ARE ENERGY MARKETS EFFICIENTS?
THE CASE OF REAL AND VIRTUAL STORAGE

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joint work with
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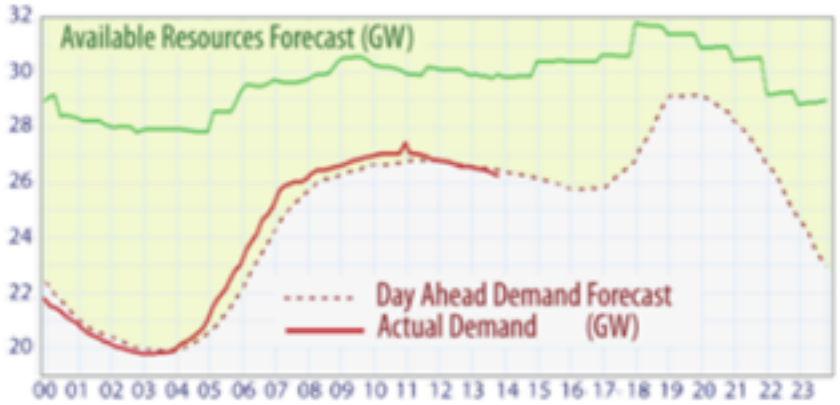
Wind and solar energy make the grid less predictable



Mean error: 1–2%

Mean error: 20%

Storage can mitigate volatility

- Batteries, Pump-hydro

Limberg III, switzerland

- Demand Response = Virtual Storage

Voltalis Bluepod switches off thermal load for 60 mn

Questions addressed in this talk

1. Does markets leads to a socially optimal use of storage?
2. Is there a difference between demand response and storage?

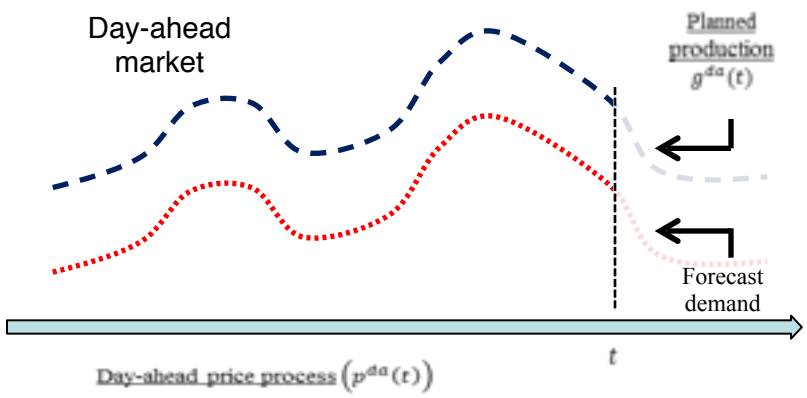
1.

