Generation Capacity Expansion in Risky Reorganized Electricity Markets with uncertain Wind Penetration

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Wind Power and Market design

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Introduction

1. The traditional capacity expansion model

- The simplest view: two periods
  - period 0: invest in a mix of technologies
  - period 1: operate the capacities

- Objective

  Satisfy a time segmented, price insensitive demand so as to minimize total (annual in this simple case) cost

- They expanded and progressively became quite sophisticated and included reliability criteria like the LOLP

3. And a standard optimization model

- Operations

$$Q(x) \equiv \min_{y,z} \sum_{\ell \in L} \tau(\ell) \left[\sum_{k \in K} c(k)\, y(k,\ell) + PC\ \ z(\ell) \right] \tag{1}$$

s.t.

$$0 \le x(k) - y(k,\ell) \qquad \mu(k,\ell) \tag{2}$$

$$0 \le \sum_{k \in K} y(k,\ell) + z(\ell) - d(\ell) \qquad \pi(\ell) \tag{3}$$

$$0 \le NAP - \sum_{\ell \in L} \tau(\ell) \sum_{k \in K} e(k) y(k,\ell) \qquad \lambda \tag{4}$$

$$0 \le y(k,\ell). \tag{5}$$

- Investment

$$\min_{x \ge 0} \sum_{k \in K} I(k)\, x(k) + Q(x). \tag{6}$$

4. Resource adequacy and security of supply

- Former capacity expansion models used under the obligation to serve guaranteed the necessary capacity

- Do these models still make sense in a competitive system ?

- If not, what should replace them ?

- Do we have clear cut ideas on incentive to invest ?

5. A first step: move from optimization to complementarity (or from optimization to economic equilibrium)

- Operations

$$0 \leq x(k) - y(k,\ell) \perp \mu(k,\ell) \geq 0 \tag{7}$$

$$0 \leq \sum_{k \in K} y(k,\ell) + z(\ell) - d(\ell) \perp \pi(\ell) \geq 0 \tag{8}$$

$$0 \leq NAP - \sum_{\ell \in L} \tau(\ell) \sum_{k \in K} e(k)\, y(k,\ell) \perp \lambda \geq 0 \tag{9}$$

$$0 \leq c(k) + \mu(k,\ell) + e(k)\lambda - \pi(\ell) \perp y(k,\ell) \geq 0 \tag{10}$$

$$0 \leq PC - \pi(\ell) \perp z(\ell) \geq 0. \tag{11}$$

- Investment

$$0 \leq I(k) - \sum_{\ell \in L} \tau(\ell)\, \mu(k,\ell) \perp x(k) \geq 0. \tag{12}$$

1. Discussion: the incentive to invest

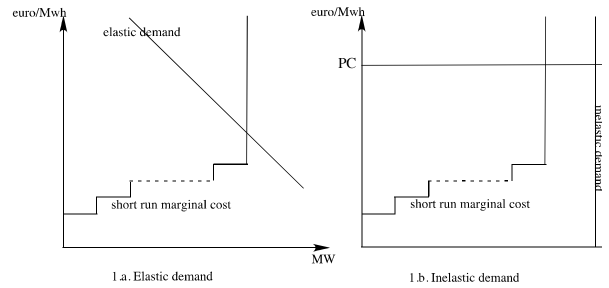
- Does one need subsidies for investment in a competitive market ?

  No in well functioning markets ?

  Yes in case of market failure

- Are there market failures in reorganized electricity systems ?

2.Market failure in reorganized electricity systems (1) – Stoft (2002)



Price setting when capacity is used up

3. Market failure in reorganized electricity systems (2) – Joskow (2007) adapted to Carbon trade

Suppose price is set on a PX with no market power, then

- operating plants are remunerated at fuel cost + allowance opportunity cost of last running unit
- which implies that the last operating plant only receives the opportunity cost of free allowances to remunerate its capital cost

Specifically, it receives 0 if there is no free allowance

$\Rightarrow$ Capital cost is not remunerated if there is no free allowance:

MARKET FAILURE

4. Remedies

- Energy only market: set regulated price PC (ideally VOLL) during curtailment

- Capacity market: create a market for capacities; investor receive
  - electricity price when they operate
  - capacity value when they invest

- Other means not discussed here

5. A third step: update the model

- Energy only model: no change

$$0 \leq I(k) - \sum_{\ell \in L} \tau(\ell)\, \mu(k,\ell) \perp x(k) \geq 0. \tag{13}$$

- Capacity market

  Replace

$$0 \leq I(k) - \sum_{\ell \in L} \tau(\ell)\, \mu(k,\ell) \perp x(k) \geq 0. \tag{14}$$

  by

$$0 \leq \sum_{k \in K} x(k) - \max_{\ell \in L}\, d(\ell) \perp \nu \geq 0 \tag{15}$$

$$0 \leq I(k) - \nu - \sum_{\ell \in L} \tau(\ell)\, \mu(k) \perp x(k) \geq 0 \tag{16}$$

