The Supply Function Equilibrium and its Policy Implications for Wholesale Electricity Markets

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- Use of market power in theory and practice
- Examples
- Two market designs

Wholesale electricity market

- Producers sell electricity to retailers and large consumers.
- Production costs are well-known (≈ common knowledge)
- Few producers in the market => Market power
- Many consumers/retailers in the market => ≈Price takers
- Demand is very inelastic (not very price sensitive)

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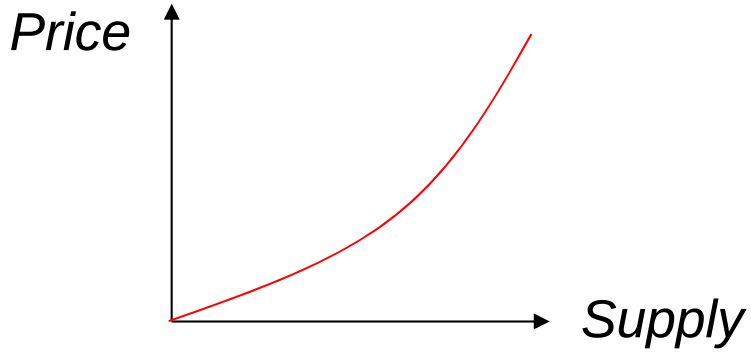
Reverse auction

Producers sell output in a multi-unit/divisible good auction.

Producers submit offers to this auction where they commit to supply functions. Demand is uncertain when offers are submitted.



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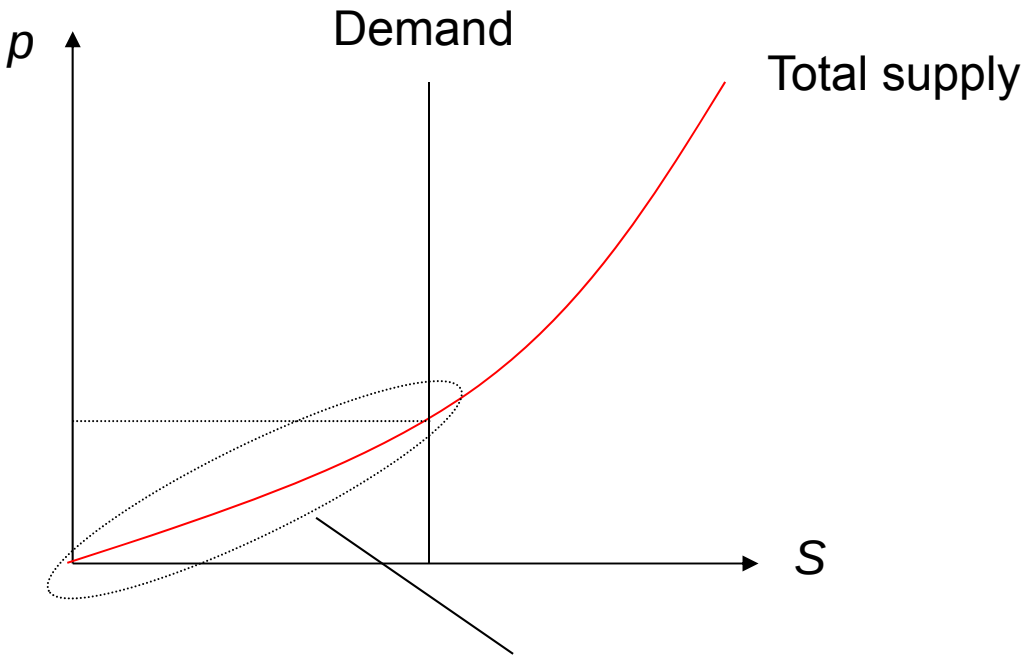
Two market designs



Uniform-price: All accepted bids are paid the highest accepted bid. Used in most electricity markets

Pay-as-bid: Accepted bids are paid their bid. Used in Britain, Iran and Italy, and in Nordic counter-trading.

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Price cap (maximum price)

Imperfections with electricity:

* Consumers do not have full control of their electricity consumption =>
We cannot always turn off electricity when the price becomes too high. =>
Someone has to switch them off if the price becomes too high on average.

* In competitive markets, optimal price cap = VOLL (value of lost load)

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Game theory

Game: A situation where a group of agents' payoffs are influenced by other members' decisions.

Nash equilibrium: Each agent chooses the strategy that maximizes its payoff given strategies chosen by competitors.

In practice agents may need to play the game a couple of times before the game reaches a Nash equilibrium (learning).

Game theory tends to work relatively well when applied to auctions, as the strategy (make a bid) and the market process is well-defined.

Pure strategy equilibrium: Agents use deterministic strategies

Mixed strategy equilibrium: Agents use randomized strategies (stone, scissor and paper).

The supply function equilibrium (SFE)

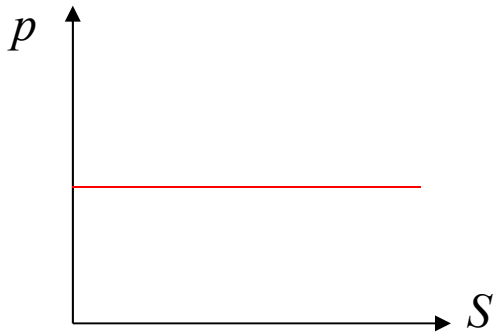
Strategy: Choose a supply curve.

