The Energy Transition:
Markets and Policies

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The Energy Transition

A challenge for the power sector

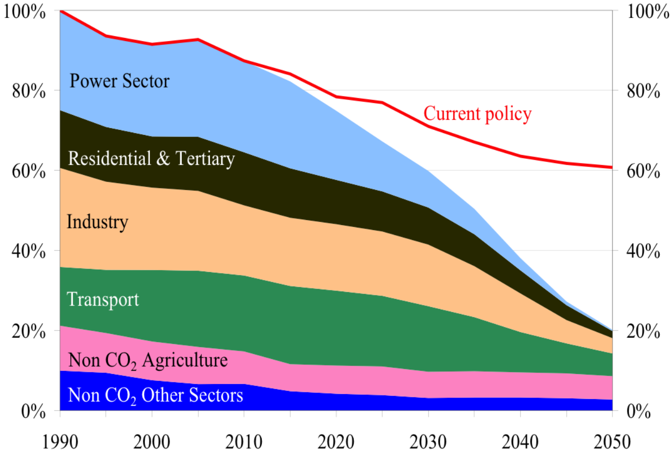

Figure: Emissions reductions in Europe with respect to 1990 levels (Source: EC's 2050 Energy Roadmap)

The Energy Transition

Renewables' key role

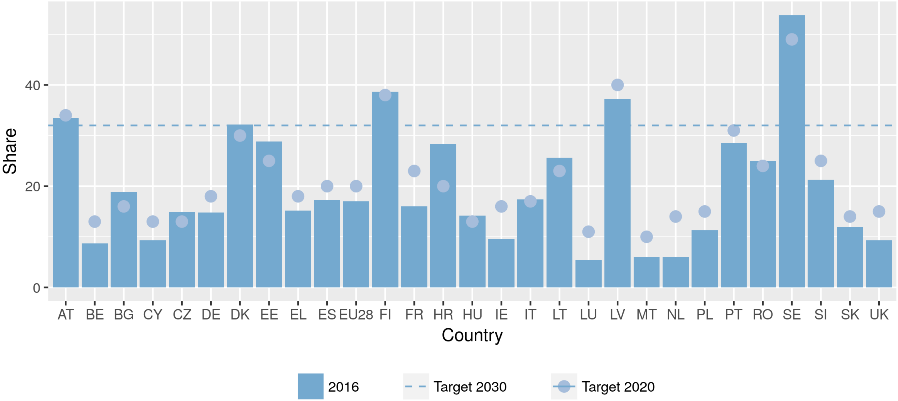

Figure: Share of renewables over total energy consumption (Eurostat)

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Renewables' key role

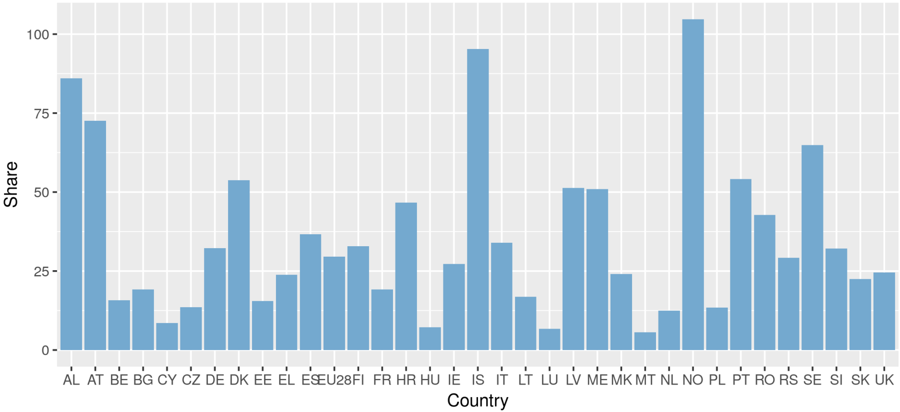


Figure: Share of renewable generation over total electricity production (Eurostat)

The Energy Transition

A research agenda

How can we achieve a least-cost energy transition?

Focus on **market design** and **market struture** in **electricity markets**

Renewables:

1. How will renewables-dominated **electricity markets** work?
2. How to design the **auctions for renewable investments**?

Coping with renewables' intermittency: GO

3. How to manage **electricity storage**?
4. What to expect from the **demand response** to dynamic pricing?

The Energy Transition

A research agenda

How can we achieve a least-cost energy transition?

