Game-theoretic Evaluation of Balancing Power Auctions

Austrian Institute of Technology (AIT)

Fabian Ocker
PhD Candidate
Agenda

1. Motivation: Game theory and balancing power
2. Status quo: European aFRR auctions
3. Detailed analysis: Austria and Germany
4. Outlook: A future European aFRR auction
Motivation: Game theory and balancing power (1/2)

- Balancing power is an important **short-term balancing mechanism**.
  - Power demand and supply are volatile (e.g. wind and solar power plants).
  - Grid frequency in AC grids must stay constant over time.

- In Europe, different **types of balancing power** are distinguished.
  - **Quality** of balancing power:
    - Frequency Containment Reserve (FCR),
    - Automatic Frequency Restoration Reserve (aFRR) and
    - Manual Frequency Restoration Reserve (mFRR)
  - **Direction** of balancing power:
    - Positive: Balancing power needs to assure *increased* power supply.
    - Negative: Balancing power needs to assure *reduced* power supply.

- Allocation of balancing power via **procurement auctions**.
  - Prequalified suppliers compete for provision balancing power.
  - **Capacity costs** for keeping *balancing power* available: Power bid [Euro/MW].
  - **Calling costs** for the actual delivery of *balancing energy*: Energy bid [Euro/MWh].
Motivation: Game theory and balancing power (2/2)

- **Previous research** to balancing power auctions include:
  - Empirical analyses (Rammerstorfer and Wagner, 2009; Hirth and Ziegenhagen, 2015),
  - Theoretic modelling (Bushnell and Oren, 1995; Chao and Wilson, 2002) and
  - Macroeconomic investigations (Müsgens, Ockenfels and Peek, 2014).

- **European harmonization** of the aFRR auction starting 2019:
  - Austrian-German auction design, but *two* crucial design changes:
    1. Introduction of *Uniform Pricing* as pricing rule,
    2. and voluntary energy bids after the regular aFRR auction.

- **Bidders’ strategic interactions & possibilities** are usually neglected.

- **Appropriate method**: *Game theory*.
  - Game theory as decision theory with *interdependent payoffs* (e.g. in auctions).
  - Scientific approach for *strategic thinking and acting*.
  - Solution concept: *Bayes-Nash Equilibrium* (steady strategic situation).
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Status quo: European aFRR auctions (1/2)

How are European aFRR auctions designed?

- Investigation of **seven European aFRR auctions**.
  - **Rules and results** of the auctions must be publicly available.
  - Auction designs cover a **broad design spectrum**.
  - Criteria yield the following countries:
    - Austria, Germany, Portugal, Romania, Spain, Switzerland and the Netherlands

**What is the game-theoretic “performance” of the aFRR auctions?**

1) Identification of the **aFRR supply side**.
2) Derivation of the **bidder’s calculus** and the induced incentives.
3) Collection of the **empirical auction results** (01/2014 - 05/2016).
4) **Game-theoretic evaluation**, i.e.:

| Game-theoretic incentives | vs. | Empirical auction results |
### Status quo: European aFRR auctions (2/2)

<table>
<thead>
<tr>
<th>Country</th>
<th>aFRR products</th>
<th>Activation strategy</th>
<th>Bid components</th>
<th>Scoring rule</th>
<th>Pricing rule</th>
<th>Game-theoretic evaluation (incentives vs. auction results)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>pos. &amp; neg.</td>
<td>merit-order</td>
<td>power bid &amp; energy bid</td>
<td>power bid</td>
<td>Pay-as-bid</td>
<td>• power bids converge to 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• energy bids extremely high</td>
</tr>
<tr>
<td>Germany</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portugal¹</td>
<td>symmetric</td>
<td>pro-rata</td>
<td>power bid</td>
<td>power bid</td>
<td>Uniform Pricing</td>
<td>• auction elements yield ambiguous bidding incentives</td>
</tr>
<tr>
<td>Spain¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>the Netherlands²</td>
<td>pos. &amp; neg.</td>
<td>merit-order</td>
<td>power bid &amp; energy bid</td>
<td>energy bid</td>
<td>Uniform Pricing</td>
<td>• bids reflect bidding incentives</td>
</tr>
<tr>
<td>Romania³</td>
<td>pos. &amp; neg.</td>
<td>merit-order</td>
<td>total bid</td>
<td>total bid</td>
<td>Uniform Pricing</td>
<td>• bids in line with bidding incentives</td>
</tr>
<tr>
<td>Switzerland</td>
<td>symmetric</td>
<td>pro-rata</td>
<td>power bid</td>
<td>power bid</td>
<td>Pay-as-bid</td>
<td>• bids too high</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• energy mix (hydro)</td>
</tr>
</tbody>
</table>


1) The uniform energy prices are based on the costs of the mFRR procurement (positive and negative).
2) The procurement of FRR capacities is done on a yearly basis (no data available); determination of the merit-order on a daily basis (each 15 minutes).
3) Suppliers only offer capacities to the FRR auction that were not contracted in the regular wholesale market.
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**Detailed analysis: Austria and Germany (1/4)**

*Game-theoretic solution (Bayes-Nash Equilibrium)*

- **Positive aFRR auction**
  - power bid = capacity costs – energy bid profits + bid-shading mark-up
  - energy bid = variable costs + bid-shading mark-up

- **Negative aFRR auction**
  - power bid ≈ 0
  - energy bid = - variable costs + bid-shading mark-up

**Properties** of the game-theoretic solution

- The current German aFRR design has **desirable economic properties**.
  - An efficient (overall) market outcome is guaranteed.
  - The resulting prices – in particular for energy – are competitive.
  - The profits of all bidders are greater than on the wholesale market.

