

Competition Among Renewables

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Introduction

Renewable Targets over Energy Consumption

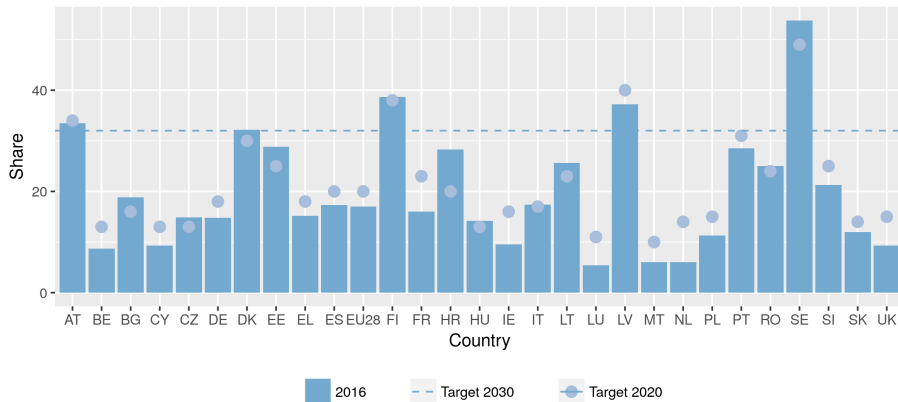


Figure: Renewables share over total energy consumed (Eurostat)

2025-2030 capacity mix in the Spanish electricity market

Figura 3 Potencia instalada en el Sistema Español Peninsular escenarios MITECO Tendencial y Objetivo H2025 y H2030

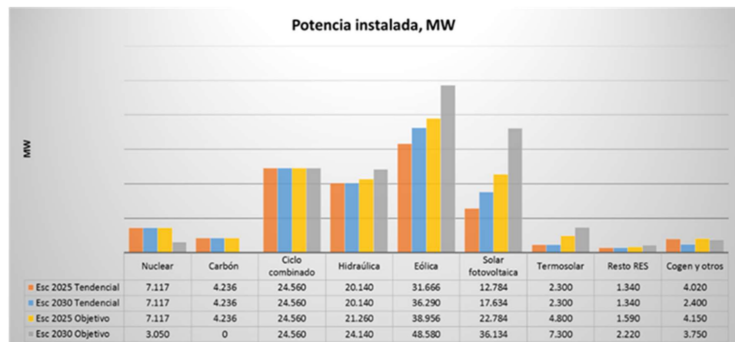


Figure: 2025-2030 capacity mix, Spanish electricity market (PNIEC, MITECO)

Introduction

Will these targets be achieved?

- Need to understand how renewable-dominated electricity markets would perform, in order to:
 - Analyze investment incentives
 - Assess the need for regulatory instruments, e.g. auctions
 - If so, shed light on auction design:
 - Technology neutral or technology specific auctions
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 - First stage: capacity decisions
 - Second stage: bidding decisions; dispatch, prices, and profits

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But, do we know how to solve the second stage?

This Paper

What if competition is not perfect?

Objective of the paper:

- Analyze the nature and effects of strategic interaction among renewable energy producers.
- Beyond electricity, analyze **multi-unit auctions with private information** regarding bidders' capacities (or maximum demand)

This Paper

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What makes renewables **different** (beyond being carbon-free)?

- 1 They have **low marginal cost**
 - Renewable energy displaces higher marginal cost technologies and, thus, it depresses prices. By how much?
- 2 They are **volatile**:
 - The ratio of renewables over total demand moves across time.
- 3 Capacities are **private information**:
 - Forecast errors when forecasting rivals' capacity.

