Competition Among Renewables

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Introduction

Renewable Targets over Energy Consumption

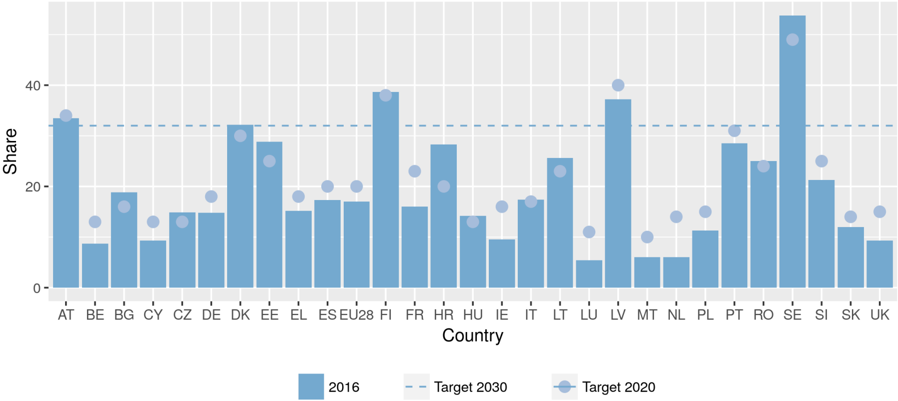


Figure: Renewables share over total energy consumed (Eurostat)

Introduction

Need to deploy more renewable generation

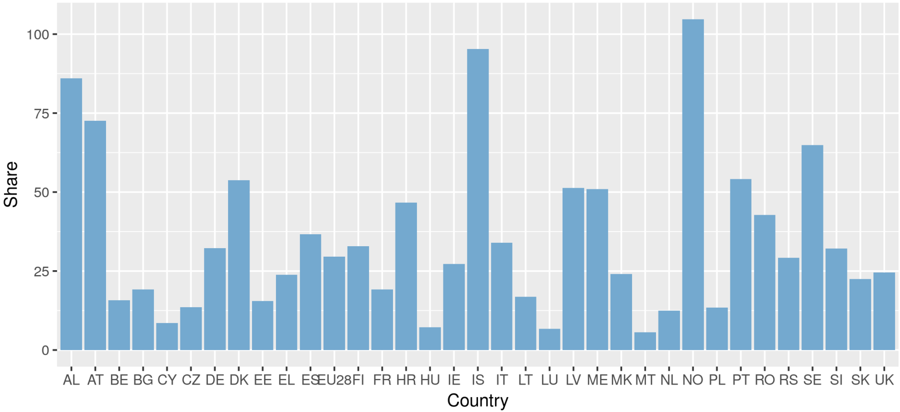


Figure: Source: Eurostat.

Introduction

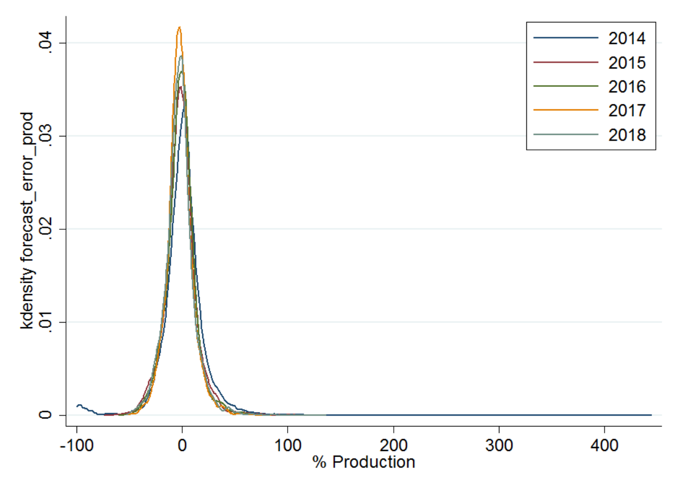
A new paradigm in electricity markets

- 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.

Renewables are Volatile and Difficult to Forecast

Distribution of Wind Forecast Errors (Spanish Electricity Market).



