Designing fair and stable pricing mechanisms for consumers: a mixed approach between coalitional game theory and bilevel models

Olivier BEAUDE (*EDF R&D*)

olivier.beaude@edf.fr

with H. LE CADRE (*EnergyVille*, Belgium),
T. HONEM-DE-MELLO, and B. PAGNONCELLI
(School of Business, Univ. A. Ibanez, Chile)

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Outline

1. The proposed model: a mix between bilevel and coalitional games

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   - Sketch of the model
   - Algo 1 to solve cons. load scheduling pb
   - Imbalance cost
   - Aggregator problem

Sketch of the model

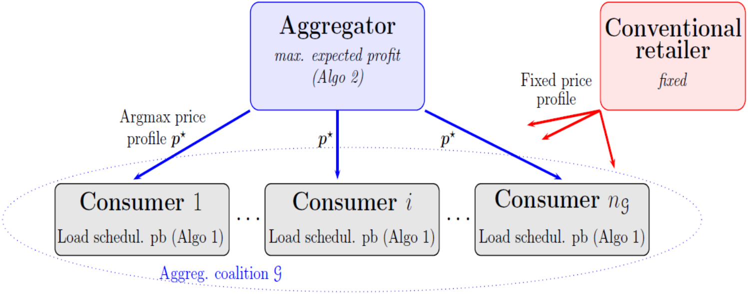

Figure: Global - bilevel - scheme of proposed approach. *At the lower level, a colational game problem.*

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And **repeat, period after period**...

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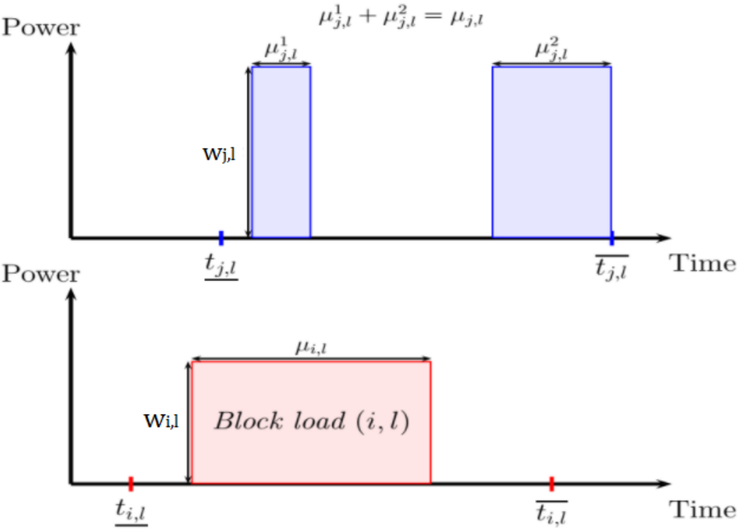
- constant power (resp. *duration*) $w_{i,l}$ ($\mu_{i,l}$)
- *per-unit reservation price* $r_{i,l}$, chosen privately by i

$$\sum_{t=0}^{nT-1} p^\star(t) x_{i,t} \leq r_{i,l} w_{i,l} \mu_{i,l} \tag{1}$$

Structuring assumption: constant power profiles

2 types of loads: *interruptible* (top), *block* (bottom)



→ **combinatorial** problems...

Load scheduling for a flexible consumer: Algo 1

Algo 1: exhaustive search, block by block (independent)

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For **block load** $l \in \mathcal{B}_i$

1. Sort $\tau \in \{\underline{t}_{i,l}, \overline{t}_{i,l} - \mu_{i,l} + 1\}$ by increasing

$$\sum_{t=\tau}^{t=\tau+\mu_{i,l}-1} p^\star(t)$$

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2. Following this order,
   1. If $\sum_{t=\tau}^{t=\tau+\mu_{i,l}-1} p^\star(t) \leq r_{i,l}\mu_{i,l}$, schedule load on time-slots τ, $\tau+1$, ..., $\tau+\mu_{i,l}-1$. **STOP**
   2. Else, while $\tau < \overline{t}_{i,l} - \mu_{i,l} + 1$, $\tau = \tau + 1$, **GO TO 2)1)**.

