How to design markets with allocation externalities?

The case of the demand function in capacity markets

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February 2021

Why do we need reserve markets ?

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

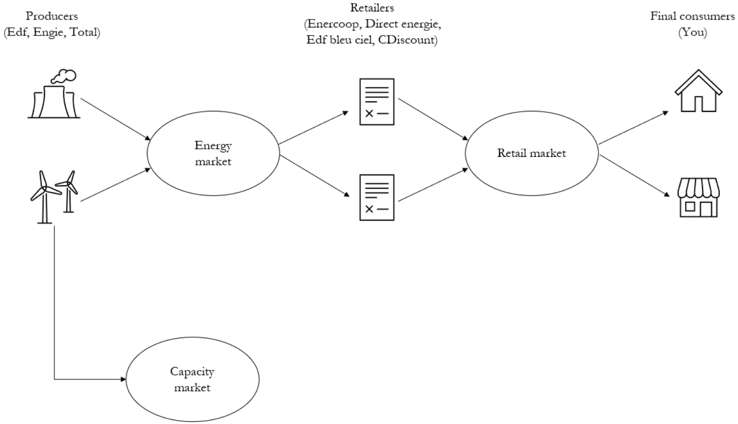
Relying on private incentives is sometimes not always efficient to provide sufficient investment: fixed costs, uncertainty, technical constraints, political intervention, unpriced externalities.

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.

How to keep the light on?

So we implement a capacity market. It is a **reserve market** where producers sell a promise to be available. The supply function is straightforward.



But how to design a reserve market ?

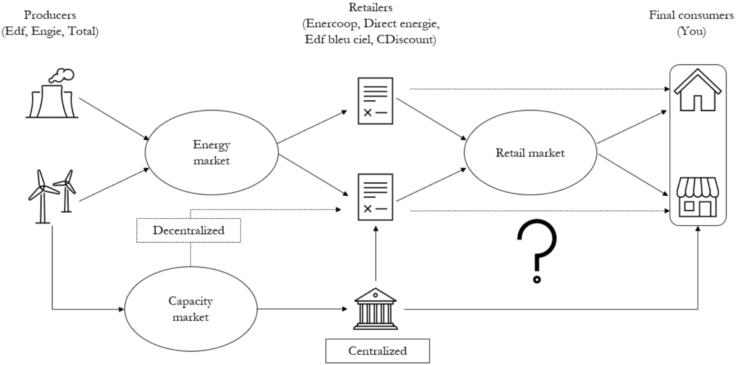
- But even if a market is implemented, **it does not ensure that trades take place** : significant public good externalities of investments.

In this paper :

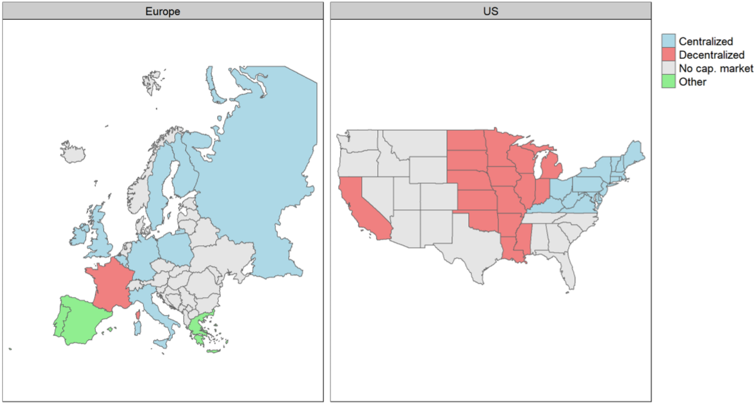
- How to create an exogenous demand function in a reserve market?
- What are the effects of a specific market design on efficiency when there are strong interdependencies between markets (upstream / downstream / reserve)?
- How does market power in the retail market affects the outcomes ?
- What is the redistribution effect of each design option?

What we do

Consumers do not willingly buy electricity and capacity. Who should be buying those capacities?



A diversity of market design



What we find

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

We find that each demand design has a distinct indirect effect :

- **How retailers are included in the market design ?**
- **How the capacity cost allocation is marginally related to retailers profit function ?**
- **How it indirectly impacts the investment decisions via the retailers demand function on the upstream market ?**

What we find

Centralized design: How does the cost of buying enough capacity impact marginal retailer cost?

