Investing in inflexible generation capacity

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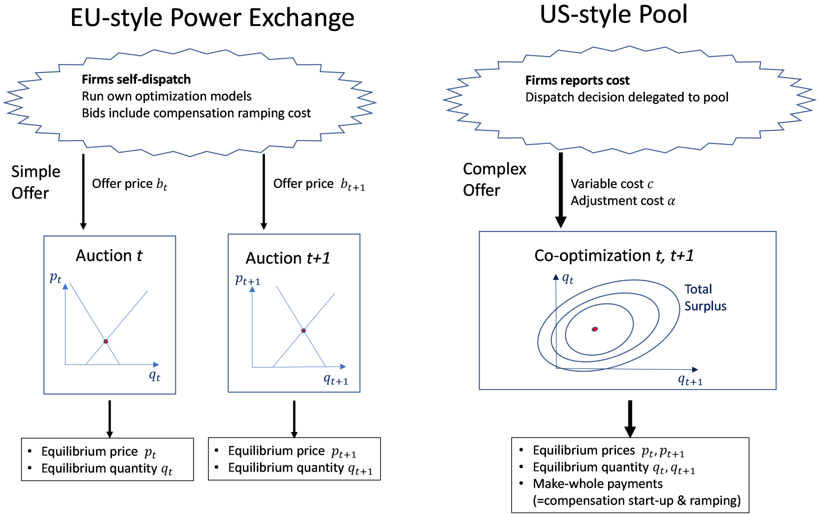
Overview

Motivation

- Higher penetration of RES requires **more flexibility energy resources**
  - Flexible conventional generation
  - Storage operators
  - Demand response
- In an **ideal, perfectly competitive market**, spot prices will provide the right incentives
  - More volatile spot prices $\rightarrow$ higher rewards for flexibility
- **However, in practice market failures** exist
  - Start-up costs: production costs are non-convex: Theory does not apply
  - Missing financial markets (forward contract does not hedge flexible generation)
  - Entry barrier or market power in operational stage
  - Spot prices do not reflect true scarcity (price cap, no linkage balancing & spot market)

2 Market designs to deal with Start-up costs



Different treatment of Start-up costs

- Different treatment of start-up costs will affect investment patterns
- **EU Power Exchange**
  - Firms need to internalize start-up costs
  - Bids $\neq$ MC, as firm has to make provisions for start-up costs
  - Inefficient scheduling as coordination is lacking
- **US Power pool**
  - Side-payment provides compensation for start-up costs
  - Side-payments might be a reward for inflexible generation.

Goal of this project

- Understand how market design affects equilibrium investment levels.
  - What is the effect of different treatment of start-up costs in US and EU?
  - We focus on (in)flexible conventional generation
- Analytical tractable model for optimal portfolio model with start-up costs
  - Continuum of technologies (base-load to peakers)
  - Continuum of firms: each firm is small and a price-taker
  - No risk aversion (missing financial markets does no matter)
  - No entry barriers: each firm makes zero profit in expectation

Overview

Model: Demand Side

- Two representative demand periods, $i = 1, 2$
- Price responsive stochastic demand with additive price shocks

$$p_i = p(q) + \varepsilon_i$$

- Shocks are independent with cumulative distribution $H(\varepsilon_i)$ on $[\underline{\varepsilon}, \bar{\varepsilon}]$.

Model: Production costs

- Continuum of technologies (base-load to peak) with **marginal cost** c on $[\underline{c}, \bar{c}]$ with per period **investment cost** $k(c)$ and **adjustment cost** α:

$$\underbrace{c \cdot (q_1 + q_2)}_{\text{Fuel Cost}} + \underbrace{\alpha \cdot (q_1 - q_2)^2}_{\text{Adjustment Cost}} - \underbrace{2 \cdot k(c)}_{\text{Investment cost}}$$

- Power plant can either be on or off: $q_i \in \{0, 1\}$
- **Opportunity cost** for producing one unit in period 1
  - If producing in period 2 for sure ($q_2 = 1$): $c - \alpha$
  - If not producing in period 2 for sure ($q_2 = 0$): $c + \alpha$
- **Aggregate market supply curve** $G(c)$ represents investment equilibrium

Overview

European market equilibrium

- Let $h(c)$ be the probability that firm c produces. **Free entry** then requires

$$h(c) = \frac{\mathrm{d}k(c)}{\mathrm{d}c}$$

- **Optimal bid** is expected opportunity cost

$$b(c) = c - \alpha(2h(c) - 1)$$

- **Market clears**

$$b(c) = p(G(c)) + \varepsilon(c)$$

- Probability of production $h(c)$ depends on distribution of demand shock $H(\varepsilon)$

$$h(c) = 1 - H(\varepsilon(c))$$

US market equilibrium

- Given continuum of small firms, side-payment are not necessary in our model.
- **Free entry** still requires