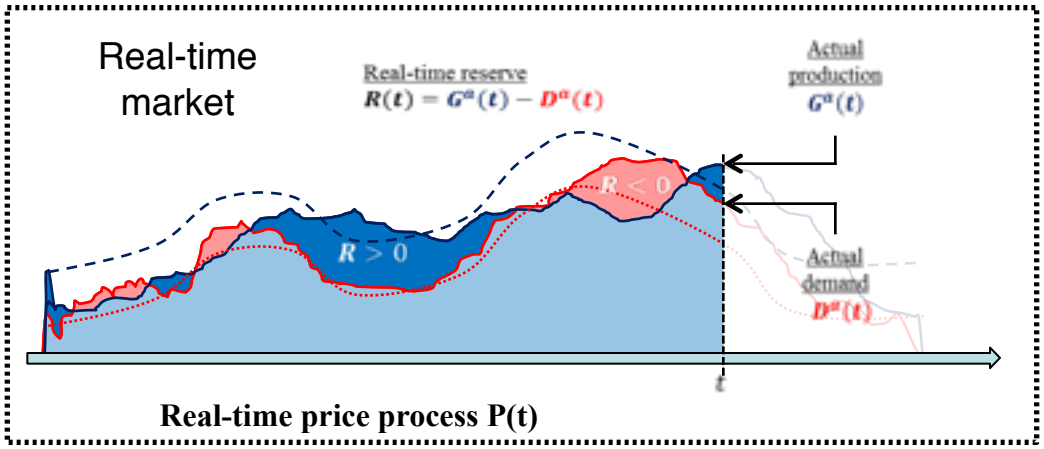
IMPACT OF STORAGE ON MARKETS

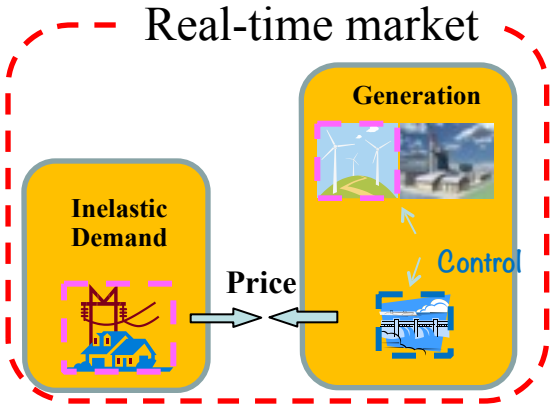
[Gast et al 2013] N. G. Gast, J.-Y. Le Boudec, A. Proutière and D.-C. Tomozei. Impact of Storage on the Efficiency and Prices in Real-Time Electricity Markets. e-Energy '13, Fourth international conference on Future energy systems, UC Berkeley, 2013.

We focus on the real-time market

- Most electricity markets are organized in two stages





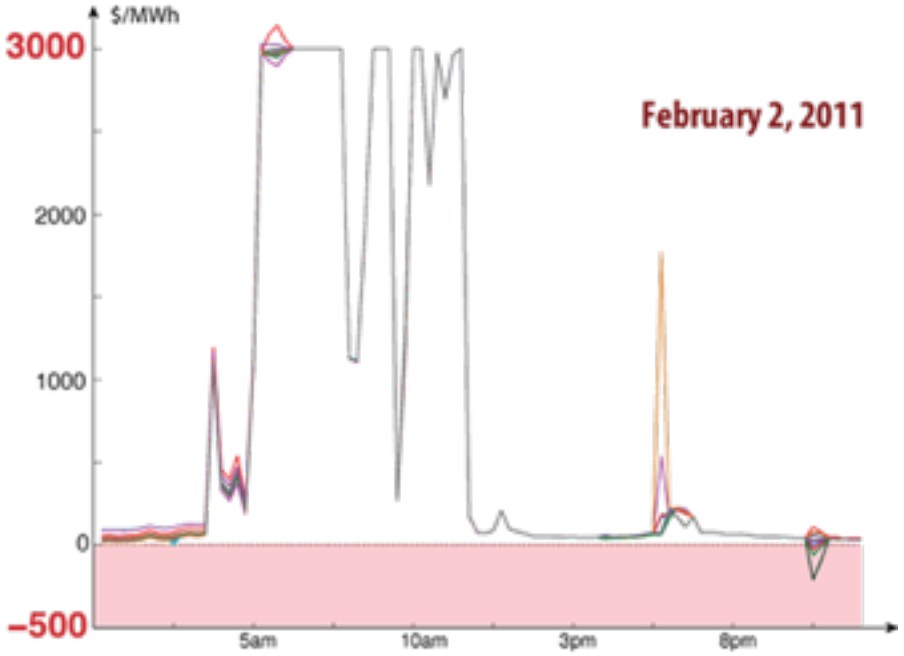


Compensate for deviations from forecast

Inelastic demand satisfied using:

- Thermal generation (ramping constraints)
- Storage (capacity constraints)

Real-time Market exhibit highly volatile prices



- Efficiency or Market manipulation?

The first welfare theorem

- Impact of volatility on prices in real time market is studied by Meyn and co-authors: price volatility is expected

