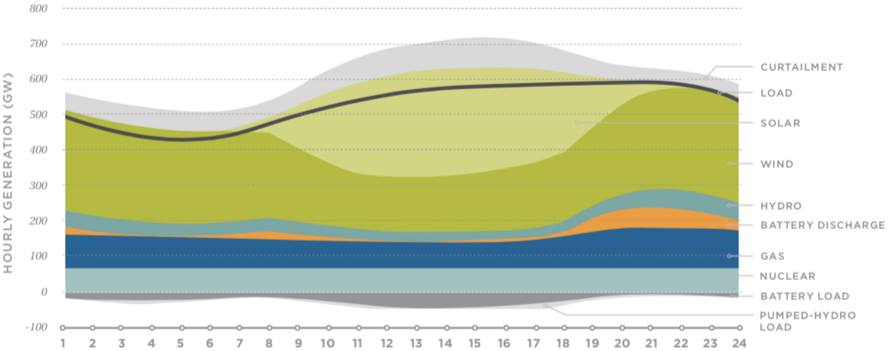

Figure: Dispatch of generation technologies during a representative day, 90% Clean case by 2035

(source: 2035report.com)

Is pricing enough to make consumers price responsive?

Real Time Pricing for Everyone (Fabra, Rapson and Reguant, 2020)

- 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

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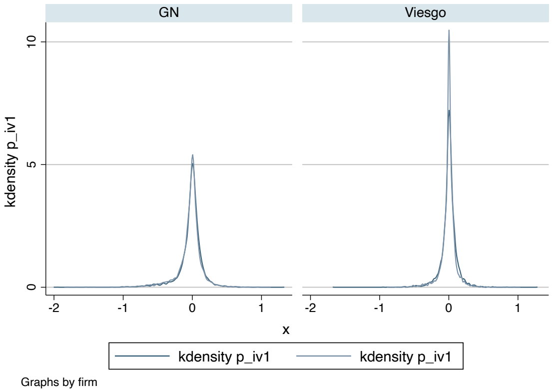

Figure: Distribution of household-level estimated elasticities

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

Dynamic Pricing

Policy implications

- Currently, RTP does not appear to engage customers
  - Automatic devices?
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RTP does not appear to engage consumers

What is the optimal combination between RTP and TOU?

Storage

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

Similar to demand response...

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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

Conclusions

The Energy Transition is a key economic and social challenge

How we design it will be critical for its success

- A source of exciting and relevant questions for IO:
  - There is much more than (just) electricity markets!
    - Transportation, cities, digitalization, pricing, taxation, trade policy, industrial policy, consumers' behaviour...
  - Theory, empirical work, experiments
- Our competitive advantages as IO economists:
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Let's push the research frontier in IO to contribute to this goal!

Thank You!

Questions? Comments?

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

This Project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 772331)

Appendix

The power sector in transition

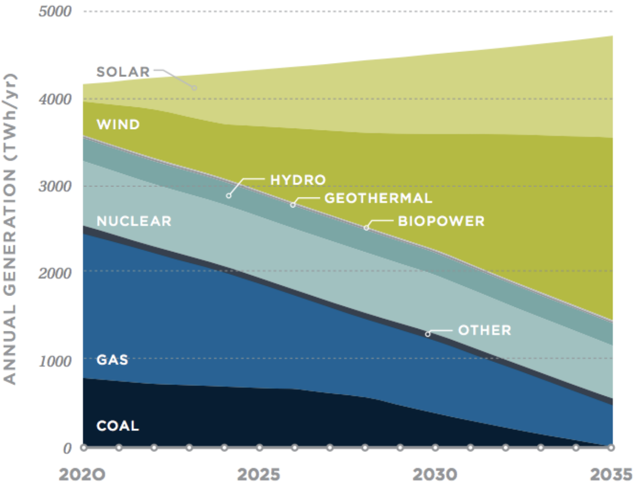

Figure: Generation mix to reach the 90% Clean Case in 2035

(source: 2035report.com, University of California at Berkeley)

Cost reductions in renewables and storage...