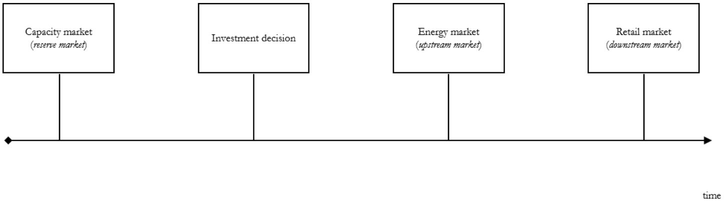
Decentralized design: how the retailers value investment, and how they control their clients' consumption?

The comparison between each market design strongly depends :

- On the regulatory parameters used to design the demand
- On the characteristics of the agents in the system (consumers, producers, retailers)

Approach

We use a Nash equilibrium model with sequential markets. We model the system as a four periods game :



We have a sequence of supply/demand functions on each market and that depend on each other

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]

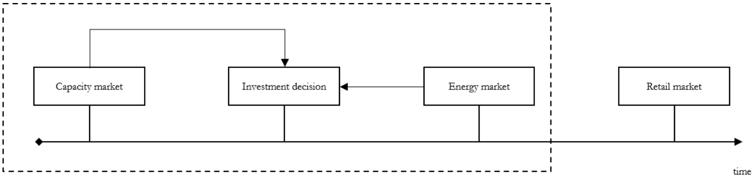
Allocation externalities : [Creti and Fabra, 2007] [Creti et al., 2013] [Teirilä and Ritz, 2018] [Brown, 2012] [Petitet, 2016]

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

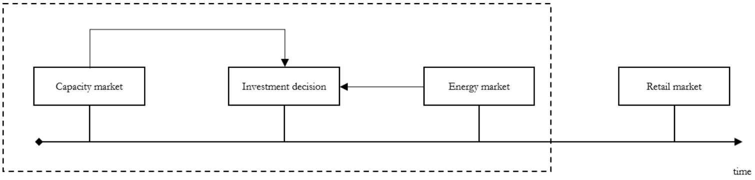
Other applications (permits markets, R&D) : [Van Long and Soubeyran, 2000] [Meister and Main, 2002] [Newbery, 1990]

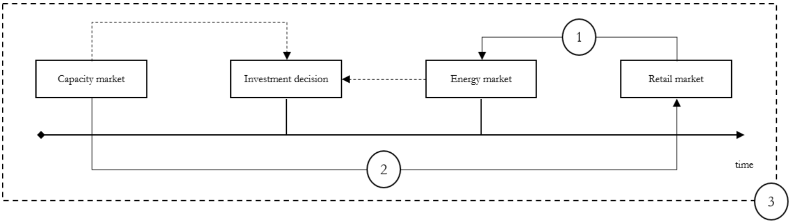
Any market with an essential good, with significant demand variability, uncertainty, limited storage possibilities, huge fixed costs, and capacity constraints. Transport and telecoms [Léautier, 2016] COVID-19 and medical supplies [Fabra et al., 2020] [Cramton, 2020]

Direct vs. Indirect effect of market design



Direct vs. Indirect effect of market design





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 $t \in [0,\infty]$,$f(t)$, $F(t)$, $P_t(q,t) > 0$

Social planner vs Market inefficiency

- How do we invest when there is demand uncertainty with no inefficiency ?

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

With $t(k,c)$ the first state of the world when the capacity is binding. Total welfare is maximized when : $\phi(k,c) = r$. Illustration

- How market power in the retail market can decrease the level of investment ?

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

Market power in the retail market implies that $p^s(q,t) < P(q,t)$. Illustration

Roadmap

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 - Centralised Demand Ex-Ante design (DCA)
- Their realized market share on the period for which we set the capacity market - Centralised Demand Ex-Post design (DCP)

Decentralized demand :

Retailers must buy the capacities directly in the capacity market to cover their sales on the retail market.
To enforce the obligation: Penalty system as in France - Decentralised Demand case design (DD).