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2. If $\sum_{\tau=0}^{\tau=\mu_{i,l}-1} p^\star(t_\tau) \leq r_{i,l}\mu_{i,l}$, schedule the load on time slots t_0, t_1, ..., $t_{\mu_{i,l}-1}$
3. Otherwise, do not schedule the load

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Imbalance = aggreg. diff. between (day ahead) estimation $\hat{d}_i(t)$ and (real time) realization $d_i(t)$ of demand of i

$$\Delta = \sum_{i \in \mathcal{G}} \hat{d}_i(t) - d_i(t)$$

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- **balancing cost of aggregator**
  - **aggreg. over-estim.:** "loss" $(p^f(t) - p^+(t))\,(\Delta)_+ > 0$
  - **aggreg. under-estim.:** pay $p^-(t)\,(\Delta)_- > 0$

with $p^+(t)$ (resp. $p^-(t)$) unit price to sell (resp. buy) on balancing at t, with $p^+(t) < p^f(t) < p^-(t)$ [1]; $p^f(t)$ day-ahead energy price

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"Share" imbalance cost between agg. and cons. (2)

- **balancing cost for consumer** i

$$B_i(t) = p^-(t)\Big(\hat{d}_i(t) - d_i(t)\Big)_- + \Big(p^f(t) - p^+(t)\Big)\Big(\hat{d}_i(t) - d_i(t)\Big)_+$$

random variable at the beginning of period $n * T$

Aggregator problem

- **cost**: buy in day-ahead... balancing cost (or profit)

$$
\begin{aligned}
c(\mathcal{G}, t) &= p^f(t) \sum_{i\in\mathcal{G}} \Big(\sum_{l\in\mathcal{L}_i} x_{i,l}(t) + \hat{d}_i(t) \Big) \\
&+ p^-(t) \Big(\sum_{i\in\mathcal{G}} (\hat{d}_i(t) - d_i(t)) \Big)_- \\
&- p^+(t) \Big(\sum_{i\in\mathcal{G}} (\hat{d}_i(t) - d_i(t)) \Big)_+
\end{aligned}
$$

- **expected profit** over horizon nT

$$
\begin{aligned}
\Pi(\mathbf{p}^\star) &= \sum_{t=0}^{nT-1} \Big\{ p^\star(t) \sum_{i\in\mathcal{G}} \Big(\sum_{l\in\mathcal{L}_i} x_{i,l}(t) + \hat{d}_i(t) \Big) \\
&+ \sum_{i\in\mathcal{G}} \mathbb{E}\left[B_i(t)\right] - \mathbb{E}\left[c(\mathcal{G}, t)\right] \Big\}
\end{aligned}
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Casted as an **optimization problem**

$$\min_{\mathbf{p}^\star} \quad \left\| \mathbf{A}\left((\mathbf{x_i})_{i\in\mathcal{G}}, \left(\hat{d}_i(t)\right)_{t=0,i\in\mathcal{G}}^{nT-1} \right) \mathbf{p}^\star - \mathbf{b}\left((\mathbf{x_i})_{i\in\mathcal{G}}, \left(\hat{d}_i(t)\right)_{t=0,i\in\mathcal{G}}^{nT-1} \right) \right\|$$

$$\text{s.t.} \qquad p^\star(t) \geq 0, \forall t \in \{0, \cdots, nT-1\}$$

Remark: problem solved with a (biased) estimation of reservation prices $(\hat{\mathbf{r}}_i)_{i\in\mathcal{G}}$

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If aggregator prices are not strictly ordered: not clear... (pessimistic versus optimistic)

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THANK YOU FOR YOUR ATTENTION!

References I

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