▸ In Levels

Renewables are Volatile and Difficult to Forecast

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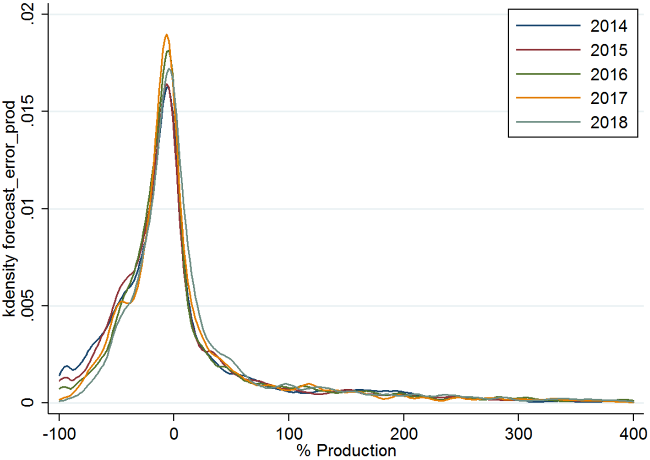

In Levels

Objective of the Paper

- Analyze the nature and effects of strategic interaction among renewable energy producers in wholesale markets
  - Key to understand investment incentives under current market design
  - Key to understand whether new regulatory instruments are needed to achieve the renewables targets at least cost
- Beyond electricity, analyze **multi-unit auctions with private information** regarding bidders' capacities (or maximum demand)
  - Other examples: Treasury auctions, auctions for permission permits, auctions for renewables

Related literature

The nature of private information matters

		Capacities are private information NO	YES
Costs are private information	NO	von der Fehr and Harbord (1992) Fabra *et al* (2016)	**This Paper**
	YES	Vives (2011) Holmberg and Wolak (2018)	

Related literature

Firms' strategies matter

Firms choose prices \ *Firms choose quantities*	NO	YES
NO	▪	Kakhbod *et al* (2018) Acemoglu *et al* (2015)
YES	Fabra *et al* (2006) Holmberg and Wolak (2018)	Vives (2011) **This Paper**

Roadmap

- Model description
- Equilibrium with known capacities
- Equilibrium when capacities are private information
- Known versus unknown capacities
- Extensions [probably no time today!]
  - Discriminatory auction
  - N firm oligopoly
  - No capacity withholding
- Conclusions

The Model

- Two (ex-ante) symmetric firms, $i = 1, 2$.
- Marginal costs equal to c.
- Firms have uncertain capacities:
  - $k_i \sim G(k_i)$ with density $g(k_i) > 0$ in $k_i \in [\underline{k}, \overline{k}]$.
- Capacities: *i.i.d.* across firms and unknown to competitor.
- Inelastic and known demand θ.
- Back up capacity is offered competitively at $C > c$.

The Model

Bids, Prices and Quantities

1. Firm i observes k_i
2. Firm i submits an inverted-L supply function (b_i, q_i); $q_i \leq k_i$
3. Firms are called to produce in increasing price order:
   - Low priced firm produces $q_i = \min\{\theta, q_i\}$
   - High priced firm produces $q_i = \max\{0, \min\{\theta - q_j, q_i\}\}$
   - Tie breaking rule is inconsequential for equilibrium outcomes
   - Back-up capacity produces if $q_i + q_j < \theta$
4. Market price equal to highest accepted bid (**uniform-price**).

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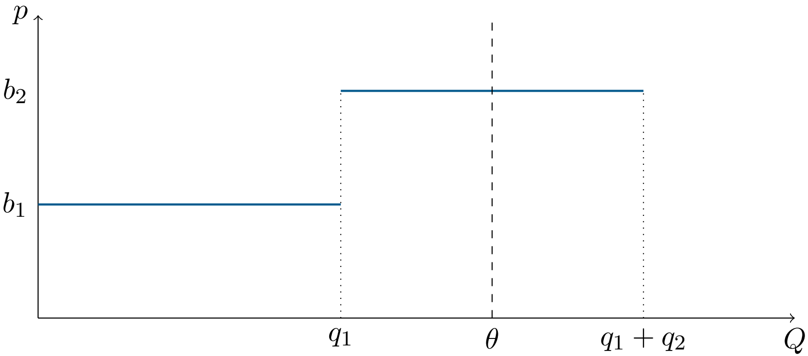
We characterize the symmetric pure-strategy Bayesian Nash equilibrium.

