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Flexibility and risk transfer in electricity markets

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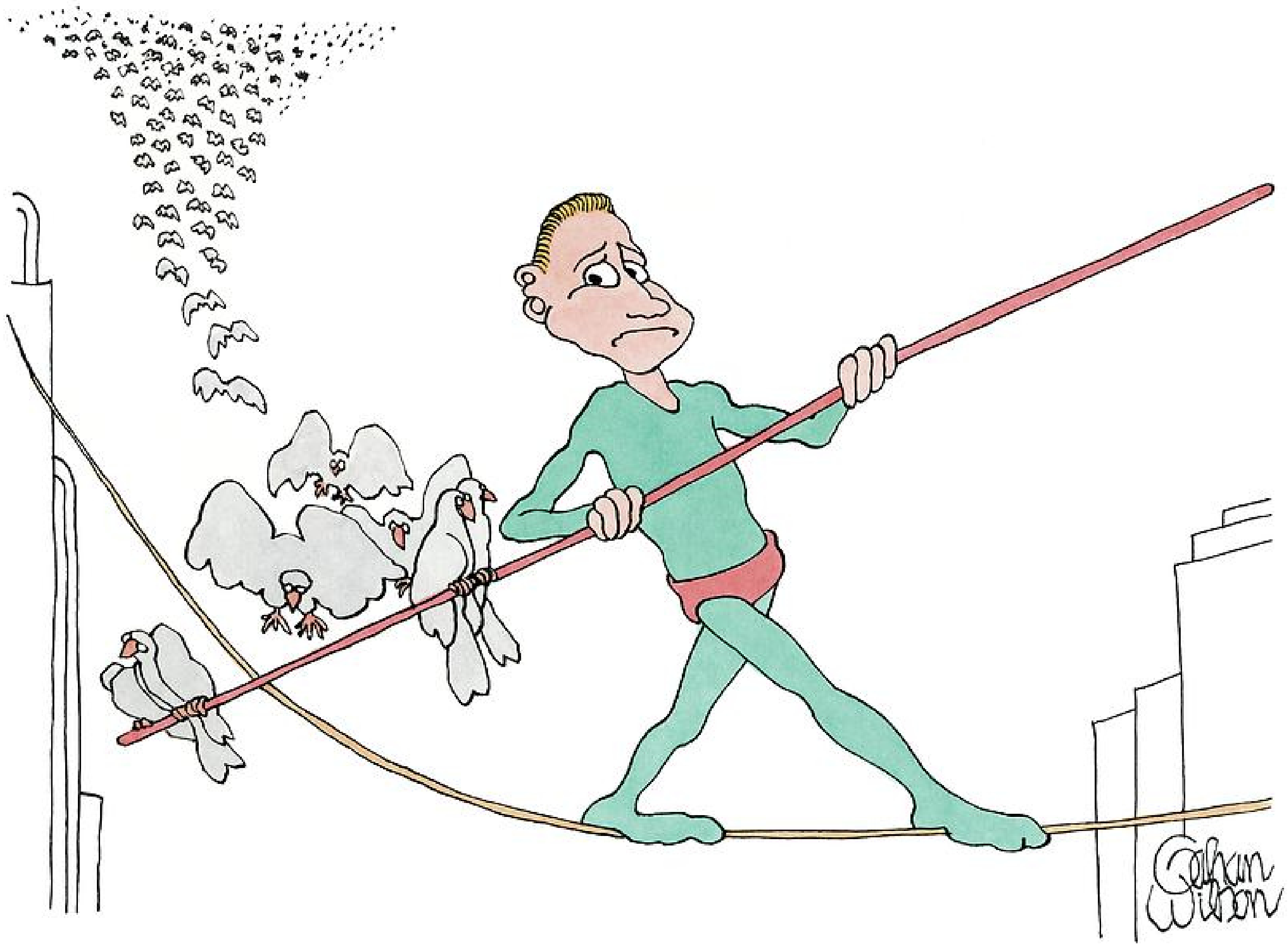
Balancing the electricity system

- Characteristics of the product
  - Transformation of primary energy
  - Not for final consumption
  - Not storable
- Supply side
  - Production constrained by installed capacities and the availability of primary fuels
  - Provision constrained by transmission capacities with specific characteristics
- Demand side
  - Plurality of uses
  - Continuous needs
  - Consumption constrained by equipment with specific characteristics



Solutions

- Rationing
- Price responsive consumer
- Import/Export through interconnections
- Storage
- Prosumers
- **Flexible dispatchable plants**

The model

$S(x, z)$: random surplus from consuming quantity x in state z.

