On Investment Decisions in Liberalized Electricity Markets: The Impact of Spot Market Design

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Wholesale Prices for Electricity, Germany (EEX) 2006

Daily average prices for Electricity, (Germany 2006, EEX)

Sorted hourly prices for Electricity, (Germany 2006, EEX)
What Drives the Prices for Electricity?

- „Fundamental“ factors as
  - Level of demand,
  - Capacity constraints, \( \leq \text{Depends on firms' invest. decsn.} \)
  - Level of production cost, \( \leq \text{Depends on firms' invest. decsn.} \)
  - Further Issues: environmental policy measures, taxes, …
- Market structure, e.g. leading to oligopolistic markups.
- Market rules, which do (not) optimally support the pricing process.

⇒ Often, firms investment decisions are assumed to be exog. fixed,
⇒ Strategic investment choice has not received very much attention…
(Even though, market power in liberalized electricity market is intensely debated!)
Typical Investment Choice in Electricity Markets

![Graph showing typical available capacity in Germany and marginal costs for different energy sources: Lignite, Gas, Nuclear, Coal. The x-axis represents typically available capacity in Germany in MW, while the y-axis represents marginal cost in €/MWh.](image)
Apply Theory of Peak Load Pricing: Welfare Maximizing Investment decisions

Welfare Maximizing Investment:
- Peak Load Pricing Literature,
  - Boiteux, Steiner
  - Crew, Kleindorfer (1986)

Question I - Overall Capacity Choice:
- Capacities have to „Earn“ Investment Cost During Hours of High Demand.
  (scarcity rents equal investment cost)

Question II-Optimal Investment Mix:
- Each Technology „Earns“ its Investment Cost when it is Inframarginal.
Roadmap of this Presentation

I) Establish a framework for strategic capacity choice prior to Spot Markets with fluctuating and uncertain demand

II) Analyze the impact of changed Spot market design:
   a) Elimination of market power at the Spot market.
   b) Uniform price cap at the spot market.

III) Empirical Illustration of the theoretical results for the German Electricity Market.
I) Establish a framework for strategic capacity choice prior to Spot Markets with fluctuating and uncertain demand.

based on:

Framework of Overall Capacity Choice

Typically available Capacity, Germany 2006 (MW)

Capacity choice:
- Shape of marginal cost curve fixed
- Firms decide on overall capacities
Timing of the Capacity Choice Models

Strategic Capacity Choice, Cournot Spot Market:
- Gabszewicz, Poddar (1997), Murphy Smeers (2005)

Strategic Capacity Choice, Bertrand/Auction Spot Market:

=> only duopoly analysis, few constructive results
Real Option Investment Models:


- In those Models Demand evolves according to a Brownian Process, firms decide (strategically) on the timing when to add install further capacities.

- Whereas the insights provided are very rich in terms of timing, they assume capacities to be always fully used, thus abstract form Spot markets.

- Fluctuations in those models have thus to be interpreted as movements of average prices
Assumptions of the Model

- Demand scenario: Random variable $\Theta$ with distribution $F(\cdot)$
- Standard Concavity Assumptions for each scenario $\square$:
  - Demand satisfies $P_q(Q, \square) + P_{qq}(Q, \square)Q < 0$.
  - $n$ symmetric firms with (weakly) convex production cost $C(q, \square)$ and investment cost $K(x)$.
- Monotonicity assumptions w.r.t. $\square$:
  - The gap between demand and marginal production cost is strictly increasing in $\square$.
  - The best reply functions are strictly increasing in $\square$. 
Welfare Maximizing Capacity Choice

- The optimal capacity choice is characterized by the following FOC

\[
\bar{\theta} \int_{\bar{\theta}^S(X^S)} \left( P(X^S, \theta) - C_q \left( \frac{X^S}{n}, \theta \right) \right) dF(\theta) = K_\chi \left( \frac{1}{n} X^S \right)
\]

Expected marginal Welfare of additional capacity (sum over all scarcity rents)

Marginal Cost of Investment

- For the case of perfect competition (overall welfare maximization) we integrate over all those scenarios where firms are capacity constrained given marginal cost pricing at the Spot market.

- Remark: We also analyze welfare maximizing capacity choice prior to an oligopolistic spot market. Integration then takes place over all scenarios where firms are capacity constrained given Cournot competition at the spot market.
Strategic Capacity Choice

- Equilibrium investment is characterised by the following FOC:

\[
\frac{\partial}{\partial \theta} \left[ P(X^S, \theta) \left( X^S + P_q(X^S, \theta) \frac{X^S}{n} - C_q \left( \frac{X^S}{n}, \theta \right) \right) \right] dF(\theta) = K_x \left( \frac{X^S}{n} \right)
\]

Expected Marginal Profit of additional Capacity  
Marginal Cost

- For Cournot competition at the spot market the two stage market game has a **unique symmetric equilibrium**

- Equilibrium investment is too low from a welfare perspective.
Result 1

We establish existence and uniqueness of the oligopoly model under demand and cost fluctuation.
I) Establish a framework for strategic capacity choice prior to Spot Markets with fluctuating and uncertain demand.