- The **negative market** fundamentally differs from the positive market.

**Source:** Belica, Ehrhart und Ocker (2017): „Harmonization of the European Balancing Power Auction – An Empirical and Theoretic Investigation“.
Empirical observations indicate market imperfections

- **2009 – 2014: Evidence for collusive behavior among the bidders.**
  - Heim (2013): Strategic supply reduction of suppliers with market power.
  - Müsgens, Ockenfels and Peek (2015): Suppliers guess the clearing price for the power bid.
  - Ocker and Ehrhart (2017): Suppliers establish non-competitive price levels by considering previous auction results when calculating their bids.

- **2014 – 2017: Subsidy-effect of the power bid and energy bid.**
  - Ocker, Ehrhart and Ott (2017): Suppliers underbid their capacity costs in the power bid and overbid their calling costs in the energy bid.
Detailed analysis: Austria and Germany (3/4)

Brachliegende Erlöspotenziale auf dem Regelenergiemarkt

energiewirtschaftliche tagesfragen, 2015

Increased aFRR supply

VS.

Constant aFRR demand

Kosten der Systemdienstleistungen der deutschen ÜNB in Mio. Euro

Monitoringbericht BNetzA, 2016

Volatile bids and inverse bid developments.

Spotlight on Germany: Quo vadis aFRR?
How to evaluate the German price trends for aFRR?

Development of an integrated market model for the electricity wholesale market and the aFRR market for 2015.

- Efficient allocation of the suppliers (interrelations of the markets)
- Integration of market data, e.g., Monitoringbericht of the regulator.

<table>
<thead>
<tr>
<th>Cost parameter</th>
<th>Real 2013</th>
<th>Real 2014</th>
<th>Real 2015</th>
<th>Model 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>aFRR costs: PB</strong></td>
<td>345</td>
<td>210</td>
<td>141</td>
<td>123</td>
</tr>
<tr>
<td>Costs pos. PB</td>
<td>143</td>
<td>132</td>
<td>102</td>
<td>123</td>
</tr>
<tr>
<td>Costs neg. PB</td>
<td>202</td>
<td>78</td>
<td>39</td>
<td>0</td>
</tr>
<tr>
<td><strong>aFRR costs: EB</strong></td>
<td>58</td>
<td>50</td>
<td>64</td>
<td>14</td>
</tr>
<tr>
<td>Costs pos. EB</td>
<td>95</td>
<td>65</td>
<td>72</td>
<td>40</td>
</tr>
<tr>
<td>Costs neg. EB</td>
<td>-37</td>
<td>-15</td>
<td>-8</td>
<td>-26</td>
</tr>
<tr>
<td><strong>Total aFRR costs</strong></td>
<td>403</td>
<td>260</td>
<td>205</td>
<td>137</td>
</tr>
</tbody>
</table>

Source: Ehrhart and Ocker (2017): „Prices and Allocations in the Electricity Wholesale Market and the Balancing Power Market“. Note that the values in the Table are stated in Mio. Euro., and that PB = power bid and EB = energy bid.
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Outlook: A future European aFRR auction (1/2)

Austrian-German aFRR cooperation as a role model?

- The **consolidation of demand and supply** within a harmonized European auction is sensible from an economic standpoint.

- The Austrian-German aFRR cooperation since 07/2016 illustrates a fundamental problem: The **frequent repetition** and **limited supply side**.

### Average energy bids [Euro/MWh], negative aFRR market (peak & off-peak)

- **aFRR cooperation**

**Future aFRR auction design must be robust against collusion – is it?**
Outlook: A future European aFRR auction (2/2)

Evaluation of the future harmonized aFRR auction design.

- **Uniform pricing** – “... bidders reveal their true costs in their bids ...“
  - Game-theoretic evaluation:
    - The **equilibrium bids** are lower than with pay-as-bid.
    - However, the **procurement costs** are **identical** as with pay-as-bid.
    - But: Uniform pricing does **not induce bidders** to report their costs in their bids.
    - On the contrary: Bidder are **incentivized to underbid** their calling costs!
  - Empirical evaluation:
    - Uniform Pricing **does not yield ”better” auctions results.**

- **Voluntary energy bids** – “... **increased competition for energy**...“
  - Game-theoretic evaluation:
    - **Equilibrium is unchanged**, i.e., desirable economic properties persist.
  - Empirical evaluation:
    - Voluntary energy bids may serve as an **upper bounder** for energy bid prices, and therefore **complicate collusive behavior.**