Bi-level providers - consumers competition model

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Outline

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2. Bi-level competition model
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     - Flexible consumer with RE and storage
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   - Preliminar simulation setting: only 2 providers
   - Simulations: convergence of the dynamics?
   - Simulations: analysis of the obtained equilibrium
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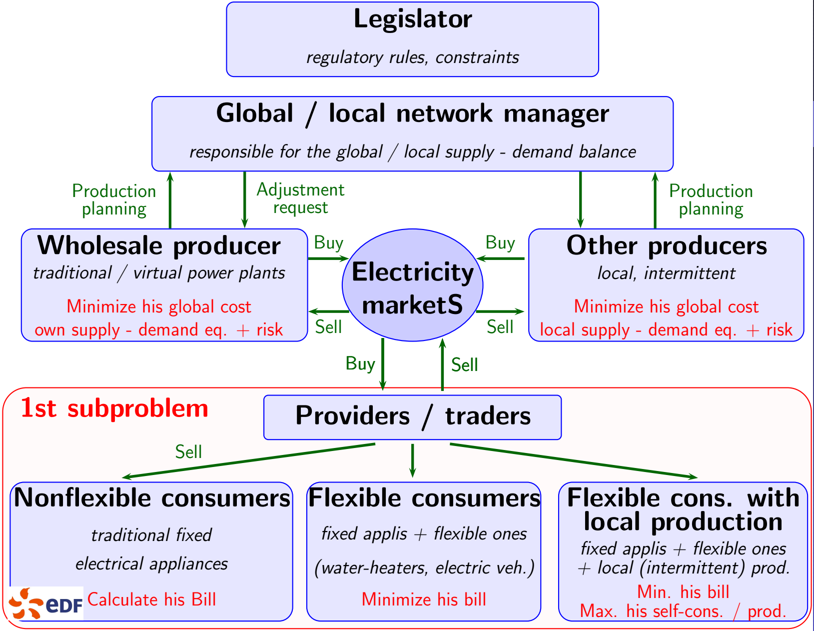
Decentralizing in electricity systems: big picture



Decentralizing in electricity systems: a few main ingredients

Decentralize = a few reasons / needs

- emergence of local actors → new (local) decision-takers
  ⇒ coordinate local VS global with prices, incentives
  Natural framework for bilevel models + mechanism design [4, 9]
- huge and complex problems
  ⇒ (stochastic) decomposition = "fictively" decentralize
- local data / information (privacy concerns...)
  ⇒ Design of (strategic) information exchange scheme [2, 5]

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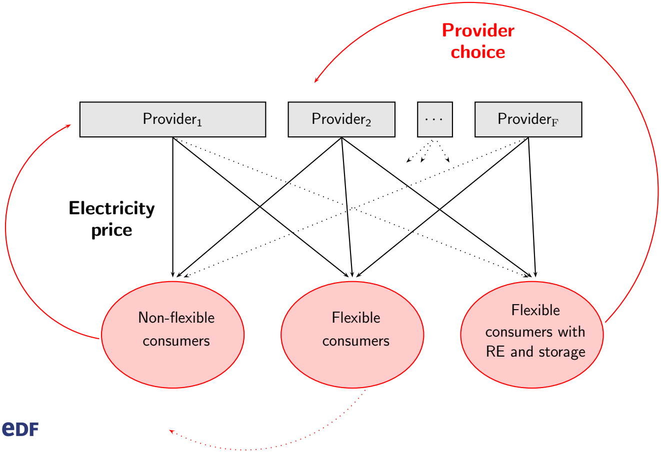
Bi-level competition model

Bi-level competition game (Stackelberg multiple-leaders / multiple-followers game):

- *Leaders* (upper level): electricity providers $f \in \mathcal{F}$
- *Followers* (lower level): electricity consumers $c \in \mathcal{C}$



Consumer electricity bill and provider profit

Yearly price for provider f is a sequence of size $D * T$ with indices $j \in \mathcal{J}$ day and $t \in \mathcal{T}$ time-slot.

Price [6]:

$$p_{fj}(t) = g_{fjt}\Big(\sum_{c \in \mathcal{C}} \ell_{cj}(t)\Big)$$

Consumer bill:

$$\sum_{j \in \mathcal{J}} \sum_{t \in \mathcal{T}} p_{fj}(t) \times \ell_{cj}(t)$$

Provider profit:

$$\sum_{c \in \mathcal{C}_f} \sum_{j \in \mathcal{J}} \sum_{t \in \mathcal{T}} p_{fj}(t) \times \ell_{cj}(t)$$

with $\mathcal{C}_f$ set of consumers choosing f as provider.

