Capacity markets and the pricing of reliability options

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Outline

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(Greener and greener) power generation in Europe

Electricity production, hystorically based on thermal plants (with few exceptions in Europe), is switching in the latest years to growingly larger market quotes of renewable energy sources (RES).
Unfortunately, most of these RES are non-programmable, or non-dispatchable (e.g. photovoltaic and wind).
What happens with a sudden drop of non-dispatchable RES?

- Price peaks!
- One or more backup technologies are (still) needed.

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The ideal back-up technology?

The necessity of the "ideal" back-up technology arises when non-dispatchable RES, which were already scheduled for a given hour, fail to be produced due to adverse weather conditions (the converse is rarer).

This is usually known with certainty only **2-3 hours in advance!**

Thus, the "ideal" back-up technology should:

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Given this scenario (common to most countries), different approaches were tackled in introducing a capacity remuneration mechanism, i.e. a way of augmenting the total capacity "in real time" by the transmit system operator (TSO).

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- France: decentralized capacity obligations;
- Colombia, Ireland*, ISO New England, Italy*: CRM based on reliability options (*: still to start).

We study this latter mechanism.

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- Day-ahead market (MGP - Mercato del Giorno Prima). pricesfor each hour of the day after. Uniform auction = same prices for everyone, regardless of bids.
- Intra-Day market (MI - Mercato Infragiornaliero). 7 auctions, from the day before to the day of delivery.
- Balancing market (MSD - Mercato per il Servizio di Dispacciamento). Still auction-based, with selling bids (how much a producer would charge to increase the scheduled load) and purchasing bids (how much a producer would pay, i.e., give back, to produce less). Discriminatory auction: what you bid is what you get.

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(Italian) access rules to CRM

The Italian CRM is **open to the participation of those agents in possession of dispatchable capacity** that is not receiving any further incentive and is not in the process of decommissioning.

Furtherly, they should be able to place bids both in the MGP (day-ahead) and in the MSD (balancing) (no intra-day needed).

- **no non-dispatchable RES** ...
- ...but (reservoir-based) hydro is still in!

Other, more technical, requirements:

- "relevant" units, i.e. capacity > 10 MW;
- start adjusting their injection within 5 minutes;
- start adjusting their injection ±10 MW within 15 minutes;
- in the case of a hydro plant: enough water in the reservoir for at least 4 hours

$$\frac{\text{daily energy [MWH]}}{\text{capacity [MW]}} > 4[h]$$

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In Italy, reliability options will be traded with an initial yearly auction, 4 years in advance w.r.t. the beginning of a 3-year period. The capacity providers receive a fixed premium, determined in the main auction and paid by the TSO.

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Reliability product

In exchange for the premium fee, capacity providers undertake to:

- offer the committed capacity in the MGP **for each hour of the delivery period**. What is not bought in MGP **must be offered in MSD** (the prices are at their choice).
- Return to the TSO any positive difference between the reference market price (day-ahead or balancing) and the strike price K.

In this way, the TSO ensures that the price (at least for the additional capacity of the RO) does not rise above K — **ex-post peak-shaving!**

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Settlement of the RO

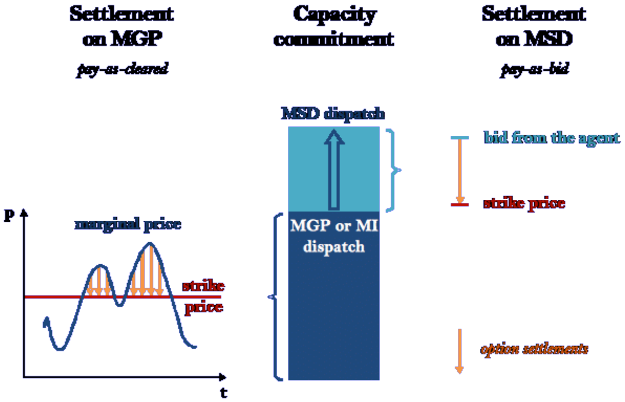

Figure: Courtesy of P. Mastropietro, F. Fontini, P. Rodilla, C. Batlle, 2017.

Reference market price

In first approximation, in general the reference market price is a convex combination of the day-ahead price P^{da} and the (taken) bid of the agent b^b in the balancing market:

$$R = \lambda P^{da} + (1 - \lambda) b^b$$

with λ depending on the country:

- $\lambda = 0$: ISO New England;
- $\lambda = 1$: Colombia;
- $\lambda \in (0, 1)$: Ireland, Italy.