Behavioural assumption: Each producer chooses its supply curve to maximize its expected profit.

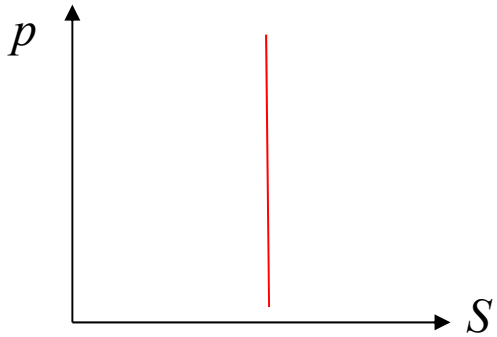
Nash equilibrium: every producer chooses a supply curve that maximizes its expected profit given competitors' supply curves and properties of the uncertain demand. Equilibrium is called Supply Function Equilibrium (SFE).

Introduced for uniform-price auctions by Klemperer & Meyer (1989). First application to electricity market by Green & Newbery (1992). Wang & Zender (2002) use the same model to analyse bidding strategies in treasury auctions.

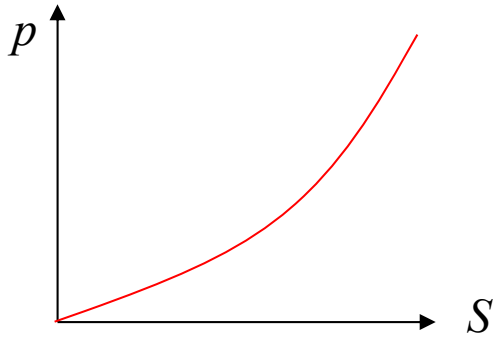
SFE is a generalization of Bertrand and Cournot



Bertrand NE: Best price given competitors' bids. Certain demand



Cournot NE: Best supply given competitors' bids. Certain demand



SFE: Best supply curve given competitors' bid curves. Uncertain demand

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Brief theory

Choose an optimal curve to maximize the expected profit=> Calculus of Variation/Optimal Control problem.

For wholesale markets with uniform price it can be shown that the optimal offer of one firm is given by:

$$S_i(p) - \sum_{j \neq i} S_j'(p)\left[p - C'\left(S_i(p)\right)\right] = 0$$

$\Rightarrow$ System of ODE (one for each firm).

The optimal supply curve maximizes profit for each demand outcome => The optimal supply curve does not depend on the probability density of the demand.

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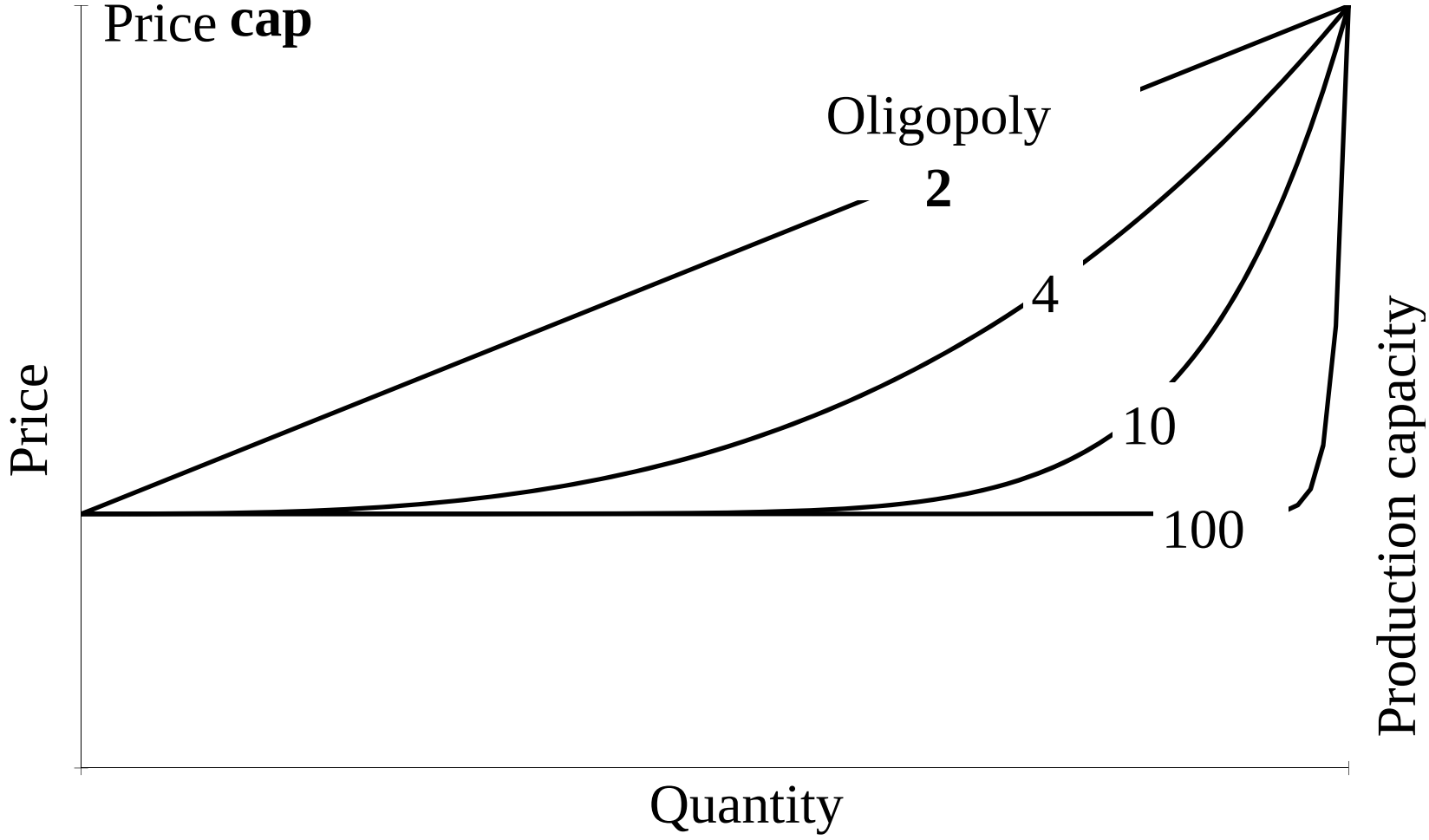
Example: Symmetric firms with constant MC