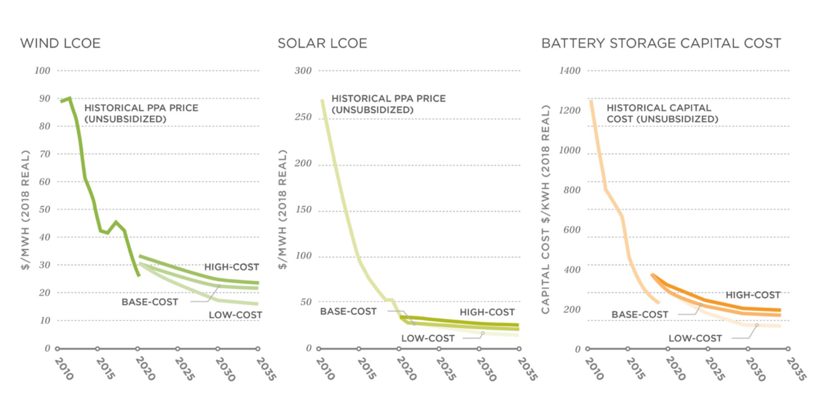

Figure: Historical and projected cost declines for wind, solar and storage

(source: 2035report.com)

BACK

...will lead to lower electricity costs

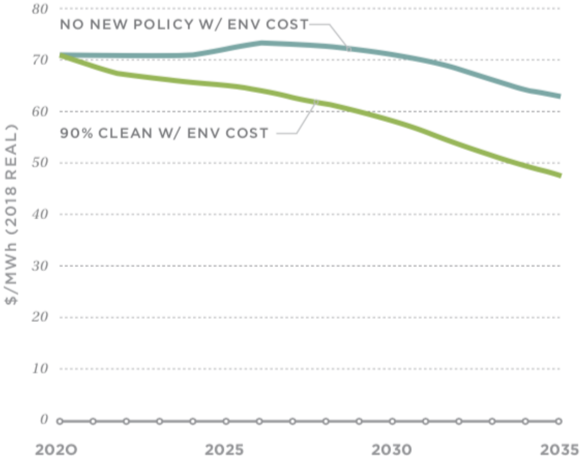

Figure: Wholesale electricity costs with environmental costs for the 90% Clean and No new policy cases

(source: 2035report.com)

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 information		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

Private information reduces forecast errors

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

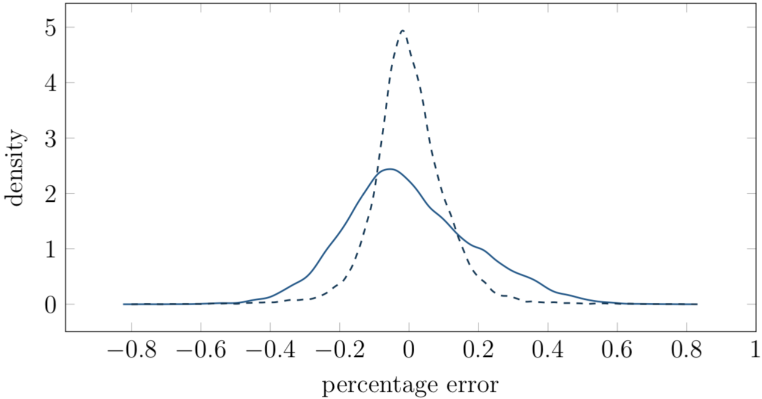

Figure: Distribution of forecasts errors

Symmetric equilibrium

Small installed capacities

Proposition

Assume $\overline{k} < \theta$.