Focus on **market design** and **market struture** in **electricity markets**

Renewables:

1. *"Auctions with unknown capacities: Understanding competition among renewables", with G. Llobet
2. "Prices *versus* Quantities with Multiple Technologies", with J.P. Montero

Coping with renewables' intermittency:

3. "The Economics of Strategic Energy Storage", with D. Andres Cerezo ▸ GO
4. "Real-Time Pricing for Everyone", with D. Rapson and M. Reguant ▸ GO

Auctions with unknown capacities: Understanding competition among renewables

Joint with Gerard Llobet (CEMFi)

A new paradigm in electricity markets:

- The shift from fossil fuels to renewables: new paradigm
- Competition-wise, two key differences:
  - **Conventional plants**: known capacities, plausibly unknown (heterogeneous) marginal costs
  - **Renewables**: unknown capacities, known (zero) marginal costs

Renewables fundamentally **change the nature of strategic interaction** among electricity producers.

Firms have private information on their avalaible capacities

(a) Meteo station (wind)

(b) Meteo station (solar)

Private information allows for better forecasts

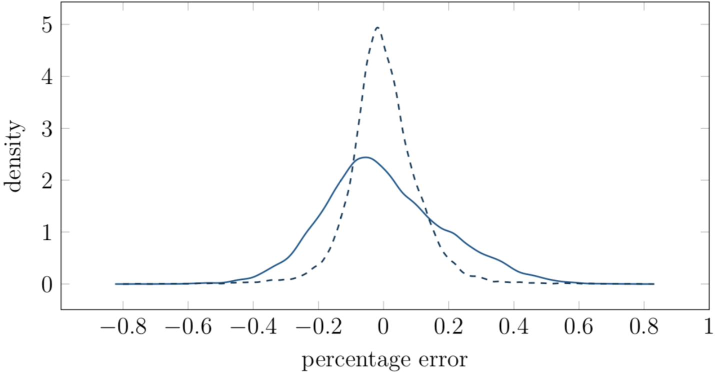


Figure: Kernel distribution of wind forecasts errors at the plant level using private (dashed) vs. plubic (solid) information (Private info increases R^2 from 0.4 to 0.8)

Beyond electricity....

- Many other goods are bought/sold through multi-unit auctions:
  - Pharmaceuticals, emission permits, toxic assets, T-bills...
  - Hotel bookings, cab services...
- Bidders are **privately informed** about their **costs/valuations**...
- ... and/or about the **maximum quantities** they can sell/buy
  - **Pharmaceuticals**: labs' capacities
  - **Emission permits**: firms' expected emissions
  - **Toxic assets**: banks' amount of toxic assets
  - **Treasury bills**: banks' hedging needs
  - **Hotels/cabs**: rooms/taxis availability

The Model

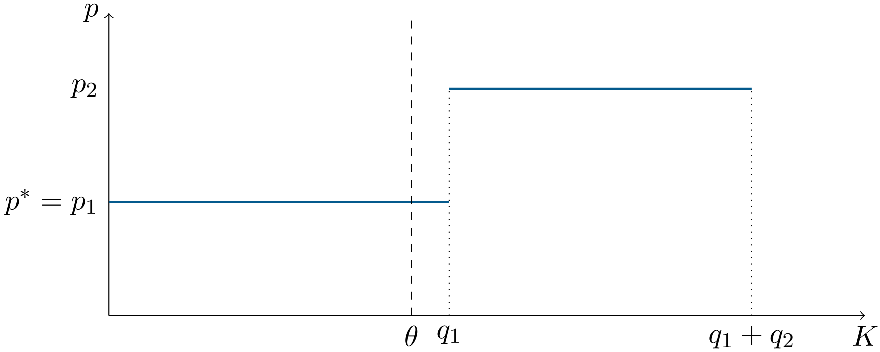
- Two (ex-ante) symmetric firms, $i = 1, 2$.
- Marginal costs equal to c.
- Firms' available capacities are uncertain:
  - $k_i = \beta\kappa + \varepsilon_i$
  - $\varepsilon_i \sim \Phi(\varepsilon_i|\kappa)$, with $E(\varepsilon_i) = 0$
  - ε_i is known to firm i but unkown to firm j
  - $k_i \sim \Phi(k_i - \beta\kappa|\kappa) = G(k_i)$ in $k_i \in \left[\underline{k}, \overline{k}\right]$
- Inelastic and known demand θ.
- Market reserve price $P > c$.

