How to design reserves markets?

The case of the demand function in capacity markets

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Why do we need reserve markets ?

For some "*essential*" goods, we need to have sufficient investment to produce them when needed (peak demand). Example 1

Relying on private incentives (eg. wholesale prices) is sometimes not always efficient to provide sufficient investment: fixed costs, uncertainty, technical constraints, political intervention, unpriced externalities.

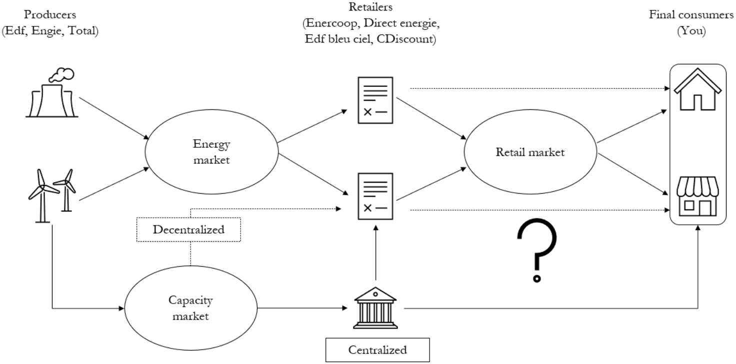
Reserve markets can be a solution: a producer sells the 'availability' of its investment in return for additional remuneration.

In this paper, we focus on capacity markets where electricity producers offer their power plant availability. But we can apply it to facemask/gel production facilities, laboratories.

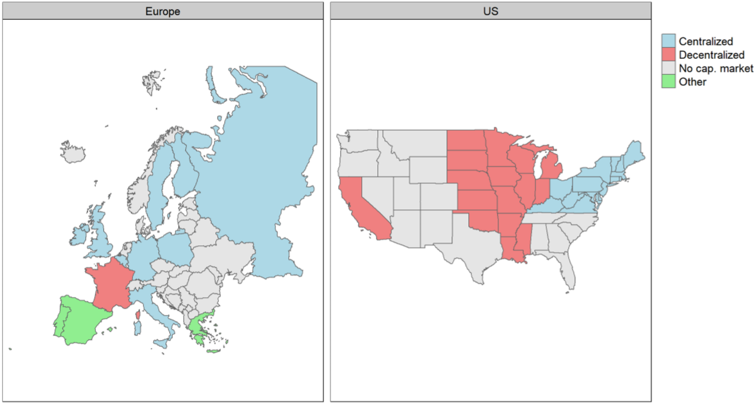
But how to design a capacity market ?

- We have an issue : even if a capacity market is implemented, **it does not ensure that trades take place**.
- Producers sell a promise to be available. The supply function is straightforward.
- **Consumers do not willingly buy electricity and capacity**. Investments (availability) during peak periods are a public good with positive externalities.
- **Who should be buying those capacities and how ?**

A tale of two design



A diversity of market design



What do we do ?

- *Direct effect* : different demand functions = different capacity prices ([Brown, 2018a] [Fabra, 2018] [Hobbs et al., 2007b]).

- **Indirect effect** : Incentives on the demand side + the participation of retailers and elastic consumers.

- **Global effect** : What are the effects of a specific market design on equilibria when there are strong interdependencies between markets (wholesale / retail / capacity).

Boils down to a practical comparison:

- **Centralized design**: How the cost is allocated to final consumers ?

- **Decentralized design**: How retailers value a marginal capacity ?

What we find

We build a complete and tractable model to assess various market design options' side effects on the economic system.

A simple centralized market is optimal if you simply want to have enough investment.

More complex market design can bring some benefits depending on the cause of under investment, on the initial assumptions (market structure, demand, costs ...) and on regulatory parameters (penalty).

Endogeneity of the first-best solution given a set of inefficiencies.

- When the optimal equilibrium depends on the path to reach it.
- Sometimes it is better to approximate the first-best than to reach it.