Holmberg (2008)

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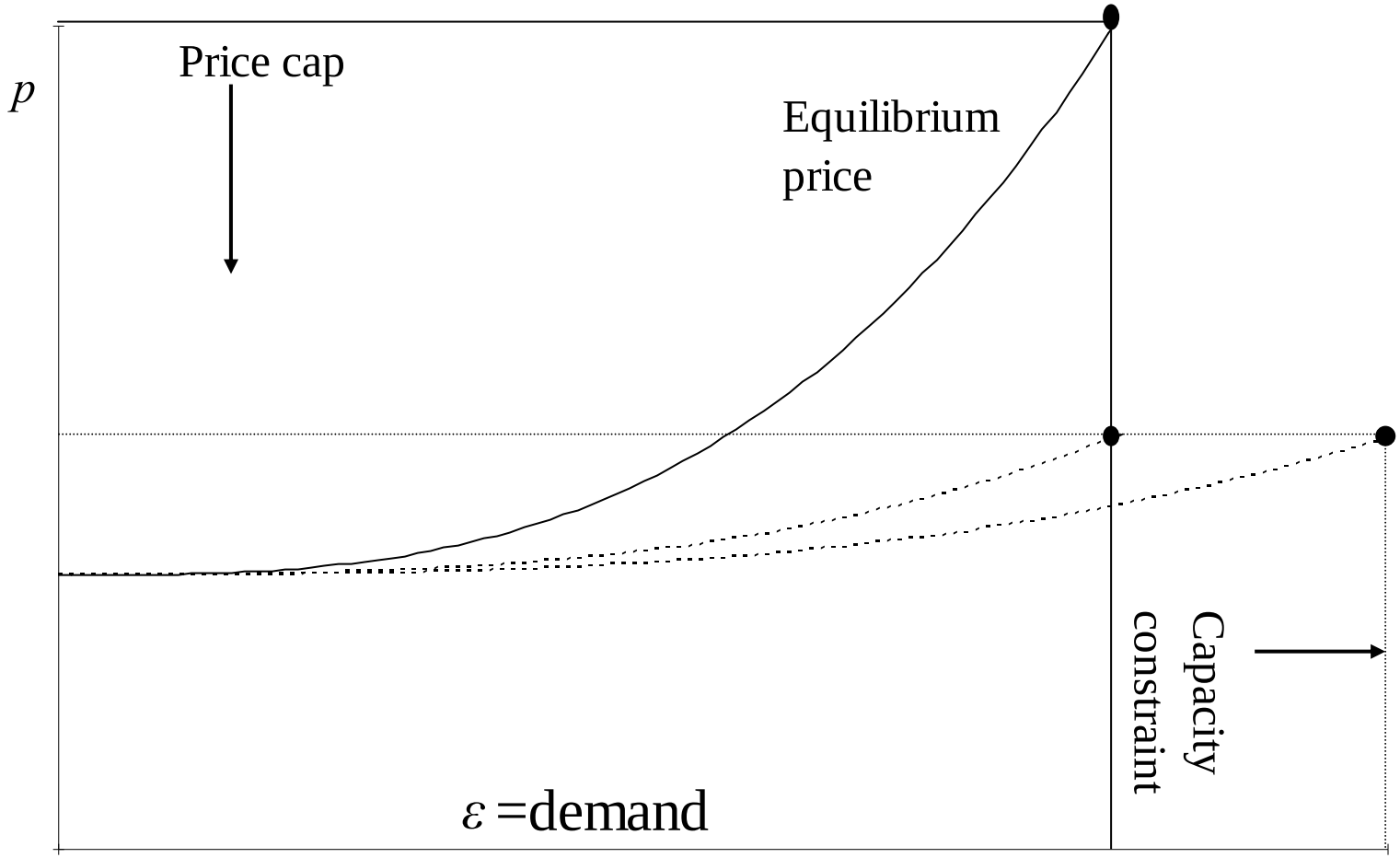
The price caps influence on market prices



A lower price cap reduces the price but also reduces investments.