$C(Q, q)$: cost of producing Q before knowing z, and $x = Q + q$ after observing z:

$q > 0$ or < 0

$Q + q \geq 0$

$C(x,0) < C(0,x)$

Quadratic specification:

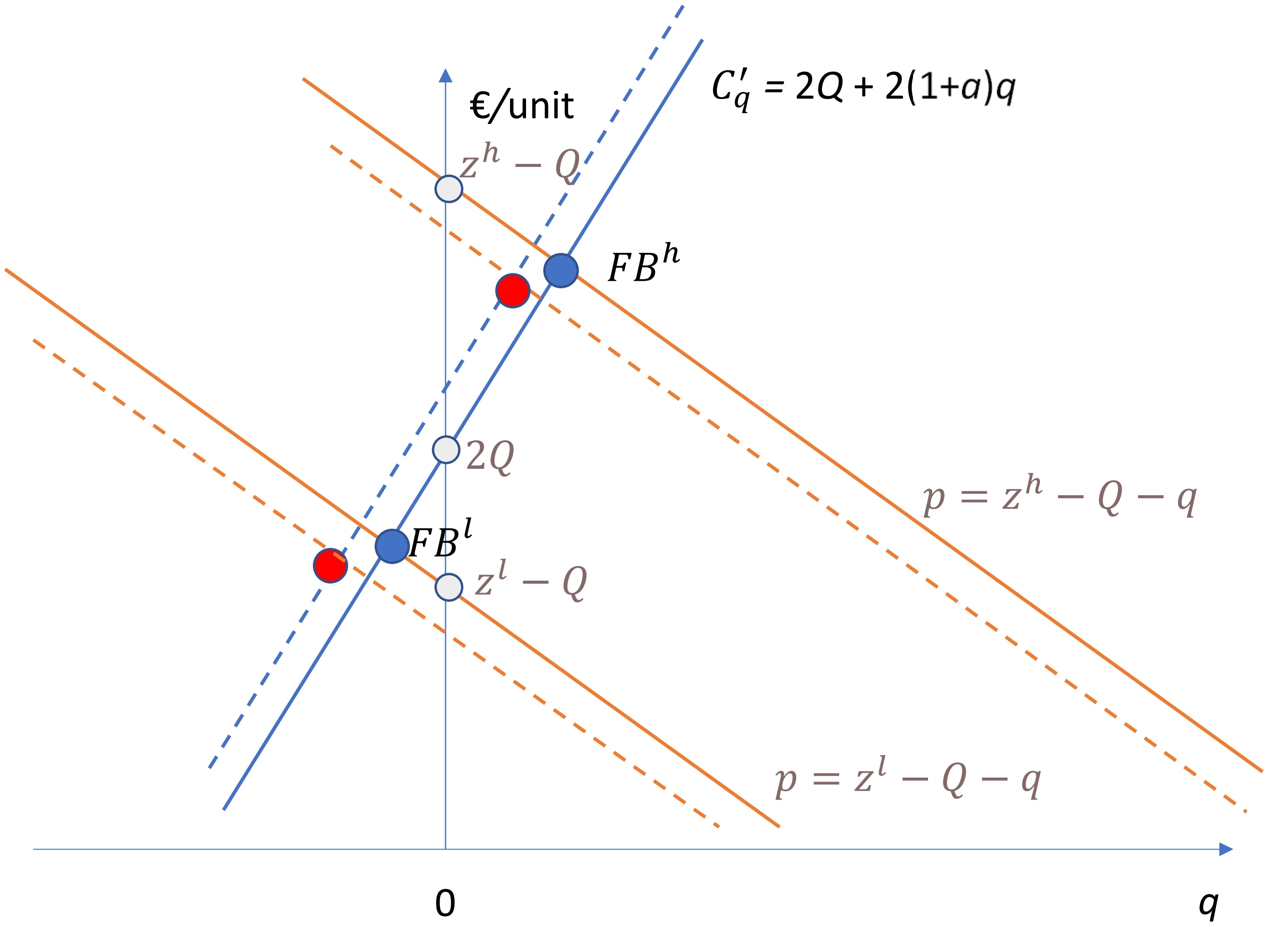
$S(x, z) = (z - x/2)x$ $\qquad\qquad$ $C(Q, q) = (Q + q)^2 + aq^2$

Market organization

- One market: $Q + q$ is sold ex-post at spot price
- Two markets: Q is sold day-ahead at expected price and q is sold intraday at spot price
- Crampes and Renault (2019)
  - Under perfect competition, the outcome is the same whatever the market organization
  - Under imperfect competition, outcomes differ. **In which direction?**

First-best trade-offs

- An increase in Q decreases residual demand in state z.
- An increase in Q pushes the marginal cost of adjustment up (down) under diseconomies (economies) of scope.
- Then an increase in Q results in ambiguous effects on price and quantity in the adjustment market.