Contributions

Investment decisions in electricity : [Boiteux, 1949] [Crew and Kleindorfer, 1976] [Borenstein and Holland, 2003] [Zöttl, 2011] [Léautier, 2016] [Holmberg and Ritz, 2020]

Capacity markets : [Joskow and Tirole, 2007] [Newbery, 2016] [Fabra et al., 2020] [Brown, 2018a] [Brown, 2018b] [Allcott, 2012] [Scouflaire, 2019]

Allocation externalities : [Creti and Fabra, 2007] [Creti et al., 2013] [Teirilä and Ritz, 2018] [Brown, 2012] [Petitet, 2016]

Sequential markets and endogenous marginal cost: [Salant and Shaffer, 1999] [Andersen and Jensen, 2005]

Other applications (permits markets, R&D) : [Van Long and Soubeyran, 2000] [Meister and Main, 2002] [Newbery, 1990]

Any market with an essential good, with significant demand variability, uncertainty, limited storage possibilities, huge fixed costs, and capacity constraints. Transport and telecoms [Léautier, 2016] COVID-19 and medical supplies [Fabra et al., 2020] [Cramton, 2020]

Roadmap

Formal model

Producers : *perfect competition + Single technology to produce an homogeneous good*

- c : marginal cost
- r : fixed cost
- k : capacity

Retailers : *sell at no cost to final consumers + play à la Cournot on the retail market*

- n^r : # of retailers
- $p^s(q,t)$: inverse demand function (energy price)

Consumers : *homogeneous uncertain individual demand + price elastic*

- $P(q,t)$: inverse demand function (retail price)
- $D(P,t)$: Demand function such as $D(P(q,t),t) = q$
- t : state of the world such as $t \in [0,\infty]$,$f(t)$, $F(t)$, $P_t(q,t) > 0$

First-best solution

- The optimal level of investment is given by maximizing social welfare $W(k)$

$$\underbrace{\boxed{\int_0^{t_0(k)} \int_0^{q_0(t)} (p(q,t)-c)dq\ f(t)dt}}_{\text{Offpeak welfare}} + \underbrace{\boxed{\int_{t_0(k)}^{+\infty} \int_0^{k} (p(q,t)-c)dq\ f(t)dt}}_{\text{Onpeak welfare}} - \quad rk$$

- With $t_0(k)$ the first state of the world when the capacity is binding.

Similar to have the equality between the net wholesale expected revenue and the fixed cost Illustration

$$\phi(k) = \int_{t_0(k)}^{+\infty} (p(k,t)-c)\ f(t)dt = r$$

Market equilibrium

- Electricity markets are plagued by a set of inefficiencies

Price caps (Explicit and implicit)

$$\phi^w(k) = \int_{t_0(k)}^{t_0^w(k)} (p(k,t) - c)\, f(t)dt + \int_{t_0^w(k)}^{+\infty} (p^w - c)\, f(t)dt$$

With $t_0^w(k)$ the first state of the world when the price cap is binding.

Inefficient rationing (rolling blackout) Illustration

$$W^{bo}(k) = W(k) - \int_{t_0^w(k)}^{+\infty} J(\Delta_0 k) f(t)dt$$

With $\Delta_0 k$ the difference between installed capacity and the quantity consumed at the price cap. $J(.)$ is the function mapping the delta with the rationing loss. Illustration

How can we implement the demand function in a reserve market ?

Centralized demand :

A single regulated entity builds the demand function in the capacity market and allocates the capacity cost to the retailers based on :

- Their past market share - Ex-Ante design
  - Exogenous : lump sum tax (**design 1**)
  - Endogenous : unitary tax (**design 2**)
- Their realized market share - Ex-Post design (**design 3**)

Decentralized demand :

Retailers must buy the capacities directly in the capacity market to cover their sales. To enforce the obligation: Penalty system (**design 4**).