Formally

- $P^c(\theta)$: capacity price (and transfer price)
- θ : capacity level
- θ_i : capacity level bought by retailer i

Centralized demand - DCA :

- $\hat{\beta}_i$: past market share such as $\sum_{i=1}^{n^r} \hat{\beta}_i = 1$ and $\hat{\beta}_i \in [0, 1]$

Centralized demand - DCP :

- β_i : current market share such as $\beta_i = \frac{q_i}{q_i + q_{-i}}$

Decentralized demand :

- S : penalty administrative value such that if a retailer do not buy enough capacities he pays the delta between q_i and θ_i at a price S.

Retailers' profit function

Centralized demand - DCA :

$$\Pi_i^r(q_i,\theta) = \pi_i^r(q_i) - P^c(\theta)\hat{\beta}_i\theta$$

Centralized demand - DCP :

$$\Pi_i^r(q_i,\theta) = \pi_i^r(q_i) - P^c(\theta)\theta\frac{q_i}{q_i + q_{-i}}$$

Decentralized demand :

$$\Pi_i^r(q_i,\theta) = \pi_i^r(q_i) - P^c(\theta)\theta_i + \begin{cases} +0 \quad \text{if} \qquad q_i \leq \theta_i \\ \\ -S(q_i-\theta_i) \quad \text{if} \quad q_i > \theta_i \end{cases}$$

What we do

The following equation gives the expected inframarginal rent:

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

How each market design modifies $p^s(k,t)$?

DCA retail equilibrium

Proposition

*With a centralized demand ex-ante, **the capacity market is neutral** regarding the equilibrium on the retail market. The demand function on the energy market is strictly equal to the demand function without a capacity market.*

$$p^s(q,t) = P(q,t) + \frac{q}{n^r} P_q(q,t)$$

Proof. FOC :

$$P(q,t) + \frac{q}{n^r} P_q(q,t) - p^s(q,t) = 0$$

Remarks. Lump sum payment needed

DCP retail equilibrium

Proposition

The equilibrium quantity depends on the quantity purchased in the capacity market by the regulated entity, on the capacity price and on the degree of competition in the retail market. ***The demand function on the energy market is always lower*** *than in the ex-ante case and is equal to :*

$$p^s(q,t) = P(q,t) + \frac{q}{n^r}P_q(q,t) - P^c(\theta)\theta\frac{1}{q}\frac{n^r-1}{n^r}$$

Proof. FOC :

$$P(q,t) + \frac{q}{n^r}P_q(q,t) - p^s(q,t) = P^c(\theta)\theta\frac{1}{q}\frac{n^r-1}{n^r}$$

Remarks. No lump sum payment needed

DD retail equilibrium - Sketch of the proposition

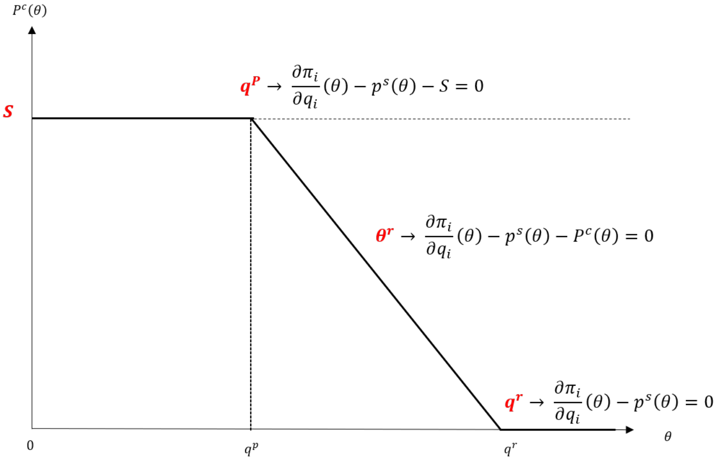


Figure: Demand function in capacity markets

Full proposition

Sketch of the proof

We proceed using backward induction for symmetric equilibrium :

1. We find the equilibrium on the retail market given the level of individual θ

2. We deduce obvious dominant strategies on capacity markets

3. We chose the level of capacity that maximizes profit function given a $P^c(\theta)$

Full proof

Roadmap

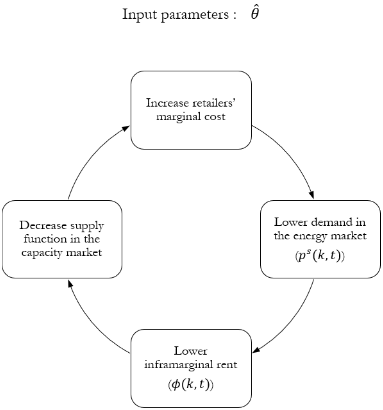
Some remarks on the indirect effect

- **DCA design:** the market design is a surplus transfer between consumers and producers, **there is no indirect effect** as individual retailers' strategy does not dictate the level of investment needed.