Nonflexible consumer

Nonflexible consumption profile: $\boldsymbol{\ell}_c^0 = (\ell_{cj}^0(t))_{j \in \mathcal{J}, t \in \mathcal{T}}$

Pb = provider choice

$$\min_{f \in \mathcal{F}} \sum_{j \in \mathcal{J}} \sum_{t \in \mathcal{T}} p_{fj}(t) \times \ell_{cj}^0(t)$$

Flexible consumer

Fixed consumption profile: $\ell^0_c = (\ell^0_{cj}(t))_{j\in\mathcal{J},t\in\mathcal{T}}$

$+$ Flexible consumption profile: $\ell^1_c = (\ell^1_{cj}(t))_{j\in\mathcal{J},t\in\mathcal{T}}$

Pb $=$ flexible consumption scheduling $+$ provider choice

$$\min_{f\in\mathcal{F}} \sum_{j\in\mathcal{J}} \min_{\ell^1_{cj}\in\mathbb{R}^{\mathcal{T}}_+} \sum_{t\in\mathcal{T}} p_{fj}(t) \times (\ell^0_{cj}(t) + \ell^1_{cj}(t))$$

$$\text{s.t.} \begin{cases} \ell^1_{cj}(t) \le \ell_{\max}, \ \forall j \in \mathcal{J}, \forall t \in \mathcal{T}, \\ \sum_{t\in\mathcal{T}} \ell^0_{cj}(t) + \ell^1_{cj}(t) = L_{cj}, \ \forall j \in \mathcal{J} \end{cases}$$

Flexible consumer with renewable energy (RE) and storage

- Fixed consumption ℓ_c^0 + flexible consumption ℓ_c^1
- RE generation profile $\widetilde{\mathbf{w}}$
- storage charging /discharging profile $\mathbf{s}$

  $\rightarrow$ storage energy level $e_{cj}(t) = e_{cj}(t-1) + s_{cj}(t)$

Pb = consumption/storage scheduling + provider choice

$$\min_{f \in \mathcal{F}} \sum_{j \in \mathcal{J}} \min_{\substack{\boldsymbol{\ell}^1_{\mathbf{cj}} \in \mathbb{R}_+^T, \\ s \in \mathbb{R}^{J \times T}}} \sum_{t \in \mathcal{T}} p_{fj}(t) \times [\ell^0_{cj}(t) + \ell^1_{cj}(t) - \widetilde{w}_{cj}(t) + s_{cj}(t)]^+$$

$$\text{s.t.} \begin{cases} \ell^1_{cj}(t) \leq \ell_{\max}, \ \forall j \in \mathcal{J}, \forall t \in \mathcal{T}, \\ \sum_{t \in \mathcal{T}} \ell^0_{cj}(t) + \ell^1_{cj}(t) = L_{cj}, \ \forall j \in \mathcal{J}, \\ 0 \leq e_{cj}(t) \leq E_c, \ \forall j \in \mathcal{J}, \forall t \in \mathcal{T}, \end{cases}$$

where $[x]^+ = \max(x, 0)$.

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Providers model

For provider $f \in \mathcal{F}$

$$\Pi^f(\mathbf{p}^f, \mathbf{p}^{-f}) = \sum_{c \in \mathcal{C}_f(\mathbf{p}^f, \mathbf{p}^{-f})} \sum_{j \in \mathcal{J}} \sum_{t \in \mathcal{T}} p_{fj}(t) \times \ell_{cj}(t)$$

where $\mathbf{p}^{-f}$ the prices proposed by alternative providers

$$\mathbf{p}^{-f} = (\mathbf{p}^1, \cdots, \mathbf{p}^{f-1}, \mathbf{p}^{f+1}, \cdots, \mathbf{p}^F)$$

Pb = profit maximization

$$\max_{\mathbf{p}^f \in \mathcal{P}^f} \Pi^f(\mathbf{p}^f, \mathbf{p}^{-f})$$

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Consumer's/provider's decisions update: a yearly dynamics

Consumer's choices $\neq$ perfect rationality $\rightarrow$ *Discrete choice models* [8]

1. Class choice

Proportions in different classes for the year to come

$$\gamma_i^y = \frac{e^{-\alpha_{cons} C_i^y}}{\sum_{i \in \{0,1,2\}} e^{-\alpha_{cons} C_i^y}}$$

with y index of year, i index of the classes (0 non-flexible, 1 flexible, 2 flexible with RE and storage), C_i cost, α_{cons} price sensibility for consumers.