Roadmap

The canonical capacity market (design 1)

Proposition

Assuming that :

- *Producers offers at their marginal opportunity cost , and*
- *Price caps bind and/or an inefficient rationing exists, and*
- *The regulated entity built a vertical demand at the optimal level*

Then the capacity price is equal to the optimal payment to restore the first-best solution

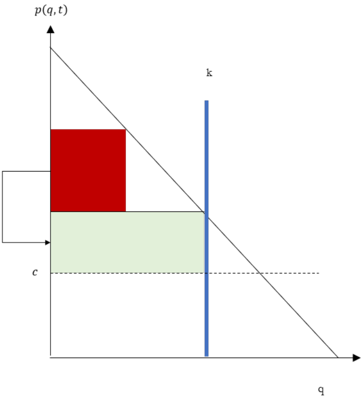
Remarks:

- No indirect effect: The mechanism is just a surplus transfer from consumers to producers
- A centralized mechanism is optimal given the set of inefficiency
- Recall the debate price vs quantity instrument [Weitzman, 1974]

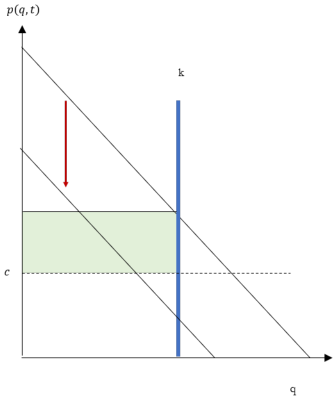
Equations Illustration

Exogenous vs Endogenous allocation

Exogenous capacity price



Endogenous capacity price



The endogenous capacity market without rationing (design 2)

Proposition

Assuming that a price cap binds (but no inefficient rationing) then allocating the capacity cost on a unitary basis :

- *Always lower the first best investment level.*
- *Always lower the social welfare at the the first best investment level.*

Remarks:

- With only a Missing Money then it is better to allocate the capacity cost without distorting the demand.
- The proof relies on changing the final consumer demand similarly to a tax : $p(q,t) - p^c(k)$ (+small algorithm to find the equilibrium).
- **The intuition** : it rearranges the occurrence between offpeak/onpeak, and reduces the consumer surplus during offpeak. Equations

The endogenous capacity market with rationing(design 2)

Proposition

Assuming that a price cap binds and generates inefficient rationing then allocating the capacity cost on a unitary basis :

- *Always lower the first best investment level.*
- *Can generate* ***a higher social welfare*** *at the the first best investment level if the rationing cost is sufficiently high.*

The tradoff between a lower surplus vs lower rationing cost Equations :

- **(-)** Lower the quantity sold during offpeak periods
- **(-)** Lower the expected revenue because more offpeak periods
- **(+)** Lower the occurrence of inefficient rationing because the price cap binds less often
- **(+)** Lower the consumer surplus during rationing hence the cost

The ex-post centralized demand (design 3)

Proposition

When the capacity price is allocated onto the retailers based on their realized market share then the outcome is between the endogenous and exogenous centralized ex-ante design.

Remarks: Equations

- The allocation is similar to an increase of the retailer marginal cost.
- The degree of competition determines the magnitude of the cost pass-through
- An increase of n^r tends to increase the cost pass-through
- **Beware of the indirect effects of n^r with respect to first-best solution**
- **Redistribution properties**

Roadmap

The no uncertainty case

Retailers need to choose the level of capacity knowing the future level of demand and given a penalty S

$$\pi_i^r(q_i,k_i) = q_i(p(q)-p^s) - p^c(k)k_i - \begin{cases} 0 \quad \text{if} \quad \forall i \quad q_i \leq k_i \\ \\ S(q_i-k_i) \quad \text{if} \quad q_i > k_i \end{cases}$$