The Model

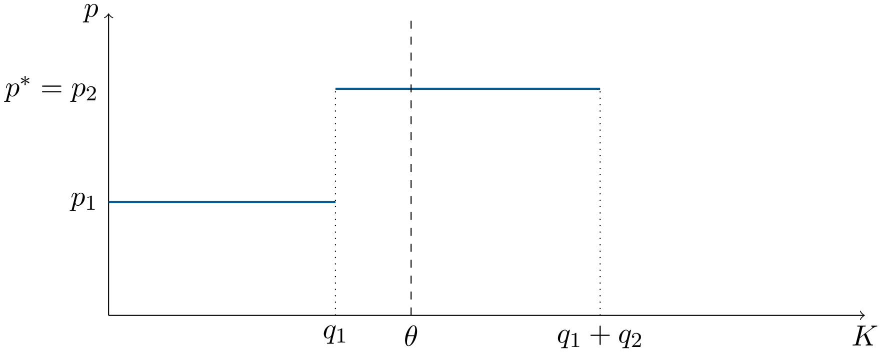
Bids, Prices and Quantities

1. Firm i observes k_i and submits a bid $b_i(k_i) = (p_i(k_i), q_i(k_i))$
   - with $p_i \leq P$ and $q_i \in [\underline{k}, k_i]$
2. Firms are called to produce in increasing price order:
   - If $p_i < p_j$: firm i produces $\min\{\theta, q_i\}$
   - If $p_i > p_j$: firm i produces $\max\{0, \min\{\theta - q_j, q_i\}\}$
   - Tie breaking rule is inconsequential for equilibrium outcomes
3. All production is paid at the market-clearing price (**uniform-price**).

Market-clearing price



Market-clearing price



Equilibrium Characterization

- We characterize the pure-strategy Bayesian Nash equilibria
- **Ass**: capacity is always enough to cover demand $2\underline{k} \geq \theta$
- Two well known cases:
  1. If $\underline{k} > \theta$: competitive pricing $p^* = c$.
  2. If $\overline{k} < \theta/2$: firms obtain P with no need to compete.
- Two relevant cases:
  1. **Small installed capacities**: $\overline{k} \leq \theta$.
  2. **Large installed capacities**: $\overline{k} > \theta$.

Equilibrium properties

Small installed capacities

Since $\overline{k} \leq \theta$:

- Market price is set by the high bidder.
- Low bidder is fully disptached.

Lemma

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

(i) Withholding is never optimal. Hence, $q_i^* = k_i$.

(ii) All Bayesian Nash Equilibria must be in pure strategies.

(iii) The optimal price offer of firm i, $p_i^*(k_i)$, is non-increasing in k_i.

Asymmetric equilibria

Small installed capacities

Asymmetric equilibria allow to sustain highest admissible price P

Proposition

There exist asymmetric pure-strategy Bayesian Nash equilibria, in all of which $p^* = P$. In these equilibria, $p_i^*(k_i) = P$ and $p_j^*(k_j) < \underline{p}$, $i, j = 1, 2$.

Asymmetric bidding:

- One firm bids at P.
- The other firm bids low enough to discourage undercutting.

Asymmetric profits:

- The low bidder makes higher profits.
- Hence, firms face a **coordination problem**.

Characterizing the symmetric equilibrium

Small installed capacities

Expected profits are:

$$\begin{aligned}\pi_i(p_i; k_i, p_j(k_j)) &= \int_{\underline{k}}^{p_j^{-1}(p_i)} (p_j(k_j) - c) k_i g(k_j) dk_j \\ &\quad + \int_{p_j^{-1}(p_i)}^{\bar{k}} (p_i - c)(\theta - k_j) g(k_j) dk_j\end{aligned}$$

Under symmetry, $p_j(k) = p_i(k)$, the **FOC** is:

$$\frac{1}{p_i'(k_i)} g(k_i)(p_i(k_i) - c)(k_i - (\theta - k_i)) + \int_{k_i}^{\bar{k}} (\theta - k_j) g(k_j) dk_j = 0$$

Symmetric equilibrium

Small installed capacities

At the symmetric equilibrium **firms bid below P**, and **price offers are strictly decreasing in k_i**

Proposition

At the unique symmetric pure-strategy Bayesian Nash Equilibrium, 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