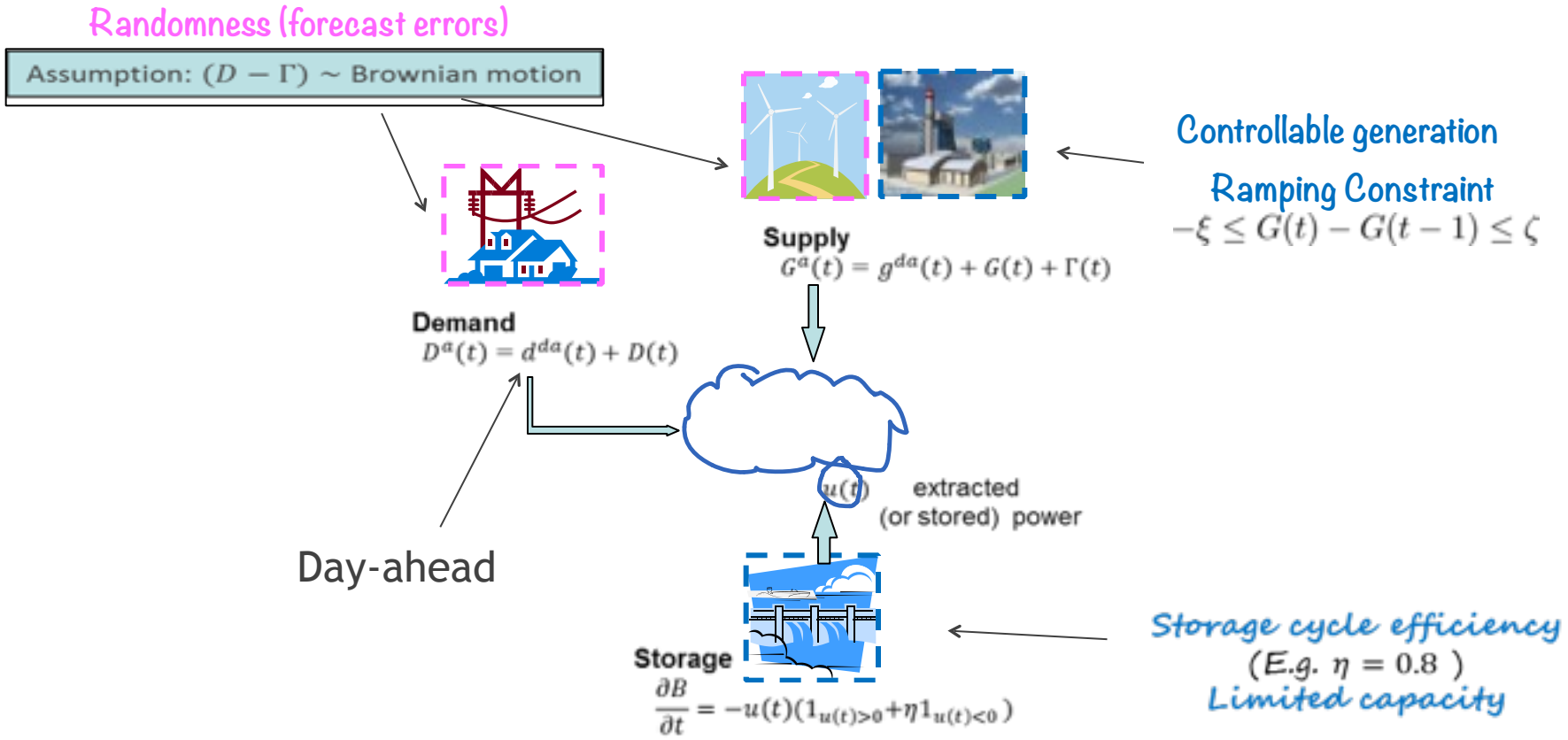
> Theorem (Cho and Meyn 2010). When generation constraints (ramping capabilities) are taken into account:
>
> - Markets are efficient
> - Prices are never equal to marginal production costs.

What happens when we add storage to the picture ?

- Does the market work, i.e. does the invisible hand of the market control storage in the socially optimal way ?

[Cho and Meyn, 2010] I. Cho and S. Meyn *Efficiency and marginal cost pricing in dynamic competitive markets with friction,* Theoretical Economics, 2010