2. Provider's choice

Same model with α_{prov}

Consumer's/provider's decisions update: a yearly dynamics

Provider f's price-update $\rightarrow$ *best-response strategy* [3]

$$\mathbf{p}^{f,y} \in arg \max_{\mathbf{p}^f \in \mathcal{P}^f} \Pi^f(\mathbf{p}^f, \mathbf{p}^{-f,y-1})$$

with y year index,

$-f = (1, \cdots, f-1, f+1, \cdots, F)$ alternative providers.

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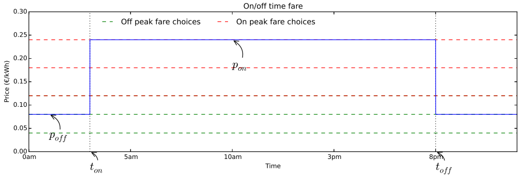
Simulation setting: only 2 providers

- Two providers: $\mathcal{F} = \{1, 2\}$
- Two classes of consumers: non-flexible, flexible
- Consumers daily energy need $\rightarrow$ "Recoflux" ERDF data:
  - nonflexible consumption = base consumption
  - flexible consumption = water-heating

  No yearly evolution of energy needs
- Daily <u>*exogenous*</u> on/off peak fare:

$$\tilde{p}^f = (t^f_{on}, t^f_{off}, p^f_{on}, p^f_{off})$$



- Other parameters: α_{prov}, α_{cons}, $\ell_{\max}$ max. flexible load, $\gamma^{y=0}_{\text{flex}}$ initial proportion of flexible consumers

Pseudo-code for the yearly dynamics simulation

Initial year $\tilde{p}^{f,y=0}$ randomly chosen

Calculate initial consumers consumption
$+$ provider choice

while $\sum_{f\in\mathcal{F}} \|\tilde{p}^{f,y} - \tilde{p}^{f,y-1}\| >= \epsilon$ **and** $y \leq Y$ **do**

Next year $y = y + 1$

for $f \in \mathcal{F}$ **do**

for $\tilde{p}^f \in \widetilde{\mathcal{P}}_f$ **do**

Simulate consumers consumption
$+$ provider choice

Calculate $\Pi^f(\tilde{p}^f, \tilde{\mathbf{p}}^{-f,y-1})$

end for

Choose $\tilde{p}^{f,y}$ maximizing $\Pi^f(\cdot, \tilde{\mathbf{p}}^{-f,y-1})$

end for

end while

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Simulations: convergence of the dynamics

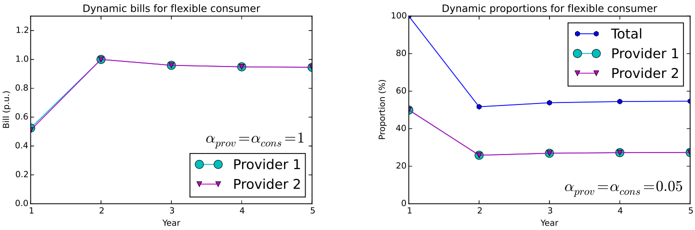
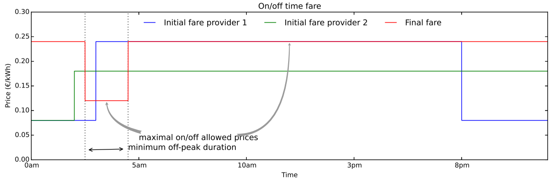


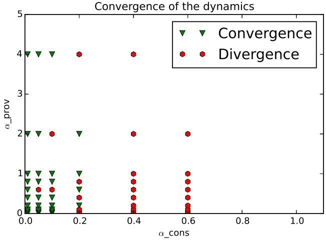
Figure: $\gamma_{\text{flex}}^{y=0} = 100\%$ and $\ell_{\max} = 3\text{kW}$

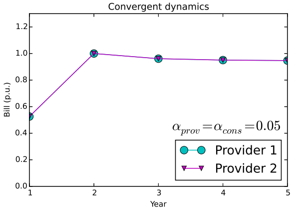


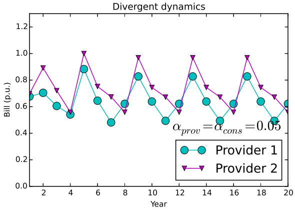
$\Rightarrow$ same final fare for both providers with minimum off-peak duration and maximum prices levels

Convergence: impact of discrete choice models

$\alpha_{cons} \in \{0.01, 0.05, 0.1, 0.2, 0.4, 0.6, 0.8, 1\}$
$\alpha_{prov} \in \{0.01, 0.05, 0.1, 0.2, 0.4, 0.6, 0.8, 1, 2, 4\}$







