Securing investment for essential goods.

How to design the demand side of capacity markets?

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CHAIRE EUROPEAN ELECTRICITY MARKETS

What are capacity markets ?

Specific mechanisms that allows capacity owners to sell their investment availability.

1. Producers build their investment.
2. They sell their 'capacity' against a capacity price.
3. If needed, they produce a good and receive a wholesale price.

Well known in the electricity sectors : most of the liberalized power systems have some form of a capacity market.

Can also exist in other sectors (supply chain, '*reservation markets*') and may be useful for specific good (vaccines).

Why do we need capacity markets ?

We need to have sufficient investments to produce essential good when needed (mostly during peak demand: cold wave/ heat wave / pandemic).

Relying on private and uncertain incentives (e.g., wholesale prices) **is sometimes inefficient to provide sufficient investment**:

- Prices are tow low (e.g. *pice caps*)
- Investment as a public good (e.g. *inefficient rationing*)
- Other causes (e.g. *market power*)

There is an inadequacy between the social value of an investment and the private value : **need for an additional price signal, hence the capacity price**

But how to design a capacity market ?

Consumers do not willingly buy quantity and capacity. Investments (availability) as a public good with positive externalities / asymmetric information / transaction costs.

What are the economics implications of building an administrative demand function in a capacity market?

Capacity market can cause **indirect effects** beyond the initial objective of providing an additional remuneration and more investment.

We show in this paper that the first-best investment level (and the expected social welfare) is endogenous to the **allocation rule** of the capacity market.

Take aways

We build a analytical model that formally prove the existence of a first-best and **the positive/negative effects** on the expected social welfare at the first-best.

We develop the model first to study the **cost allocation design** between capacity buyers and final consumers.

We use the framework on **different policy / technical extensions** :

- Inefficient rationing.
- Imperfect competition (market share allocation + market power).
- Decentralized capacity market.

Contribution

Model of investment decisions [Zöttl, 2011] [Léautier, 2016] [Holmberg and Ritz, 2020]

Capacity markets : [Brown, 2018a] [Brown, 2018b] [Scouflaire, 2019] [Fabra, 2018] [Joskow and Tirole, 2007] [Allcott, 2012] [Petitet, 2016] [Teirilä and Ritz, 2018]

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

Initial assumptions

Producers

- Perfectly competitive / Single technology / Homogeneous good
- c : marginal cost / r : fixed cost / k : capacity

Production and capacities are normalized.

Consumers

- Homogeneous / Price responsive
- $p(q, t)$: inverse demand function (with decreasing marg. returns)

t : state of the world such as $t \in [0, \infty]$,$f(t)$, $F(t)$, $p_t(q, t) > 0$. Uncertainty only on the intercept of the demand function.

Timing

Initial Model

Uncertain expected demand	Realized demand for state t
Investment decision	Wholesale market
$(k, W(k), p^c)$	$(q(t) p^s(t))$

Extension with retailers

Uncertain expected demand	Realized demand for state t	
Investment decision	Wholesale market	Retail market
$(k, W(k), p^c)$	$(q(t) p^s(t))$	$(q(t) p(t))$

Wholesale market equilibrium

When the capacity k is not binding : **off-peak**.

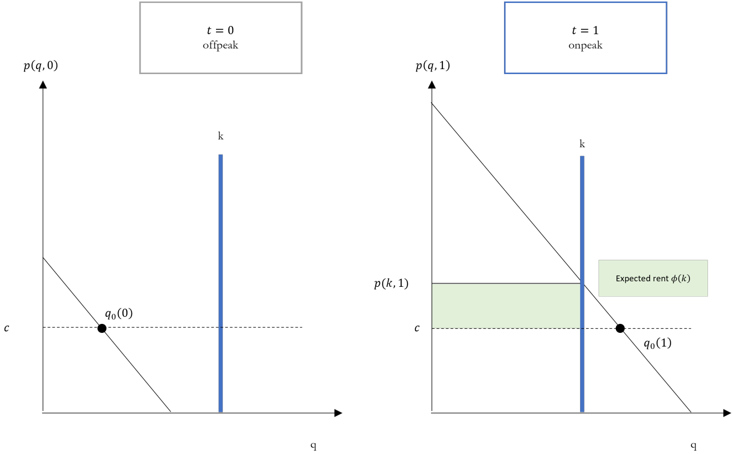
When the capacity k is binding : **on-peak**.

The threshold is determined by the quantity exchange $q_0(t)$ at the short term marginal cost c s.t. $p(q_0, t) = c$. We define the critical threshold for any states of the world : $t_0(k)$ s.t. : $p(k, t_0) = c$.

