The "demand side" effect of price caps

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- Economic analysis of price caps (reviewed below) has sofar focussed on supply-side impact
- Including demand-side impact, in particular rationing, provides new insights for economists and policy makers

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- Extremely important results, as they provide strong justification for the use of price caps

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- The capacity maximizing cap sets the first term to zero. (Under reasonable assumptions), increasing the cap increases gross surplus when customers are rationed
- Therefore, the welfare-maximizing cap is higher than the capacity-maximizing cap (Proposition 1)

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- Empirical relevance of results illustrated on a simplified representation of the French electric power market

Overview of the talk

- Relation to the literature
- Cournot competition with uncertain demand and a price cap
- Capacity- and welfare-maximizing caps for price reactive customers
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- Numerical illustration

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  - dichotomy between "price reactive" customers and "constant price customers" was developed by Borenstein and Holland (2005) and Joskow and Tirole (2007)

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Assumption

$\forall t \geq 0$, $\forall q \leq Q$, the inverse demand $P(Q;t)$ satisfies

$$P_q(Q,t) < \min(0, -qP_{qq}(Q,t)) \text{ and } P_t(Q,t) > q\left|P_{qt}(Q,t)\right| \geq 0$$

For example $P(Q,t) = a(t) - bQ$, with $b > 0$ and $a'(t) > 0$

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- Single production technology, with marginal cost $c > 0$ and investment cost r. $P(0,t) > c$ and $\mathbb{E}[P(0,t)] > (c + r)$

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- $K = \sum_{n=1}^{N} k^n$ is aggregate installed capacity

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- $\bar{p}^W$ verifies

$$(c + r) \leq \bar{p}^W \leq p^\infty$$

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- If rationing is not perfectly anticipated, more complex (Joskow and Tirole, 2007)

Value of lost load

- When rationing occurs, the Value of Lost Load ($VoLL$) represents the value consumers would place on an extra unit

$$v\left(p,\gamma,t\right)=\frac{\frac{\partial\mathcal{S}}{\partial\gamma}}{\frac{\partial\mathcal{D}}{\partial\gamma}}\left(p,\gamma,t\right)$$

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$$v(p,\gamma,t) = \frac{\frac{\partial \mathcal{S}}{\partial \gamma}}{\frac{\partial \mathcal{D}}{\partial \gamma}}(p,\gamma,t) = \frac{S(p,t)}{D(p,t)} > p$$

Impact of price on VoLL and surplus

Assumption

The VoLL is higher than the price, and, ceteris paribus, increasing in price:

$$v(p,\gamma,t) > p \text{ and } \frac{\partial v}{\partial p} > 0$$

The total impact of an increase in price is an increase in gross consumer surplus:

$$\frac{d\mathcal{S}}{dp} = \frac{\partial \mathcal{S}}{\partial p} + \frac{\partial \mathcal{S}}{\partial \gamma}\frac{\partial \gamma^*}{\partial p} > 0$$

Holds if rationing is anticipated

$$\frac{\partial v}{\partial p} = \frac{D(p,t)\frac{\partial S(p,t)}{\partial p} - S(p,t)\frac{\partial D(p,t)}{\partial p}}{(D(p,t))^2} = \frac{p - v(p,\gamma,t)}{D(p,t)}\frac{\partial D(p,t)}{\partial p} > 0$$

Spot market equilibria without a price cap

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- The first on-peak state of the world, denoted $\hat{t}\left(K,c\right)$, is defined by

$$Q^C\left(c,\hat{t}\right)=K\Leftrightarrow P\left(Q^C\left(c,\hat{t}\right),\hat{t}\right)+\frac{Q^C}{N}\left(c,\hat{t}\right)P_q\left(Q^C\left(c,\hat{t}\right),\hat{t}\right)=c$$

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  $\hat{t}\,(K, c)$ is increasing in both arguments by inspection

- On-peak, in state $t \geq \hat{t}\,(K, c)$, firms produce at capacity, wholesale price is $P\,(K, t)$