II) Analyze the impact of changed Spot market design:
   a) Complete elimination of market power at spot market.

based on:

Consider the extreme case that a regulator is able to enforce perfectly competitive Spot behavior. (eliminate all inframarginal markups, but allow all scarcity rents)

Firms can still choose their investment strategically!
Impact of Changed Spot Market Design: 
(a) Perfectly Competitive Behavior at Spot Market

\[
\int_{\bar{\theta}^S(X^S)}^{\tilde{\theta}} \left[ P(X^S, \theta) + P_q(X^S, \theta) \frac{X^S}{n} - C_q \left( \frac{X^S}{n}, \theta \right) \right] dF(\theta) = K_x \left( \frac{X^S}{n} \right)
\]

- Similar equilibrium condition as above, however the range of integration starts at a lower realization of demand (why: for strategic spot markets withholding leads less often to a tight market).

- We show: There exist multiple symmetric, but no asymmetric equilibria
Impact of Changed Spot Market Design: (a) Perfectly Competitive Behavior at Spot Market

- All equilibria imply lower capacity than the strategic market game
  
  Motivation: Withholding of capacity is more attractive since prices can raise above marginal cost only if capacity is scarce.

- Profits of each firm are lower than under the unconstrained market solution
  
  => in a free entry equilibrium, concentration will thus increase.

- The welfare effect is ambiguous....
  
  Motivation: Welfare for low demand scenarios is increased due to marginal cost pricing, it is reduced for high demand scenarios due to reduced investment activities. (quantification: see empirical part)
Result 2

Elimination of market power at the spot market (i.e. cost based bid caps) leads to
- a decrease of industry investment,
- a decrease of firms profits (less firms active),
- an ambiguous impact on social welfare.
Illustration of the theoretical Results for the German Electricity Market
Bring the Model to the Data - Demand:

- Assume linear demand, with deterministic slope, i.e. $P(Q, \theta) = \theta - b \cdot Q$
- Derive distribution of intercepts based on hourly P-Q data (Germany 2006)
- Assume firms accurately predict the observed frequencies at the time of investment
At the capacity bound, gas turbines determine production and investment cost of all firms, assume this to be independent of market structure and rules.

- Annuities of investment cost for GT are given by [34863,45998] €/MWa
- Production cost of GT are determined by daily gas and CO2-prices (below)

![Graph of Marginal Cost and CO2 Prices]
Empirical Results: Predicted and Actual Capacities

First Best Solution
Empirical Results: Predicted and Actual Capacities

First Best Solution

Strategic Investment

Gregor Zoettl: Investment Incentives under Uncertainty
Empirical Results: Predicted and Actual Capacities

First Best Solution

Strategic Investment

Elimination of market power at spot market

Gregor Zoettl: Investment Incentives under Uncertainty
Empirical Results:
Welfare Effects, Differences to the Cournot Market Game

![Graph showing welfare differences to the Cournot case](image-url)
Empirical Results: Welfare Effects, Differences to the Cournot Market Game

![Graph showing welfare differences to the Cournot case](image-url)
Price Distribution for Hours of High Demand (upper 12% of the hours, when capacity is binding)

$p^{FB}$: First Best Benchmark
$p^{observed}$: Observed Prices, EEX 2006
Price Distribution for Hours of High Demand (upper 12% of the hours, when capacity is binding)

- $P^C$: Strategic Market Solution
- $P^{FB}$: First Best Benchmark
- $P^{observed}$: Observed Prices, EEX 2006

The graph shows the distribution of prices in euros per megawatt-hour (€/MWh) for hours of high demand, with the x-axis representing the hours and the y-axis representing the prices.
Price Distribution for Hours of High Demand
(upper 12% of the hours, when capacity is binding)

\begin{itemize}
  \item $P_{MC}$: Elimination of Market Power at the Spot Market
  \item $P_{C}$: Strategic Market Solution
  \item $P_{FB}$: First Best Benchmark
  \item $P_{\text{observed}}$: Observed Prices, EEX 2006
\end{itemize}
I) Establish a framework for strategic capacity choice prior to Spot Markets with fluctuating and uncertain demand.

II) Analyze the impact of changed Spot market design:
   a) Elimination of market power at the spot market.
   b) uniform price cap at the spot market.

based on:

Impact of Changed Spot Market Design: (b) uniform price cap at Spot Market

- Limit the prices payed to suppliers independently of scarcity (e.g. P<300€/MWh, compare, maximum price in Germany 2006: 2437€/MWh)
- We thus allow for inframarginal markups but cut scarcity rents
Impact of Changed Spot Market Design:
(b) uniform price cap at Spot Market

- Problem of such price cap:
  - It could limit un-justified markups due to market power,
  - but it also would cut scarcity rents and lead to **reduced investment**.
  - Intuition: „If you earn less in a market you invest less“

- **Attention:** We show, this argument implicitly relies on assumtion of perfect competition, not necessarily true for strategic context!
Impact of Changed Spot Market Design:  
(b) uniform price cap at Spot Market

- Conventional Wisdom: e.g. Joskow, Tirole RAND 2007: „… price caps can significantly reduce the scarcity rents required to cover the costs of investment in peaking capacity, lead to underinvestment, …“

- We show in our framework that the strategic market game with spot market price cap has a unique equilibrium.