- **DCP design:** the market design internalizes the cost of the reserve market for the retailers. Individual retailers' strategy participates in the restoration of the level of investment needed, **which implies the indirect effect**.

- **DD design:** letting the retailers chose the level of investment relies on two important rationales which dictate the magnitude of the indirect effect :
  - How suppliers control the demand of final consumers ? *(fully with our current assumptions)*
  - What is the value of an additional capacity for retailers ?

DCP design - A self actualizing mechanism ?



We create reserve markets to increase the level of investment given an expected demand.

However, when looking at the demand side effect of those markets, it decreases the expected demand ("*effacements diffus*" [RTE, 2014]).

What is the optimal level of investment if you endogenize the cost of procuring enough investment?

Numerical illustration

DD design - the value of investment for retailers

Lemma

Assuming price taker retailers in the capacity market, ***a decentralized market never restore efficiency****, as retailers are not incited to increase the level of capacity: demand function crosses the supply curve at a price* $P^c(\theta) = 0$ *and a quantity* k^c*.*

Proof. If retailers are price takers on the capacity market :

$$\frac{\partial k}{\partial \theta_i} = 0 \qquad \frac{\partial t^r(k,c)}{\partial \theta_i} = 0 \qquad \frac{\partial \Pi_i^r(q_i,\theta_i)}{\partial \theta_i} = -P^c(k)$$

DD design - the value of investment for retailers

Lemma

Assuming price maker retailers in the capacity market, ***a decentralized market can restore efficiency*** *if and only if* ***an increase of capacity has a positive value for retailer****. Then capacity prices can be positive, and the cleared capacity is above k^c*

Proof. If retailer are price making in the capacity market :

$$\Pi_i^r(q_i,\theta_i) = \overbrace{\int_0^{t^c(k,c)} \frac{q}{n^r}(P(q,t)-c)f(t)dt}^{\text{Pos. effect : } \frac{\partial t^c}{\partial k} > 0} + \overbrace{\int_{t^c(k,c)}^{\infty} \frac{k}{n^r}(\frac{k}{n^r}P_q(k,t))f(t)dt}^{\text{Ambig. effect : } t^c \text{ vs } k \text{ and } \frac{\partial P_q}{\partial k} \lesseqgtr 0}$$

$$- \underbrace{P^c(k)}_{\text{Capacity market cost}}$$

Investments could be valuable for strategic retailers ! Don't forget the penalty

The data

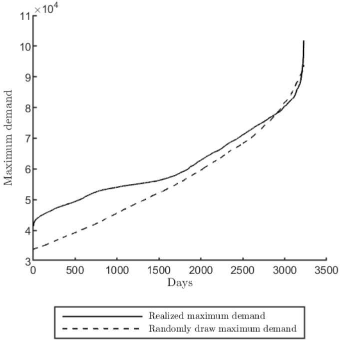
Linear demand function for final consumers + uncertainty from the intercept of the demand function.

$$P(q,t) = a(t) - bq$$

Where $a(t)$ is the uncertain intercept such as : $a(t) = a_0 + a_1 e^{-\lambda_1 t}$
We assume that t follows an exponential distribution : $f(t) = -\lambda_2 e^{-\lambda_2 t}$