- Mixed strategies considered only if PSE do not exist.

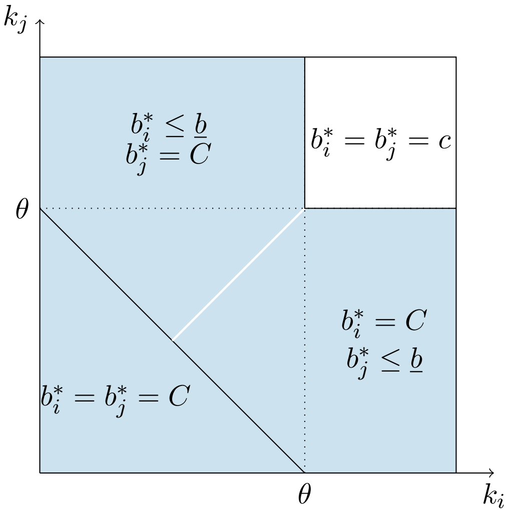
The Model

How prices are set: an example



Equilibria with known Capacities

Fabra, von der Fehr and Harbord (2006)



Capacities are private information

- Firm i knows k_i but does not know k_j.
- Bids can only be conditioned on own's capacity, $b(k_i)$ and $q(k_i)$.

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- Bids can only be conditioned on own's capacity, $b(k_i)$ and $q(k_i)$.
- The equilibria with known and unknown capacities coincide iff:
  1. If $\underline{k} > \theta$: firms are never pivotal, competitive pricing $p^* = c$.
  2. If $\overline{k} < \theta/2$: aggregate capacity is never enough, $p^* = C$.

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- We will focus on the remaining cases:
  1. **Baseline model:** $\theta/2 < \underline{k} < \overline{k} < \theta$.
  2. Renewables not always enough: $\theta > 2\underline{k}$.
  3. Uncertain pivotality: $\overline{k} > \theta$.

Equilibrium bids

Baseline model

Proposition

(i) Ass. $\theta/2 < \underline{k} < \overline{k} < \theta$*. There is a unique* **Symmetric Pure Strategy Equilibrium***: firm* $i = 1, 2$ *chooses a bid that is strictly decreasing in* k_i*:*

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

where

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

with $b(\underline{k}) = C$ *and* $b(\overline{k}) = c$*. (ii) Capacity withholding is not optimal,* $q^*(k_i) = k_i$*.*

- Capacity uncertainty operates as a randomization device: the PSE of firm i is perceived by firm j as a distribution of bids generated by k_i.

Equilibrium bids

Baseline model

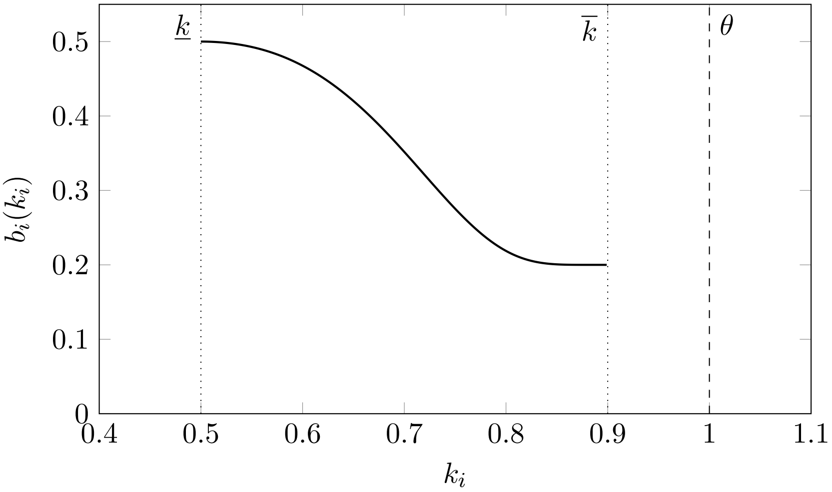


Figure: Equilibrium bids when $k_i \sim U[0.5, 0.9]$, $\theta = 1$, $c = 0.2$, and $C = 0.5$.