Renewables are volatile and difficult to forecast

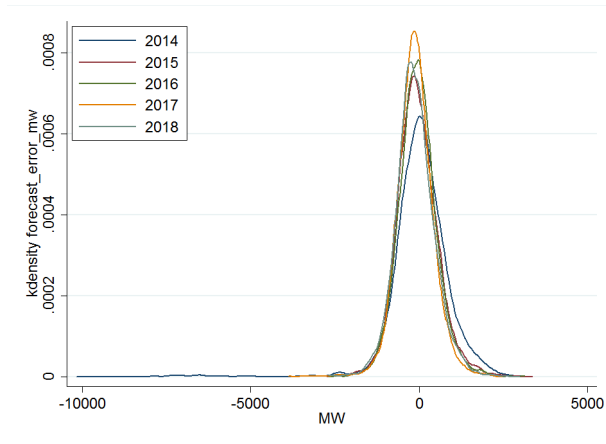


Figure: Distribution of wind forecast errors (Spanish electricity market)

Renewables are volatile and difficult to forecast

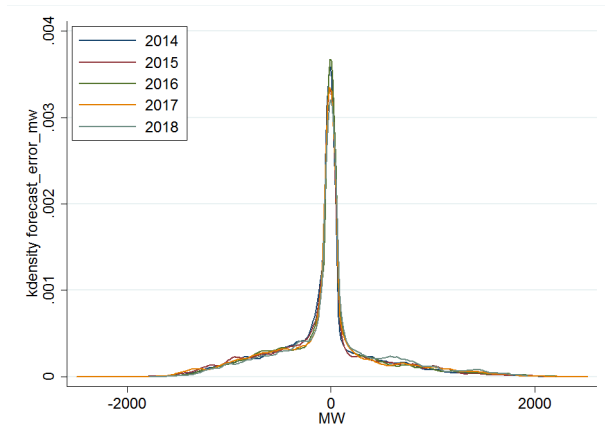


Figure: Distribution of solar forecast errors (Spanish electricity market)

Roadmap

- Model description
- Equilibrium with known capacities
- Equilibrium when capacities are private information
- Known versus unknown capacities
- Comparative statics
- Extensions [no time today!]
 - Affiliated capacities
 - Discriminatory auction
 - N firm oligopoly
- 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 submits a bid (b_i, k_i) .
- 2 Firms are called to produce in increasing price order:
 - Low bidder produces $q_i = \min \{\theta, k_i\}$
 - High bidder produces $q_i = \max \{0, \min \{\theta - k_j, k_i\}\}$
 - Tie breaking rule is inconsequential for equilibrium outcomes
 - Back-up capacity produces if $k_i + k_j < \theta$
- 3 Market price equal to highest accepted bid (**uniform-price**).

The Model

Bids, Prices and Quantities

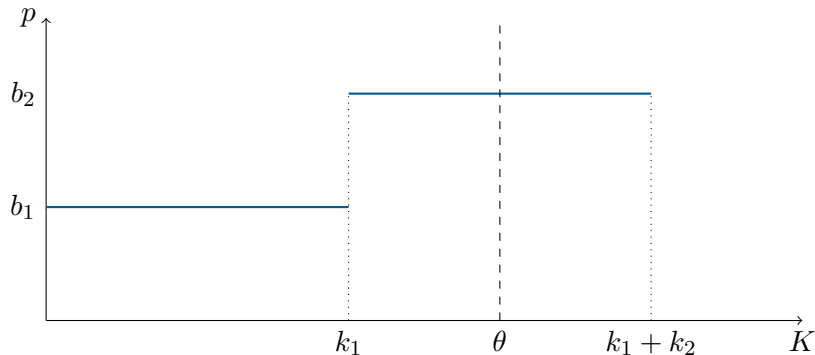
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We characterize the symmetric pure-strategy Bayesian Nash equilibrium.

- Mixed strategies considered only if PSE do not exist.

The Model

How prices are set: an example



Known Capacities

Fabra, von der Fehr and Harbord (2006)

Definition (Pivotality Status)

Given realized capacities (k_i, k_j) , firm i is pivotal if $\theta - k_j > 0$.

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Given realized capacities (k_i, k_j) , firm i is pivotal if $\theta - k_j > 0$.

- Equilibrium price: $p^* = c$ if no firm is pivotal; $p^* = C$ otherwise.
- Potentially many equilibria, but all outcome equivalent.