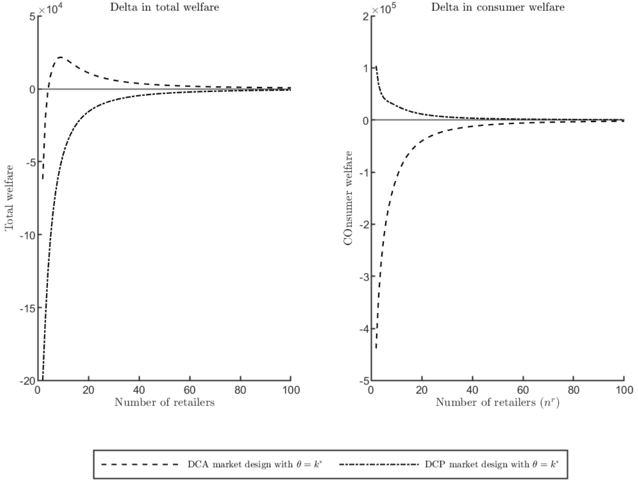
Others exogenous variables are summarised in table and also follow the French data [Léautier, 2014] :

Definition	Index	Value
Coefficient distribution	λ_1	1.78
Coefficient exponential intercept	λ_2	1
Coefficient intercept 1	a_0	3 845
Coefficient intercept 2	a_1	2 472
Maximal demand (GW)	Q_{Inf}	92.4
Marginal cost ($ /MWh)	c	49
Fixed cost ($ /MWh)	r	8
Demand slope	b	0.20



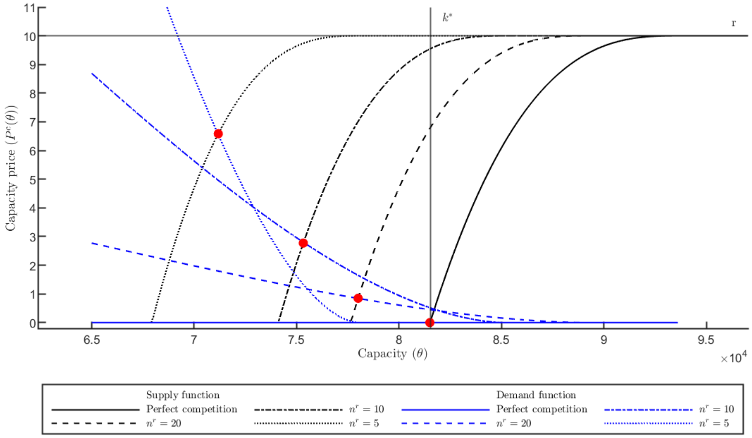
Centralized design and economic efficiency

An ex-ante design increases the total welfare, but it is not Pareto efficient for consumers. An ex-post design increases the consumer's welfare.



Demand functions in decentralized market design

Decreasing market power also decreases the value of additional investment for retailers.



Roadmap

Conclusions - main results

On capacity markets - demand-side : the choice of the market design matters :

- Centralized ex-ante demand: capacity markets are neutral
- Centralized ex-post demand: retailers internalized capacity price in their strategy (increase in their marginal cost)
- Decentralized demand: capacity market can restore efficiency depending on the value of capacity for a retailer.

Important point: a self-actualizing economic instrument implemented to provide sufficient capacity for a given demand. However, some market designs decrease the demand, which reduces the need for a capacity market. Effacement diffus [RTE 2014]? How to include the capacity price in pricing [Alcott 2012]?

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., 2007] [RTE, 2014]

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

Roadmap

Supply function in capacity market

The supply function in the capacity market is equal to the marginal cost associated with the deviation from the initial investment level k^θ :

$$X(\theta) = \begin{cases} 0 \quad \text{if} \quad \theta \leq k^\theta \\ \\ r - \phi(\theta, t) \quad k^\theta < \theta \leq k_0 \\ \\ r \quad k_0 < \theta \end{cases}$$

Below k^θ, the opportunity cost is null.

Above k^θ, the opportunity cost is positive and equal to the fixed marginal cost minus the revenue. The opportunity cost is caped by the marginal cost.