Interpreting the equilibrium

Baseline model

- Incentives for marginally decreasing the price:

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

- **Quantity Effect:** If $k_j = k_i = k$ (with prob. $g(k)$), $b_i = b_j$. Marginally reducing b_i implies an *output gain* of $k-(\theta-k) = 2k-\theta$.
- **Price Effect:** If $k_j > k_i = k$, then $p^* = b_i$. Marginally reducing b_i implies a *price reduction* which affects the firm's sales, $\theta - k_j$.

Interpreting the equilibrium

Baseline model

The equilibrium bid function $b^*(k_i)$ is *strictly* decreasing since:

- The **quantity effect** is increasing in k_i.
- Ties are ruled out by Bertrand arguments.

Interpreting the equilibrium

Baseline model

The equilibrium bid function $b^*(k_i)$ is *strictly* decreasing since:

- The **quantity effect** is increasing in k_i.
- Ties are ruled out by Bertrand arguments.

Capacity withholding is not optimal:

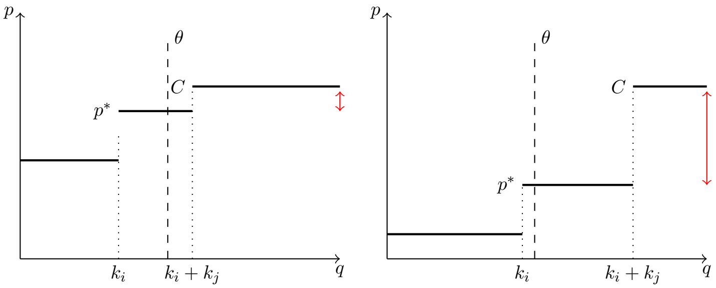
- If $b_i < b_j$, firm i wants to sell as much as possible, $q_i = k_i$
- If $b_i > b_j$, firm i sells $\theta - k_j$; offering $q_i < k_i$ would either not affect the market price or be unprofitable

Interpreting the equilibrium

Implications for market prices

When there is more available capacity...

- Supply functions shift downwards and outwards
- Market prices fall down



(a) Small capacity realizations (b) Large capacity realizations

Known versus unknown capacities

Proposition

Expected prices are lower when capacities are private information as compared to when they are known.

- Firms cannot condition their bids on the rival's capacity.
- They cannot perfectly correlate their roles of high and low bidder to sustain high equilibrium prices.

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Renewables depress market prices, both because they have low variable costs, and also because they mitigate market power.

Equilibrium when renewables are not always enough

- Allowing $\underline{k} < \frac{\theta}{2}$ only adds a flat region at C for $k_i < \frac{\theta}{2}$.

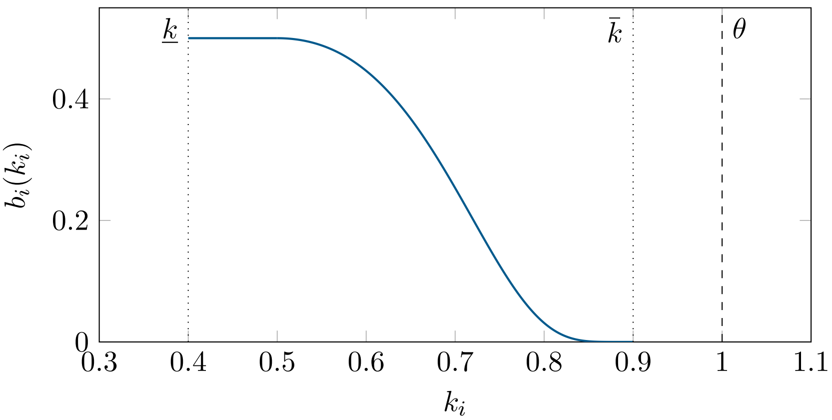

Figure: Equilibrium bids when $k_i \sim U[0.4, 0.9]$, $\theta = 1$, $c = 0$, and $C = 0.5$.