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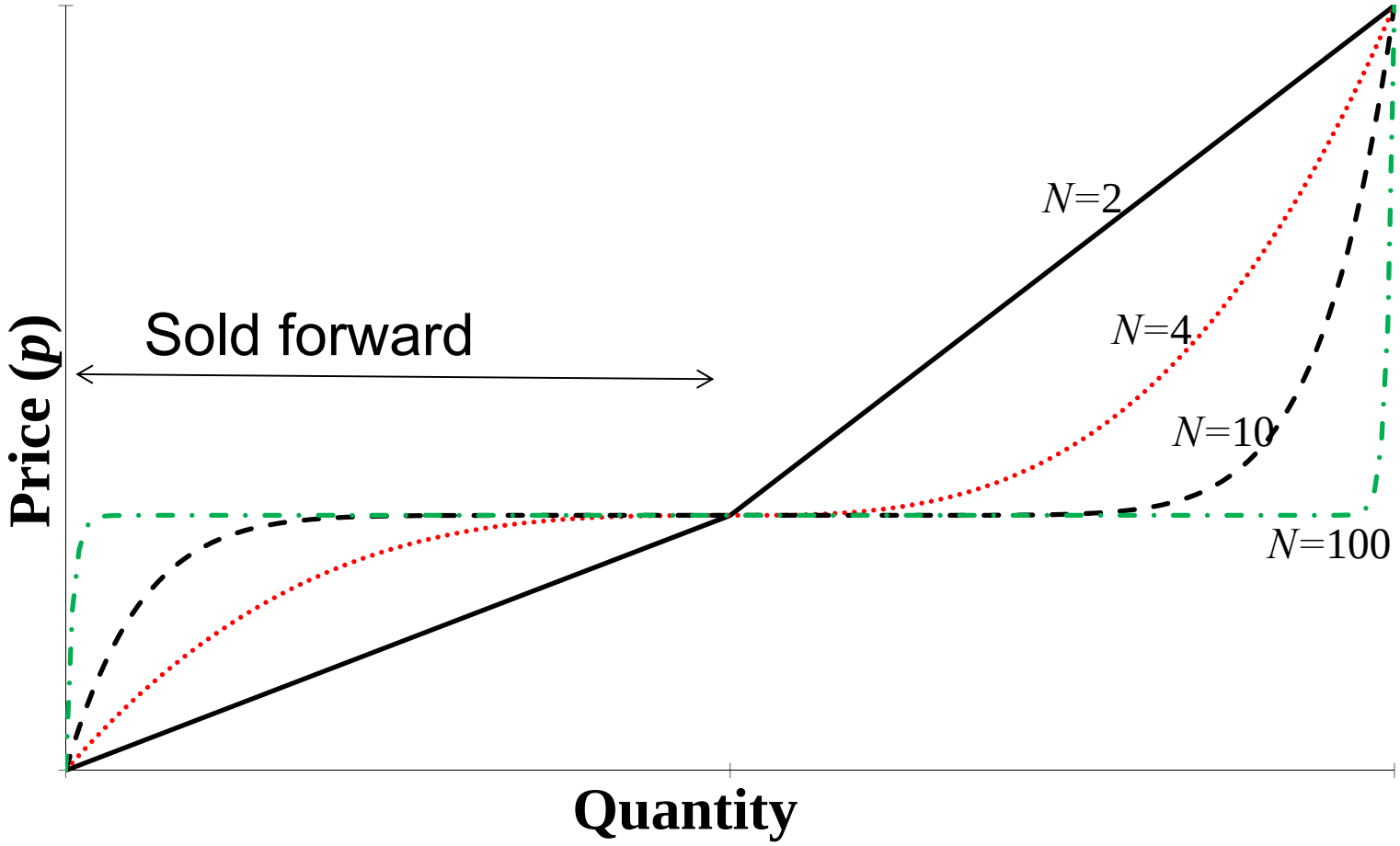
Same example with contracts