A Macroscopic Model of Real-time generation and Storage



Macroscopic model

- At each time: generation = consumption

$$G^a(t) + u(t) = D^a(t)$$

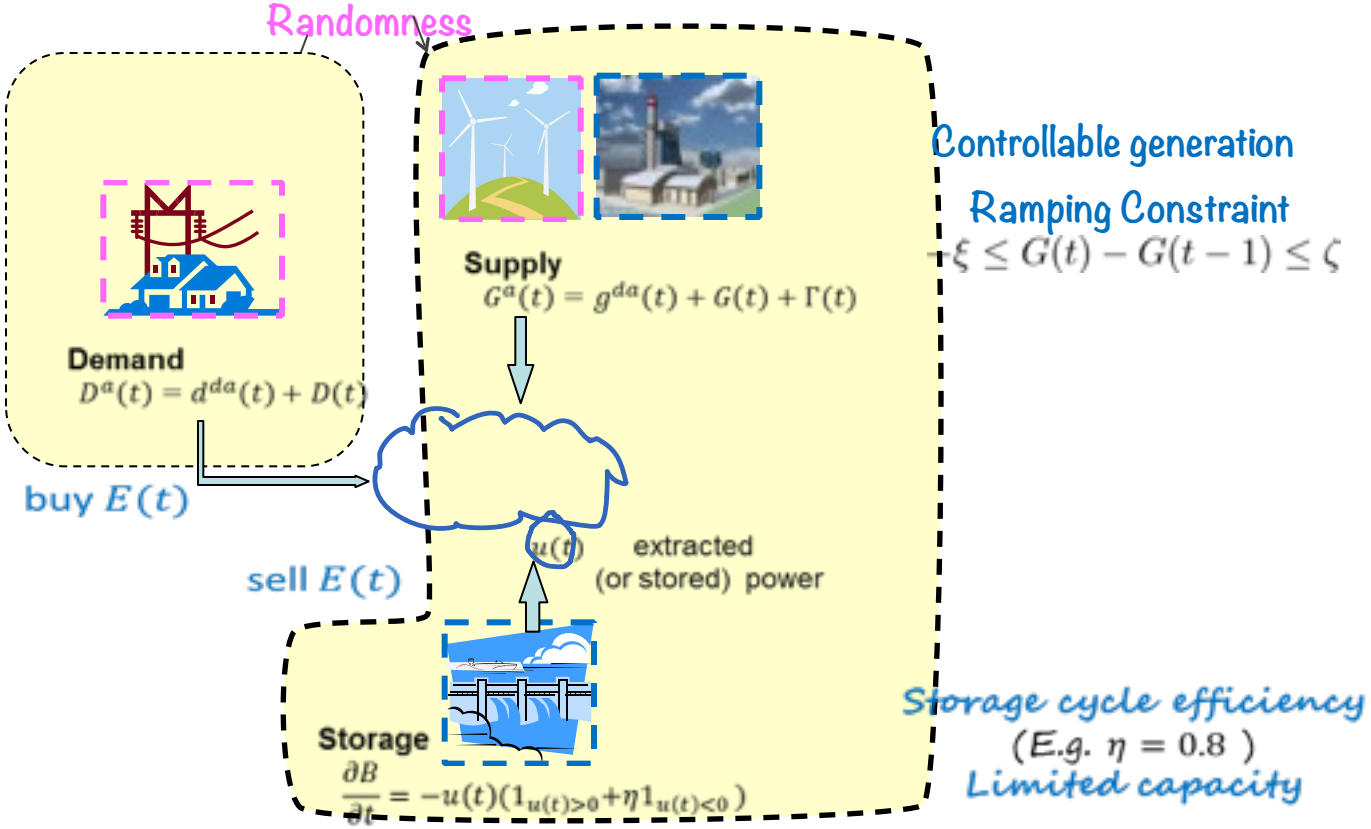
A Macroscopic Model of Real-time generation and Storage

We consider 3 scenarios for storage ownership:

1. Storage ∈ Supplier (this slide)
2. Storage ∈ Consumer
3. Independent storage

(ownership does mostly not affect the results)

$P(t)$ = stochastic price process on real time market



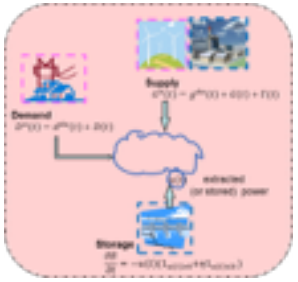
- Consumer's payoff: $W_D(t)$

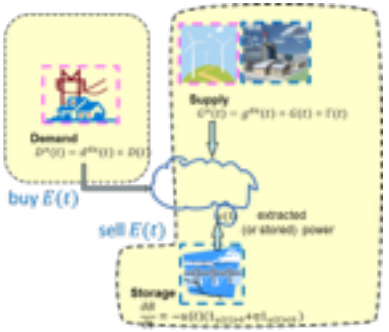
$$= \underbrace{v \min(D^a(t), E(t) + g^{da}(t))}_{\text{satisfied demand}} - \underbrace{c^{bo}\left(D^a(t) - G^{da}(t) - u(t)\right)^+}_{\text{Frustrated demand}} - \underbrace{P(t)E(t) - p^{da}(t)g^{da}(t)}_{\text{Price paid}}$$