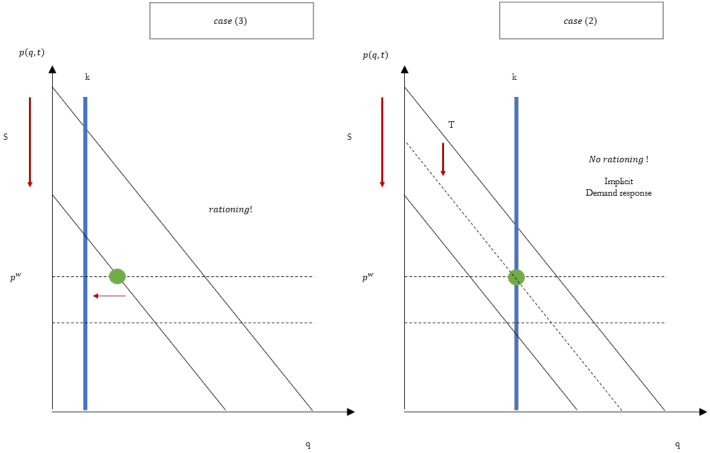
The set of dominant strategies in the retail market given a capacity price is:

$$\begin{cases} [q^p,q^r] \qquad \text{if} \qquad p^c(k) \leq S \\ \\ \{0,]q^p,q^r]\} \qquad \text{if} \qquad p^c(k) > S \end{cases}$$

With a serie of Cournot equil. : q^r is given by a marg. cost of $p^s(q)$, q^p is given by a marg. cost of p^s+S and $\forall q \in]q^p,q^r[$ is given by marg. cost $p^s+p^c(k)$

The central idea is that retailers strategy always follow the level of capacity bought on the capacity market

Retailer strategy, the canonical model and the social welfare



Demand function on the capacity market

Given the indirect effect of the penalty system, we can compute the expected profit function for the retailers Equations :

- Case (1) Business as usual
- Case (2) Demand lowered by the implicit demand response
- Case (3) Demand lowered by the penalty + expected penalty

Then we find the marginal value of an additional capacity Equations :

- Market structure
- Penalty value + price cap
- Penalty cost pass-through

The overall market equilibrium of the model can then be found and compared to the centralized case.

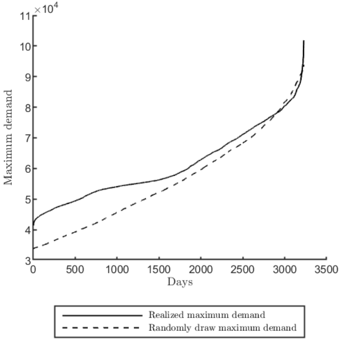
The data

Linear demand function for final consumers + uncertainty from the intercept of the demand function. $p(q,t) = a(t) - bq$. Where $a(t)$ is the uncertain intercept such as : $a(t) = a_0 + a_1 e^{-t}$. We assume that t follows an exponential distribution : $f(t) = -e^{-t}$.

Inefficient rationing : the ratio is determined such as $q_0^w(k)(1 - h(t)) = k$

Others exogenous variables are summarised in table and also follow the French data [IAE, 2015] [Léautier, 2014]

Coefficient intercept 1 ($)		18 827
Coefficient intercept 2 ($)		12 360
Maximal demand (GW)		102
Marginal cost ($ /MWh)	c	79.55
Fixed cost ($ /MWh)	r	17.62
Demand slope	b	0.18



Conclusions - extensions

Final consumer heterogeneity ([Léautier, 2014] [Zöttl, 2011])

- Flat rate vs Price reactive consumers
- Voll & Rationing

Cause of underinvestment [Meunier, 2013] [Léautier, 2016] [Holmberg and Ritz, 2020]

- Price cap
- Public good
- Risk and risk aversion
- Multiple technologies

Information [Hobbs et al., 2007a] [RTE, 2014]

- Heterogeneity in the quality and quantity of information
- Small / Large retailers & Regulated entity / Private retailer
- Private / Common Value & Signaling game

Will capacities always be there for us?