At the unique symmetric BNE, each firm $i = 1, 2$ *offers all its capacity,* $q^*(k_i) = k_i$*, at a price*

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

where

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

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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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(Speculative, COVID-related) Empirical Evidence

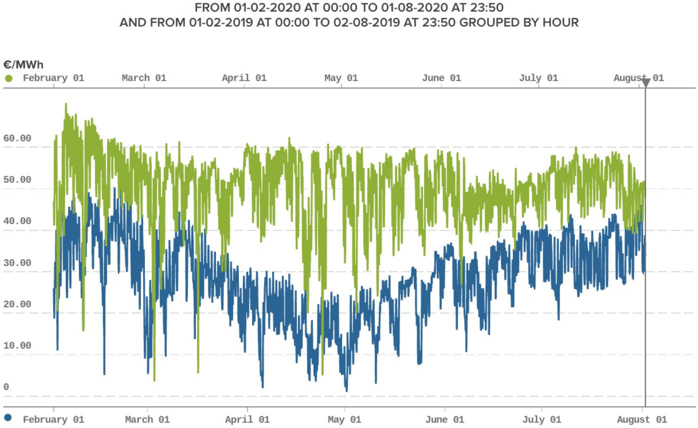

Figure: Wholesale prices in the Spanish electricity market, February-August 2019 (green) vs. 2020 (blue)

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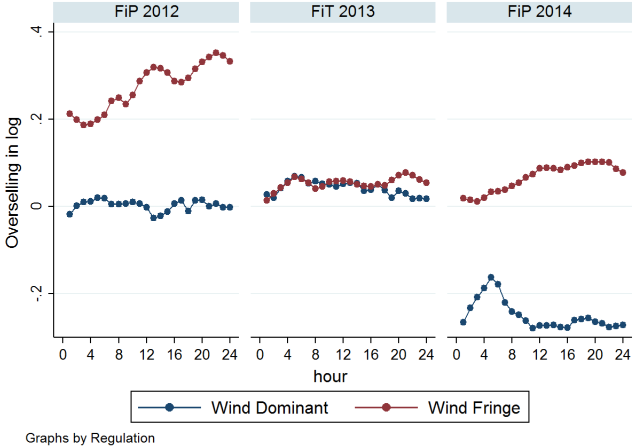
Overselling and withholding by wind producers



This figure shows the hourly average of the day-ahead commitments minus the final commitments of the wind producers, split in three regulatory regimes.

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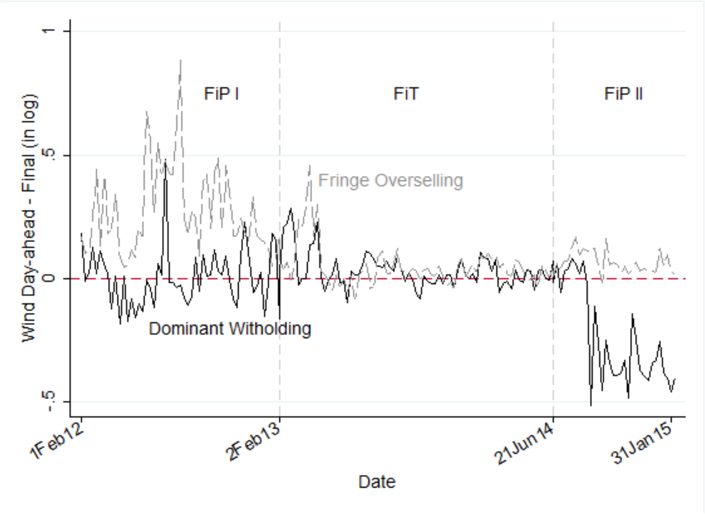
Arbitrage and withholding by wind



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

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Markups across pricing regimes

Table 5: Average Markups on Day-ahead Market

	FiP I		FiT		FiP II	
	Mean	SD	Mean	SD	Mean	SD
Markups (in %) – Simple average						
All	8.3	(3.3)	6.3	(3.3)	10.7	(3.7)
Firm 1	7.0	(2.2)	7.0	(2.6)	12.1	(4.4)
Firm 2	12.3	(4.1)	8.2	(5.1)	14.7	(4.4)
Firm 3	7.7	(2.3)	6.0	(3.3)	10.3	(3.3)
Slope of day-ahead residual demand (in MWh/euros)						
All	524.2	(78.2)	553.6	(120.7)	418.2	(73.0)
Firm 1	506.6	(50.5)	458.4	(72.7)	411.0	(62.4)
Firm 2	508.5	(71.8)	556.4	(165.0)	453.8	(99.8)
Firm 3	538.2	(88.7)	573.3	(117.2)	418.0	(73.2)

Notes: Sample from February 2012 to January 2015, includes the markups for those units bidding within a 5 Euro/MWh range around the market price, for hours with prices above 25 Euro/MWh. FiP I is from 1 February 2012 to 31 January 2013; FiT is from 1 February 2013 to 21 June 2014; FiP II is from 22 June 2014 to 31 January 2015.