Equilibrium with uncertainty pivotality

- Allowing for $\overline{k} > \theta$ makes **withholding optimal**.
- When $k_i > \theta$, the firm behaves as if k_i was slightly below θ.
- Otherwise, the shape of the bid function remains unchanged.

As there is more investment, the probability that $k_i > \theta$ goes up. As more mass is put on c, expected market prices smoothly go down.

Discriminatory Auctions

Equilibrium bidding

Proposition

Assume $\theta/2 < \underline{k} < \bar{k} < \theta$. In the discriminatory auction, there exists a unique symmetric Pure Strategy Equilibrium: each firm $i = 1, 2$ chooses a bid that is strictly decreasing in k_i according to the function

$$b_d^*(k_i; \underline{k}, \bar{k}) = c + (P - c)\exp\left(-\omega_d\left(k_i\right)\right),$$

where

$$\omega_d\left(k_i\right) = \int_{\underline{k}}^{k_i} \frac{(2k - \theta)g(k)}{kG(k) + \int_k^{\bar{k}}(\theta - k_j)g(k_j)dk_j} dk,$$

with $b_d^*(\underline{k}) = P$.

- Firms have now stronger incentives to increase their bids as they are relevant even if they are outbid.

Discriminatory *versus* Uniform Auctions

Comparison of equilibrium bids

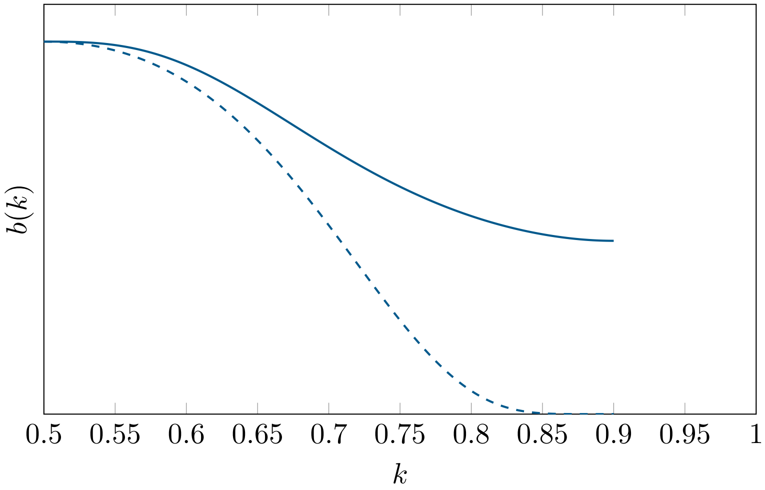

Figure: Comparison between the optimal bid under the uniform auction (dashed line) and the discriminatory one (solid line). Parameter values: $k_i \sim U[0.5, 0.9]$,

Discriminatory *versus* Uniform Auctions

Comparison of firms' payments

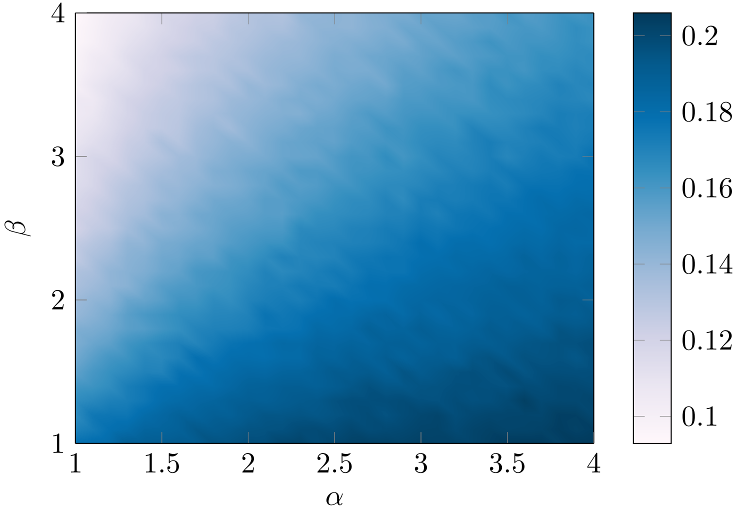

Figure: Difference in prices between the discriminatory and the uniform auction

Oligopoly

- What happens when $N > 2$? Two main questions:
  1. The effect of entry and the corresponding capacity expansion
  2. The effect of changes in market structure
- The cumulative distribution function and density of the lowest capacity (and highest bid) becomes:

$$\begin{aligned}\Phi(k_j) &= 1 - (1 - G(k_j))^{N-1} \\ \varphi(k_j) &= (N-1)\, g(k_j)\, (1 - G(k_j))^{N-2}\end{aligned}$$