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

Symmetric equilibrium

Small installed capacities

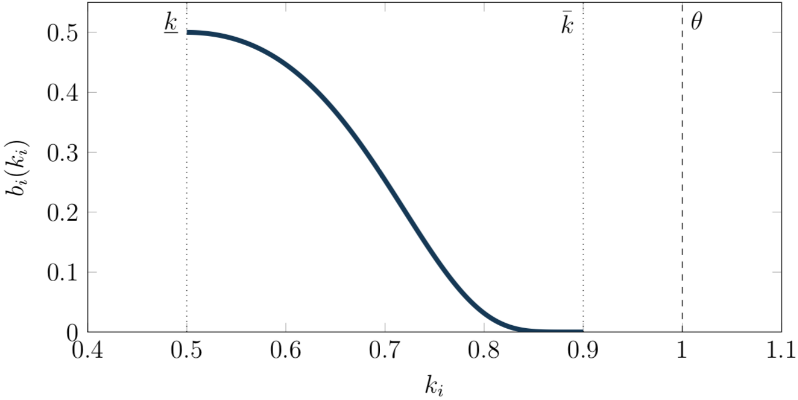


Figure: Equilibrium bids when $k_i \sim U[0.5, 0.9]$, $\theta = 1$, $c = 0$, and $P = 0.5$.

Equilibrium with large installed capacities

Proposition

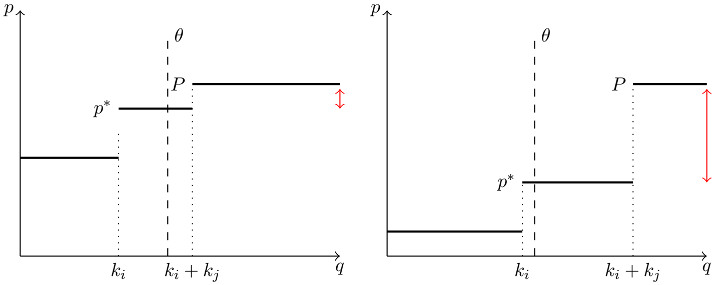
If $\overline{k} > \theta$, in equilibrium, $p_i^*(k_i) = c$ and $q_i^*(k_i) = \theta$ for all $k_i > \theta$, $i = 1, 2$. For $k_i \leq \theta$, Propositions 1 and 2 apply with $G(k_i)$ now adjusted to $G(q_i^*(k_i))$, $i = 1, 2$.

- Allowing for $\overline{k} > \theta$ makes **withholding optimal**.
- When $k_i > \theta$, the firm behaves as if k_i was θ.
- The shape of the price function is similar as in the baseline case, with $G(k_i)$ adjusted to accumulate a mass $1 - G(\theta)$ at θ.

Comparative statics

More available capacity

- When realized capacities are larger relative to demand...
  - Supply functions shift downwards and outwards
  - Market prices fall
- Market power mitigates the price-depressing effects of renewables (different channel than in Acemoglu *et al.* (2015))



(a) Small price reduction (b) Large price reduction

Comparative statics

More installed capacity

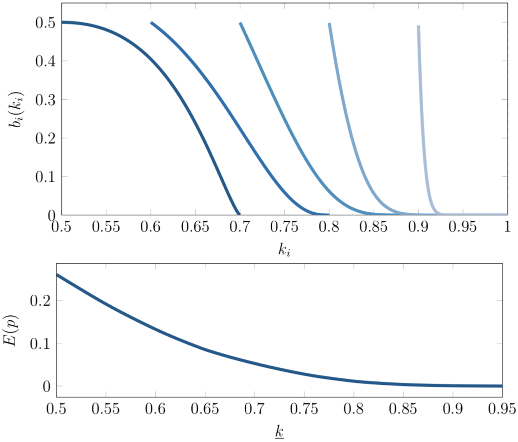


Figure: Equilibrium bids and expected prices as installed capacity increases; $\theta = 1$, $c = 0$, and $P = 0.5$

The impact of private information

We consider two benchmarks w/o private information:

1. Capacities are publicly known (Fabra *et al.*, 2006).
2. Capacities are unknown to both firms prior to bidding.

Regarding **private information**, we find that....

- It leads to lower prices than with publicly known capacities, but higher than with unknown capacities.
- An increase in the precision of the signal leads to higher prices.

Renewables mitigate market power as compared to other technologies whose capacities are known.
Information exchange would enhance market power.

Extensions

1. **Discriminatory Auctions**
   - Firms offer higher prices but there is no withholding.
   - Equilibrium prices increase if installed capacities are small; trade-off is they are large.
2. **Asymmetric firms**
   - Explicit solution with uniformly distributed capacities.
   - Asymmetric equilibria if capacity intervals do not overlap.
   - Firms choose the same strategy in the range in which they overlap.
   - Equilibrium prices increase with ex-ante capacity asymmetries.
3. N **firms oligopoly**
   - Disentangle the effect of more competition from more information.
4. **Withholding not possible**
   - Equilibrium in pure strategies for $k < \theta$ and in mixed strategies for $k \geq \theta$.