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Reference market price: the Italian case

The reference price changes, accordingly to where the committed capacity is really sold (or not) between the two markets, day-ahead (DA) or balancing (B):

Offered and accepted DA	P^{da} $(\lambda = 1)$
Offered and accepted B	b^b $(\lambda = 0)$
Offered in B at price lower than K, not accepted	K (null payoff)
Offered in B at price higher than K, not accepted	$\max(P^{da}, P^b)$ (nonlinear λ)

where P^b is the highest accepted bid in the balancing market (NOT a "price").
When part of the capacity is accepted in DA and part in B, λ is distributed accordingly.

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Strike price

The strike price K is officially determined by the TSO as "the variable cost of the reference peak technology", i.e. the dispatchable technology that would be included in the optimal generation mix with the lowest unitary investment cost.

The resulting technology is communicated by the TSO to the agents at least 30 days in advance.

The strike price varies weekly, as a function of fuel costs, CO_2 certificates, etc.

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The mathematical modelling of the general (Italian, but also Irish) RO is quite complex, as two auctions and two prices are involved (work in progress).

Is this complexity really needed?

To have an idea of the involved math (and complexity), let us see the case when the balancing market's highest accepted bid P^b is near to the day-ahead price P^{da}: in this case these two coincide with R $\rightsquigarrow$ only one state variable needed for the price!

Also: Colombian case $R = P^{da}$.

Even with this (much) simplifying assumption, we must distinguish between two cases: thermal plant or hydro plant.

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To have an idea of the involved math (and complexity), let us see the case when the balancing market's highest accepted bid P^b is near to the day-ahead price P^{da}: in this case these two coincide with $R \rightsquigarrow$ only one state variable needed for the price!

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Thermal plant

A thermal plant with total capacity Q converts a fuel (oil, gas, coal, etc.), whose spot price we represent with $C = (C_t)_t$ (gross of CO_2 price, operational costs, etc.) into electricity, whose spot price is $P^{da} = P = (P_t)_t$.

This happens every time t the power plant wins the day-ahead auction, i.e. when its bid b_t is less than or equal to P_t.

With the usual simplifications (continuous time instead of hourly granularity, no ramping penalties/constraints, etc.), since the plant can decide its bid process $b = (b_t)_t$ to maximize its revenues in the time period $[T_1, T_2]$, it must solve the problem

$$V(T_1, T_2) = \sup_b \mathbb{E}\left[\int_{T_1}^{T_2} e^{-r(s-T_1)} Q \mathbf{1}_{b_t \le P_t} (P_t - C_t)\, dt \,\middle|\, \mathcal{F}_{T_1} \right]$$

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Obviously it will be optimal to have $\mathbf{1}_{b_t \leq P_t}$ if and only if $P_t > C_t$
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Final payoff:

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If the thermal plant writes a RO, it must always place a bid (but the bidding price b_t remains at its choice), and must **always** pay back $(P_t - K_t)^+$, even when it's not producing!

Total payoff:

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It turns out that $b_t = C_t$ is an optimal bidding also in this case! (Bad) result:

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The value of the RO

In a risk-neutral world, the value $RO(T_1, T_2)$ of a RO written on the time interval $[T_1, T_2]$ should make the investor indifferent between having the original plant without the RO, and having it with the RO written on it plus the sum $RO(T_1, T_2)$:

$$V(T_1, T_2) = V_{ro}(T_1, T_2) + RO(T_1, T_2)$$

With a thermal plant (and the whole lot of mathematical simplifications above), the final result is

$$\begin{aligned} RO(T_1, T_2) &= V(T_1, T_2) - V_{ro}(T_1, T_2) = \\ &= \mathbb{E}\left[\int_{T_1}^{T_2} e^{-r(s-T_1)} Q(P_t - K_t)^+ \, dt \middle| \mathcal{F}_{T_1} \right] \end{aligned}$$

Thus, the value of a reliability option is **just that of an "insurance contract"** against price peaks!
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(reservoir-based) hydro plant

A reservoir-based hydro plant (no mini/micro plants) with total capacity Q converts a water flow in a reservoir, whose total volume we represent with Q_t, into electricity, whose spot price is still $P^{da} = P = (P_t)_t$. The basin fills with an instantaneous inflow $I = (I_t)_t \geq 0$ and can be emptied with an outflow $q = (q_t)_t$, with $q_t \in [0, \overline{q}]$ (linked to Q). The water balance at all times is

$$dQ_t = I_t \; dt - q_t \; dt, \qquad Q_t \in [0, Q_{max}]$$

Simplifying assumptions here: $q_t \in \{0, \overline{q}\}$ (bang-bang control, quite realistic), $I_t \equiv I(t)$ deterministic (less realistic), with $\overline{q} > I(t)$ (the basin can be emptied before it overflows).
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Less trivial than before, leading to a true stochastic control problem! The trivial strategy $\mathbf{1}_{b_t \le P_t}$ if and only if $P_t > 0$ could simply be **not admissible** (at a certain point, possibly $Q_t = 0$).

