Supply function equilibrium, price caps, and investment[1]

Andy Philpott
EPOC
University of Auckland.

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Motivation

- Some recent discussion on Energy News about undesirable trading situations and price spikes.
- Question: Australia has a price cap why don't we?
- Several responses to this question.
  1. What level should the cap be?
  2. Suppressing prices results in missing money.
  3. Generators just price up to the cap so prices become too high.
- Can theoretical models shed some light on this?

Overview of talk

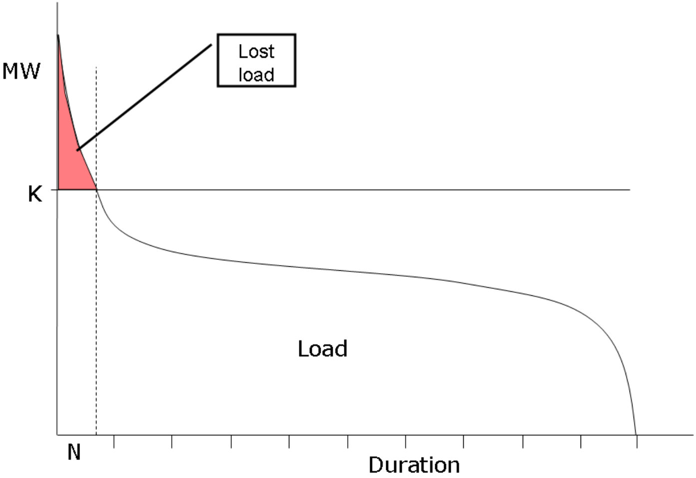
- Some simple theory for competitive electricity markets (taken almost verbatim from Stoft's book).
- The theoretical reason for price caps in pool markets.
- Price caps and market power: some supply function models.
- Conclusions

The theory according to Steven Stoft
(Power System Economics, 2002, p 15)

There are two demand-side flaws in electricity markets:

1. Lack of real-time metering and billing.
   - No customer response to high prices in real time.
2. Lack of real-time control of power flow to specific customers.
   - No market for reliability.

Excess inelastic demand leads to rationed supply



The installed capacity K is not sufficient to meet demand in N trading periods per year. There is “lost load”.

The value of lost load (VOLL)

Consumers cannot respond to high prices in real time. If prices are very high then consumers buy when they would have chosen otherwise. It is welfare enhancing to disconnect them at the threshhold price

VOLL= "value of lost load"

VOLL price caps are optimal

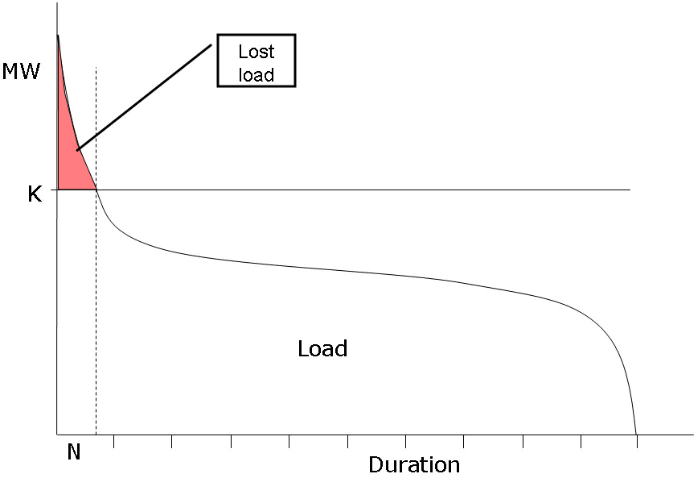
If it were possible to estimate VOLL accurately then setting a price cap P at VOLL would be a long-run equilibrium. Suppose demand exceeds plant capacity K for N hours per year. Let

$$\begin{aligned} f &= \text{the fuel cost (SRMC) at capacity (\$/MWh);} \\ C_K &= \text{the risk-adjusted annual amortized} \\ &\quad\ \text{capital cost of a peaking plant (\$/MW);} \end{aligned}$$