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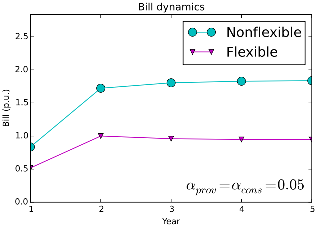
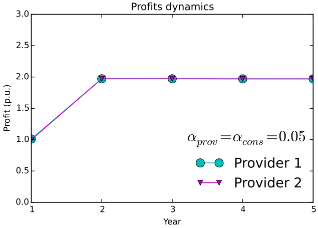
Consumer's bill / provider's profit at equilibrium

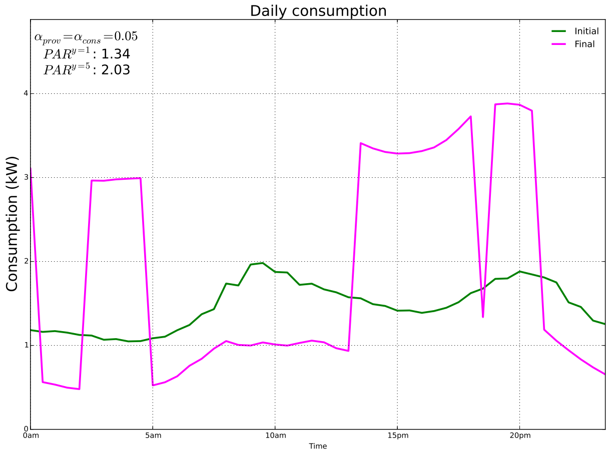




$\Rightarrow$ nonflexible consumer's bill $>$ flexible consumer's bill

$\Rightarrow$ providers' profit nearly doubled (strongly depends on the min./max. prices allowed to the providers)

Estimated impact on the electricity network metrics



$\Rightarrow$ Peak-to-Average-Ratio $\mathrm{PAR} = \frac{\max(\ell)}{mean(\ell)}$ almost doubled!

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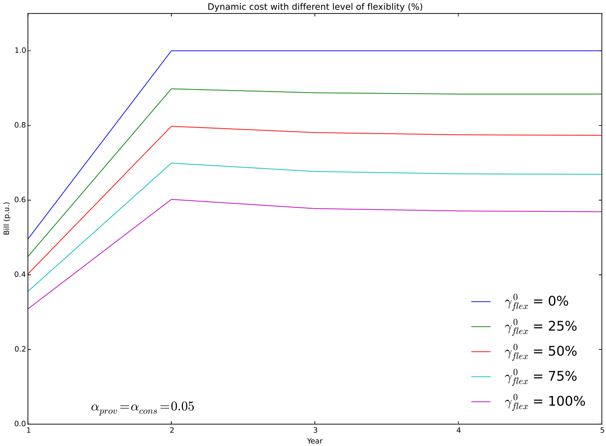
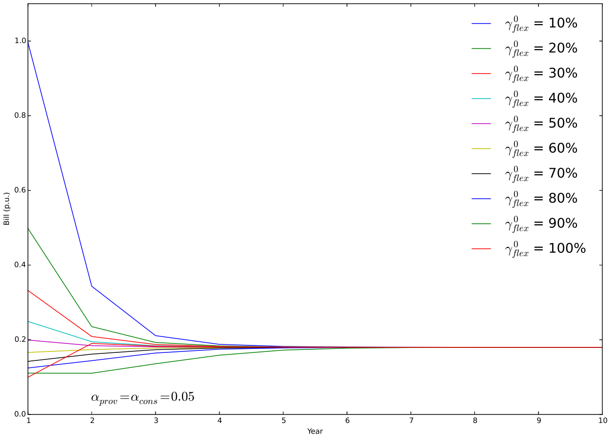
Consumers interest for flexibility

Flexible x%: consumer with x% of flexibility (SAME TOTAL ENERGY NEED)

ex Flexible 0% = nonflexible / Flexible 100% = flexible



Sensibility to initial consumer pool



$\Rightarrow$ no effect of initial pool on the obtained (final) equilibrium

Outline

Conclusion and perspectives

- **generic bilevel model** to analyze providers - consumers competition
- **intuitive preliminary simulation results** on a simple setting
  $\rightarrow$ to be enriched with sourcing part (end of good times for providers...)
- **theoretical study of a simplified Stackelberg model** with
  - only $F = 2$ providers
  - only nonflexible and flexible consumers
  - endogenous polynomial prices (link with existing results in routing games [7, 1]).

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