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 $t = 1, 2$:

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

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:

- $B(Q)$, 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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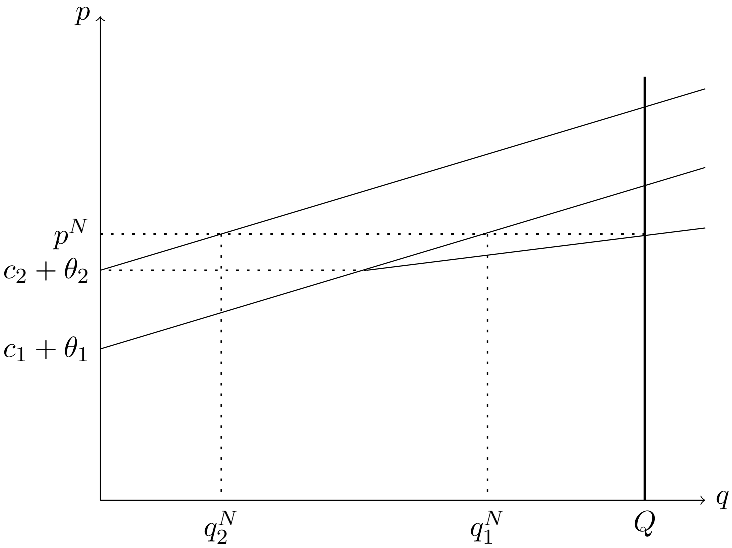
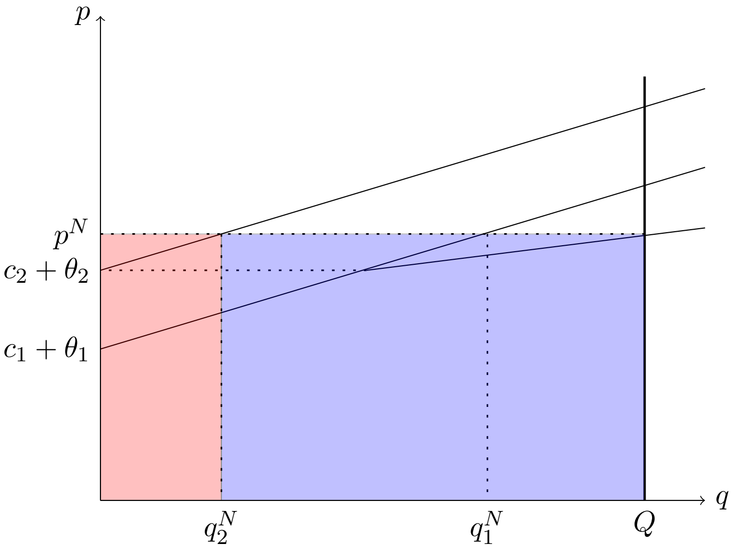
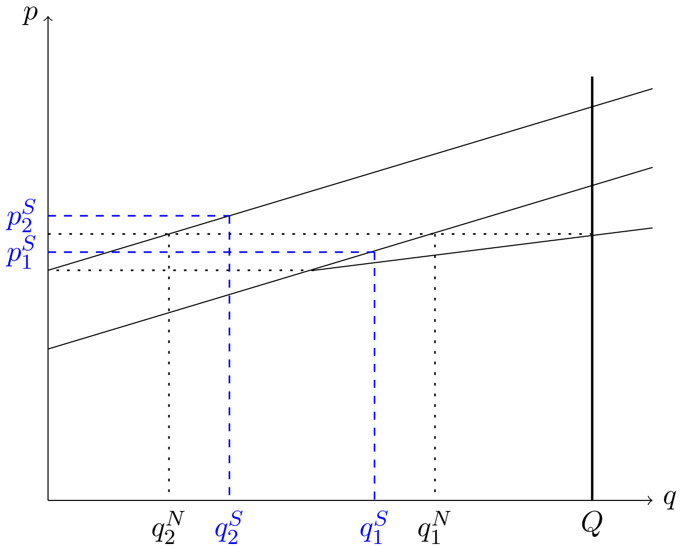
Graphical representation