Two price-taker firms : additional trade-off

- Should we share the load, or should we specialize the production units?
  - Increasing marginal cost *vs*. diseconomies of scope

- First-best outcome with two firms
  - $Q_i^* = \frac{E}{4}, \quad q_i^*(z) = \ (1 + a_{-i})(z - E)\gamma^{-1}, \mathbb{E}W^* = \frac{E^2}{4} + \frac{2+a_1+a_2}{2\gamma}V$
    where $E = \mathbb{E}[z], V = \mathbb{E}[z^2] - E^2$, and $\gamma = 4 + 3(a_1 + a_2) + 2a_1 a_2$.
  - Decentralized by $p(z) = z - \frac{E}{2} - (2 + a_1 + a_2)(z - E)\gamma^{-1}, P = \frac{E}{2}$
  - If $a_1 = 0, a_2 = +\infty, q_2^* = 0, \mathbb{E}\Pi_1^* = \frac{E^2}{16} + \frac{V}{9} > \mathbb{E}\Pi_2^* = \frac{E^2}{16}$

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Duopoly (ex post)

- One market: profit of i in state z

$$\Pi_i(Q_i Q_{-i}) = p(Q+q,z)(q_i+Q_i) - C_i(Q_i,q_i)$$

FOC in state z

$$p(Q+q,z) + \boxed{(q_i+Q_i)p'} = C'_{iq}(Q_i,q_i),\ i\text{=1,2} \Rightarrow q_i^C(\vec{Q},z)$$

- Two markets: profit of i in state z

$$\widetilde{\Pi}_i(Q_i,Q_{-i},q_i\,,q_{-i},z) = PQ_i + p(Q+q,z)q_i - C_i(Q_i,q_i)$$

FOC in state z

$$p(Q+q,z) + \boxed{q_i p'} = C'_{iq}(Q_i,q_i),\ \ i\text{=1,2} \Rightarrow \tilde{q}_i^C(\vec{Q},z)$$

$$\boxed{\tilde{q}_i^C(\vec{Q},z) > q_i^C(\vec{Q},z)} \quad \text{Allaz-Vila effect}$$

Duopoly (ex ante)

- One market: expected profit of i

$$\Pi_i(Q_i, Q_{-i}) = \mathbb{E}_z\left[p^C\,(\vec{Q}, z)\left(q_i^C(\vec{Q}, z) + Q_i\right) - C_i(Q_i, q_i^C(\vec{Q}, z))\right]$$

FOC $$\mathbb{E}_z\left[p^C + \left(q_i^C + Q_i\right).\,p^{C\prime}.\left(\frac{\partial q_{-i}^C}{\partial Q_i} + 1\right) - C'_{iQ}\right] = 0\ ,\ i\text{=1,2} \Rightarrow Q_i^C$$

- Two markets: expected profit of i

$$\tilde{\Pi}_i(Q_i, Q_{-i}) = \mathrm{P}(Q_i + Q_{-i})Q_i + \mathbb{E}_z\left[\tilde{p}^C(Q, z)\left(\tilde{q}_i^C(\vec{Q}, z)\ \right) - C_i(Q_i, \tilde{q}_i^C(\vec{Q}, z))\right]$$

FOC $$P + P'Q_i + \mathbb{E}_z\left[\tilde{q}_i^C.\,\tilde{p}^{C\prime}.\left(\frac{\partial \tilde{q}_{-i}^C}{\partial Q_i} + 1\right) - C'_{iQ}\right] = 0,\ i\text{=1,2} \Rightarrow \tilde{Q}_i^C$$

$$\tilde{Q}_i^C < Q_i^C$$

Net effect

$$\tilde{Q}_i^C < Q_i^C$$

$$\tilde{q}_i^C(\vec{Q}, z) > q_i^C(\vec{Q}, z)$$

Then what about the sum?

Results in the quadratic case with one market

- Two firms competing in quantities produce less than at first best.
- If the firms have the same cost function, the higher the adjustment cost, the lower the planned outputs and the higher the (negative) expected adjustment.
- If the firms are asymmetrical, the less flexible firm plans a higher level of output and adjusts less ex post than its competitor.

Gains from inflexibility

- When the demand variance is low, being inflexible is more profitable than being flexible.
- "*Are units inflexible because they are old and inefficient, because owners have not invested in increased flexibility or because they serve as a mechanism for the exercise of market power*?“ PJM 2018

Results in the quadratic case with two markets

- Adding a day-ahead market has the following effects:
  - each firm produces less at the first stage $\tilde{Q}_i^C < Q_i^C$, but its average total production is larger $\tilde{Q}_i^C + \mathbb{E}_z \tilde{q}_i^C > Q_i^C + \mathbb{E}_z q_i^C$
  - expected prices are lower,
  - consumers are better off
  - firms are worse off
  - total welfare is higher

Risk transfer

- Adding a day-ahead market transfers risks from firms to consumers
  - $V\left(\widetilde{\Pi}_i^C\right) < V\left(\Pi_i^C\right)$
  - $V\left(\tilde{S}_n^C\right) > V(S_n^C)$
- When a firm is totally inflexible and the other is perfectly flexible, if a day-ahead market is added to the spot market the inflexible firm is fully insured by consumers.
- Innocuous as long as consumers are not averse to monetary risk transfers.

Conclusion

- Need to relax modeling hypotheses
- On the supply side,
  - non quadratic cost functions to have statistical moments higher than variance
  - economies of scope
- On the demand side,
  - most consumers are sticky $\Longrightarrow$ they do not participate in the balancing, then supply flexibility is mandatory.
  - most consumers are risk averse to monetary lotteries