Forward sales make markets more competitive

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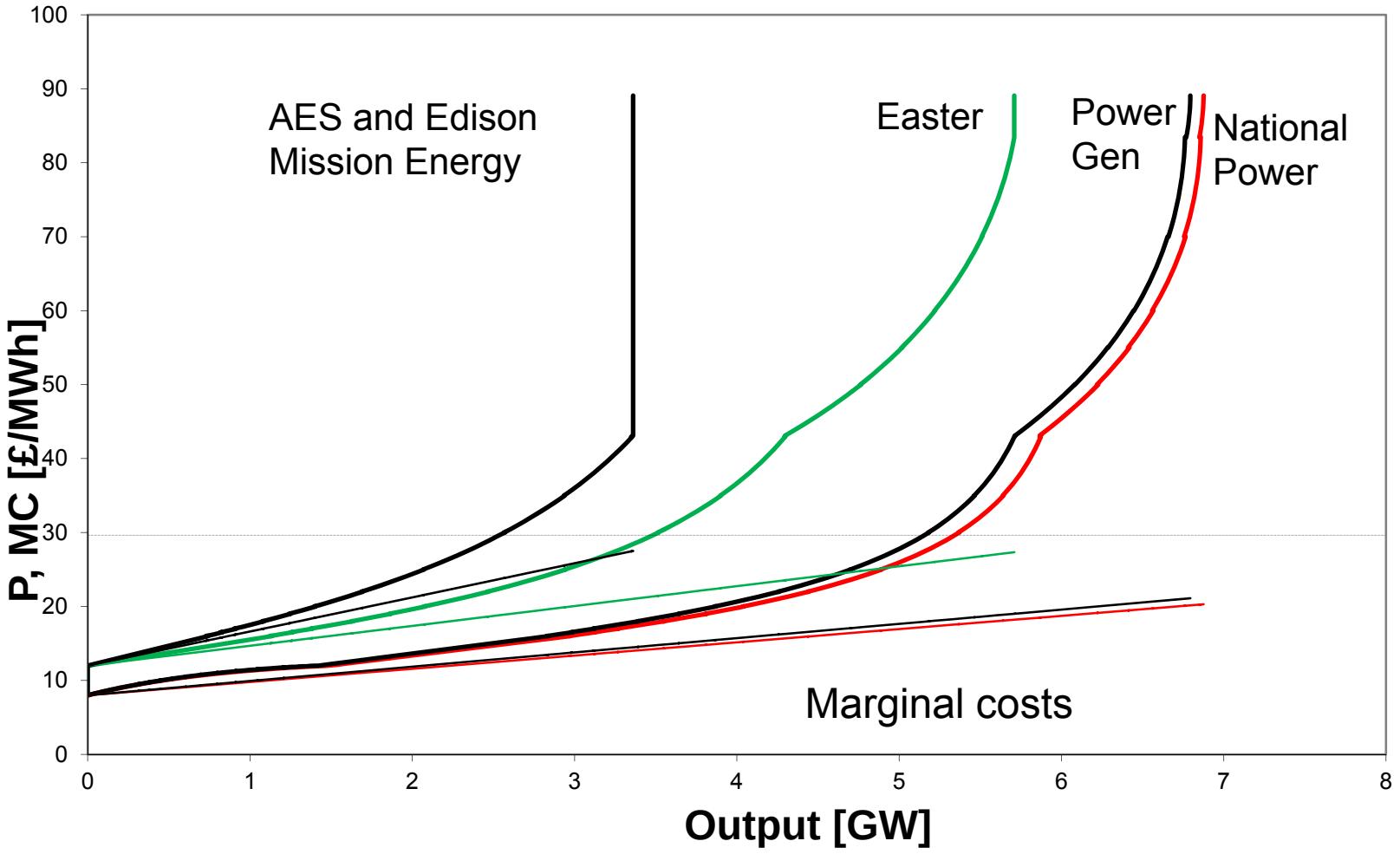
Example from Britain 1999



Anderson & Hu (2008) and Holmberg (2009)

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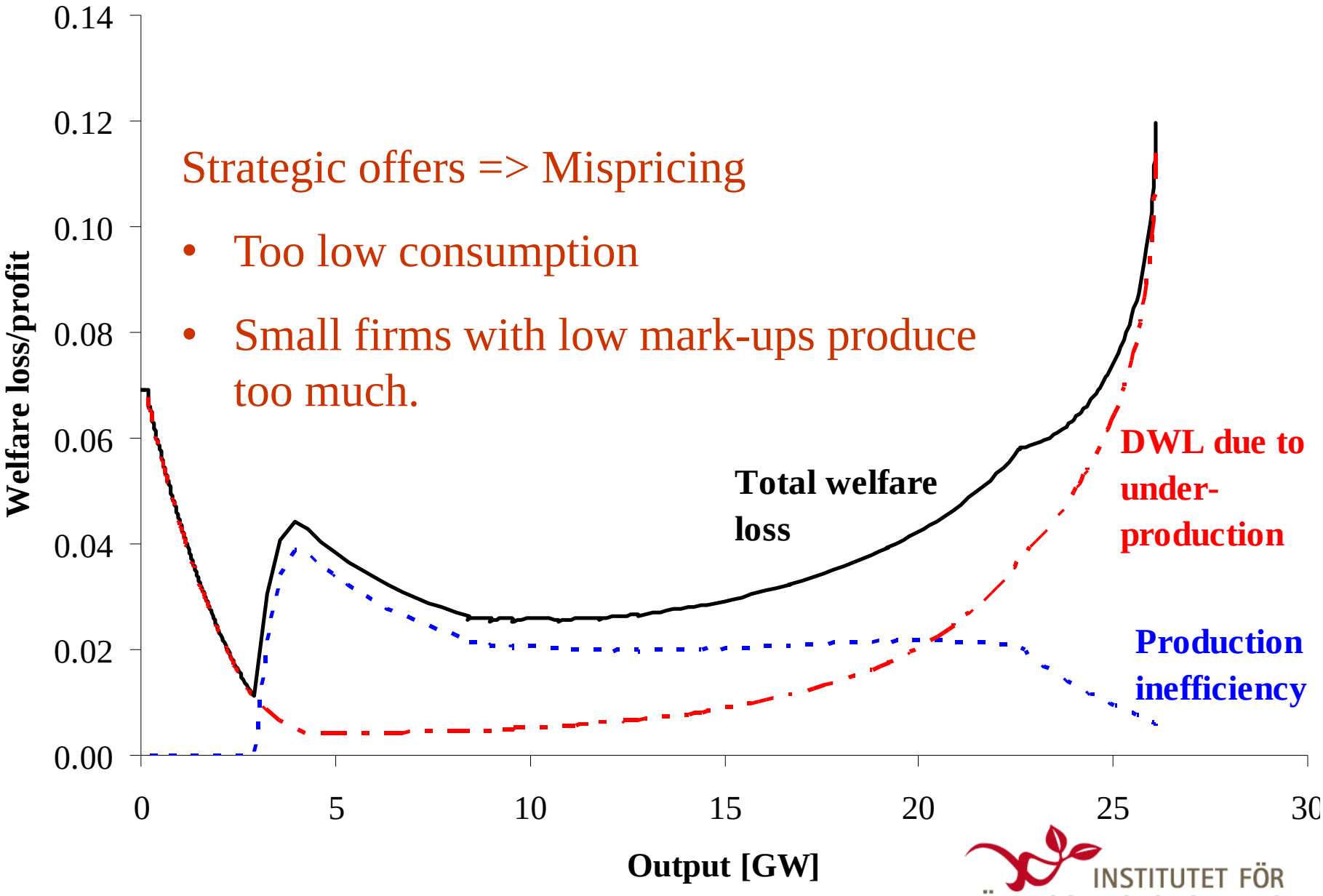
Inefficiency in British simulation