Supply function in capacity market

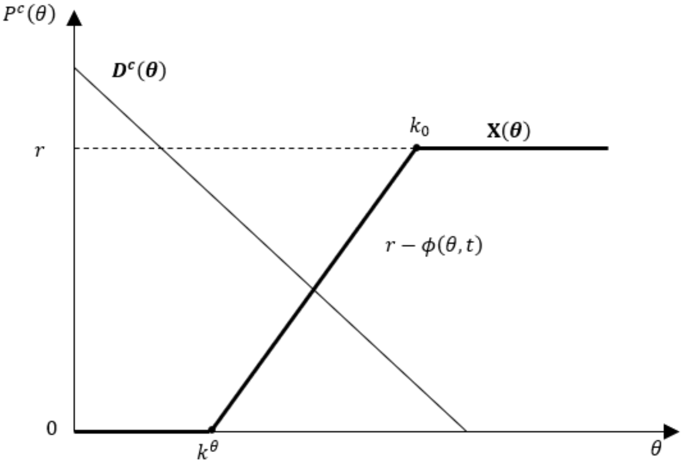


Figure: Theoretical supply function in capacity markets

Looping back to investment decisions

If the market design modifies the retailer demand function, so is the inframarginal rent and the supply function on the capacity market.

Lemma

Centralized demand DCA *: neutral*

$$X^{dca}(\theta) = X(\theta)$$

Centralized demand DCP *: lower*

$$X^{dcp}(\theta) \geq X^{dca}(\theta) = X(\theta)$$

Decentralized demand DD *: lower*

$$\begin{cases} X^{dd}(\theta) > X^{dca} = X(\theta) & \text{if} \quad \theta < q^p \\ X^{dcp}(\theta) = X^{dca} = X(\theta) & \text{if} \quad \theta \geq q^p \end{cases}$$

Inframarginal rent without inefficiency

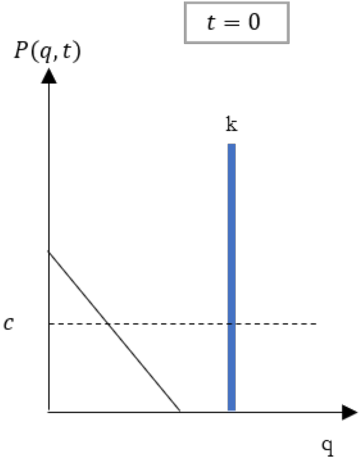
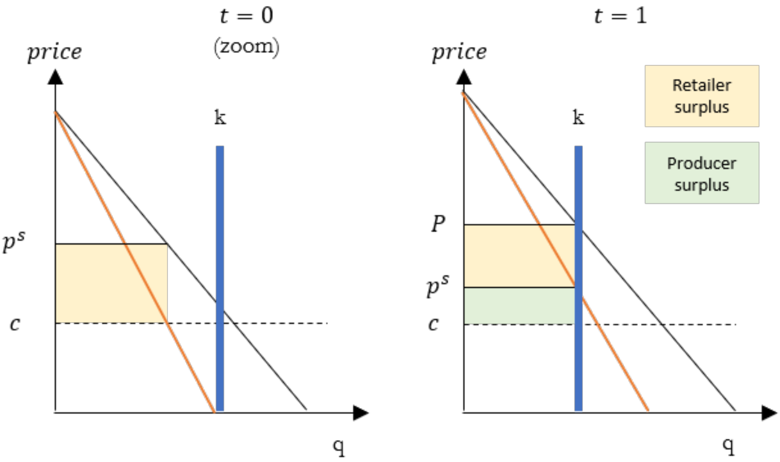


Figure: Theoretical supply function in capacity markets

Go back

Inframarginal rent with market power in the retail market



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DD retail equilibrium - simple symmetric case without uncertainty

Proposition (Demand function - capacity market)

The demand function $D^c(\theta)$ in the capacity market is a decreasing function of the capacity price and is capped at S :

$$D^c(\theta) = \begin{cases} 0 & \text{if} \quad P^c(\theta) \in]S, +\infty[\\ \theta^r & \text{if} \quad P^c(\theta) \in [0, S] \end{cases}$$

With θ^r the optimal quantity sold given the marginal cost $p^s(q,t) + P^c(\theta)$

DD retail equilibrium - simple symmetric case without uncertainty

Proposition

The demand function on the energy market depends on the threshold value $\hat{\theta}$ which delimits the case when the supply function reaches the cap or not :

$$p^s(q,t) = \begin{cases} P(q,t) + \frac{q}{n^r} P_q(q,t) - S & \text{if} \quad \hat{\theta} \leq q^p \\ \\ P(q,t) + \frac{q}{n^r} P_q(q,t) - P^c(\theta) & \text{if} \quad q^p < \hat{\theta} \end{cases}$$