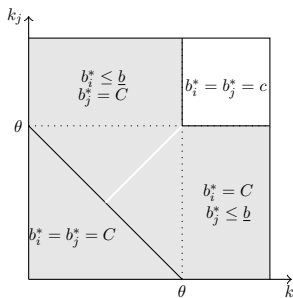


Figure: Equilibrium bids and outcomes with known capacities

Capacities are private information

- Firm i knows k_i but does not know k_j .
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- The equilibria with known and unknown capacities coincide iff:
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 - 2 If $\bar{k} < \theta/2$: aggregate capacity is never enough, $p^* = C$.
- We will focus on the remaining cases:
 - 1 **Baseline model:** $\theta/2 < \underline{k} < \bar{k} < \theta$.
 - 2 Renewables not always enough: $\theta/2 > \underline{k}$.
 - 3 Uncertain pivotality: $\bar{k} > \theta$.

Equilibrium bids

Baseline model

Proposition

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

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

where

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

with $b(\underline{k}) = C$ and $b(\bar{k}) = c$.

- 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

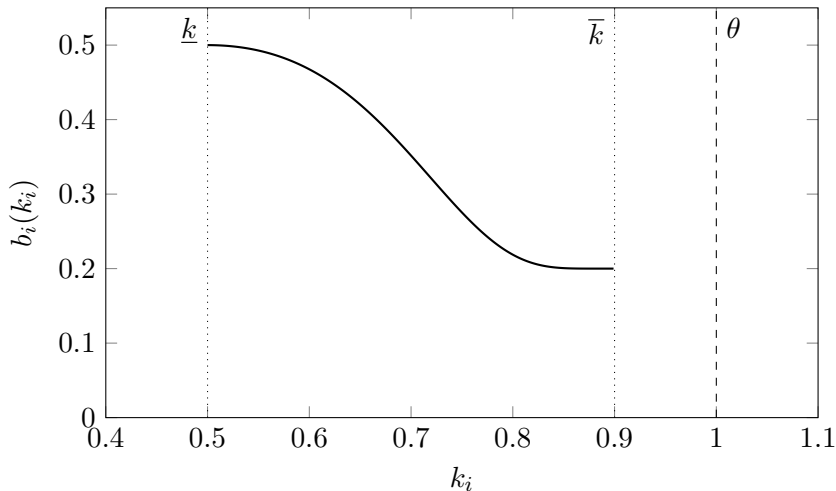


Figure: Equilibrium bids when $k_i \sim U[0.5, 0.9]$, $\theta = 1$, $c = 0.2$, and $C = 0.5$.

Interpreting the equilibrium

Baseline model

- Incentives for marginally decreasing the bid:

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

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

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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.

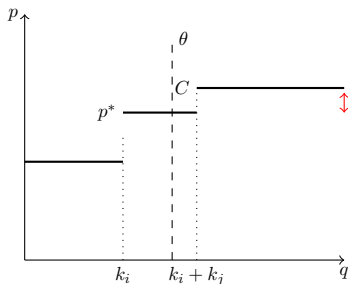
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Implication: prices are lower when there is more renewable availability



(a) Small capacity realizations

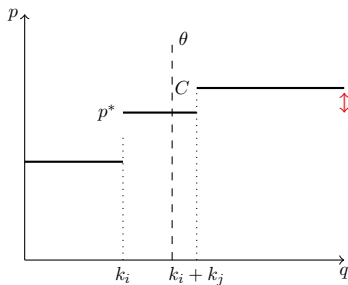
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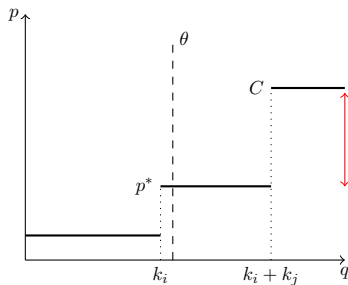
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(a) Small capacity realizations



(b) Large capacity realizations

Known versus unknown capacities

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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.

