Real-Time Electricity Pricing with Heterogeneous Consumers and Variable Renewable Energy Supply: Welfare and Distributional Effects

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Motivation

a) vRES entry causes growing need/benefit of price responsive demand.

b) Large-scale smart meter roll-out in EU power systems.

c) How to catch most of potential welfare gains from real-time pricing?

Source: European Commission JRC and DG ENER
Motivation
Lack of Real-time pricing (RTP) is the fundamental market flaw

Allocative Inefficiency in real electricity markets from flat pricing:

\[ w_t \]
\[ Q_{\text{op}} \]
\[ Q_p \]
\[ Q^S \]
\[ Q_{\text{true}} \]
\[ Q_{\text{true}} \]

Christian Gambardella, Sustainable Solutions, PIK
Motivation

Problem: Social Acceptance Barriers to Dynamic Retail Pricing

Largest efficiency gains may stem from potential “losers” of RTP:

[Graph showing EEX Spot Price, Aggregate, Residential, Services, Industry, and Hour (Wed/01/03/2013)]

Source: Own calculations based on data from Entso-e, Eurostat and energinet.dk
Research Questions

1. How does the amount of redistributed costs from RTP adoption change in a market with variable electricity supply?

2. What are the welfare gains left on the table if mainly large (industrial) consumers with „flat“ demand profiles adopt RTP?
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   • Comparative statics
   • Numerical partial equilibrium model
   • Data
3. Preliminary Results
4. Conclusion
METHOD
Long-Run Partial Equilibrium Model
(Borenstein & Holland 2005)

- Retailers sells to RTP consumers
- Retailers buys from Producers
- Producers

Retail Market

\( Q_t^*, w_t^*, K^* \)

\( p_t^*, \bar{p}_n^*, \ldots, \bar{p}_N^* \)

Wholesale Spot Market

\( \max \pi(p_t, \bar{p}_n, \ldots, \bar{p}_N | w_t, \alpha) \)

\( \max \pi(q_t^s, K^{NV}, a \nu_t K^V | w_t, m_c_i, r_i) \)

\( \alpha Q_t^D(\cdot) = \sum_n^N \alpha^n q_t^n(p_t | a_t^n) \)

\( (1 - \alpha) Q_t^D(\cdot) = \sum_n^N (1 - \alpha^n) q_t^n(\bar{p}_n^n | a_t^n) \)

\( q_t^d(p) = a_t p^{-\varepsilon} \)
Method

Perfect competition in retail sector (zero-profits)

- Retail **real-time prices** $p_t$ in hour $t$:

$$ \pi = \sum_t^T (p_t - w_t) \cdot \alpha Q^D_t(p_t) = 0 $$

- **Flat rates for each consumer type** $\bar{p}^n$ (no cross subsidization):

$$ \pi^n = \sum_t^T (\bar{p}^n - w_t) \cdot (1 - \alpha^n) \cdot q^n_t(\bar{p}^n | \alpha^n) = 0, \forall n \in N $$

- **Uniform flat price** $\bar{p}$ (cross subsidization):

$$ \pi = \sum_t^T (\bar{p} - w_t) \cdot (1 - \alpha) Q^D_t(\bar{p}) = 0 $$
Method
Create heterogeneous consumption time series ...

<table>
<thead>
<tr>
<th>Hour</th>
<th>Residential [GW]</th>
<th>Services&amp;Trade [GW]</th>
<th>Industry [GW]</th>
<th>Total Demand [GW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15.09</td>
<td>12.25</td>
<td>12.54</td>
<td>39.87</td>
</tr>
<tr>
<td>2</td>
<td>13.89</td>
<td>12.04</td>
<td>12.45</td>
<td>38.39</td>
</tr>
<tr>
<td>⋮</td>
<td>⋮</td>
<td>⋮</td>
<td>⋮</td>
<td>⋮</td>
</tr>
<tr>
<td>8760</td>
<td>16.82</td>
<td>13.03</td>
<td>17.21</td>
<td>47.06</td>
</tr>
</tbody>
</table>

| Total [GWh] | 136,000 (27%) | 145,835 (29%) | 224,269 (44%) | 506,104 |

- **Entso-e**: Total hourly electricity demand data (2013)
- **Eurostat**: Final annual sector-specific electricity consumption
- **BDEW**: Standard Load Profiles (SLPs) **H0 (Residential)** and **G0 (Trade & Services)**; Industry demand equals residual demand
PRELIMINARY RESULTS
Results