- Supplier's payoff: $W_S(t)$

$$= P(t)E(t) + p^{da}(t)g^{da}(t) - cG(t) - c^{da}g^{da}(t)$$

Theorem: the market is efficient





- Social planner's problem:

Maximizes the sum of the utility

- Competitive equilibrium:

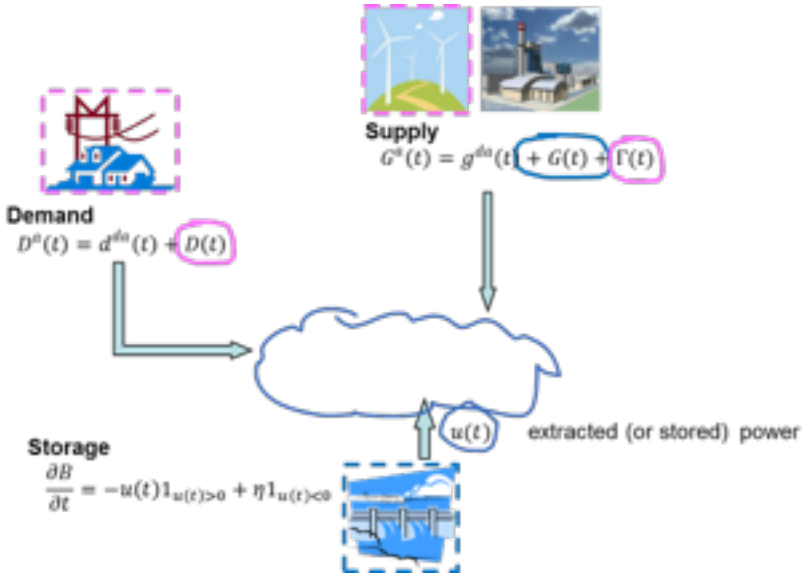
Users are selfish

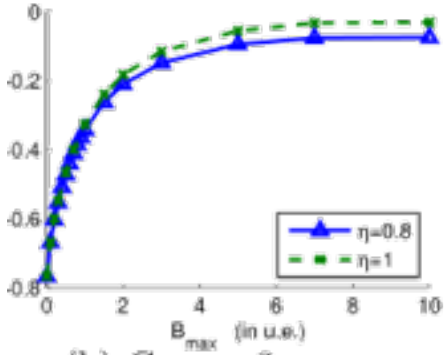
Users are price-takers

Theorem [G et al. 2013].
- Dynamic competitive equilibria exist and are essentially independent of who is storage owner
- Any dynamic competitive equilibrium for any of the three scenarios maximizes social welfare

The Invisible Hand of the Market may not be optimal

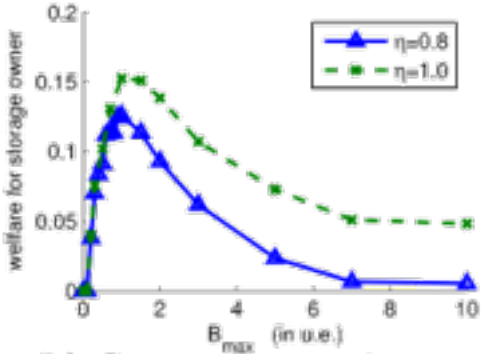
- Any dynamic competitive equilibrium for any of the three scenarios maximizes social welfare
- However, this assumes a given storage capacity.
- Is there an incentive to install storage ?
  - No, stand alone operators or consumers have no incentive to install the optimal storage





(b) $C_{\max} = 3$ u.p.

Expected social welfare



(b) $C_{\max} = D_{\max} = 3$ u.p.

