Application of agent-based modeling to the analysis of balancing market design and integration

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Content

• Introduction
  – Balancing market design
  – Balancing market integration
  – Agent-based modeling (ABM)

• Suitability ABM for balancing markets

• Application
  – Analysis of design variables
  – Model simulation of imbalance pricing mechanism
  – Analysis of balancing market market integration
Introduction
Balancing market design

Three actors
- System Operator (SO)
- Balance Responsible Party (BRP)
- Balancing Service Provider (BSP)

Three pillars
- Balance planning
- Balancing service provision
- Balance settlement
# Introduction

## Balancing market design

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<td>BRP accreditation requirements</td>
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### Important design variables:

**General**
- Program Time Unit (settlement period)
- Service classes (reserve types)

**Planning & settlement**
- Open vs. closed position
- Net vs. separate balances prod/cons
- Final gate closure time
- Imbalance pricing mechanism

**Balancing service provision**
- Reserve requirements
- Methods of procurement
- Timing of balancing service markets
- Pricing in balancing service markets

**Multinational – service provision**
- Distribution of reserves
- Cross-border market arrangements
- Reservation of transfer capacity
Introduction design framework
Balancing market integration

Control area 1
- Balance planning
- Balancing service provision
- BRPs
- SO
- Balance settlement

Control area 2
- Balance planning
- Balancing service provision
- BRPs
- SO
- Balance settlement

Balancing region

interconnector
Introducing Agent-based Modeling

Definition
- A relatively new *modelling paradigm* that focuses on the modelling of *individuals* who can make decisions. In an agent-based model, actors are represented as *agents*. Actor behaviour can be formalised using algorithms (van Dam, 2009).

Key words
- bottom-up approach
- autonomous decision-making
- interaction between subsystems / agents
- emerging system behaviour
- evolution / learning
Introduction
Agent-based modeling

Chappin (2009)
Introduction
Agent-based modeling

Features

- The key distinguishing element is a focus on individuals who can make decisions (van Dam, 2009)
- Agent-based models are suitable for simulating dynamic systems, or for testing different configurations (van Dam, 2009)
- “Agent-based Computational Economics (ACE) researches the two-way feedback between regularities on the macro level and interaction of economic actors on the micro level. The actors are modeled as computational agents.” (Weidlich and Veit, 2008)
Introduction
Agent-based modeling

Applicability in power market research
- ABM can be used to take into account asymmetric information, imperfect competition, strategic interaction, collective learning and the possibility of multiple equilibria (Tesfatsion, 2006)
- Complexities of electricity markets ‘drives most classical modeling methods to their limits’. Agent-based modeling (ABM) has ‘the potential to overcome some shortcomings of traditional methods’ (Weidlich and Veit, 2008)
- ABM incorporates economic, social and environmental factors, and is (thus) a suitable tool to assess electricity market designs (Maenhoudt and Deconinck, 2010)
Introduction
Agent-based modeling

Survey of agent-based electricity market models (Weidlich and Veit, 2008)

- **Subjects**: strategic bidding, market power, uniform vs. pay-as-bid pricing
- **Agents**: generators, supply companies
- **Decision variables**: (ask/bid) price, quantity, price forecast method, generator supply functions, learning rules
- **Conclusion**: AB electricity modeling is maturing, but no consensus yet on methodology and procedures

- *Bunn and Oliveira (2001, 2003)*: interrelation bilateral market (incl. power exchange) and balancing mechanism (also imbalance settlement)
- *Weidlich and Veit (2006)*: interrelation day-ahead market and day-ahead balancing power market
Introduction
Agent-based modeling

Four strands of ACE research (Tesfatsion, 2006):

A) *Empirical/descriptive*: to understand why and how global regularities result from the interplay of agents

B) *Normative*: to analyze economic design (policy) alternatives

C) *Theory generation*: analysis of dynamic behaviours of economic systems under alternative initial conditions

D) *Methodology improvement*: develop support tools that facilitate building agent-based models

Second strand is most common for electricity research (market power mitigation studies) (Weidlich and Veit, 2008)

Three agent-based simulation frameworks on electricity markets: EMCAS, AMES and OPTIMATE (Maenhoudt and Deconinck, 2010)
Introduction
Agent-based modeling

Strengths
- Incorporation of individual (strategic) behaviour
- Systematic analysis of single variables
- Generate new insights into complex systems*

Weaknesses
- Uncertainty of actual decision rules applied by agents
- ‘Qualitative nature of ABM’ *
- Difficulty of model validation*

Introduction
Agent-based modeling

Modeling procedure (Tesoatsion, 2002)
1) Define research questions
2) Construct an economy comprising an initial population of agents
3) Specify initial state of the economy
   a) Agents’ attributes (characteristics, knowledge, behavioral rules)
   b) Structural framework of the electricity market
4) Run the model (let the economy evolve over time without further intervention)
5) Analyze simulation results
Introduction
Agent-based modeling

References


Tesarfiston, L., 2002. Agent-based computational economics: growing economies from the bottom up. Artificial Life 8, 55–82.