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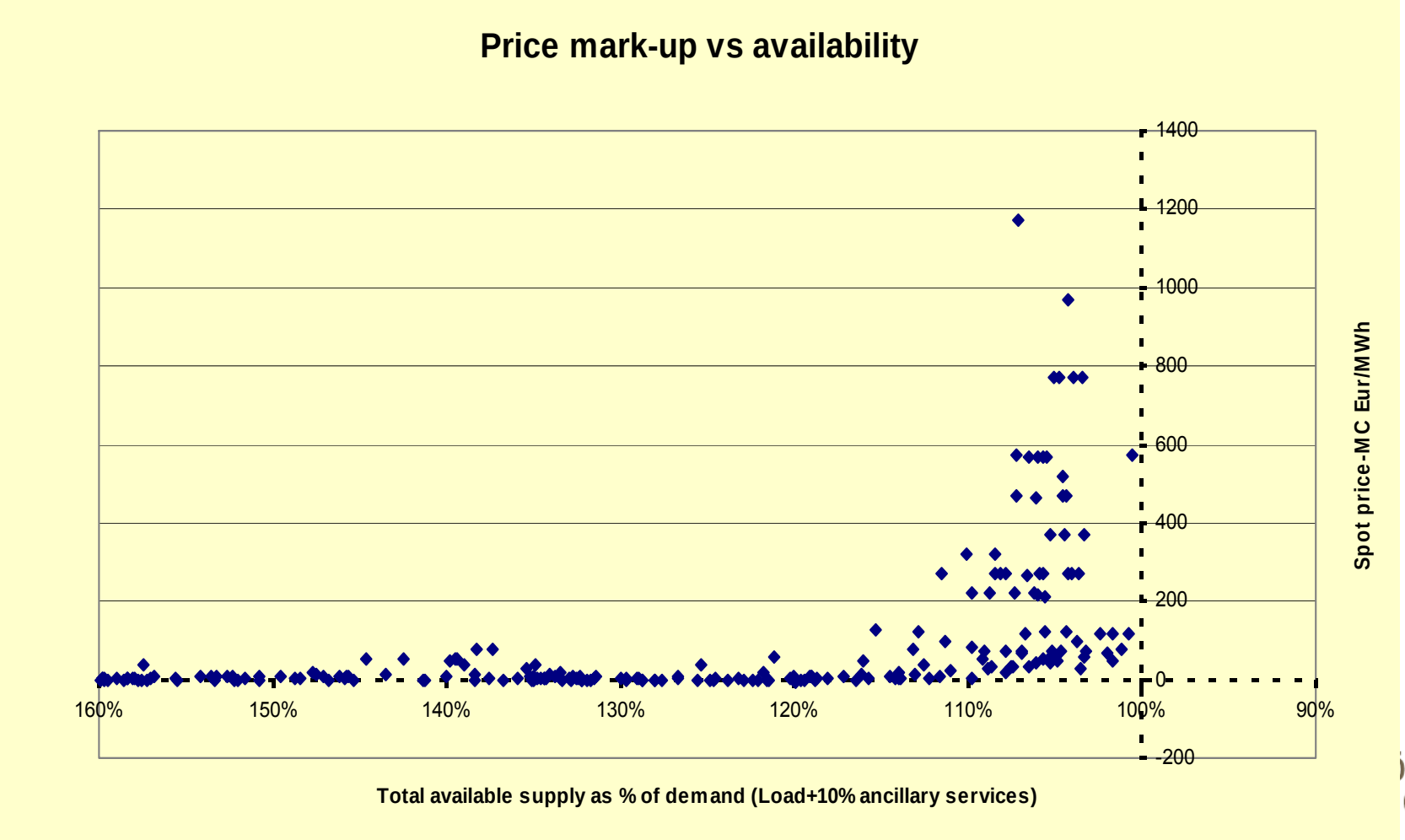
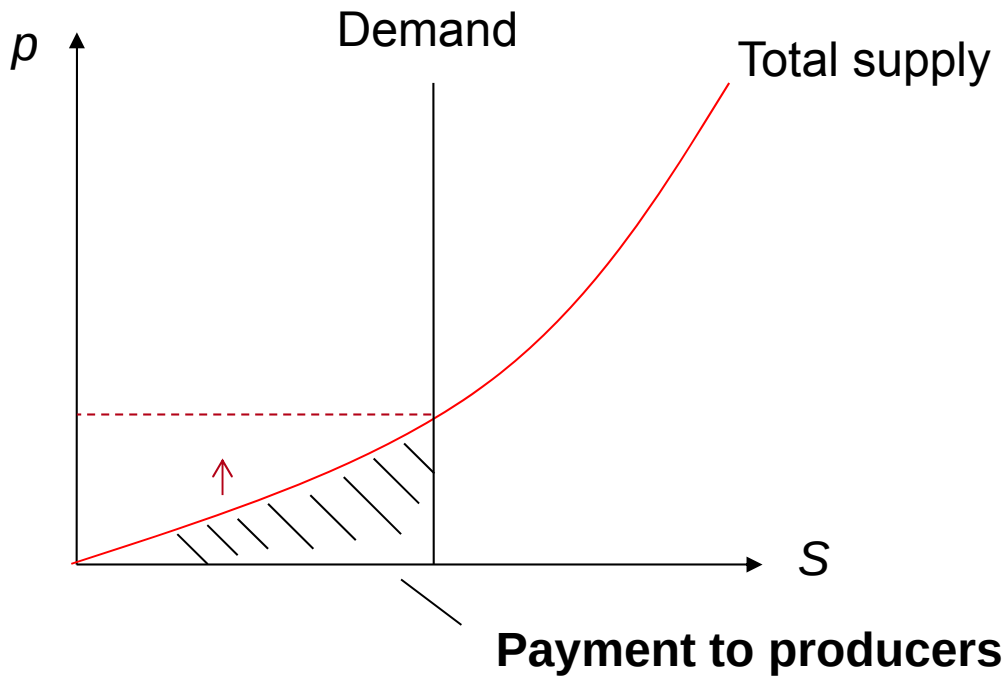
Strategic bidding in practice