California May Knock Out Power to 5 Million People Tonight

National Grid issues second warning on stretched electricity supplies

Low renewables output, scarce generators and high demand combine to challenge capacity

E.ON runs down power stations despite blackout warning

German firm plans to close one station and reduce output at three others, leaving UK with precious little spare capacity

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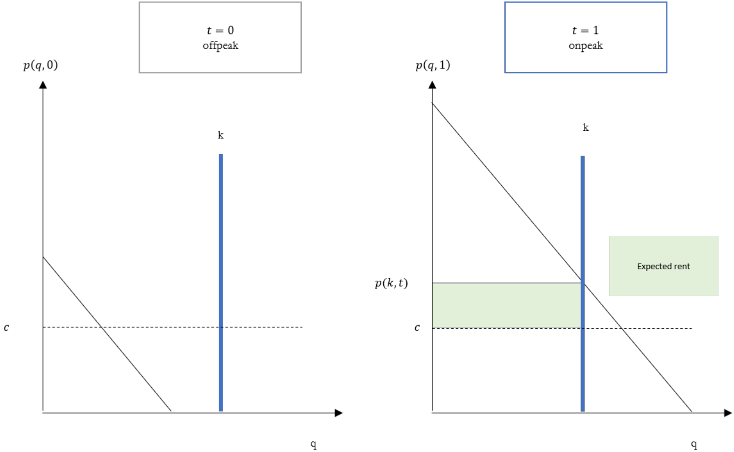
Inframarginal rent without inefficiency



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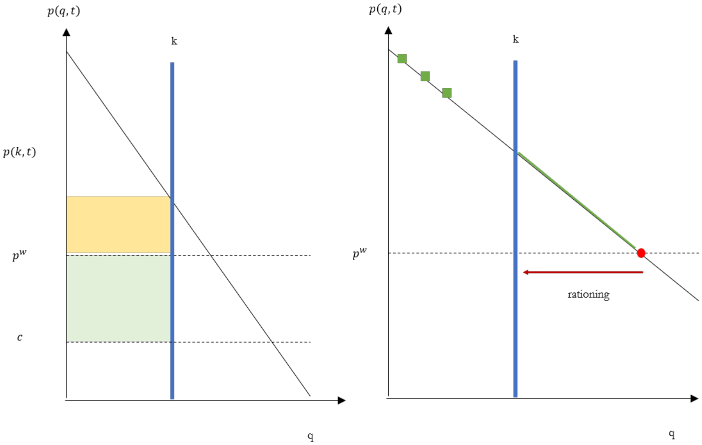
Price cap and inefficient rationing



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Example of rationing cost specification

Example of a rationing cost function based on a ratio $h(t)$

$$W^{bo} = W(k) - \int_{t_0^w(k)}^{+\infty} (1 - h(t)) \int_0^k (p(q,t) - p^w) dq f(t) dt$$

The ratio is determined such as $q_0^w(k)(1 - h(t)) = k$.

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Optimal payments to producers

Retail cournot (expected mark-up)

$$\bar{z}(k) = \int_{t_0(k)}^{+\infty} \frac{-k}{n} p_q(k,t) f(t) dt \tag{1}$$

Price cap (missing money)

$$z^w(k) = \int_{t_0^w(k)}^{+\infty} (p^s(k,t) - p^w) f(t) dt \tag{2}$$

Inefficient rationing (marginal value)

$$z^{bo}(k) = -\int_{t_0^w(k)}^{+\infty} J_k(\Delta_0 k) + J_k(\Delta_0 k) \frac{\partial \Delta_0 k}{\partial k} \tag{3}$$

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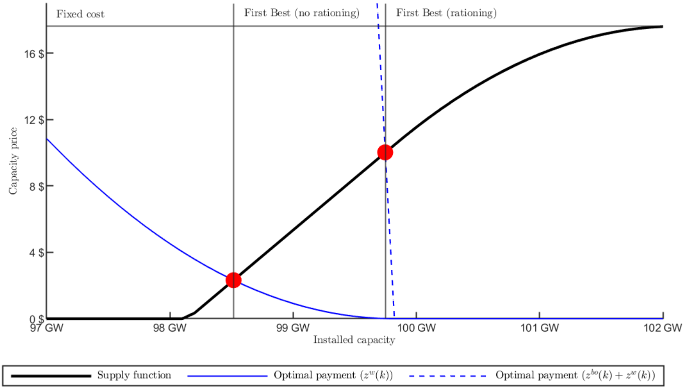
From expected rent to supply function