Risk Factors

1. Wind power

- The physical properties of wind make the integration of large shares of wind power challenging in a deregulated market:
  - predictions about the amount of wind capacity in the system change from study to study (difficult to model since non-market based) $wind(n)$
  - the combination of high load and low wind output creates the risk of outages
  - otherwise the market has to provide a flexible back-up system for a large share of the wind capacity
  - demand response might reduce the problem
  - the fixed costs of the back-up system have to be paid in a limited number of hours

2. The standard (traditional) risk factors

- Fuel prices and demand evolution
- Fuel prices: $c(k, f)$
- demand risk: $D(w)$

3. A fourth step (1): introduce uncertainty in operations model

for all (f, n, b, w)

$$0 \leq x(k) - y(k, \ell, f, n, b, w) \perp \mu(k, \ell, f, n, b, w) \geq 0 \tag{17}$$

for all (f, n, b, w)

$$0 \leq \sum_{k \in K} y(k, l, f, n, b, w) + z(\ell, f, n, b, w) - d(\ell) \perp \pi(\ell, f, n, b, w) \geq 0 \tag{18}$$

for all n

$$0 \leq NAP(n) - \sum_{\ell \in L} \tau(\ell) \sum_{k \in K} e(k) y(k, \ell, f, n, b, w) \perp \lambda(\ell, f, n, b) \geq 0 \tag{19}$$

for all (f, n, b, w)

$$0 \leq c(k, f) + \mu(k, \ell, f, n, b, w) + e(k)\lambda(f, n, b, w) - \pi(\ell, f, n, b, w) \tag{20}$$

$$\perp y(k, \ell, f, n, b, w) \geq 0$$

for all (f, n, b, w)

$$0 \leq PC - \pi(\ell, f, n, b, w) \perp z(\ell, f, n, b, w) \geq 0. \tag{21}$$

4. A fourth step (2): update the investment part accordingly

- Energy only market

for all k

$$0 \leq I(k) - \sum_{f\in F, n\in N, b\in B, w\in W} pb(b)pf(f)pn(n)pw(w)a(k,b)\lambda(f,n,b,w)) \qquad (22)$$
$$- \sum_{\ell\in L, f\in F, n\in N} \tau(\ell)pb(b)pf(f)pn(n)pw(w)\mu(k,\ell,f,n,b,w) \perp x(k) \geq 0.$$

- Capacity market

$$0 \leq \sum_{k\in K} x(k) - \max_{\ell\in L} d(\ell) \perp \nu \geq 0 \qquad (23)$$

for all k

$$0 \leq I(k) - \sum_{f\in F, n\in N, b\in B, w\in W} pf(f)pn(n)pb(b)pw(w)a(k,b)\lambda(f,n,b,w)) - \nu \qquad (24)$$
$$- \sum_{\ell\in L, f\in F, n\in N, b\in B, w\in W} \tau(\ell)pf(f)pn(n)pb(b)pw(w)\mu(k,\ell,f,n,b,w) \perp x(k) \geq 0.$$

5. Risk neutral (RN) vs. risk averse (RA) investors

- Sometimes heard about the EU-ETS
  - "risk is not an issue! The industry is used to deal with it"
  - "bankruptcy is just a transfer of ownership"
- Suppose one wants to go beyond these comforting statements. Apply CAPM or APT: the β are not very significantly $\neq 0$?
- What else ? Introduce risk functions

6. Risk averse investors

- Invest according to a different probability

- Recall from mathematical finance P and Q

  P: the "statistical probability"
  here $pf(f)pn(n)pb(b)$: given

  Q: a "risk neutral probability"
  noted $\phi(k; f, n, b)$: to be found

- Principle: replace $pf(f)pn(n)pb(b)pw(w)$ by $\phi(k; f, n, b, w)$

- Question: where does $\phi(k; f, n, b, w)$ come from ?

7. Reminder: the CVaR

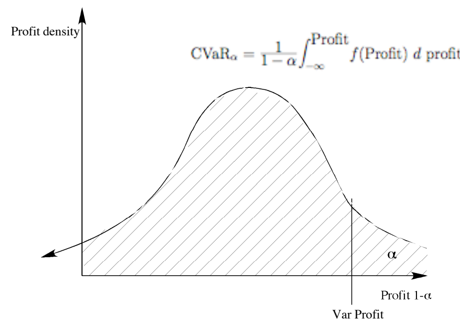


Illustration of the CVaR$_\alpha$

Assume investors behave according to a CVaR (which is a coherent risk function (Artzner et al., 1989))

8. The net margin and the investment criterion

- Let

$$\text{margin}(k; f, n, b) \equiv \sum_{\ell \in L} \tau(\ell)\mu(k; \ell, f, n, b) + \nu - I(k) \qquad (25)$$

for the capacity market

$$\text{margin}(k; f, n, b) \equiv \sum_{\ell \in L} \tau(\ell)\mu(k; \ell, f, n, b) - I(k) \qquad (26)$$

for the energy only market

- Investment criterion

$$0 \leq -\sum_{f \in F, b \in B, n \in N, w \in W} \phi(k; f, n, b, w)\text{margin}(k; f, n, b, w) \perp x(k) \geq 0 \qquad (27)$$

9. How does one relate CVaR and ϕ

$$0 \leq -\text{CVaR}_\alpha[\text{margin}(k; f, n, b, w)] \perp x(k) \geq 0 \tag{28}$$

and

$$0 \leq -\sum_{f \in F, b \in B, n \in N} \phi(k; f, n, b, w)\text{margin}(k; f, n, b) \perp x(k) \geq 0 \tag{29}$$

are identical expressions provided one uses the duality theory introduced by Artzner et al. (1989) and developed in computational form by Rockafellar and Uryasev (2002).