Graphical representation



Graphical representation



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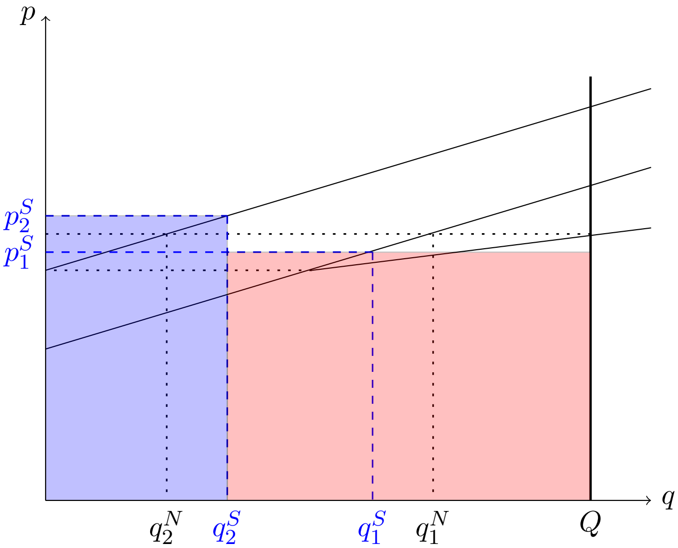
Graphical representation



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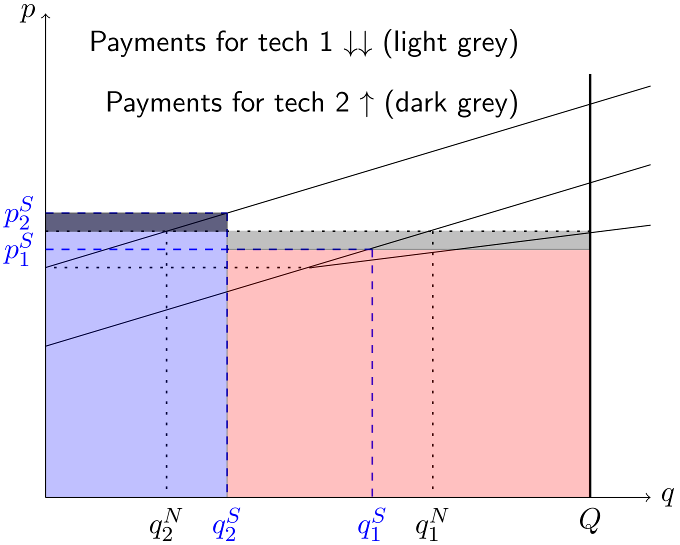
Graphical representation



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Technology neutrality vs. separation: prices

Computing the prices (Euro/MWh) for each technology under neutrality vs. separation for various sets of parameters

ρ	λ	Neutral	Specific solar	Specific wind
-0.8	0	33.1	23.5	33.6
	0.2		22.8	33.6
	0.4		22.4	33.7
0	0	33.4	24.1	33.5
	0.2		23.5	33.5
	0.4		22.8	33.6
0.8	0	33.1	28.8	33.2
	0.2		23.5	33.5
	0.4		22.8	33.6

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Technology neutrality vs. separation: efficiency and equity

Computing the ratios between market outcomes under neutrality (numerator) vs. separation (denominator) for various sets of parameters

ρ	λ	Costs	Payments	Social Costs
-0.8	0	97.1%	135.5%	97.1%
	0.2	97.0%	138.6%	104.5%
	0.4	96.7%	140.0%	109.8%
0	0	98.9%	131.6%	98.9%
	0.2	98.6%	133.7%	105.0%
	0.4	97.9%	136.0%	109.5%
0.8	0	99.9%	113.0%	99.9%
	0.2	98.9%	132.4%	105.1%
	0.4	98.2%	134.8%	109.4%

