A model-based market power analysis of the German market for Frequency Containment Reserve

Samir Jeddi, 28th April 2018
Agenda

1. Challenges for the German balancing power market
2. Methodology
   • Bi-level market models
   • Solution approach
3. Results
   • Historic market power analysis
   • Alternative market design
   • Future market behaviour
4. Conclusion
Challenges for the German balancing power market
Market development favours market power

Breakdown of costs for system services

- Balancing power: 42.1%
- Energy loss: 17.8%
- Redispatch: 5.0%
- Reserve power plants: 7.2%
- Other: 27.8%

Projection of the balancing power demand

<table>
<thead>
<tr>
<th>Demand [MW]</th>
<th>+ aFRR</th>
<th>- aFRR</th>
<th>+ mFRR</th>
<th>- mFRR</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2033</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost [Mio. EUR]</th>
<th>FCR</th>
<th>aFRR</th>
<th>mFRR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prequalified Suppliers</td>
<td>23</td>
<td>34</td>
<td>46</td>
</tr>
</tbody>
</table>

Challenges for the German balancing power market

Just a few model-based market power analysis in the literature:

Econometric and theoretical analysis:

• Impact of the formation of the GCC

• Correlation analysis between spot and balancing power markets
  Growitsch und Weber (2008), Haucap et al. (2012)

• Analysis of bidding behavior
  Heim und Götz (2013), Müsgens et al. (2014)

• Theoretical analysis of the pricing scheme
  Belica et al. (2016)

Market power indices:

<table>
<thead>
<tr>
<th>Concentration ratio</th>
<th>CR₁</th>
<th>CR₃</th>
<th>CR₄</th>
<th>CR₅</th>
<th>HHI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>0.37</td>
<td>0.84</td>
<td>0.95</td>
<td>0.98</td>
<td>2,674</td>
</tr>
<tr>
<td>Critical value</td>
<td>(0.33)</td>
<td>(0.5)</td>
<td>(0.67)</td>
<td>(0.67)</td>
<td>(2,500)</td>
</tr>
</tbody>
</table>

Source: Own illustration based on Heim und Götz (2013).

Model-based market power analysis:

• Models based on decision theory
  Ocker et al. (2015)

• Market models
  Wieschhaus und Weigt (2008)

• Structural analysis of modelled market results
  Knaut et al. (2017)
Methodology
Bi-level market models simulate real market behaviour

Optimization models: MPEC

Optimization problem Firm \( j \)

\[
\max_{p_i, DV} \pi_j = \sum_{i \in \Omega_j} (\lambda - c_i) * g_i
\]

s.t.

\( ULR_j \)

\[
\min_{g_i} C_{SO} = \sum_{i=1}^{n} p_i * g_i
\]

s.t.

\( \sum_{i=1}^{n} g_i - D = 0 : \lambda \)

Market clearing of the TSO

Equilibrium models: EPEC

Optimization problem Firm \( 1 \)

\[
\max_{p_i, DV} \pi_1 = \sum_{i \in \Omega_1} (\lambda - c_i) * g_i
\]

s.t.

\( ULR_1 \)

\[
\min_{g_i} C_{SO} = \sum_{i=1}^{n} p_i * g_i
\]

s.t.

\( \sum_{i=1}^{n} g_i - D = 0 : \lambda \)

Market clearing of the TSO

Optimization problem Firm \( j \)

\[
\max_{p_i, DV} \pi_j = \sum_{i \in \Omega_M} (\lambda - c_i) * g_i
\]

s.t.

\( ULR_j \)

\[
\min_{g_i} C_{SO} = \sum_{i=1}^{n} p_i * g_i
\]

s.t.

\( \sum_{i=1}^{n} g_i - D = 0 : \lambda \)

Market clearing of the TSO

Optimization problem Firm \( M \)

\[
\max_{p_i, DV} \pi_M = \sum_{i \in \Omega_M} (\lambda - c_i) * g_i
\]

s.t.

\( ULR_M \)

\[
\min_{g_i} C_{SO} = \sum_{i=1}^{n} p_i * g_i
\]

s.t.

\( \sum_{i=1}^{n} g_i - D = 0 : \lambda \)

Market clearing of the TSO

Source: Own illustration based on Ventosa et al. (2005).
# Methodology

Linearization is the preferred solution approach

<table>
<thead>
<tr>
<th>Linearization:</th>
<th>Diagonalization:</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Analytical</td>
<td>Heuristic</td>
</tr>
<tr>
<td>+ Identification of all equilibriums</td>
<td>Convergence problems</td>
</tr>
<tr>
<td>~ Guarantee for optimality</td>
<td>No guarantee for optimality</td>
</tr>
<tr>
<td>~ Extensive analysis possible</td>
<td>No identification of all equilibriums</td>
</tr>
<tr>
<td>~ Inclusion of a high number of variables</td>
<td></td>
</tr>
</tbody>
</table>

**NLP-Formulation:**

- Differentiation of dual variables
- High number of variables
- Limited scope of analysis
Results
Individual suppliers can just moderately influence the market price

<table>
<thead>
<tr>
<th></th>
<th>EPEC</th>
<th>Competition</th>
<th>MPEC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>EON</td>
</tr>
<tr>
<td>Average price</td>
<td>2,427</td>
<td>2,302</td>
<td>2,379</td>
</tr>
<tr>
<td>[EUR/MW]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average yearly</td>
<td>6.50</td>
<td>0.00</td>
<td>4.28</td>
</tr>
<tr>
<td>Lerner index [%]</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
Results
Shorter contract durations increase the market power potential
Results
Shorter contract durations might lead to welfare losses

Welfare effects of different contract durations

Weekly
Daily Contract duration
Hourly

- Competition
- Difference
- Strategic behavior

System cost [Mio. EUR]
Results
Battery storages improve the market efficiency in 2025

Scenario A (NEP 2015)
- Low market penetration of RES
- Constant demand
- Biggest share of conventional generation

Low-Flex_Therm
- 300 MW battery storage

High-Flex_Therm
- 500 MW battery storage

Scenario C (NEP 2015)
- High market penetration of RES
- Demand reduction
- Lowest share of conventional generation

Low-Flex_EE
- 300 MW battery storage

High-Flex_EE
- 500 MW battery storage

Competitive System Costs
- LowFlex-RES
- LowFlex-Conv
- Ref. 2015
- HighFlex-RES
- HighFlex-Conv

27th April 2018
TU Dresden, Chair of Energy Economics, Prof. Dr. Möst
Conclusion

- Equilibrium model with discrete supply function
- Solution by innovative combination of linearization techniques
- Model validation
- Analysis of alternative market design and future market behaviour

- Historic market results: Limited market power
- Shorter contract durations: Lower system costs and increased market power
- Battery storage investments: Reduction of market power potential with decentralized ownership, as well as decreasing system costs

- Further research on modelling EPECs in real markets
- Modelling the optimization problem under consideration of stochastic opportunity costs


Literature


Literature

»Wissen schafft Brücken.«