With q^p the quantity sold when the marginal cost is $p^s(q,t) + S$

Go back

Some preliminary notations

Two thresholds based on the FOC:

- **Cournot equilibrium** : q^r found by solving

$$P(q,t) + q_i P_q(q,t) - p^s(q,t) = 0$$

- **Penalty equilibrium** : q^p found by solving

$$P(q,t) + q_i P_q(q,t) - p^s(q,t) - S = 0$$

Decentralized demand retail equilibrium

We have three possible cases, each with a unique equilibrium on the retail market :

case(i) $\theta > q^r$. All retailers are in positive deviation. However, the equilibrium in the retail market is still q^r.

case(ii) $q^r \geq \theta > q^p$. All retailers have bought the same quantity in the capacity market that they have sold on the retail market. The equilibrium in the retail market is θ.

case(iii) $q^p \geq \theta$. All retailers have not bought enough capacity, and all retailers have to pay penalties. The equilibrium in the retail market is q^p.

Decentralized demand retail equilibrium

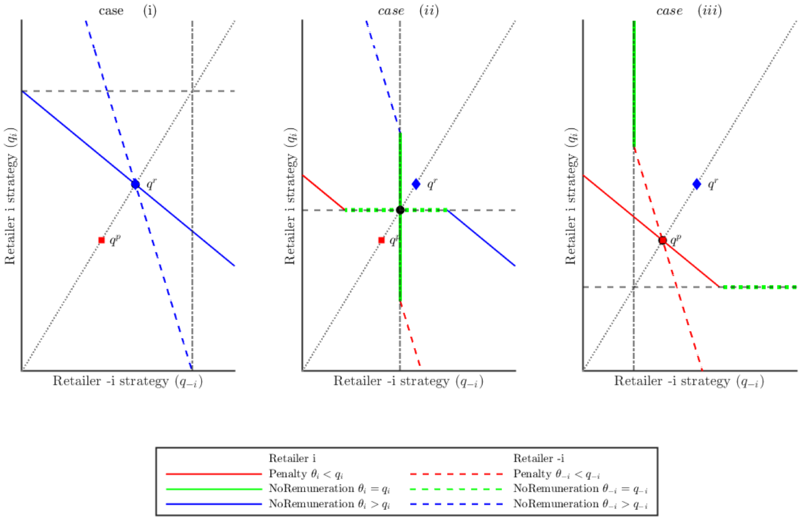

Figure: Retail equilibrium with different level of capacity

Dominant strategies in the capacity market

We look for the dominant strategies in the three case.

It is straightforward for case (i): $\theta_i = q^r$ as buying more capacities is costly and does not bring any benefit. Same for case (ii) as the equilibrium is always the exact level of capacity.

For case (iii), it depends on the value of the penalty S relative to the capacity price $P^c(\theta)$:

- If $P^c(\theta) \leq S$ then it is a dominant strategy to buy $\theta = q^r$
- If $P^c(\theta) > S$ then it is a dominant strategy to buy $\theta = 0$

The set of dominant strategies in the capacity market is :

$$\begin{cases} [q^p, q^r] & \text{if} \quad P^c(\theta) \leq S \\ \{0,]q^p, q^r]\} & \text{if} \quad P^c(\theta) > S \end{cases}$$

Optimal level of capacity

Retailers choose the profit-maximizing capacity θ_i given a capacity price.

If $P^c(\theta) \leq S$. The full profit function of retailers $\Pi_i^r(q, \theta)$ with $q_i = \theta_i$

$$\max_{\theta_i} \Pi_i^r(\theta_i, \theta_i) = (P(\theta_i, t) - p^s(\theta_i, t))\theta_i - P^c(\theta_i)\theta_i$$

Given $P^c(\theta)$, the optimal level θ^r is the solution of :

$$P(\theta^r, t) + \frac{\theta^r}{n^r} P_q(\theta^r, t) - p^s(\theta^r, t) - P^c(\theta^r) = 0$$

The optimal level of capacity asked by retailer is similar to a *Cournot* equilibrium with the marginal cost $p^s(\theta, t) + P^c(\theta)$.

