Course on Energy Economics

Theoretical Analysis of Competition and Market Power in Wholesale Electricity Markets

Natalia Fabra

Universidad Carlos III de Madrid

Motivation

The **absence of market power**, a necessary condition for efficiency

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- Different types of market organizations, or **'market designs'**, give rise to different types of strategic opportunities for exercising market power.
- An **understanding of how market power will be exercised** in any particular market requires an understanding of the strategies available to firms, and an equilibrium analysis of the market game being played.

Outline

1. Supply Function Model
2. Multi-Unit Auction Model
    - Symmetric duopoly
    - Asymmetric duopoly
    - Symmetric Oligopoly

The Supply Function Approach

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  - Each firm has **a set of profit maximizing points**, one corresponding to each realization of its residual demand.
  - If firms must decide on their strategies in advance of the realization of demand, then they are better off specifying an entire supply curve.

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  - Each firm has **a set of profit maximizing points**, one corresponding to each realization of its residual demand.
  - If firms must decide on their strategies in advance of the realization of demand, then they are better off specifying an entire supply curve.
- Green and Newbery (1992) observed that demand uncertainty in K&M is formally identical to **demand variation** over time when firms' bids remain valid for a given period of time.

Model Description I

- Two symmetric firms, $i = 1, 2$.
- Demand $D(p, t)$: known; decreasing and concave in p, varies over t.
- Cost $C(q)$: non-decreasing and convex, $C'(p) \geq 0$ and $C''(p) > 0$.

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- The auctioneer determines the lowest price p^* such that each firm produces over its supply function and the market clears, $S_1(p^*) + S_2(p^*) = D(p^*, t)$.

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- The auctioneer determines the lowest price p^* such that each firm produces over its supply function and the market clears, $S_1(p^*) + S_2(p^*) = D(p^*, t)$.
- A **Nash equilibrium in supply functions** is a supply function pair $\{S_1(p), S_2(p)\}$ such that $S_i(p)$ maximizes i's expected profits given $S_j(p)$.
- **Market clearing** implies firms produce on their Residual Demand,

$$q_i(t) = S_i(p) = D(p, t) - S_j(p).$$

Model Description II

- Firm i 's profits are given by

$$\pi_i\,(p,t) = p\left[D(p,t) - S_j(p)\right] - C_i\left(D(p,t) - S_j(p)\right).$$

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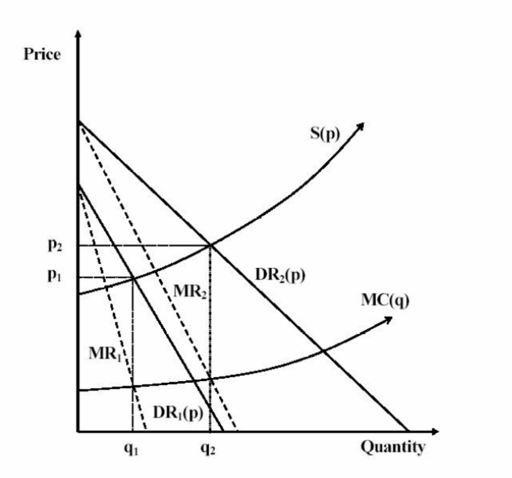
- Assuming that i's set of ex-post profit maximizing points can be described as a supply function which intersects each realisation of i's residual demand curve once and only once,
  - e.g. RD curves shift in a parallel fashion,
- ...firm i's profit maximization problem can be expressed as

$$\max_p \pi_i\,(p,t)\,.$$

Optimal Supply Function



Source: Frank Wolak

Model Description III

- Differentiating profits w.r.t. p yields the FOC:

$$\frac{dq_j}{dp} = \frac{q_i}{p - C'(q_i)} + D_p$$

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- Supply functions must be non-decreasing, so that $\frac{dq}{dp} \in (0, \infty)$, or

$$C'(q) < p < C'(q) - \frac{q}{D_p}$$

Results I

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Bounds:

- Perfectly competitive price: $p = C'(q)$
- Cournot price: $p = C'(q) - \frac{q}{D_p}$
  - If firm j has an unresponsive output k_j:

$$\pi_i(p, t) = p\left[D(p,t) - k_j\right] - C_i\left(D(p,t) - k_j\right).$$

$$FOC : q_i + \left[p - C'(q_i)\right] D_p = 0 \Rightarrow p = C'(q) - \frac{q}{D_p}$$

Results II

- For a given price, there is **continuum of possible supply functions** supporting it.
  - If **demand is certain** (i.e., no demand variation), each firm's residual demand is also certain. Thus, there is a single price-quantity pair that max. its profits.
  - Hence, **whatever supply function passing through it, is ex-post optimal** as all other points in its supply function will not be reached in equilibrium.