Market data => Large producers in Texas (Hortacsu and Puller, 2008; Sioshansi and Oren, 2007) and Australia (Wolak, 2003) bid roughly as predicted by theory. Example from Europe below:



The pay-as-bid auction



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First-order condition for pay-as-bid

Each unit has an individual price => This price is chosen to maximize the expected profit from the unit. Let *F* and *f* be probability distribution and probability density of the demand shock, respectively. Pure-strategies=>

$$\underbrace{1-F\left[S_{-i}(p)+S_i\right]}-\underbrace{\left(p-C'(S_i)\right)\left(S_{-i}'(p)-D'\right)f\left[S_{-i}(p)+S_i\right]}=0.$$

”Marginal revenue” of increasing offer =Acceptance probability:

”Marginal cost” of increasing offer is proportional to mark-up, slope of residual demand and probability density.

Holmberg (2009)

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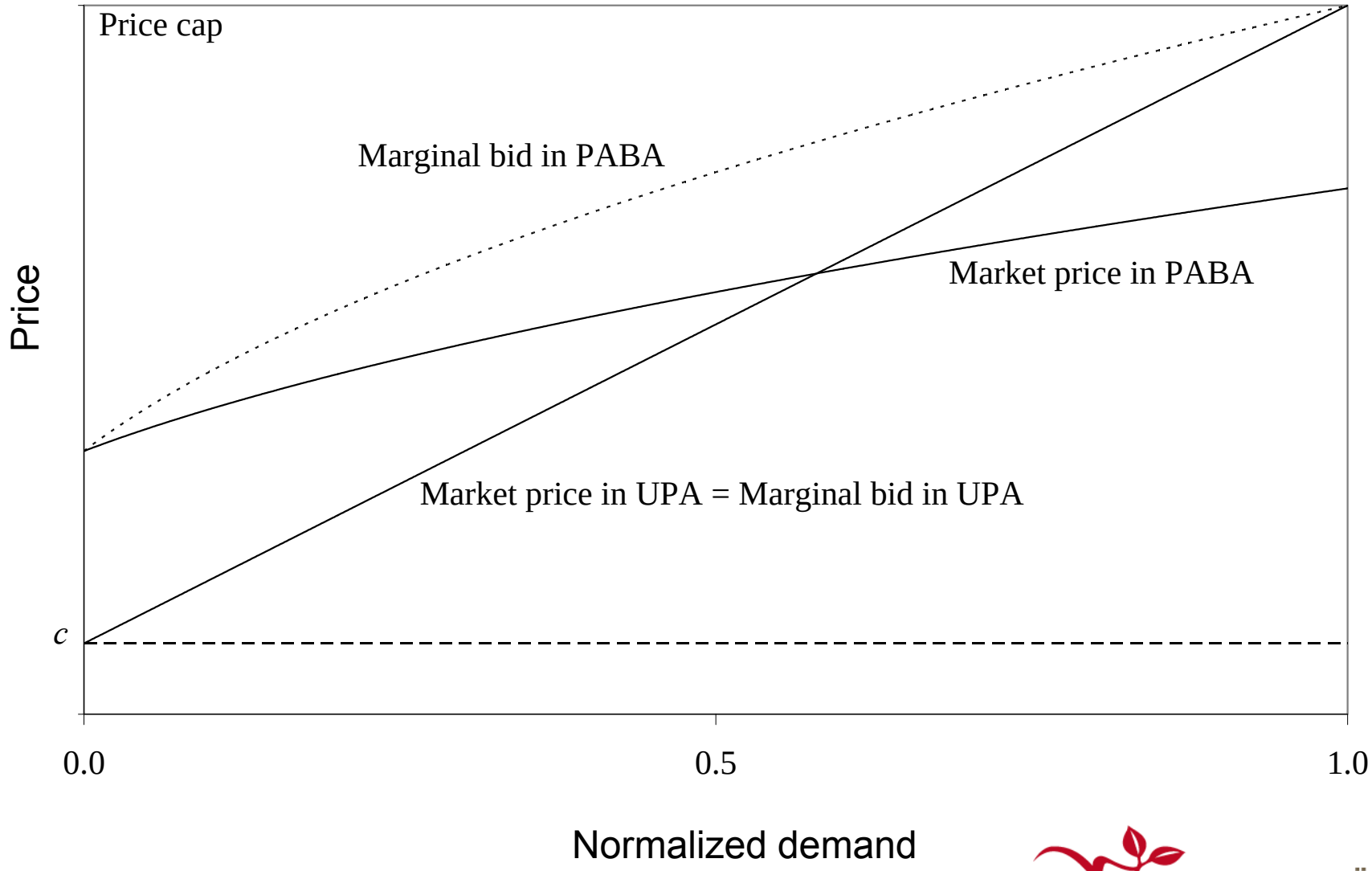
Comparing pay-as-bid (PABA) and uniform-price auctions (UPA)



