Long-term modelling of electricity market prices to examine prospective revenues of storage agents

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The challenge

- CO₂ emissions
- air pollution

⇒ Renewable energy

- Wind & PV
  - non-dispatchable
  - missing reliability
  - volatile output

⇒ Flexibility options

- Flex options
  - different timescales
  - expensive

⇒ When profitable?
⇒ What amounts?
The challenge
Profitability of arbitrage

Storage profitability

- Block Median: Peak-to-peak
- Block hours ⇔ Energy-to-power ratio (E2P)
- Profitability ⇔ price fluctuations

⇒ Shape of price curve important for storage operators
The challenge
Price modelling

Fundamental model REMix
- Linear optimization
- Electricity + sector coupling
- Scope: Europe
- Transport grid restrictions

How to improve price variability modelling?
AMIRIS
Agent-based electricity market simulation

Fundamental modelling
- electricity prices
- actor revenues

Policy influence
- curtailment
- storage dispatch
- prosumer behaviour

Input Data
Feed-in Renewables, Balance Energy Price, Marginal Costs Conventional Power Plants, Load...
**AMIRIS**

**Price formation**

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**Demand**

- Inflexible demand
- High-res supply bids

**Merit order**

- Marginal cost = bid price
- Power blocks: type-specific
- Efficiencies interpolated

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**Supply**

- Marginal cost / (€/MWh)
- Energy / (MWh)
AMIRIS
Conventionals - marginal costs

power blocks

η_max

η_min

other variable cost

block efficiencies

CO_2 price

cost

Not considered
- Control power markets
- Individual power plants
- Start-up cost
- Heat constraints
- …
AMIRIS
Resulting price

Consider missing effects … but how?
Hybrid approach
Add markups & markdowns

Marginal cost (€/MWh)

Energy (MWh)

$\eta_{\text{min}}$

$\eta_{\text{max}}$

Bids (€/MWh)

Energy (MWh)

➤ Fit markup & markdown values

markup
markdown
Gene pool

-200 -10

-30 10

-50 30

Nuclear
Coal
Gas CC

Generation

AMIRIS

evaluate fitness

kill weak

Price optimisation criterion | Unit | Target | Weight
--- | --- | --- | ---
Pearson correlation | 1 | 1 | 3
Mean average error | €/MWh | 0 | 5
Standard deviation | €/MWh | 12.64 | 3
Mean | €/MWh | 30.30 | 3
Minimum | €/MWh | -130.09 | 1
Maximum | €/MWh | 104.96 | 1
Hours with negative prices | 1 | 223 | 2

Fit to price data 2012 – 2014
Markup determination

Validation

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson correlation</td>
<td>0.86</td>
</tr>
<tr>
<td>Mean average error /€/MWh</td>
<td>4.91</td>
</tr>
<tr>
<td>Root mean square error /€/MWh</td>
<td>6.82</td>
</tr>
</tbody>
</table>

Validation with price data 2015 – 2016

- 🧐 almost forecast level
- 🧐 good variability
- 😧 slightly too low
- 😧 deep minima
- 😧 high peaks
- 😧 slightly overestimated

<table>
<thead>
<tr>
<th>Price optimisation criterion</th>
<th>Target /€/MWh</th>
<th>Model /€/MWh</th>
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</thead>
<tbody>
<tr>
<td>Standard deviation /€/MWh</td>
<td>12.64</td>
<td>11.68</td>
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<tr>
<td>Mean /€/MWh</td>
<td>30.30</td>
<td>28.37</td>
</tr>
<tr>
<td>Minimum /€/MWh</td>
<td>-130.09</td>
<td>-46.78</td>
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<tr>
<td>Maximum /€/MWh</td>
<td>104.96</td>
<td>83.75</td>
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<tr>
<td>Hours with negative prices</td>
<td>223</td>
<td>366</td>
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</tbody>
</table>

- 🧐 slightly overestimated
Markups

Results

➡ Good replication of low prices
➡ Slightly too low price level
➡ Good stylized facts replication
➡ Consequences for storage?
Impact on storage
Dispatch & Surplus

Storage Parameters

- 2.5 GW
- E2P = 5 ➞ 12.5 GWh
- $\eta = 80\%$

<table>
<thead>
<tr>
<th></th>
<th>Discharge hours / (h/a)</th>
<th>Discharged energy / (GWh/a)</th>
<th>Charge hours / (h/a)</th>
<th>Charged energy / (GWh/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No markups</td>
<td>1,719</td>
<td>2,438</td>
<td>1,994</td>
<td>3,009</td>
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<tr>
<td>With markups</td>
<td>2,570</td>
<td>3,318</td>
<td>2,628</td>
<td>4,097</td>
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</tbody>
</table>

Surplus / (k€/MWa)

<table>
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<th>No markups</th>
<th>With markups</th>
</tr>
</thead>
<tbody>
<tr>
<td>No markups</td>
<td>20.5</td>
<td>16.9</td>
</tr>
<tr>
<td>With markups</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

With markups: More dispatch, ok, but why less surplus?
Markups improve shape parameters
More precise profitability estimates

Data 2015 – 2016

no markups
markups
Impact of storage
Price feedback

E2P = 5  \( \eta = 80\% \)

Storage dampens price variability

⇒ Verify storage dispatch
Storage dispatch
Model vs. data

E2P = 5  \( \eta = 80\% \)  2 GW

\( \Rightarrow \) Markups: better stylised facts of dispatch
\( \Rightarrow \) Markups: higher correlation to measured dispatch
Wrap up

**Price variability**
- good reproduction necessary
- fundamental modelling: complex
- hybrid approach: markups

**Application to storage**
- markups: better dispatch correlation
- more precise surplus assessment

**Markups**
- fitted via genetic algorithm
- price: better reproduction of stylised facts
- room for improvement

**Future work**
- include AT & LU
- connect neighbouring market zones
- improve storage dispatch algorithm
- fundamental markup / bid modelling?