$$h(c) = \frac{\mathrm{d}k(c)}{\mathrm{d}c}$$

- **Optimal bidding:** bid equal to marginal cost c

$$b(c) = c$$

- **Market clears**

$$b(c) = p(G(c)) + \varepsilon(c)$$

- Probability of production $h(c)$ depends on co-optimization problem

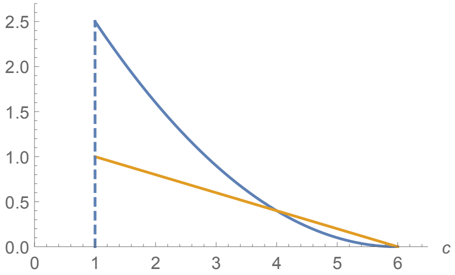
$$h(c) = \begin{cases} 1 - \int_{\varepsilon_L}^{2\varepsilon(c)-\varepsilon_L} H(2z(c) - \varepsilon_1)\, dH(\varepsilon_1) & \text{if } \varepsilon(c) - \alpha < \varepsilon_L \\ 1 - H(\varepsilon(c) - \alpha) - \int_{\varepsilon(c)-\alpha}^{\varepsilon(c)+\alpha} H(2z(c) - \varepsilon_1) dH(\varepsilon_1) & \text{if } \varepsilon_L \leq \varepsilon(c) - \alpha \leq \varepsilon_H \\ 1 - H(2\varepsilon(c) - \varepsilon_H) - \int_{2\varepsilon(c)-\varepsilon_H}^{\varepsilon_H} H(2z(c) - \varepsilon_1) dH(\varepsilon_1) & \text{if } \varepsilon_H \leq \varepsilon(c) - \alpha \end{cases}$$

Overview

Functional form

- Available technologies / Technology Mix

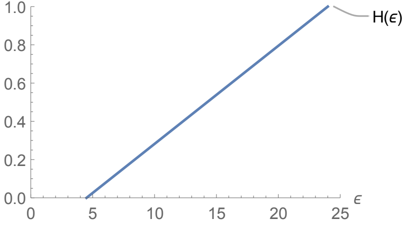
$$k(c) = \frac{1}{2}\frac{(\bar{c}-c)^2}{\bar{c}-\underline{c}} \qquad h(c) = \frac{\bar{c}-c}{\bar{c}-\underline{c}}$$



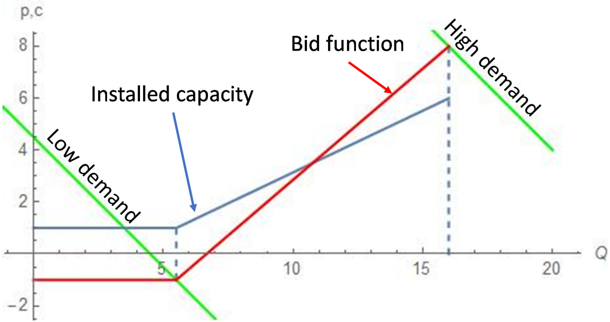
- Inverse linear demand function

$$p = \varepsilon + p(q) = \varepsilon - \beta \cdot q$$

- Uniform Distribution $H(\varepsilon)$



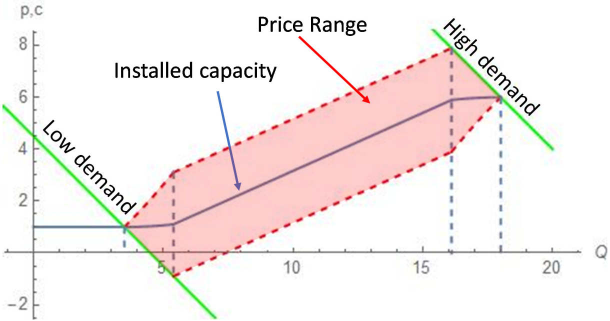
EU Market design



- Peaker bids above cost
- Baseload bids below cost

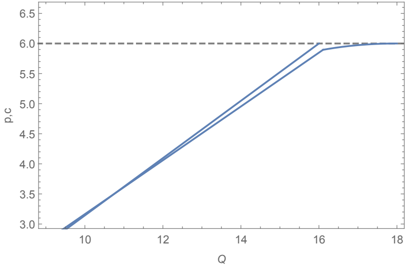
- Firms sometimes sell below cost (for low demand) but make zero profits in expectation.

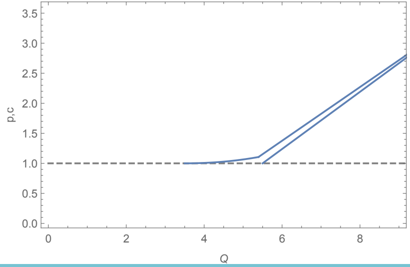
US Market design



- Price at which capacity is sold depends on realization of demand shock in other period.

Comparison US Vs EU





- US-market design is efficient
- EU-market design
  - less investment in peakers, more in basedload (long-run)
  - less efficient use of power plants (short-run)
  - In simulation results: short-run inefficiencies dominate

Overview

Conclusion

- **Complex US-style auctions are efficient**
  - allows for better inter-temporal operational decisions & optimal investments
  - bidding requires less information about the market conditions (only own production cost)
  - less risky for bidders (not selling below marginal cost)
- **Efficiency result depends on assumption of small firms**
  - Side-payments are not necessary
  - Numerical simulations are necessary if this assumption is dropped
- **Simple EU-style auction**
  - too little investment in peakers, too much in baseload
  - might depend on modeling assumptions.

Possible extensions

- Correlated demand shocks
- Technology specific adjustment cost $\alpha(c)$
- Endogenize adjustment cost α