What have we learnt

Understanding competition among renewables

1. Because of their uncertainty, **renewables mitigate market power**.
2. Still, **market power and price dispersion** will prevail.
3. Market power will involve **above marginal cost pricing when capacities are small**, or **capacity withholding** when large.
4. Lower bids and prices at times with more renewables availability.
5. Investment in renewables will **depress market prices smoothly**.

The Energy Transition is a source of great research questions...
whose answers should prove very relevant for key public policies

ENERGYECOLAB

Thank You!

Questions? Comments?

More info at nfabra.uc3m.es

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Coping with Renewables

Storage and demand response

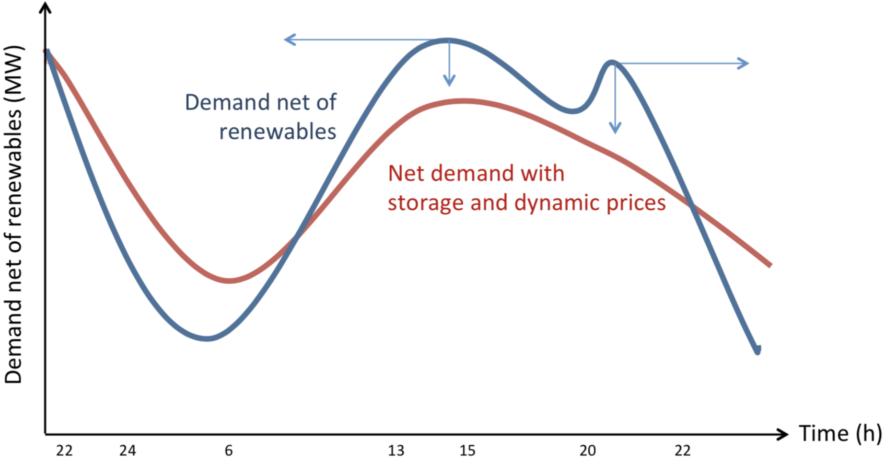

Figure: Demand net of renewables, storage and demand response

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The Economics of Strategic Storage

Joint with David Andres Cerezo (EUI)

- We introduce **storage** in a model of wholesale market competition with different degrees of **market power in generation**.
- We only consider predicted demand/supply, e.g. seasonal/diurnal.
- 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 consider alternative **market structures for storage**:
  - Central planner (First Best)
  - Competitive storage
  - Independent storage monopolist
  - Integrated storage monopolist

The Economics of Strategic Storage

Joint with David Andres Cerezo (EUI)

Main take-aways:

- **Over-investment** or **under-investment**? It depends on the relative market power in generation vs. storage:
  1. Mkt power in generation $\rightarrow$ larger price diff. $\rightarrow$ storage more valuable
  2. Mkt power in storage $\rightarrow$ under-storage $\rightarrow$ storage less valuable
- The **integrated storage monopolist** yields worst social outcome.
  - It buys relatively more energy in periods of low demand and sells relatively less in periods of high demand.
- With **competitive storage**, market power in generation induces over-investment in storage (e.g. electric vehicles).
- **Independent storage** mitigates market power in generation but...
- **Integrated storage** strengthens it.

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Real-Time Pricing for everyone

Joint with David Rapson (UC Davis) and Mar Reguant (Northwestern)

- April 2014: Spain becomes the only country so far in which RTP is the **default option for all households**.

		Network component	
		non-TOU	TOU
Energy component	RTP	**Default**	**Default with opt-in**
	non-RTP	**Commercial tariff**	**Commercial tariff**

Empirical strategy for RTP response

- We estimate the short-run price elasticity of consumers
- Main regression (individual by individual or zip-code level):

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

- In baseline specifications, we control for:
  - Temperature bins by hour.
  - Fixed effects: hour x month, year x month, day of week.
  - Interact with zip for zip-level regressions.
  - Use wind power as an instrument for short-run price variation.

Main findings

- **RTP vs non-RTP** consumers appear to behave in a similar manner *at the margin*.

  → Limited impact of short run variation of real-time prices.

  → Stronger impact in the medium-run.

  → Puzzle: measurable average response for both types.

- **TOU vs non-TOU** consumers appear to behave differently.

  → Selection or actual response?

  → Important to disentangle for policy implications.

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