- We show that for the case of strategic firms there always exist desirable price caps.

- We determine the optimal price cap and show that it is increasing in the number of firms
Result 3

- In oligopoly there always exist desirable price caps which increase investment.
- The optimal price cap is increasing in the number of firms.
- Price caps cannot implement the first best outcome.
Illustration of the theoretical Results for the German Electricity Market
Empirical Results: Impact of a Uniform Price Cap on Capacity Choice

Industry capacities for different price caps and market structures:

Price caps maximizing capacity:
Empirical Results: Impact of a Uniform Price Cap on Welfare

Welfare for different price caps and market structures:

Price caps maximizing welfare:
Empirical Results, Uniform Price Cap versus Elimination of Market Power at the Spot Market

Graph showing welfare (difference to the Cournot case in Euro*10^6) vs. number of firms. The graph includes two lines:
- $\Delta W^F_B$ (First Best)
- $\Delta W^M_C$ (No MP at Spot Market)
Empirical Results, Uniform Price Cap versus Elimination of Market Power at the Spot Market

![Graph showing welfare differences for different market scenarios](image.png)

- $\Delta W^{FB}$ (First Best)
- $\Delta W^{MC}$ (No MP at Spot Market)
- $\Delta W^{PC}$ (Price cap at Spot Market)
Impact of Changed Spot Market Design:
(b) uniform price cap at Spot Market, a remark

- We showed that the „missing money“ (reduced scarcity rents) argument against price caps at the spot market is not necessarily appropriate in a context of strategically behaved firms. Well chosen caps on scarcity rents lead to more investment.

- However, when worried about free entry of firms to the market (at some fixed cost) one can still make a point against those price caps. They clearly reduce firms profits, and thus can lead to higher market concentration through reduced entry.

=> Under this perspective, however, one should oppose to any type of intervention which leads to reduced profits of firms…
Summary of this Talk

- We provide a framework of capacity choice under demand and cost uncertainty, we show existence and uniqueness of the equilibrium in oligopoly.
  
a) We analyze the impact of **complete elimination of market power** at the spot market (i.e. cost based bid caps): It reduces capacity choice, the impact on welfare is ambiguous.
  
b) We analyze the impact of a **uniform price cap** at the spot market: Well chosen price caps lead to an increase of capacity choice and welfare.

- We empirically illustrate our results for Investment Decisions in the German Electricity Market.
END
just a quick glimpse:

Investment in Several Technologies

based on:
Zoettl (2008), A framework of Peak Load Pricing for Strategic Firms
A Framework of Peak Load pricing under Imperfect Competition

Strategic firms can choose to invest in many different technologies.
Result 5

- We establish existence and uniqueness of firms strategic investment choices.
- We are able to compare to the benchmarks derived in the Peak load pricing literature (FB and Monopoly).
- We show under which conditions strategic firms overinvest in efficient technologies.
Empirical Analysis, Results: Investment Decisions for Different Market Structures
Empirical Analysis, Results: Investment Decisions for Different Market Structures

- We should expect strategic under-investment only in peak and middle load technologies (25-75€/MWh).

- Strategic interaction might trigger over-investment in base technologies (<25 €/MWh).
END
Considerable Replacement Needed in Germany – Including Nuclear Phase Out

Note: Including plants currently under construction. General plant lifetime is 40 years. Decommissioning of nuclear power plants under the terms of the German government’s nuclear phase-out program.

Gregor Zoettl: Investment Incentives under Uncertainty
Considerable Replacement Needed in Germany (Excluding Nuclear Phase Out)

Note: Including plants currently under construction. Decommissioning in each case after 40 years. If the remaining periods of operation for nuclear power plants specified in the German government’s nuclear phase-out program are stipulated, the replacement requirements up to 2020 will be higher.
Planned Power Plant Projects in Germany and UK by Fuel Type

- **Net capacity in MW**

  - **Germany**
    - Hard Coal: 21,410 MW
    - Other: 600 MW
  - **UK**
    - Gas: 12,965 MW
    - Hard Coal: 2,680 MW
    - Lignite: 3,885 MW
    - Other: 2,250 MW

*450 MW included in Germany’s Hard coal and Lignite capacity (not yet decided)*

Sources: VDEW, Platts

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Prices at Various European Power Exchanges (Monthly Averages)

Investment and Production Cost, different Technologies:

- Nuclear
- Lignite
- Coal
- CCGT
- Gas Turbine