Expected welfare of stand alone operator

Can lead to market manipulation (undersize storage and generators)

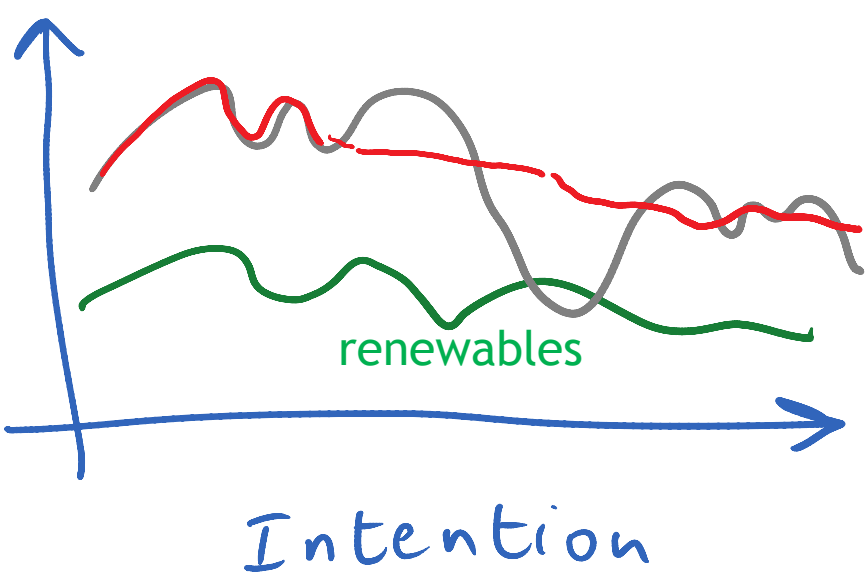
2.

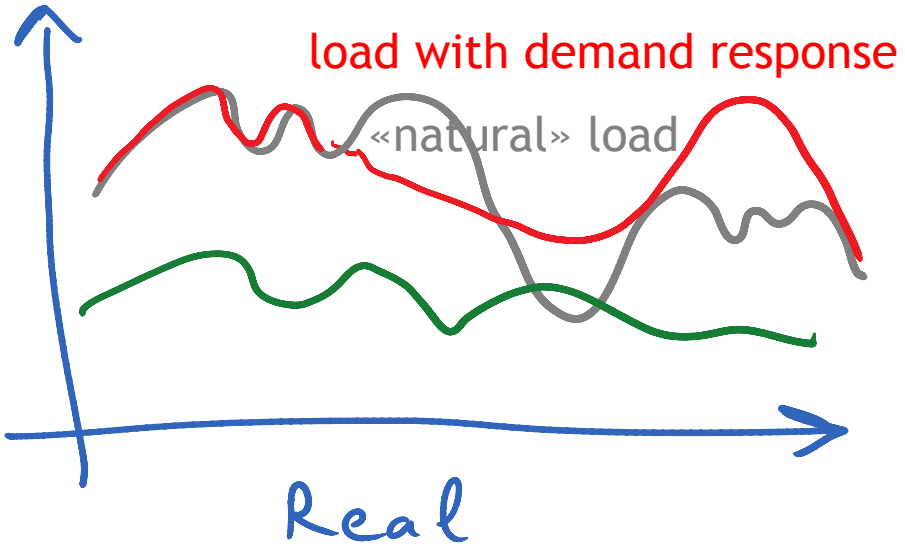
DEMAND-RESPONSE AND PRICES

[Gast et al 2014] N. Gast, J.-Y. Le Boudec and D.-C. Tomozei. Impact of demand-response on the efficiency and prices in real-time electricity markets. e-Energy '14, Cambridge, United Kingdom, 2014.