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  - If **demand can be arbitrarily high** with some probability (i.e. if the support of the random variable is unbounded), there is a **unique equilibrium.**
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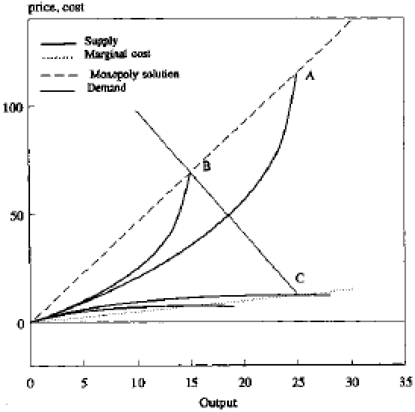
  - If **demand can be arbitrarily high** with some probability (i.e. if the support of the random variable is unbounded), there is a **unique equilibrium.**
    - As the FOC has to be satisfied at infinitely many points, there is only one such supply function passing through them all.
  - In all intermediate case, there is a **connected set of equilibria** lying between the perfectly competitive and the Cournot solutions.
  - Some authors restrict attention to **linear supply functions**, $S(p) = A - bp$, as there is a unique equilibrium in linear functions- intuition: there is unique line connecting (at least) two ex-post price-quantity pairs.

Feasible Supply Function Equilibria



Source: Green and Newbery (JPE, 1992)

Discussion

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- If the (short-run) elasticity of **demand for electricity is zero** then the model has no solution in the sense that the Cournot solution is undefined.
- The assumption that generators submit **continuously differentiable supply functions** is contrary to reality:
  - Original market design in England and Wales: generators were allowed to submit up to three incremental prices per unit
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- The assumption that generators submit **continuously differentiable supply functions** is contrary to reality:
  - Original market design in England and Wales: generators were allowed to submit up to three incremental prices per unit
  - Spain: firms are allowed to submit up to 25 price-quantity pairs per unit.
- Further, this assumption yields equilibria which do not exist in models in which **generating units are discrete...**

Main References

- Akgün, U. (2004) "Mergers with Supply Functions," *Journal of Industrial Economics*, 52(4).
- Baldwick et al. (2004) "Theory and Application of Linear Supply Function Equilibrium in Electricity Markets," *Journal of Regulatory Economics*, 25.
- Delgado, J. (2006) "Coalition-proof supply function equilibria under capacity constraints," *Economic Theory* 29(1), 219-229.
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- (fixed) capacity constraints k (extension to endogenous capacities)
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Bids

- each supplier makes one bid (b_1, b_2) (extension to multi-units)
- constrained by "market reserve price" P

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Price formation

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- both firms are paid at the highest accepted bid ("System Marginal Price")

$$p^* = \begin{cases} b_j & \text{if } b_i \leq b_j \text{ and } \theta > k_i \\ b_i & \text{otherwise} \end{cases}$$

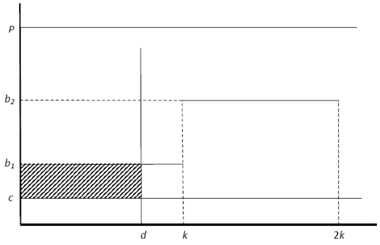

Figure 1: Low demand $\theta < k$

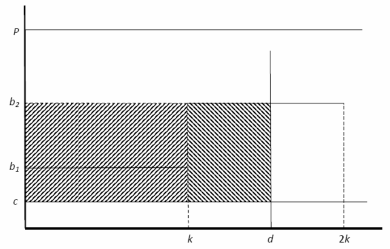

Figure 2: High demand $\theta > k$

Equilibrium prices and profits

Proposition

(i) (Low demand) if $\theta \leq k$*, in the unique pure-strategy equilibrium the highest accepted price offer equals* c *and suppliers make no profits.*

(ii) (High demand) if $\theta > k$*, in any pure-strategy equilibrium one firm bids at* P *whereas the rival submits bids no greater than* $c + [P - c][\theta - k]/\theta$*. The high-bidding supplier makes profits* $[P - c][\theta - k]$ *whereas the low-bidding supplier makes profits* $[P - c]k$*.*

Equilibrium prices

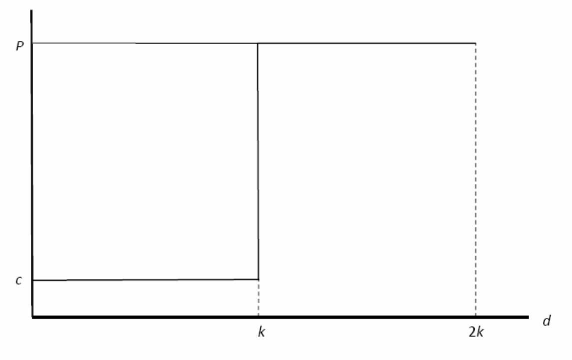

Figure 3: Equilibrium prices as a function of demand

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- On $(\underline{b}, P)$, the net gain from raising the bid must be zero:

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- *Price effect*: increasing the bid increases profits if the rival bids below, $F(b)[\theta - k]$, but
- *Quantity effect*: reduces the prob. of selling at capacity instead of residual demand, $-f(b)(b-c)[k-(\theta-k)]$.