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Expected welfare under the endogenous regime

The endogenous capacity price only modifies the occurrence between off-peak - on-peak periods and the welfare during off-peak periods. During on-peak periods it only redistribute welfare between consumers and producers.

$$W_1(k) = \int_0^{t_1(k)} \int_0^{q_1(t)} (p(q,t) - c) dq \; f(t) dt + \int_{t_1(k)}^{+\infty} \int_0^{k} (p(q,t) - c) dq \; f(t) dt - rk$$

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Change in social welfare for endogenous design

$$\Delta W(k) = -\int_0^{t_0(k)} \int_{q_1(t)}^{q_0(t)} (p(q,t) - c)dq\, f(t)dt$$ Lower offpeak weflare

$$-\int_{t_0(k)}^{t_1(k)} \int_{q_1(t)}^{k} (p(q,t) - c)dq\, f(t)dt$$ More offpeak periods

$$+\int_{t_0^w(k)}^{t_1^w(k)} J(\Delta_0 k)$$ Less rationing periods

$$+\int_{t_1^w(k)}^{+\infty} (J(\Delta_0 k) - J(\Delta_1 k)) f(t)dt$$ Lower consumer surplus

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Equilibrium under the ex-post design

The profit function under an ex-post capacity market :

$$\pi_i^r(q_i, k) = q_i(p(q) - p^s) - p^c(k)k\frac{q_i}{q_i + q_{-i}}$$

The final equilibrium is given by solving the following equation which is the equality between the capacity price and the endogenous supply function on the capacity market :

$$p^c(k) = r - \left(\int_{t_n(k)}^{t_n^w(k)} (p(k,t) - c - p^c(k)\frac{n-1}{n})\, f(t)dt + \int_{t_n^w(k)}^{+\infty} (p^w - c)\, f(t)dt \right)$$

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Decentralized demand equations

The new social welfare function :

$$W_1(k) = W^{bo}(k) \quad - \int_{t_d^w(k)}^{+\infty} S(q_d^w(t)+k) + \int_{t_0^w(k)}^{t_d^w(k)} J(\Delta_0 k) + \int_{t_d^w(k)}^{+\infty} J(\Delta_0 k) - J(\Delta_d k) f(t) dt$$

Retail profit function :

$$\begin{aligned} \pi^r(k,t) = \quad & \int_0^{t_0(k)} -\frac{q_0(t)^2}{n} p_q(q_0(t),t) f(t) dt + \int_{t_0(k)}^{t_0^w(k)} -\frac{k^2}{n} p_q(k,t) f(t) dt \\ & + \int_{t_0^w(k)}^{t_d^w(k)} k(p(k,t) - p^w - T(k,t)) f(t) dt \\ & + \int_{t_d^w(k)}^{+\infty} k(p(k,t) - p^w - S) f(t) dt - \int_{t_d^w(k)}^{+\infty} S(q_0^w - S) f(t) dt \\ & - p^c(k) k_i \end{aligned}$$

Decentralized demand equations

Retailers' capacity market demand function :

$$
\begin{aligned}
D^c(k) = \quad & -\int_{t_0}^{t_0^w(k)} \left(\frac{2}{n} k p_q(k,t) + \frac{k^2}{n} p_{qq}(k,t)\right) f(t)dt \quad + \\
& -\int_{t_0^w(k)}^{t_d^w(k)} \left(\frac{2}{n} k p_q(k,t) + \frac{k^2}{n} p_{qq}(k,t)\right) f(t)dt \quad + \\
& \int_{t_d^w(k)}^{+\infty} \left(p(k,t) - p^w + k p_q(k,t)\right) f(t)dt
\end{aligned}
$$

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