Comparative statics

- We study how the equilibrium bid functions and the equilibrium price change with changes in:
 - 1 Demand
 - 2 Expected capacity
 - 3 Precision of forecast errors
- We focus on the **baseline model**'s assumptions

Demand increases

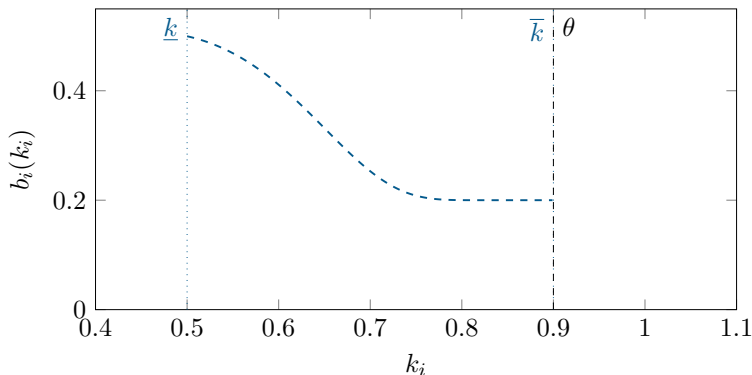


Figure: Equilibrium bids when **demand increases** from $\theta = 0.9$ (dashed) to $\theta = 1$ (solid). Parameters: $k_i \sim U[0.5, 0.9]$, $c = 0.2$, and $C = 0.5$.

Change	Parameters	Expected Price
↑ demand	$\theta = 0.9 \rightarrow \theta = 1$	$0.363 \rightarrow 0.4129$

Demand increases

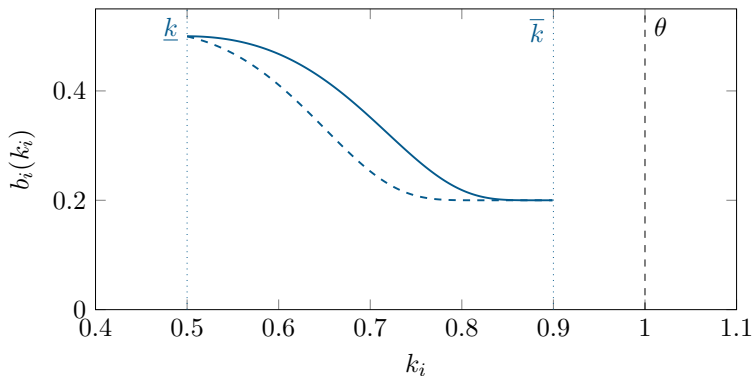


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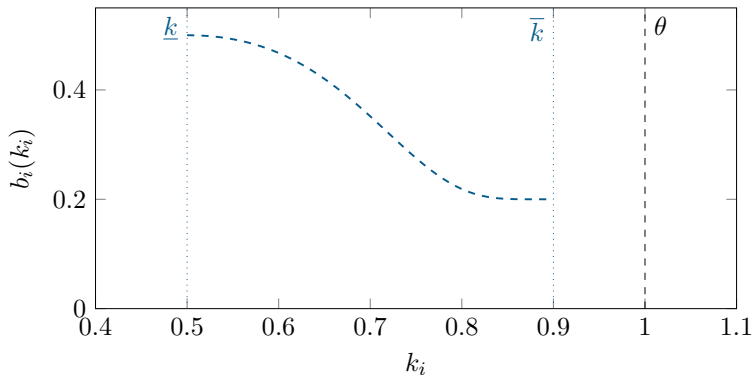


Figure: Equilibrium bids when capacity increases from $k_i \sim U[0.5, 0.9]$ (dashed) to $k_i \sim U[0.6, 1]$ (solid); $\theta = 1$, $c = 0.2$, and $C = 0.5$.

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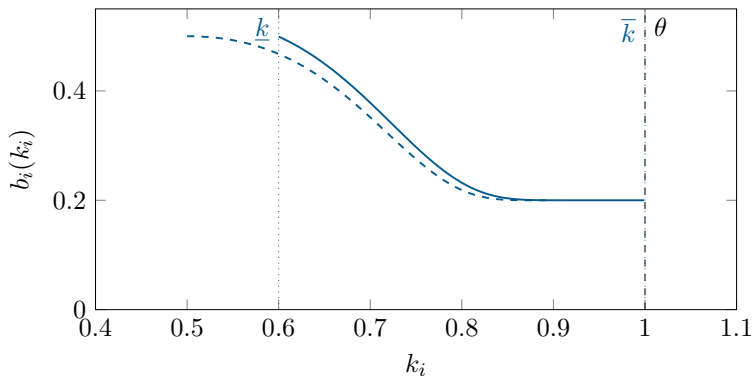


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Conclusions

- Strategic interaction among renewable producers:
 - capacities are volatile and difficult to forecast
- Key impacts on:
 - nature of equilibria
 - impact on price levels and price volatility
- We have found that...
 - more renewable investments, reduce prices (non-linear relationship)
 - two channels: low cost and market power mitigation
 - stronger price depressing effect:
 - when high availability relative to demand
 - because capacities are unknown

Thank You!