Optimal level of capacity

If $P^c(\theta) > S$. We need to compare $\Pi_i^r(\theta^r, \theta^r)$ and $\Pi_i^r(q, 0)$, with :

$$\Pi_i^r(q^p, 0) = \pi_i^r(q^p) - S\frac{q^p}{n^r}$$

This gives the threshold :

$$\hat{P}^c = \frac{\pi_i^r(\theta^r) - \pi_i^r(q^p)}{\theta^r} - S\frac{q^p}{\theta^r}$$

If $S > \hat{P}^c$

$$\Pi_i^r(q^p, 0) \geq \Pi_i^r(\theta^r, \theta^r) \qquad \longrightarrow \qquad \theta = 0$$

If $S < \hat{P}^c$

$$\Pi_i^r(q^p, 0) \leq \Pi_i^r(\theta^r, \theta^r) \qquad \longrightarrow \qquad \theta = \theta^r$$

Optimal level of capacity

For simplicity, we assume that the penalty value S is always above $\hat{P}^c$. Hence, if the capacity price goes above S, retailers stop buying capacities.

The inverse demand function in the capacity market is

$$P^c(\theta) = \begin{cases} S & \text{if} \quad 0 \leq \theta < q^p \\ P^c(\theta^r) & \text{if} \quad q^p < \theta \end{cases}$$

θ^r is the solution of :

$$P(\theta^r, t) + \frac{\theta^r}{n^r} P_q(\theta^r, t) - p^s(\theta^r, t) - P^c(\theta^r) = 0$$

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Energy demand functions under DCP design

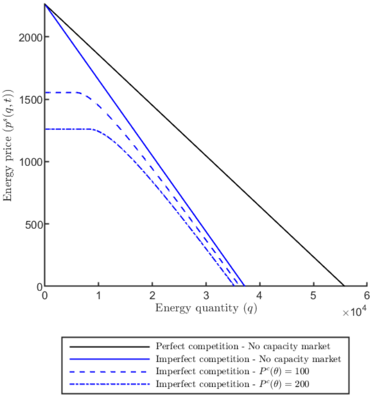

Figure: Demand functions in the energy market given capacity prices

Capacity supply functions under DCP design

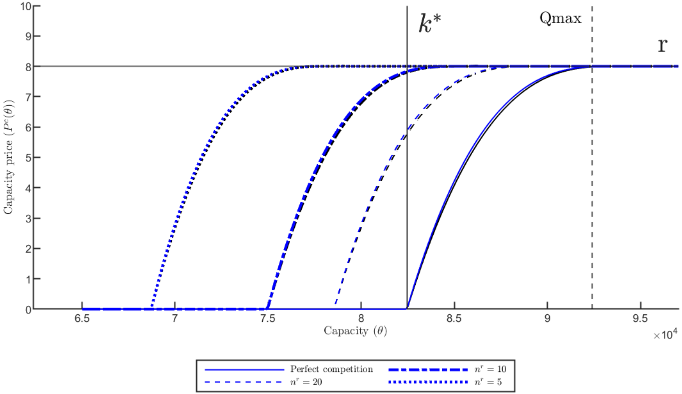

Figure: Supply functions in the energy market given capacity prices

Go back

Don't forget the tradeoff

When a retailer sells too much relative to the capacity bought :

$$\Pi_i^r(q_i, \theta_i) = \overbrace{\int_0^{+\infty} \frac{q}{n^r}(P(c,t) - c) f(t) dt}^{\text{Retail market net expected revenue}} - \overbrace{\int_{t^c(k,c)}^{\infty} S\left(\frac{q}{n^r} - \theta_i\right) f(t) dt}^{\text{Expected penalty cost}}$$

$$- \underbrace{P^c(k)\theta_i}_{\text{Capacity market cost}}$$

Go back

Will capacities always be there for us?

Électricité : cet hiver, il se pourrait que le courant ne passe plus par moments

Par crainte d'un black-out ce vendredi, RTE demande à limiter sa consommation d'électricité en France

Santé

Coronavirus: pourquoi les masques ont-ils disparu?

ABONNÉS **La campagne de vaccination est-elle menacée par une pénurie de seringues ?**

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