Equilibrium investment with a price cap

The equilibrium capacity $K^C\left(\bar{p}^W\right)$ is characterized by:

$$\Psi\left(K^C, \bar{p}^W\right) = 0,$$

where $\Psi\left(K, \bar{p}^W\right)$ is defined piecewise

1. If the price cap is reached on-peak (i.e., $\hat{t}(K, c) \leq \hat{t}_0\left(K, \bar{p}^W\right)$),

$$\begin{aligned} \Psi\left(K, \bar{p}^W\right) &= \int_{\hat{t}(K,c)}^{\hat{t}_0\left(K,\bar{p}^W\right)} \left(P(K;t) + \frac{K}{N} P_q(K;t) - c\right) f(t)\, dt \\ &\quad + \int_{\hat{t}_0\left(K,\bar{p}^W\right)}^{+\infty} \left(\bar{p}^W - c\right) f(t)\, dt - r. \end{aligned}$$

2. If the price cap is reached off-peak (i.e., $\hat{t}_0\left(K, \bar{p}^W\right) < \hat{t}(K, c)$),

$$\Psi\left(K, \bar{p}^W\right) = \int_{\hat{t}_0\left(K,\bar{p}^W\right)}^{+\infty} \left(\bar{p}^W - c\right) f(t)\, dt - r.$$

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Capacity-maximizing cap

- Differentiation of first-order conditions yield:

$$\frac{dK^C}{dp} = \frac{1 - F\left(\hat{t}_0\left(K^C(p), p\right)\right) - (p-c)\, f\left(\hat{t}_0\left(K^C(p), p\right)\right)\frac{\partial \hat{t}_0}{\partial p}}{\left(-\frac{\partial \Psi}{\partial K}\right)}$$

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- Illustrates results from Earle and al. (2007) and Zöttl (2011)

Welfare-maximizing cap

Proposition

Increasing the cap from the capacity-maximizing cap always increases welfare. If $K^C(.)$ is globally concave, the unique capacity-maximizing cap is lower than the welfare-maximizing cap, which is strictly lower than p^∞.

Proof of Proposition 1

Suppose the cap is reached on-peak. Social welfare is then

$$
\begin{aligned}
W(K,p) = & \int_0^{\hat{t}(K,c)} \left(S\left(P\left(Q^C,t\right),t\right) - cQ^C \right) f(t)\,dt \\
& + \int_{\hat{t}(K,c)}^{\hat{t}_0\left(K,\bar{p}^W\right)} \left(S\left(P\left(K,t\right),t\right) - cK\right) f(t)\,dt \\
& + \int_{\hat{t}_0\left(K,\bar{p}^W\right)}^{+\infty} \left(\mathcal{S}\left(\bar{p}^W,\gamma^*,t\right) - cK\right) f(t)\,dt - rK,
\end{aligned}
$$

After manipulations

$$
\begin{aligned}
\frac{dW}{d\bar{p}^W} = & \begin{pmatrix} \int_{\hat{t}\left(K^C\left(\bar{p}^W\right),c\right)}^{\hat{t}_0\left(K^C\left(\bar{p}^W\right),\bar{p}^W\right)} -\frac{K^C}{N} P_q\left(K^C,t\right) f(t)\,dt \\ + \int_{\hat{t}_0\left(K^C\left(\bar{p}^W\right),\bar{p}^W\right)}^{+\infty} \left(v\left(\bar{p}^W,\gamma^*,t\right) - \bar{p}^W\right) f(t)\,dt \end{pmatrix} \frac{dK^C}{d\bar{p}^W} \\
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Introducing constant price customers

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$$\rho(Q;t) = P\left(\frac{Q-(1-\alpha)\mathcal{D}\left(p^R,\gamma^*;t\right)}{\alpha};t\right)$$

where γ^* is the optimal serving ratio in state t for production Q

Rationing of constant price customers absent a price cap

- Off-peak, firms play a symmetric Cournot equilibrium for residual demand $\rho(Q, t)$. On-peak, demand is equal to installed capacity K, wholesale price is $\rho(K; t)$. As long as $\rho(K; t) \leq v\left(p^R, 1; t\right)$, constant price customers are not curtailed in state t. If $\rho(K; t) > v\left(p^R, 1; t\right)$, then, $\gamma^* < 1$ is such that