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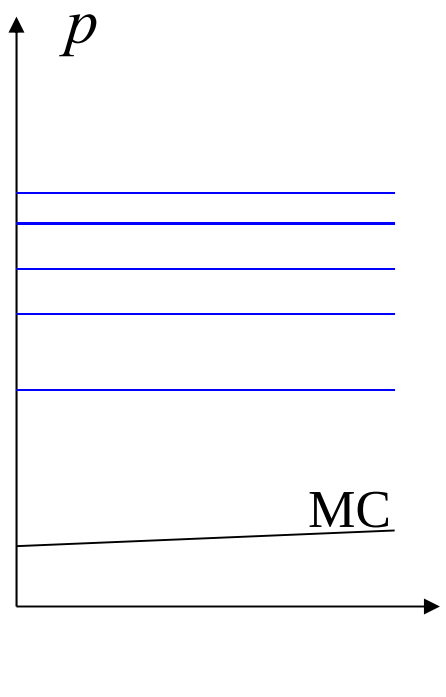
Different Pay-as-bid equilibria

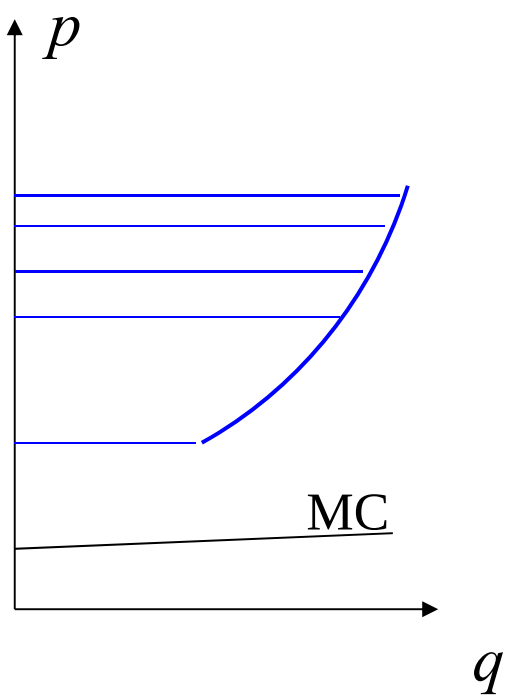
=> character depend on probability density, costs and price cap

High *(p-C')/C"*=>
Horizontal mixture



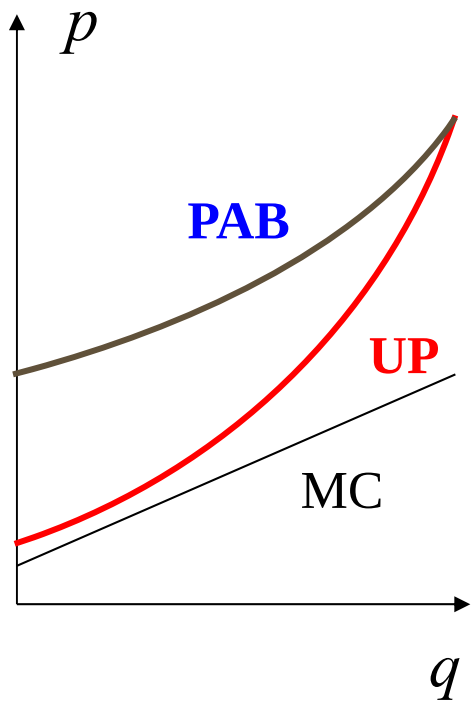
Bertrand-Edgeworth with demand uncertainty
Fabra et al; Genc; Anderson et al.

Medium *(p-C')/C"*
=> Hockey-stick mixture



Anderson et al (2009)

Low *(p-C')/C"*
=> Pure strategy NE



Holmberg (2009)

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Pay-as-bid vs uniform auctions

- Ranking of auctioneer revenues uncertain if cost are uncertain (Ausubel & Cramton, 2002)
- If costs are common knowledge, PAB preferable for auctioneer/consumers (Son et al, 2004; Fabra et al, 2006; Hästö & Holmberg, 2006)
- Experiments contradict (Rassenti et al.)
- Lower British prices after reform 2001: more capacity and divestitures, not market design (Evans and Green, 2005). No significant difference between formats in treasury auctions (Ausubel & Cramton, 2002)

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Pay-as-bid vs uniform auctions

Mixed strategies in Pay-as-bid auction increase production inefficiency and bidding is more complicated.

Each agent is selling at different prices in the pay-as-bid auction => it is difficult to standardize contracts => low turn-over in British futures market.

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Tack för uppmärksamheten!

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