Issue with Demand Response: Non Observability

- Widespread demand response may make load hard to predict





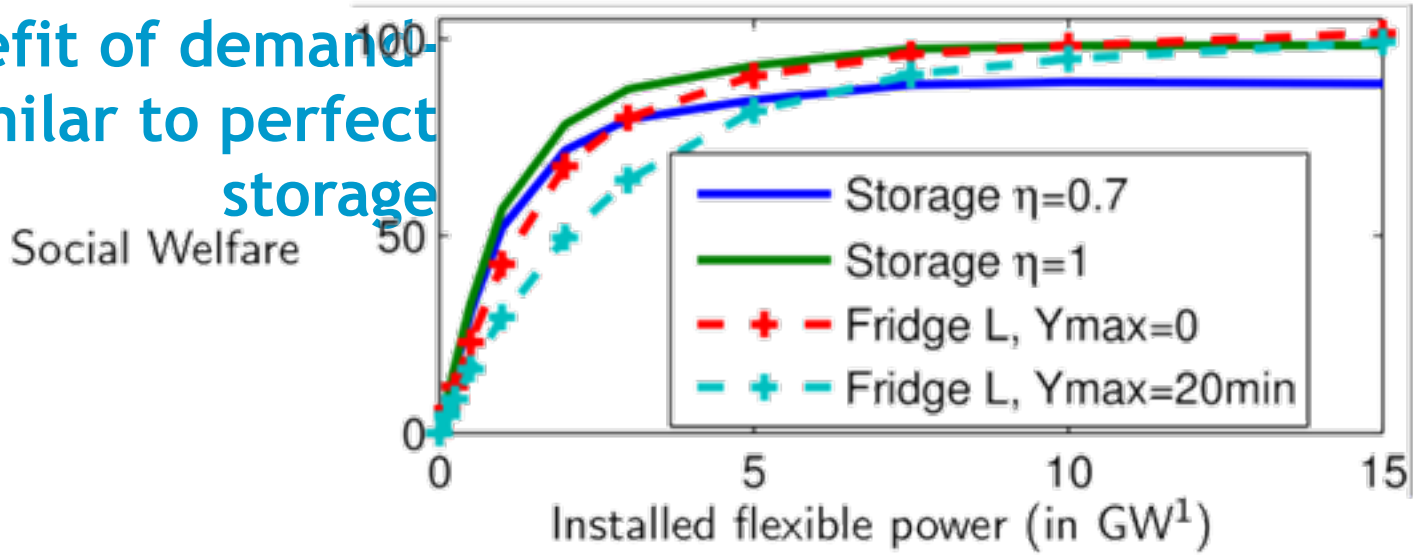
Our Problem Statement

Does it really work as virtual storage ?

Side effect with load prediction ?

To this end we add demand response to the previous model

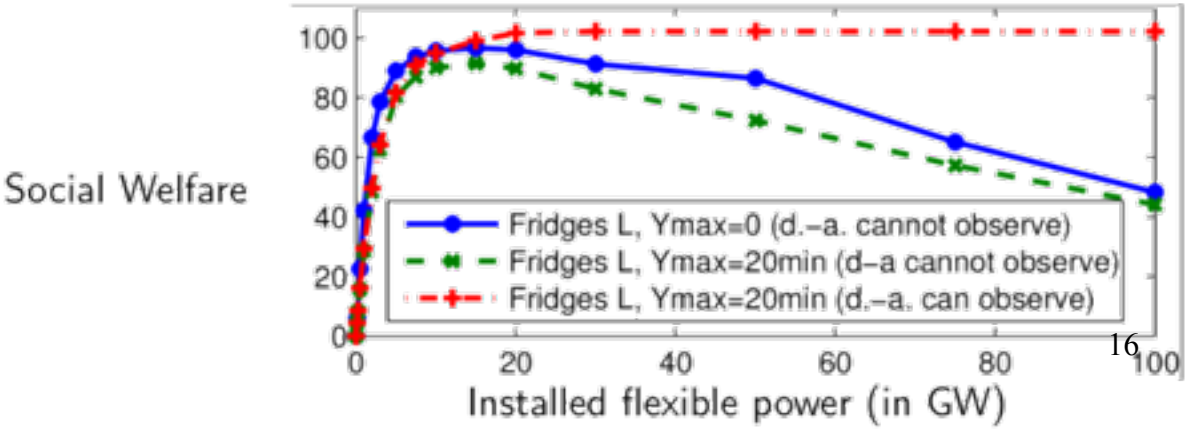
The Benefit of demand-response is similar to perfect storage



Non-Observability Significantly Reduces Benefit of Demand-Response

We assume that:

- The demand-response operator knows the state of its fridges
- The day-ahead forecast does not.



What this suggests :

- With a free and honest market, storage and demand response can be operated by prices
- However there may not be enough incentive for storage operators to install the optimal storage size / demand response infrastructure

- Demand Response is similar to an ideal storage that would have close to perfect efficiency
- However it is essential to be able to estimate the state of loads subject to demand response (observability)

- Market can be used for decentralized optimization (Lagrangian decomposition / ADMM)

Thank You !

- slides available:
  http://mescal.imag.fr/membres/nicolas.gast/research/