The outcome on the wholesale market in terms of price-quantity pair is :

$$\begin{cases} \{c, q_0(t)\} \quad \forall \quad t \in [0, t_0] \\ \\ \{p(k, t), k\} \quad \forall \quad t \in [t_0, +\infty) \end{cases} \tag{1}$$

Investment, market outcomes and stochastic demand



First-best solution

Optimal investment level

- It is given by maximizing expected social welfare $W(k)$

Off-peak welfare / On-peak welfare

$$\boxed{\int_0^{t_0(k)} \int_0^{q_0(t)} (p(q,t)-c)dq\, f(t)dt} + \boxed{\int_{t_0(k)}^{+\infty} \int_0^{k} (p(q,t)-c)dq\, f(t)dt} - rk$$

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

Similar to have the equality between the net wholesale expected revenue (marginal log term revenue) and the fixed cost (long term marginal cost).

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

Inefficient market equilibrium (1) : price cap

Market Investment equilibrium

- Electricity markets are plagued by a set of inefficiencies. Example : **Price caps** (Explicit and implicit). It implies market equilibrium $\neq$ first-best solution

When taking their investment decisions producers choose k such as the marginal revenue of an additional capacity is equal to the marginal fixed cost r

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

We know that $\forall t > t_0^w(k)$ we have $p(k,t) > p^w$. Therefore $\phi(k) > \phi^w(k)$ which both implies a lower investment level and a lower expected social welfare.

Roadmap

A supply function

We suppose that producers offer a continuous non-decreasing supply function on the capacity market. *Similar approach to a Supply Function Equilibrium model under perfect competition*.

Given an initial market equilibrium k^w. The supply function is equal to **the marginal opportunity cost of providing an additional capacity**.

$$X(k) = \begin{cases} 0 \quad \forall \quad k \quad < k^w \\ \\ r - \phi^w(k) \quad \forall \quad k \quad \geq k^w \end{cases} \tag{2}$$

The capacity market supply function is endogenous to the equilibrium in the wholesale/retail market.

The canonical capacity market (exogenous design)

The full cost $kp^c(k)$ is allocated directly to the consumers, without any dependence on the expected and realized final demand level. **Lump sum tax**.

Proposition

The clearing price $p^c(k_0^*)$ given by the supply function $X(k)$ is always equal to the optimal payment $z_0^w(k_0^*)$ needed to restore efficiency.

- No distortion : lump sum tax approach. The capacity market does not affect consumer's behavior.
- No indirect effect: The mechanism is just a surplus transfer from consumers to producers
- A centralized mechanism is optimal given the set of inefficiency.

The endogenous capacity market - indirect effect

The full cost $kp^c(k)$ is allocated directly to the consumers such that the new final demand for the good is equal to $D(p,t) = p^s(q,t) - p^c(k)$. **Variable unitary tax**.

We first characterize the indirect effect of the capacity market :

Lemma

Only the occurrence of the two periods $t_0(k)$ and the intersection between the demand function and the marginal cost $q_0(t)$ change, the welfare function becomes:

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

The endogenous capacity market - first-best

Proposition

(i) If the first-best solution exists it solves $k_1^* = \{k : \phi_1(k) = r\}$, *with* $\phi_1(k)$ *defined as follow*

$$\phi_1(k) = \int_0^{t_1(k)} \frac{\partial q_1(t)}{\partial k} p^c(k)\ f(t)dt + \int_{t_1(k)}^{+\infty} (p(k,t) - c)\ f(t)dt$$

(ii) k_1^* *is always lower than the first-best solution under the exogenous level* ($k_1^* \leq k_0^*$). *The social welfare at the optimal investment level is also always lower than the social welfare at the optimal investment level under the exogenous regime* ($W_1(k_1^*) \leq W_0(k_0^*)$).

- **With only a price cap, it is better to allocate the capacity cost without distorting the demand**.

Inefficient rationing - Extension

The availability of investment during high-demand periods can be considered as a public good. They generate positive externalities, and their absence implies significant costs.

We represent this specific nature by assuming that when demand exceed capacity and prices cannot reduce demand then inefficient rationing exists.

Example

Suppose that consumers sustain an additional cost proportional to the share of consumers selected indifferently that is forced to stop consuming and based on their expected surplus:

$$M(k) = \int_{t_0^w(k)}^{+\infty} \frac{q_0^w(k) - k}{k} \int_0^k (p(q,t) - p^w) dq f(t) dt \tag{3}$$

Inefficient rationing - first-best and welfare results

Proposition

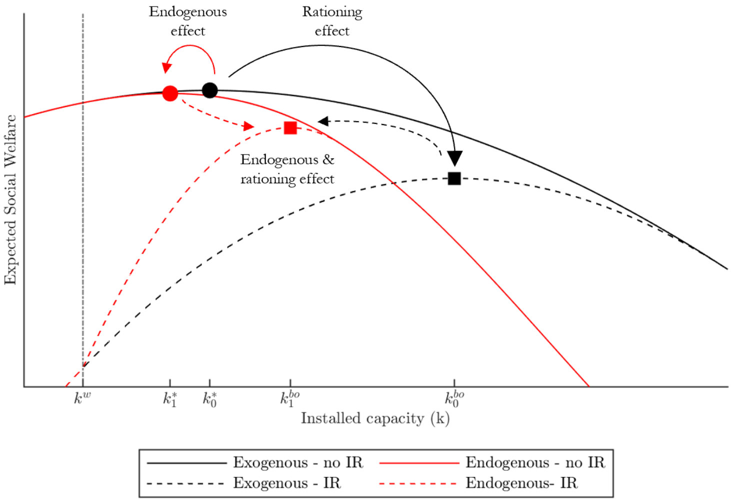
(i) Under exponential distribution and a linear demand function: $k_0^{bo} \geq k_1^{bo}$.