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$$v\left(p^{R},\gamma^{*};t\right)=\rho\left(K;t\right)$$

- For production Q, define $\bar{t}\left(Q\right)$ by

$$\rho\left(Q;\bar{t}\right)=v\left(p^{R},1;\bar{t}\right)$$

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- The cap $\bar{p}^W$ must be lower than *VoLL* v. By contradiction, suppose $\bar{p}^W > v$. When the price reaches *VoLL*, constant price customers are rationed (on-peak). If constant price customers are further rationed when the price reaches cap:

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- The serving ratio is determined by
$$\alpha D\left(\bar{p}^W,t\right) + (1-\alpha)\,\mathcal{D}\left(p^R,\mathring{\gamma},t\right) = K$$

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- The maximum admissible cap is the smallest fixed point of $v\left(p^R, 1, \bar{t}\left(K^C\,(.)\right)\right)$:

$$\Phi = v\left(p^R, 1, \bar{t}\left(K^C\,(\Phi)\right)\right),$$

and satisfies

$$\hat{t}_0\left(K^C\,(\Phi)\,,\Phi\right) = \bar{t}\left(K^C\,(\Phi)\right)$$

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- The maximum admissible cap is Φ, is lower than or equal to p^∞

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Capacity maximizing cap with constant price customers

Proposition

Suppose

$$\rho_t\left(\alpha D\left(c+r,0\right)+\left(1-\alpha\right)D\left(p^R,0\right),0\right)>rf\left(0\right), \qquad (1)$$

and, for all $p\in\left[\left(c+r\right),\Phi\right]$,

$$2+\frac{1}{h\left(\hat{t}_0\right)}\left(\frac{f'\left(\hat{t}_0\right)}{f\left(\hat{t}_0\right)}-\frac{\rho_{t^2}}{\rho_t}\right)\left(K^C\left(p\right),p\right)>0, \qquad (2)$$

where $h\left(t\right)=\frac{f\left(t\right)}{1-F\left(t\right)}$ *is the hazard rate.*
If

$$\rho_t\left(K^C\left(\Phi\right),\hat{t}_0\left(K^C\left(\Phi\right),\Phi\right)\right)<\left(\Phi-c\right)h\left(\left(\hat{t}_0\left(K^C\left(\Phi\right),\Phi\right)\right)\right), \qquad (3)$$

there exists a unique capacity maximizing cap $\hat{p}<\Phi$.
If condition (3) *is not met, the capacity maximizing cap is* $\hat{p}=\Phi$, *the maximum admissible cap. In this case,* Φ *is also the welfare maximizing cap, and if* $\frac{\partial v}{\partial K}=0$, *equilibrium capacity is lower than if no cap was imposed.*

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  - $K^C(\Phi) \leq K^C_\infty$ also proven

Welfare with and without a cap

Proposition

If the welfare maximizing cap yields lower investment than no cap, imposing a price cap reduces welfare.

Proof.

As shown previously, introducing a cap has an impact on installed capacity and on rationing. For $K \leq K_{\infty}^{C}$*, an increase in capacity increases welfare. Second, the intuition of Proposition 1 extends to the presence of constant price customers: a cap increases rationing, hence reduces gross surplus. This then yields the result.* □

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- This specification provides an adequate representation of actual demand, while leading to closed-form expressions

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- The unique capacity-maximizing cap $\mathring{p} > (c+r)$ is

$$\mathring{p} = c + \left(\frac{a_1 r^{\frac{1}{\lambda}}}{\alpha\lambda}\right)^{\frac{\lambda}{1+\lambda}}.$$