Suitability ABM for balancing markets

• Balancing market performance (in terms of system imbalance volumes and balancing costs) is *constrained* by design, and *determined* by behaviour of Balance Responsible Parties and Balancing Service Providers

• Presence of uncertainties, risks, and market power

• ABM can be used to consider the effect of design changes on the behaviour of market players

• Ability to analyze:
  • individual design variables (other things being equal)
  • combinations of design variables
  • different external conditions
  • different actors and actor decision strategies
Application
Analysis of design variables (1)

Issues system delineation
- Representation of physical network
- Modeling of day-ahead / intraday market
- Level of detail

Issues model assumptions
- Model rounds and sequence of actions
- Included decision variables and values
- Decision-making algorithm:
  - information, risk attitude, rationality
  - learning
  - making the final choice
**Application**
**Analysis of design variables (2)**

*Suitable balancing market design variables:*
- Imbalance pricing mechanism
- Pricing mechanism balancing service market
- Timing of balancing service markets
- Cross-border balancing arrangements

*Unsuitable balancing market design variables:*
- Service classes
- Program Time Unit
- Open vs. closed position
- Final gate closure time
- Distribution of reserves
Application
Model simulation of imbalance pricing mechanism

- BRPs submit **energy schedules**. Deviations from these schedules are **imbalances**, which are settled with an **imbalance price**.
- Imbalance volume [MWh] x imbalance price [Euro/MWh] = imbalance costs [Euro]
Application
Model simulation of imbalance pricing mechanism

Different imbalance pricing mechanisms:

• *Single pricing:* BRP surpluses and BRP shortages are settled with the same imbalance price (based on marginal balancing energy price)

• *Dual pricing:* Imbalance price for BRP surplus is based on downward regulation price; imbalance price for BRP shortage is based on upward regulation price (unless regulation is in one direction only)

• *Two-price settlement:* Imbalance price for BRP imbalance in opposite direction to system imbalance is settled with the day-ahead power exchange price

→ **Research question:** What is the impact of the imbalance pricing mechanism on balancing market performance?
Application
Model simulation of imbalance pricing mechanism

An agent-based model that analyses the impact of imbalance pricing mechanisms on BRP behaviour:

- Rounds = PTUs
- Fixed bid ladder
- Distinction unintentional and intentional imbalance
- Control variable = intentional imbalance (over/under-contracting strategy)
- System imbalance = sum of BRP imbalances
Application
Model simulation of imbalance pricing mechanism
Application
Model simulation of imbalance pricing mechanism

- Agent-based model in MATLAB
- Ten BRPs with different portfolio size
- BRPs can choose between seven intentional imbalance options (over/under-contracting strategies)
- For all options, each BRP calculates an expected Actual Imbalance Costs (AIC) value
- These values are updated whenever an option has been chosen
- Last rounds weigh more heavily (learning)
- Decision is based an AIC-based probability distribution function (exploration & exploitation)
## Application

Model simulation of imbalance pricing mechanism

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<td>58.2</td>
<td>56.8</td>
<td>56.4</td>
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<tr>
<td>Occurrence system shortage (%)</td>
<td>41.8</td>
<td>43.2</td>
<td>43.6</td>
</tr>
<tr>
<td>Average Actual Imbalance Costs (£/BRP/PTU)</td>
<td>167</td>
<td>240</td>
<td>249</td>
</tr>
<tr>
<td>Average Actual Imbalance Penalty for BRP surplus (£/MWh)</td>
<td>-1.88</td>
<td>5.09</td>
<td>13.93</td>
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## Application

Model simulation of imbalance pricing mechanism

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<tr>
<td>Average AIP for BRP surplus &amp; system surplus (€/MWh)</td>
<td>24.70</td>
<td>24.66</td>
<td>24.70</td>
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<tr>
<td>Average AIP for BRP surplus &amp; system shortage (€/MWh)</td>
<td>-38.87</td>
<td>-20.72</td>
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<td>1.88</td>
<td>10.88</td>
<td>17.88</td>
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<tr>
<td>Average AIP for BRP shortage &amp; system surplus (€/MWh)</td>
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<td>-10.89</td>
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<tr>
<td>Average AIP for BRP shortage &amp; system shortage (€/MWh)</td>
<td>38.87</td>
<td>39.56</td>
<td>39.21</td>
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Application
Analysis of balancing market integration

- Extension of BRP model
- Analysis of different cross-border balancing arrangements
  - Focus on BSPs; the number of decisions of BSPs may increase
  - Interrelation behaviour BRPs vs. BSPs
  - Dependency on available cross-border capacity
- Possible future work (for others):
  - Interrelation with DA/ID markets
  - Impact of increasing wind share + balance management rules for wind power
End of presentation

Questions?