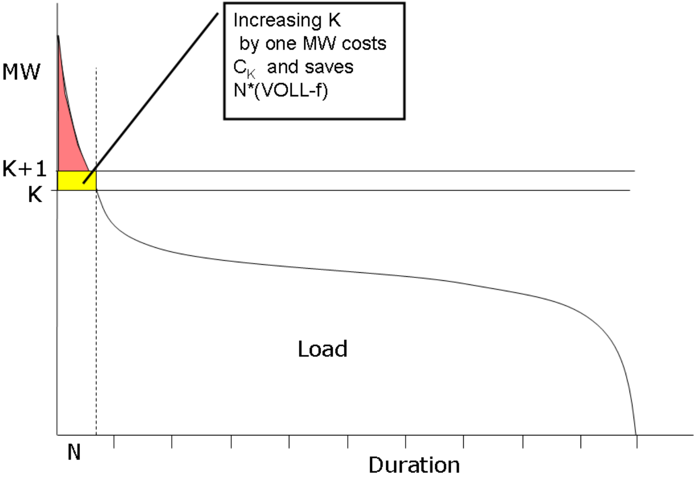
Then we get a fundamental optimality condition:

$$N * (P - f) = C_K$$

VOLL price caps are optimal



VOLL price caps are optimal



What is the actual value of lost load?

In practice, value of lost load is very difficult to estimate.

- The SPD software in New Zealand has a cap of \$100,000/MWh at which infeasibility is declared.
- Regulators in Australia have set a price cap of \$12,500/MWh.
    - (though Greg Houston said on Energy News that VOLL is more like \$50,000/MWh)
- The ERCOT market in Texas has a price cap of \$3000/MWh, but is currently looking at \$9000/MWh.

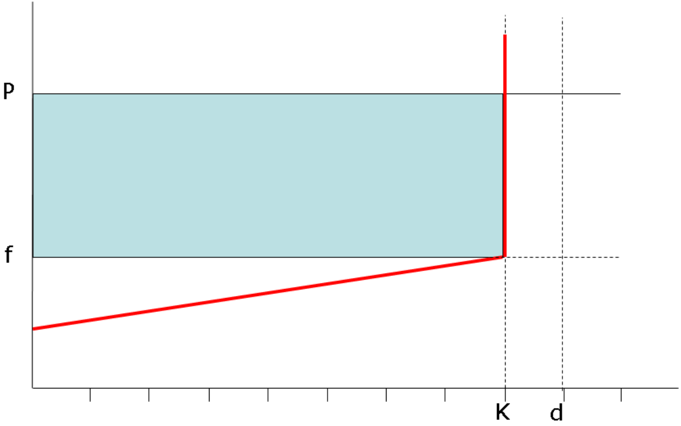
Choosing a cap value P determines system reliability

If the regulator sets a price cap P that is not equal to VOLL then in the absence of other policy settings, it is making a long-run reliability decision. The value P determines number of outage periods

$$N = \frac{C_K}{P - f}$$

1. If the cap P is high then N (number of shortages) in equilibrium will be small. Isn't small N a good thing? Yes, but it comes at a price of too much investment/entry/profit in equilibrium.
2. If the cap P is low then N (number of shortages) in equilibrium will be large. Large N is bad if consumers wish to have more reliability. The regulator must either increase P or pay generators a capacity payment to bring N down.

Competitive pricing with a VOLL cap can earn LRMC



Demand bigger than K occurs N hours per year. Each hour the generator earns a shortage rent of $(P - f)K$. In equilibrium the annual rent $N(P - f)K$ should cover the annual fixed cost.

The LRMC fallacy

"Competitive pricing causes a capacity shortage so short-term exercise of market power is necessary for generators to recover LRMC."

Where does this fallacy come from?

It is often said that the market price should never exceed the highest SRMC in the merit order. If this is the case then a peaking plant will not cover its fixed cost. Hence the perceived need for market power.

But a price cap P that exceeds SRMC can provide competitive rentals during shortages that covers fixed costs. Higher P gives higher reliability. The problem is that many want P to be lower to suppress prices.

A lower choice of P with high reliability concedes that LRMC recovery needs either capacity payments or market power, otherwise there is *missing money*.

Possible solutions to the missing money problem

$$N = \frac{C_K}{P - f}$$

1. Have no cap at all and rely on other forces (e.g. market entry) to limit market power.
2. Choose a low cap P and require a reserve margin at dispatch, so prices hit P whenever the margin is invaded.
3. Choose a low cap P and buy capacity in a separate market (*capacity market*).
4. Choose a high cap P and try and control market power somehow.