10. Reminder of the principle

- Applying Rockafellar and Uryasev, one formulates CVaR(margin($\cdot$)) as an LP.

- One writes its dual with $\phi(\cdot)$ being some variables of it.

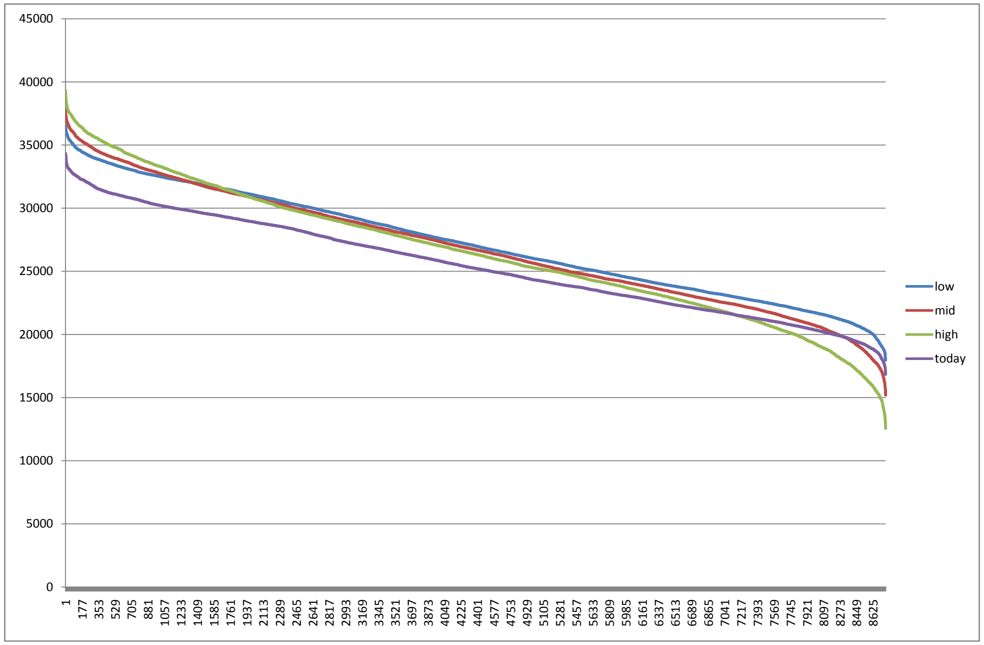
- One writes the corresponding complementarity conditions and one inserts them in the model, whether energy only or capacity market. **But this makes the problem non-convex**

Illustration

1. A test problem

- Three technologies: Coal – CCGT – OCGT
- 3 more or less peaky (because of wind) load duration curves decomposed in 20 time segments each
- Three fuel price scenarios: steady coal; low/mid/high gas
- One NAP scenario
- Three assumptions on development of existing generation

2. A test problem



Residual load curves based on existing studies on load growth and wind deployment

2. Energy only vs. capacity market

	Coal	CCGT	OCGT	Total	Max energy curtailed	Hours at PC (max)
EO/RN	27878	5583	601	34062	4400	2555
EO/RA	27876	5541	643	34062	4400	2555
CM/RN	27814	5646	4999	38462	0	0
CM/RA	27814	5646	4999	38462	0	0

Price cap: 300€/Mwh

	Coal	CCGT	OCGT	Total	Max energy curtailed	Hours at PC (max)
EO/RN	27816.48	5645.16	2476.14	35938	2524	149
CM/RN	27814.78	5646.86	4999.95	38462	0	0

Price cap: 3000€/Mwh

Conclusions

- Moving into an uncertain world
  - uncertain evolution of fuel prices
  - insufficient understanding of incentives to invest
  - "learning by doing" evolution of environmental policy

- Is all of this good ?
  - relying on the market is good, but creating markets affected by market failures is not
    * incentive to invest from PX based power prices without demand bidding creates a market failure
    * creating risky markets that do not trade risk creates incomplete market and hence a market failure

- Do we observe that in the model ?
  - yes, these models are affected by different non convexities
  - remedies should be based on removing non convexities and market failures; this is what the capacity market does; a good PC or reliability pricing would do it to (see Gürkan et al.)
  - But this technical message is difficult to convey to the Council and the Parliament

- The current feed-in tariffs for wind remove most uncertainties for wind developers but add to the uncertainties of those who build to participate in the market.
- High prices in low wind hours are necessary but might be interpreted as abuse by competition authority.