Mixed Strategy Equilibrium

- We need to solve a differential equation:

$$F(b)\left[\theta - k\right] - f(b)(b - c)\left[k - (\theta - k)\right] = 0$$

- The above expression may alternatively be written:

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$$F(P) = \widehat{A}\,(b-c)^{\frac{\theta-k}{2k-\theta}} = 1$$

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- Equilibrium profits become: $\pi=\left(P-c\right)\left[\theta-k\right]$

Empirical Evidence: UK Pool

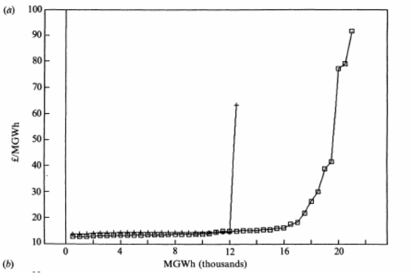

Figure 4: Low demand

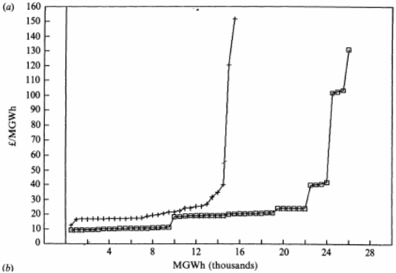

Figure 5: High demand

Source: von der Fehr and Harbord (EJ, 1993)

Asymmetric Capacities and Symmetric Costs

- Assume (possibly) asymmetric capacities $k_1 \geq k_2$ [firm 1 large]

Proposition

(i) (Low demand) if $\theta \leq k_2$, in the unique pure-strategy equilibrium the highest accepted price offer equals c and suppliers make no profits.

(ii) (High demand)

Region I: if $k_2 < \theta \leq k_1$, firm 1 bids at P whereas firm 2 submits bids no greater than $P \left[\theta - k_2\right] / \theta$.

Region II: if $\theta > k_1$, in any pure-strategy equilibrium firm $i = 1, 2$ bids at P whereas firm j submits bids no greater than $P \left[\theta - k_j\right] / \theta$.

Comparative Statics: Effects on Revenues

Symmetric costs and uniformly distributed demand

- Increasing capacity asymmetry

k_1	.5	.6	.7	.8	.9	1
k_2	.5	.4	.3	.2	.1	0
$E[R]$	.375	.420	.455	.480	.495	.5

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- Increasing aggregate capacity (symmetric capacities)

K	1	1.2	1.4	1.6	1.8	2
$E[R]$	.375	.320	.255	.180	.095	0

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- Reducing the price-cap P

P	1	.9	0.75	.5	.25	0
$E[R]$	.375	.334	.281	.188	.094	0

Symmetric Oligopoly

- Increasing the **number of (symmetric) firms** has a **pro-competitive effect**: the residual demand faced by any individual firm is smaller and hence the boundary between low and high demand realisations increases $[\widehat{\theta} = [N-1]\, K \,/\, N]$.
- With **multi-unit generators**, prices will tend to be higher than in the model in which these same units act independently.

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  - A generator which controls many units will internalize part of this externality and will thus have an greater incentive to increase its prices the more owner controls.
- The SMP will be a decreasing function of the number of owners, i.e. the industry concentration ratio.

The Number of (symmetric) Firms

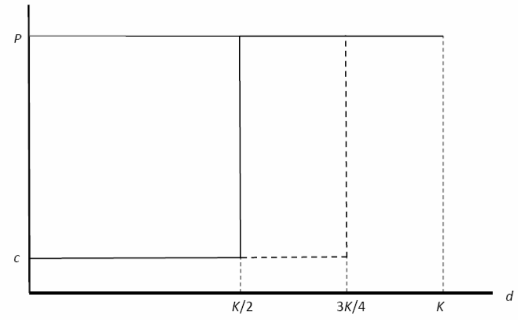

Figure 6: Equilibrium prices: two symmetric firms versus four symmetric firms

A Tale of Two States

Low demand (all but one supplier can cover demand)

- price at (constrained by) (marginal) cost
- (productive efficiency)

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High demand (all suppliers needed to cover demand)

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- price constrained by reserve price only
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- price constrained by reserve price only
- (potential productive inefficiency)

Relative incidence of low-demand states:

- aggregate capacity (for given relative capacities across firms)
- number of firms
- symmetry in capacities (if symmetric costs)
- asymmetry in costs (if symmetric capacities)
- the price-cap P

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