How do price caps change offer behaviour?

It depends on how much uncertainty there is.

1. When demand is almost certain, then we see Cournot-type equilibrium.
2. When demand is sufficiently uncertain, then we see supply-function equilibrium (Klemperer and Meyer, 1989).

These produce fundamentally different types of market outcome.

Unknown demand and supply function equilibrium

If demand is uncertain and generators offer supply curves, then outcomes can be modelled using *supply-function equilibrium* (SFE). In SFE, uncertainty in demand leads to more competitive offers than with known demand.

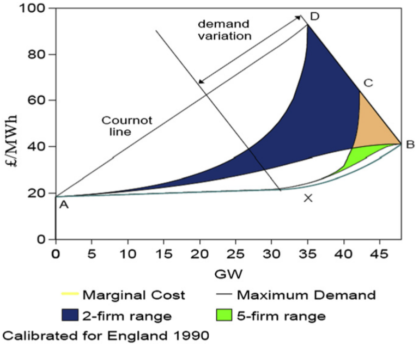
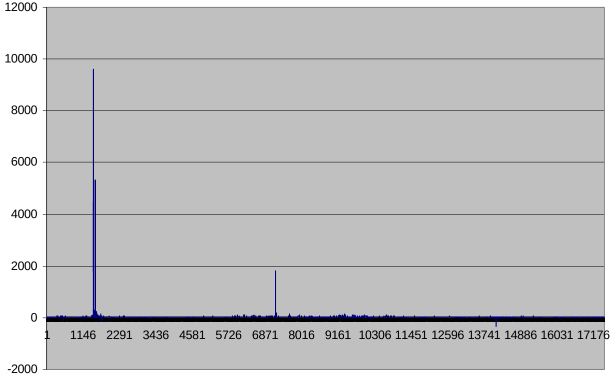


Figure 3 from Holmberg and Newbery, Utilities Policy, 2010

A common fallacy: caps provide a target for price setting

"When faced with a price cap, electricity generators just price their offers up to the price cap, giving higher prices than in the absence of a cap."

NEM Prices in VIC by half hour 2011



Half-hourly NEM prices in Victoria over 2011. Price spikes on January 31, 2011 and February 1, 2011 lasted 2 hours and 1 hour.

A theory for pricing up to the cap

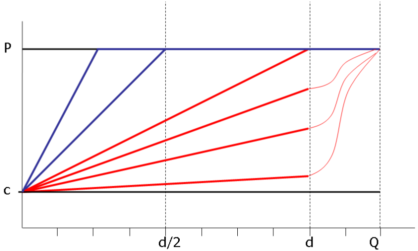
- Investigate using a simple SFE model.
- Model data
  - a cap P on prices.
  - symmetric generators with constant marginal cost c and capacity Q.
  - inelastic demand d that is random on the interval $[0, d]$.

SFE for symmetric oligopoly with d < (n-1)Q

Suppose

1. $n > 1$ identical generators with capacity Q, marginal cost c.
2. demand is inelastic and *random* on the range $[0, d]$ where $d < (n-1)Q$
3. a price cap P.

Then there are many symmetric linear supply function equilibria.



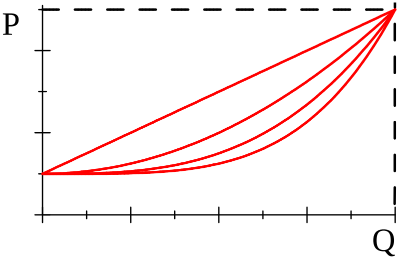
Symmetric duopoly (i.e. $n = 2$) SFE when $d < Q$. Some blue curves might not be equilibria as undercutting might be a profitable deviation.

SFE for symmetric oligopoly with d > nQ
[Holmberg, 2005]

Suppose

1. $n > 1$ identical generators with capacity Q, marginal cost c.
2. demand X is inelastic and random on the range $[0, d]$ with $\Pr(X > nQ) > 0$.
3. a price cap P.

