The customer as an active market player Demand-response & distributed systems

Mathematics and Economics of Energy Markets
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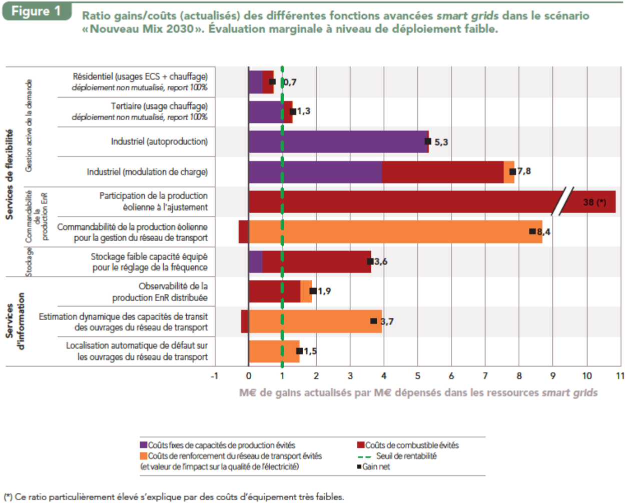
Costs of flexibility solutions



source: RTE (July, 2015). http://www.rte-france.com/sites/default/files/rei_bd_1.pdf

Conclusions

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- Most costly solution is demand-side management at the household level (water-boilers).

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Principal-Agent Model

for demand-response

Based on A., Possamaï & Touzi joint work in progress.

- Interaction between one producer (the Principal) and one consumer (the Agent).
- We consider the deviation X_t of consumer's from her baseline consumption.
- Increase (resp. decreasing) consumption with deviation X_t provide a utility (resp. disutility) to the consumer $f(X_t)$.
- Consumer can reduce her level and variation of consumption at cost $c(a, b)$ where a is the effort on the level and b the effort on the variation.
- Consumer's is happy to participate if at least she is not loosing money with the DR program (zero reservation utility).

- Efforts and costs are differentiated per usage (tv, oven, heating, cooling, refrigerator, lights...)
- Producer provides power to consumer's at energy cost (or avoided cost) $g(X_t)$ and variation cost proportional to $\langle X \rangle$.
- The objective of the producer is to minimize his total cost of generation (energy and variation) plus the payment ξ to the consumer.
- The objective of the consumer is to maximise the utility of consumption minus effort cost plus payment from the producer.
- Producer observes the deviation but not the efforts of the consumer.

Consumer's model (Agent)

Dynamic of the deviation from baseline consumption

$$dX_t^{a,b} = (-\sum_{i=1}^{N} a_i(t))dt + \sum_{i=1}^{N} \sigma_i \sqrt{b_i(t)} dW_t^i$$

Cost function for efforts $\nu := (a, b)$:

$$c(a,b) := \frac{1}{2}\left(\sum_{i=1}^{N} \frac{a_i{}^2}{\mu_i} + \frac{\sigma_i^2(b_i{}^{-\eta_i} - 1)}{\lambda_i \eta_i}\right), \ (a,b) \in [0,+\infty)^N \times (0,1]^N,$$

Consumer's objective:

$$J_A(\xi,\nu) := \mathbb{E}^{\mathbb{P}^\nu}\left[\xi + \int_0^T (f(X_s) - c(\nu_s))\, ds\right].$$

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$$\sup_{\xi} \sup_{\nu \in \mathcal{P}^\star(\xi)} \mathbb{E}^{\mathbb{P}^\nu} \mathbb{U}\left[-\xi(X^{\nu^\star}_\cdot) - \int_0^T g(X^{\nu^\star}_t)dt - \frac{h}{2}\langle X^{\nu^\star}_\cdot \rangle_T \right]$$

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- Energy variation cost.

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- Define the Hamiltonian of the agent:

$$H(z,\gamma) := \sup_{(a,b)\in[0,+\infty)^N\times(0,1]^N} \left\{ -a\cdot\mathbf{1}z + \frac{1}{2}\left|\mathrm{diag}(\sigma)\sqrt{b}\right|^2\gamma - c(a,b) \right\},$$

where $\mathbf{1}$ stands for a vector of size N with components equal to 1.

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- Her optimal response is:

$$\widehat{a}(z) := \mu z^-,\ \widehat{b}_j(\gamma) := 1 \wedge (\gamma^- \lambda_j)^{-\frac{1}{1+\eta_j}}.$$

$(z^- := \max\{-z, 0\})$

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- Cvitanic, Possamaï & Touzi (2015) prove that the optimal contract is of the form:

$$Y_t^{Y_0,Z,\Gamma} := Y_0 + \int_0^t Z_s dX_s + \frac{1}{2}\int_0^t \Gamma_s d\langle X\rangle_s - \int_0^t \left(H(Z_s,\Gamma_s) + f(X_s)\right) ds.$$

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- Minus the natural benefits the consumer earns from the consumption and the natural action she will take with payment (Z_t, Γ_t).

Optimal contracting for the Principal

The problem of the Principal now becomes

$$U^P = \sup_{Y_0 \geq R} \sup_{Z,\Gamma} \mathbb{E}^{\mathbb{P}^\nu}\left[\mathbb{U}\left(- Y_T^{Y_0,Z,\Gamma} - \int_0^T g(X_s)ds - \frac{h}{2}\langle X \rangle_T \right)\right].$$

$$\begin{cases} X_t = x_0 - \int_0^t \widehat{a}(Z_s)\cdot \mathbf{1} ds + \int_0^t \widehat{\sigma}(\Gamma_s)\cdot dW_s, \\ Y_t^{Y_0,Z,\Gamma} = Y_0 + \frac{1}{2}\int_0^t \left(\mu \cdot \mathbf{1}(Z_s^-)^2 + \widehat{\Sigma}(\Gamma_s) - 2f(X_s)\right) ds + \int_0^t Z_s \widehat{\sigma}(\Gamma_s)\cdot dW_s. \end{cases}$$

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... which is a standard stochastic control problem with state variables X and Y and controls Z and Γ.

Remarks

- The case of a pool of agent leads of single Principal-multi-Agent problem
- Solution provided in Elie, Mastrolia & Possamaï (arxiv, 2016)

Rational consumer

To decide if I switch off TV,
I just have to solve a PDE.

Incentives is sometimes

just saying

Please

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- In 2014, 52,000 people are enroled (source: RTE)

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- Modifies the bargaining relation between electric utilities and consumers

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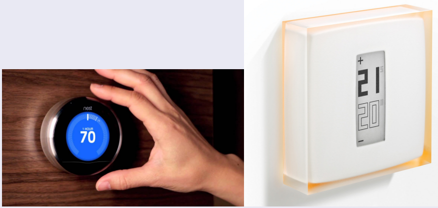

Figure: Nest and Netatmo connected thermostat