- When firms are pivotal, the decision of firm i only depends on whether it has the highest bid (and sets the price) or not.

Oligopoly

Entry of symmetric firms

Proposition

Assume $\frac{\theta}{N} < \underline{k} < \bar{k} < \frac{\theta}{N-1}$. *There exists a unique symmetric Pure Strategy Equilibrium: each firm* $i = 1, ..., N$ *chooses a bid that is strictly decreasing in* k_i *according to the function*

$$b^*(k_i) = c + (P - c)\exp\left(-\omega\left(k_i; \underline{k}, \bar{k}, N\right)\right),$$

where

$$\omega\left(k_i; \underline{k}, \bar{k}, N\right) = \int_{\underline{k}}^{k_i} \frac{\left(2k + \int_k^{\bar{k}} (N-2)\, kg(k)dk - \theta\right)\varphi(k)}{\int_k^{\bar{k}}\left(\theta - k_j - \int_{k_j}^{\bar{k}} (N-2)\, kg(k)dk\right)\varphi(k_j)dk_j} dk,$$

with $b^*(\underline{k}) = P$ *and* $b^*(\bar{k}) = c$.

Oligopoly

How to split the ownership of the existing plants?

- Changes in market structure for given capacity imply:
  - Changes in **competition**
  - Changes in **information**: the more firms there are the less information each one has on the rest.

Example

Compare two situations:

- $N = 4$ where each firm i has a unique plant of production with capacity $k_i \sim G(k_i)$.
- $N = 2$ where each firm i has total production $k_i + k_j$ arising from two plants with $k_i \sim G(k_i)$ and $k_j \sim G(k_j)$.

Oligopoly

How to split the ownership of the existing plants?

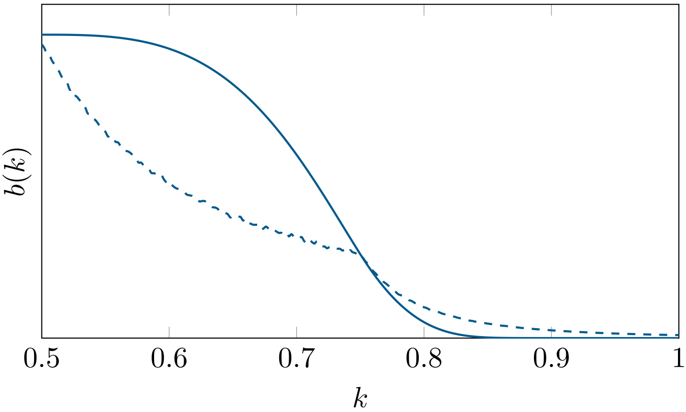

Figure: Comparison of optimal bids with $N = 2$ and $N = 4$. Dashed lines: maximum of the bids of two firms when $N = 4$ and capacities are uniformly distributed, $k_i \sim U[0.25, 0.5]$. Solid line: $N = 2$ and each firm has two plants that have the previous capacity distribution; $c = 0$, $P = 0.5$ and $\theta = 1$.

Concluding Remarks

- Renewable energy changes how firms compete in electricity markets.
  - It matters whether the **source of private information** is cost or capacity uncertainty.
- We have provided the first model that considers **optimal pricing** by renewable producers, while allowing for **capacity withholding**.
- Just a first step towards understanding the effect of renewable power sources. Further work should deal with:
  - Interaction between information and market structure
  - Incentives for firms to invest

ENERGYECOLAB

Thank You!

Questions? Comments?

More info at nfabra.uc3m.es

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