Then there is a *unique* SFE $T(q) = c + (P - c)\left(\frac{q}{Q}\right)^{n-1}$

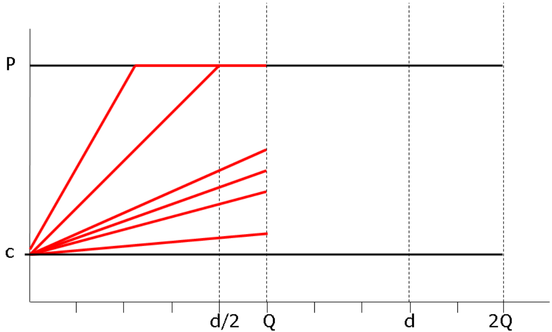


What about SFE with (n-1)Q $<$ d $<$ nQ?

- A generator is *pivotal* if demand cannot be met by all other generators operating at capacity.
- When demand is uncertain we might say a generator is pivotal "under demand realization x" or a generator is pivotal "with *positive probability*".
- (Definitions become "*net pivotal*" if we account for load obligations and contracts.)

Symmetric duopoly with a pivotal generator
[Genc and Reynolds, 2010]

Duopoly gives linear candidate SFE



Red curves satisfy Klemperer-Meyer necessary conditions for SFE.
Some curves might not be SFE.

Expected profit with a pivotal generator

Suppose demand is uniformly distributed on $[0, d]$. Expected profit of the curve through $(\frac{d}{2}, \bar{p})$ is

$$\begin{aligned} \mathbb{E}[\pi] &= \int_{x=0}^{x=d} (p(x) - c)q(x)\frac{1}{d}dx \\ &= \int_{x=0}^{x=d} \frac{x(\bar{p} - c)}{d}\frac{x}{2}\frac{1}{d}dx \\ &= \frac{d}{6}(\bar{p} - c) \end{aligned}$$

Lowest expected profit with a pivotal generator

Suppose $\bar{p} = c$, so player 2 offers $d/2$ at marginal cost c. The expected profit from player 1 offering $d/2$ at c is zero. The expected profit of player 1 offering capacity Q at P is

$$\begin{aligned}
\mathbb{E}[\pi] &= \int_{x=Q}^{x=d} (P-c)(d-x)\frac{1}{d}dx \\
&= \frac{1}{2d}(P-c)(d-Q)^2 \\
&> 0
\end{aligned}$$

So low-priced offers are ruled out in equilibrium, by an offer at price P.

Expected profit with a pivotal generator

Expected profit of the most profitable curve through $\left(\frac{d}{2}, P\right)$ is

$$\frac{d}{6}(P - c).$$

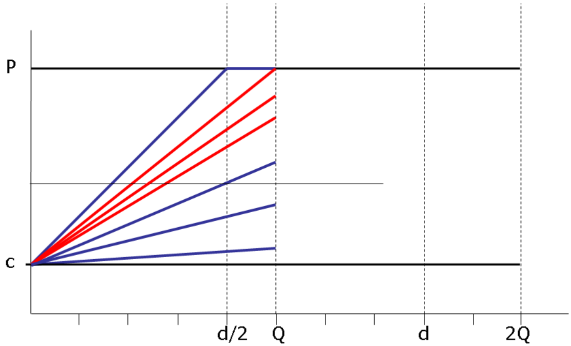
When $Q < d < 2Q$, we get

$$\frac{d}{6} > \frac{1}{2d}(d - Q)^2$$

so

$$\begin{aligned}\frac{d}{6}(P - c) &> \frac{1}{2d}(P - c)(d - Q)^2 \\ &= \text{profit from withholding}\end{aligned}$$

SFE in symmetric duopoly with pivotal generators



The red curves are SFE; the blue curves might not be, as offering at P is a profitable deviation.

Conclusions

- The NZEM needs to seriously consider a price cap to enable generators to earn LRMC in shortages.
- Supply function equilibrium models with price caps are well understood and indicate that generator gaming behaviour under uncertainty can be modelled and controlled, at least in one-shot games.
- The cap can be accompanied by discretionary intervention when generators are pivotal, or have local monopoly power.
- A cap at each node obviates the need for special attention to some specific aspects of the market e.g. spring-washer events.
- A cap enables the regulator to take a strong position about controlling short-term market power: this is not a necessary ingredient of markets to enable recovery of LRMC, but something that leads to productive and allocative inefficiency, difficulties in implementing derivative instruments, and potential lack of confidence in the market.