Questions? Comments?

More info at nfabra.uc3m.es



Renewables are not always enough

- When aggregate renewable capacity is not always enough, $\underline{k} < \theta/2$, the equilibrium bid function just adds a flat region at C for $k_i < \theta/2$.

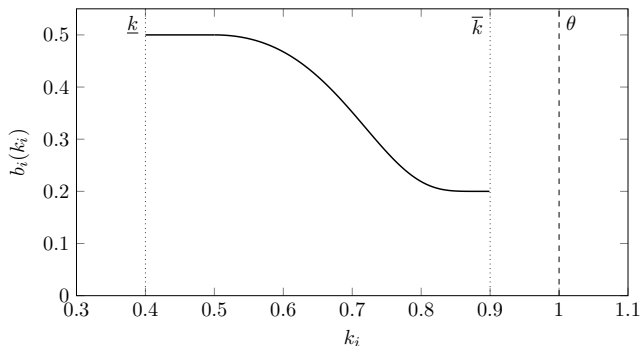


Figure: Equilibrium bids when $k_i \sim U[0.4, 0.9]$, $\theta = 1$, $c = 0.2$, and $C = 0.5$.

Uncertain pivotality

- When $\bar{k} > \theta$, firms are not certain to be pivotal:
 - For $k_i > \theta$: mixed strategy equilibrium (Bertrand-Edgeworth)
 - This also impacts the bid function for some $k_i < \theta$ as the gain from reducing prices in this region is now greater.

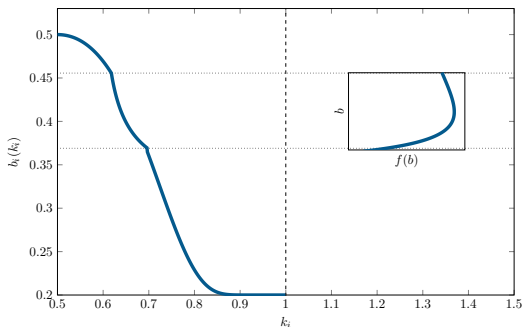


Figure: Equilibrium bids when $k_i \sim U[0.5, 1.05]$, with $\theta = 1$, $c = 0.2$, $C = 0.5$.

Uncertain pivotality

The price distribution

- Bids are concentrated close to c and close to C .
- The new MSE region adds mass to intermediate prices.

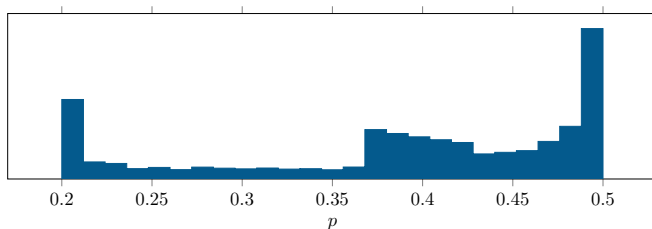


Figure: Density of the Distribution of Equilibrium Prices when $k_i \sim U[0.5, 1.05]$, with $\theta = 1$, $c = 0.2$, and $C = 0.5$.

Uncertain pivotality

The effects of increasing expected capacity

- As expected capacity goes up, bids converge to c in both regions.

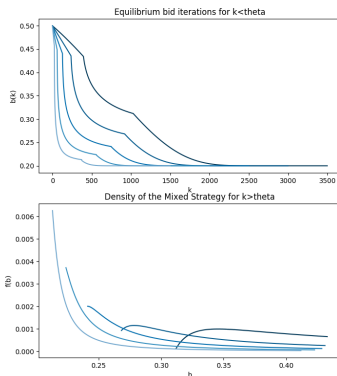


Figure: Equilibrium bids when $k_i \sim U[\bar{k} - 0.55, \bar{k}]$, with $\theta = 1$, $c = 0.2$, and $C = 0.5$ as \bar{k} increases above $\bar{k} = 1.05$