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Real-Time and TOU Prices in Spain

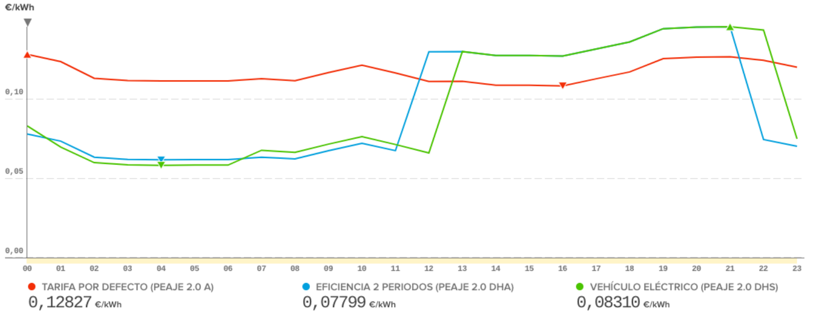

Figure: Electricity prices for final consumers for a representative day

(source: esios)

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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?

Storage

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- **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?
- 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

Storage

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Main take-aways:

1. Never optimal to invest in storage capacity so as to fully flatten production (decreasing marginal gains)

Storage

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2. Market power in generation → storage more valuable
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Storage
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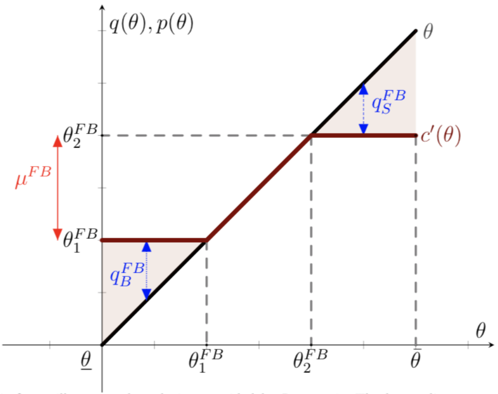
Main take-aways:

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

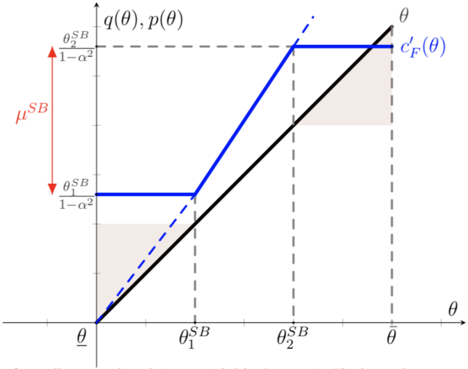
Storage under the first-best



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

Storage under the second-best



Notes: This figure illustrates the solution provided by Lemma 3. 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 is fully flattened, and the marginal value of storage is found along the price curve, as it represents the marginal costs of the fringe producers.

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

Marginal Value of Storage

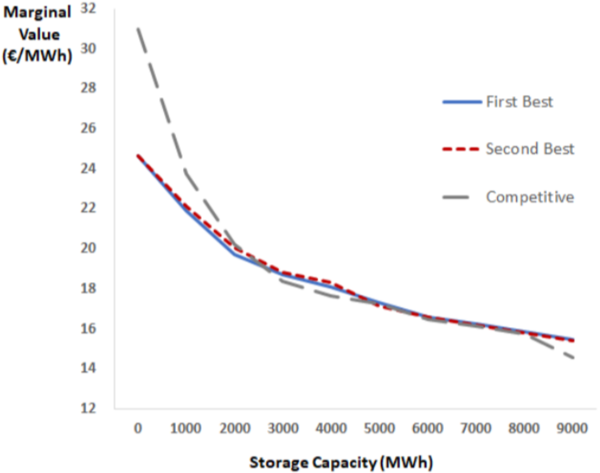


Figure: Marginal value of storage capacity; simulations of the Spanish electricity market by 2030 Back