With higher vRES supply, total redistribution of costs is lower

Bill changes if all customers switched to RTP w/o changing consumption behaviour*:

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>-8.40 (-0.15%)</td>
<td>795.74 (13.62%)</td>
<td>-790.98 (-8.80%)</td>
<td>799.40</td>
</tr>
<tr>
<td>~40%</td>
<td>247.40 (1.82%)</td>
<td>414.83 (2.84%)</td>
<td>-662.45 (-2.95%)</td>
<td>662.45</td>
</tr>
<tr>
<td>~50%</td>
<td>182.28 (1.19%)</td>
<td>209.04 (1.27%)</td>
<td>-391.31 (-1.54%)</td>
<td>391.31</td>
</tr>
<tr>
<td>~60%</td>
<td>114.10 (0.59%)</td>
<td>-43.39 (-0.21%)</td>
<td>-70.62 (-0.22%)</td>
<td>114.00</td>
</tr>
</tbody>
</table>

*Assumption: Uniform flat rate
Results
The „peakier“ the demand pattern, the higher the overall consumer surplus gains from RTP

Total consumer surplus gains for given aggregate RTP shares [€ mio./year]

<table>
<thead>
<tr>
<th>α</th>
<th>α^n</th>
<th>No vRES</th>
<th>60% vRES in GEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>10% RTP Share</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential (34%)</td>
<td>164.27</td>
<td>249.24</td>
<td></td>
</tr>
<tr>
<td>Services&amp;Trade (32%)</td>
<td>171.25</td>
<td>237.55</td>
<td></td>
</tr>
<tr>
<td>Industry (21%)</td>
<td>119.52</td>
<td>190.79</td>
<td></td>
</tr>
<tr>
<td>20% RTP Share</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential (72%)</td>
<td>330.85</td>
<td>502.83</td>
<td></td>
</tr>
<tr>
<td>Services&amp;Trade (67%)</td>
<td>351.80</td>
<td>488.14</td>
<td></td>
</tr>
<tr>
<td>Industry (44%)</td>
<td>254.18</td>
<td>405.03</td>
<td></td>
</tr>
</tbody>
</table>

- Surplus gains from putting only industrial customers on RTP to achieve $\alpha = 10\%$ or $\alpha = 20\%$ are $\sim20\%$ lower on average.

- Surplus gains are on average $33\%$ higher with 60% vRES share.
Preliminary Results

Annual surplus gains from switching to RTP per average kWh consumed by switchers to RTP:

<table>
<thead>
<tr>
<th>Scenario I ((\alpha^n = 50%))</th>
<th>Residential [€/kWh*a]</th>
<th>Services [€/kWh*a]</th>
<th>Industry [€/kWh*a]</th>
<th>All [€/kWh*a]</th>
</tr>
</thead>
<tbody>
<tr>
<td>No vRES</td>
<td>22.27</td>
<td>21.49</td>
<td>15.05</td>
<td>14.12</td>
</tr>
<tr>
<td></td>
<td>(240.25)*</td>
<td>(266.69)</td>
<td>(288.28)</td>
<td>(681.45)</td>
</tr>
<tr>
<td>~60% in GEC</td>
<td>30.51</td>
<td>28.04</td>
<td>24.05</td>
<td>24.51</td>
</tr>
<tr>
<td></td>
<td>(361.48)</td>
<td>(369.88)</td>
<td>(458.70)</td>
<td>(1081.52)</td>
</tr>
</tbody>
</table>

*Total gains in brackets in mio.€/year

- „Peakier“ consumers switching to RTP gain more per average kWh consumed (20% to 30%).

- Benefits are on average about 30% higher in the vRES market.
CONCLUSION
Conclusion & Outlook

- Efficiency gains from adopting RTP increase significantly with vRES shares.
- Potential redistribution of costs becomes less important with high vRES shares.
- Significant portion of potential welfare gains may be lost if mainly largest but „flat consuming” (industrial) consumers adopt RTP (or similar mechanisms).

What to do with this:

- **General aim**: providing insights for designing measures to induce as much efficiency in retail pricing (adoption of RTP) as possible.
- Are there other, e.g. **cognitive barriers to RTP adoption**, that should be included in the model (**Internalities**)?
References


References