(ii) Under a discrete distribution there can exist some functions $p_1^w(\theta)$ *and* $p_2^w(\theta)$ *such that* $\forall\ \theta \in [p_1^w(\theta), p_2^w(\theta)]$ *we have* $W_1^{bo}(k_1^*) \leq W_0^{bo}(k_0^*)$. *Outside the boundaries we always have* $W_1^{bo}(k_1^*) \geq W_0^{bo}(k_0^*)$.

Allocating the capacity price on a variable basis can increase the optimal social welfare while having a lower investment need.

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

Illustration of inefficient rationing and endogenous design



Market share allocation - Policy results

We allocate the capacity cost (price $\times$ quantity) on each retailers using an endogenous ratio of **their realized market share**.

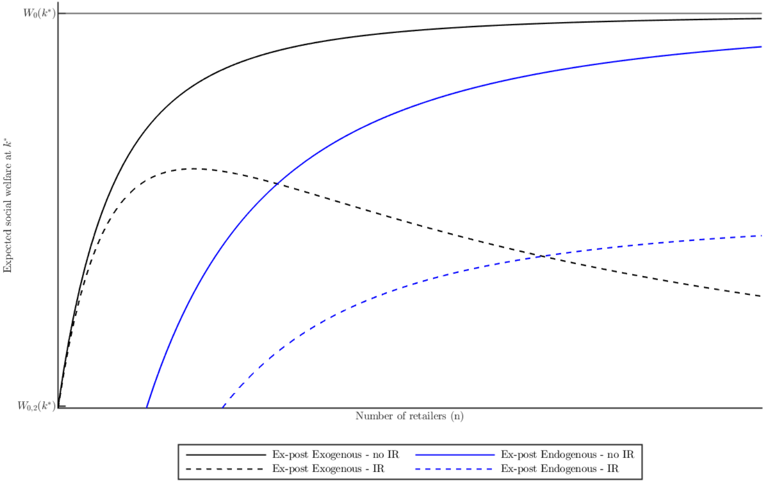
$$\pi_i^r(q_i, k) = q_i(p(q) - p^s) - p^c(k)k\frac{q_i}{q_i + q_{-i}}$$

Proposition

The first-best investment level is lower than the first-best under exogenous design and higher than the first-best under the endogenous regime ($k^*_{1,n} \leq k^*_n < k^*_{0,n}$). Moreover, the reverse is true for the expected social welfare

- 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 competitiveness tends to increase the cost pass-through**

Market power and efficiency



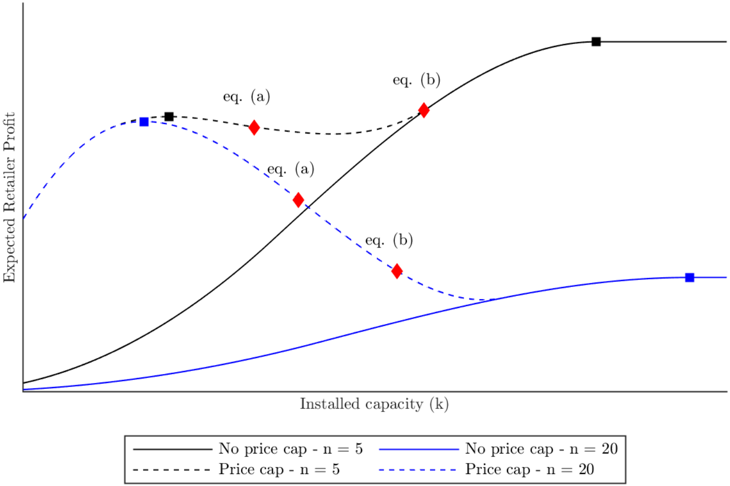
A decentralized capacity market - Methodology

Retailers need to choose the level of capacity without knowing the future level of demand **and given a penalty** S

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

- We solve the model by considering that a decentralized capacity market allows retailers to act as producers.
- We derive the marginal value retailers can have from an additional capacity : **endogenous demand function in the capacity market**
- Market equilibrium is given by the equality between the supply and demand function in the capacity market.

Illustration



Conclusions - extensions

We wanted to open the discussion on those overlooked issues for the capacity market design: (i) how the price is allocated, (ii) and how the realized demand is accounted for.

We propose a grounded theoretical model to highlight the indirect effects of each possible market design and their implications for the system.

Stress the endogeneity between the optimum a policymaker wishes to attain and the instrument used to reach it.

Possible extensions : Final consumer heterogeneity + Cause of underinvestment + Information

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