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Again, the control does **not** affect the RO part, so that we can again write

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Since, as before, the plant's owner estimates the fair value of its commitment as

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with a hydro plant, the final result is again

$$\begin{aligned} RO(T_1, T_2) &= V(T_1, T_2) - V_{ro}(T_1, T_2) = \\ &= \mathbb{E}\left[\int_{T_1}^{T_2} e^{-r(s-T_1)} Q(P_t - K_t)^+ \, dt \middle| \mathcal{F}_{T_1} \right] \end{aligned}$$

Again, **just an "insurance contract"** against price peaks, and **the operating strategy of the power plants does not change.**

RO written on the balancing market

Let us now assume that the RO is written only on the balancing market. The difference here is that you are paid what you bid, not what the final "price" is (also: there is NOT a "final" price, but a highest accepted bid P^b).

Again, only one state variable needed for the price, and only one control variable needed.

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RO written on the balancing market: thermal plant

Assume for example that the RO is written on P^b, i.e. equal for everyone.

The marginal gain at time t for a thermal plant without RO would be

$$Q\mathbb{E}[\mathbf{1}_{b_t \le P_t^b}(b_t - C_t)]$$

which is not so straightforward to maximize w.r.t. b_t.

However, the marginal gain with a RO written is

$$\begin{aligned} & Q\mathbb{E}[\mathbf{1}_{b_t \le P_t^b}(b_t - C_t) - (P_t^b - K_t)^+] = \\ = \quad & Q\mathbb{E}[\mathbf{1}_{b_t \le P_t^b}(b_t - C_t)] - Q\mathbb{E}[(P_t^b - K_t)^+] \end{aligned}$$

i.e., the marginal gain without RO plus a purely financial penalty: **the maximizing bid b_t is not changing!**

RO written on the balancing market: thermal plant

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RO with Italian rules: thermal plant

Assume now that the RO is written only on the balancing market, but with (part of) the Italian rules:

- if the bid is accepted ($b^b \leq P^b$), then $R = b^b$;
- if not ($b^b > P^b$), then $R = P^b$;

The marginal gain with a RO written is thus

$$Q\mathbb{E}[\mathbf{1}_{b_t \leq P_t^b}[(b_t - C_t) - (b_t^b - K_t)^+] - \mathbf{1}_{b_t > P_t^b}(P_t^b - K_t)^+]$$

Finally, **the maximizer b_t changes from the case without RO!**

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RO with full Italian rules

The full Italian (and Irish) rules compel to model two prices (states: P^{da} and P^{b}) and two bids (controls: b^{da}, b^{b}), together with other state variables needed (C, Q, I).

More complexity is expected (work in progress) . . .

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Conclusions

- The RO mechanism enhances the power market efficiency by making explicit and transparent the social value of power capacity.
- This is set at the intersection of social willingness to pay for security of supply, and the private cost of providing it, by either keeping existing plants operational or installing new ones.
- In this design, it is technology-neutral, preferring the most efficient technology in providing security of supply (unfortunately, usually CCGT)
- the pricing procedure is in general complex, and care must be given to contractual clauses: with some of them, the price is trivial and the RO is uneffective in the production policy!
- a "fair" price does not exist in general, as the (sell-side) price depends on the plant (thermal/hydro) that one has;

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Postdoc position available

A 1-year (and 5 months) post-doc position ("assegno di ricerca") will be issued by the University of Padova, Department of Mathematics (in collaboration with the Department of Economics):

- title: **Capacity markets and the pricing of reliability options**
- responsible: prof. Tiziano Vargiolu (`vargiolu@math.unipd.it`)
- possible deadline: December 2017 - January 2018 — possible start: January-March, 2018.

Energy Finance Italia 3

- **Location:** Pescara (Adriatic Sea, Italy)
- **Date:** February 15 - 16
- **Highlights:** Single track workshop (as here) + poster session
- **ACRI Young Investigator Training Program:** if financed, 1 month in one of the universities of the network, before or after the conference (3K Euro for European residents)

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