Maximum admissible cap

- The maximum admissible cap Φ is

$$\Phi = v\left(p^R, 1, \bar{t}\left(K^C\left(\Phi\right)\right)\right) \Longleftrightarrow \Phi + \frac{a_1}{2}\left(\frac{r}{\Phi - c}\right)^{\frac{1}{\lambda}} = \frac{a_0 + p^R}{2}.$$

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- A cap is admissible if and only if

$$\mathring{p} \leq \Phi \Leftrightarrow c + \left(1 + \frac{\lambda\alpha}{2}\right)\left(\frac{a_1 r^{\frac{1}{\lambda}}}{\alpha\lambda}\right)^{\frac{\lambda}{1+\lambda}} \leq \frac{a_0 + p^R}{2}.$$

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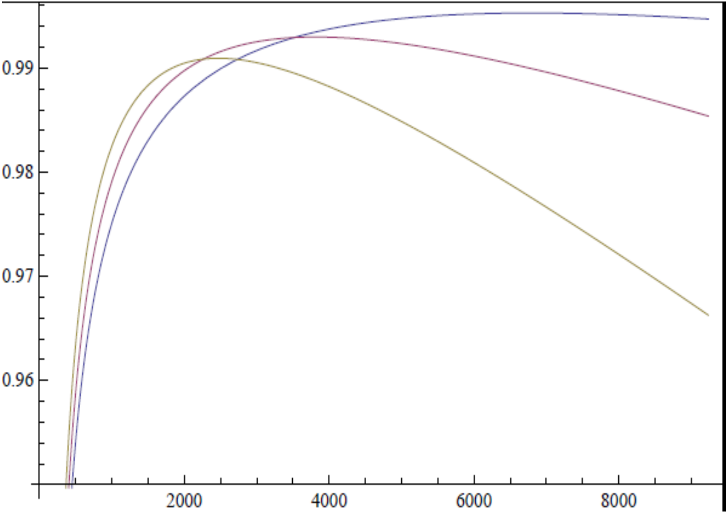
- For $N \in [6, 10]$ the price cap is reached before firms produce at capacity

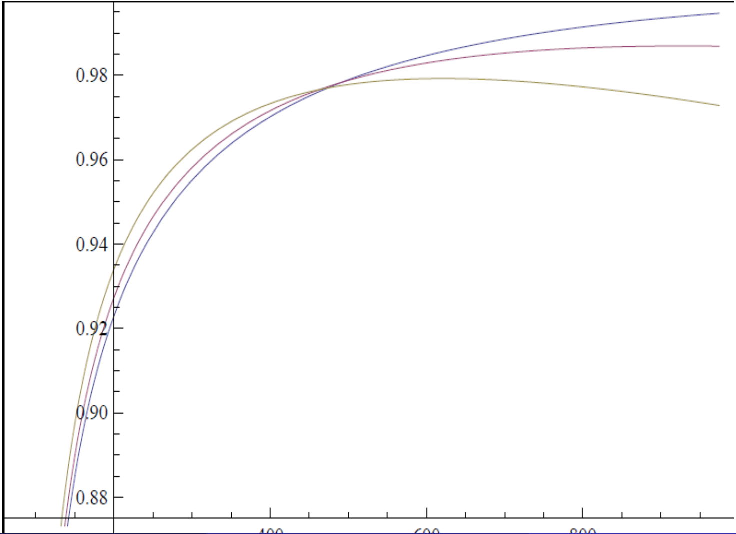
Low price elasticity

$K^C(p) / K^*(\alpha)$ for $p \in [c + r, \Phi]$ is presented below for $\alpha = 2\%$ (blue line on top), $\alpha = 5\%$ (purple line intermediate), and $\alpha = 10\%$ (brown line at the bottom)



High price elasticity

$K^C\left(\bar{p}^W\right)/K^*(\alpha)$ is presented below $\alpha = 2\%$ (blue line on top), $\alpha = 5\%$ (purple line intermediate), and $\alpha = 10\%$ (brown line at the bottom)



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- Further research: empirical analysis: other specifications for the power industry, other industries