Pricing in Crisis

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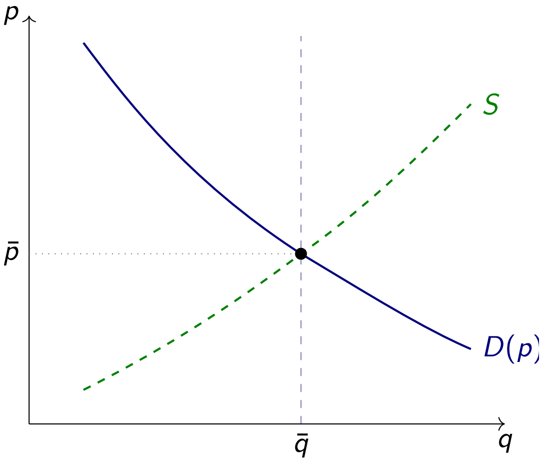
Motivation

In many markets, buyers commit before the price is known

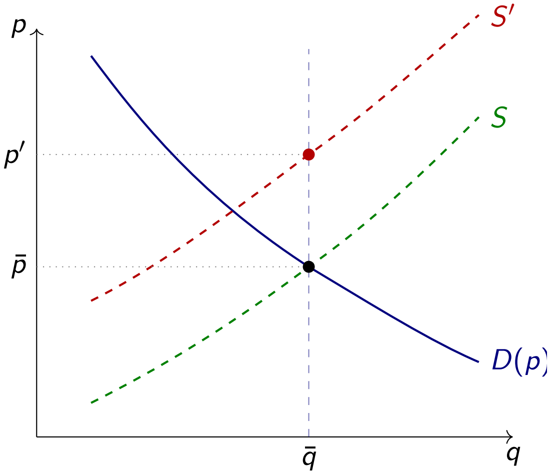
- **Short-term money markets:** banks have preset demand for overnight funding
- **Housing:** most tenants are locked into leases while rents reprice for movers
- **Health insurance:** employees choose annual plans before medical needs are realized
- **Transportation:** commuters face fixed schedules; peak demand is nearly inelastic
- **Electricity:** contracts fix quantities ahead of delivery; wholesale prices clear on the flexible margin

A flexible margin sets the price, but much of demand cannot adjust.
When supply tightens, uniform pricing can generate negative consumer surplus.

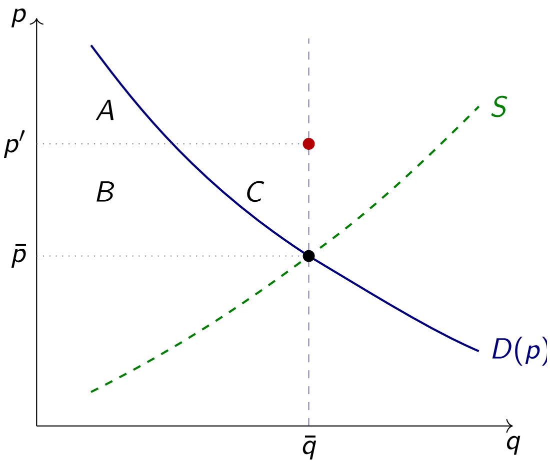
Committed demand level $\overline{q}$, given D and S



Committed demand does not adjust..



C surplus lost due to sticky $\overline{q}$

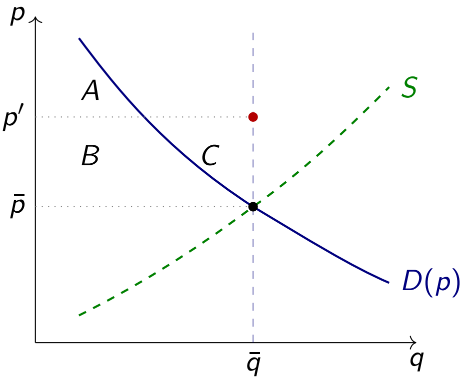


Optimal price cap

- θ fraction of demand is not committed: surplus is A.
- $(1-\theta)$ fraction is committed: surplus is $(A+B)-(B+C)=A-C$.
- For some p',

$$\theta A + (1-\theta)(A-C) = 0, \text{or}$$
$$A = (1-\theta)C$$

- Beyond this p', allowing the price to rise further is not socially optimal.
- Therefore: impose a price cap.



This paper: optimal uniform-price mechanism

- **Principle:** Let the market clear freely as long as aggregate consumer surplus is positive.
- **Intervention rule:** For each realized demand schedule $D(p)$, compute the cap p^* from demand alone:

  $$p^* D(p^*) = U(p^*).$$

  This is the price at which aggregate consumer surplus reaches zero.
- **Implementation:**

  $$\text{if } p^{mkt} \leq p^*, \text{ do nothing;} \qquad \text{if } p^{mkt} > p^*, \text{ cap and ration.}$$

- **The mechanism prevents:** Only surplus-destroying trades.
- **The mechanism preserves:** Truthful supply (VCG), efficient investments, and efficient selection into responsiveness (absent behavioral biases).

Application: France 2022–2023 energy crisis

- France: epicenter of the European energy crisis
- Three key drivers: nuclear outages, gas prices, EU price-cap rule
- Gas prices alone $\rightarrow$ no crisis
- Nuclear shortfall + EU price-cap rule $\rightarrow$ crisis
- Our mechanism $\rightarrow$ about 200bn lower expected procurement costs and crisis mitigation

Related literature

- **Price controls & rationing**: Weitzman (1977), Bulow & Klemperer (2012)
  We: cap + rationing arise endogenously as welfare-maximizing policy
- **Scarcity pricing in electricity**: Wilson (1989), Joskow & Tirole (2006, 2007), Borenstein & Holland (2005)
  We: work with aggregate demand under uniform pricing, not type discrimination
- **Supply-side mechanism design**: Vickrey (1961), Montero (2008), Ausubel et al. (2014)
  We: VCG transfers shrink to zero when price cap binds
- **Distributional market design**: Dworczak et al. (2021), Akbarpour et al. (2024)
  We: heterogeneous welfare weights shift the cap; selection remains efficient

Model setup

- Perfect competition; homogeneous good at uniform price
- Demand $D_x(p)$ and supply $S_y(p)$, state $z = (x, y)$ drawn from known distribution
- Planner observes full schedules for market clearing
- Single instrument: rationing rule $\mu_z \in [0, 1]$ scaling demand

$$D_z(p) = \mu_z D_x(p), \qquad D_z(p_z) = S_y(p_z)$$

- Demand decomposes into sticky share $(1-\theta)$ and responsive share θ:

$$D_x(p) = (1-\theta)\,\bar{d}_x + \theta\, d_x(p)$$

- Welfare:

$$W_z = \underbrace{\mu_z \Big[(1-\theta)\, u_x(\bar{d}_x) + \theta\, u_x(d_x)\Big]}_{U_z} - C_y(D_z)$$

Optimal policy

Differentiating W_z w.r.t. (D_z, μ_z):

$$dW_z = \underbrace{(u'_x - C'_y)}_{=0 \text{ at equilibrium}} \; dD_z + \left[\frac{U_z}{\mu_z} - \frac{D_z}{\mu_z}\, u'_x\right] d\mu_z$$

Proposition 1. Rationing iff consumer surplus is zero:

$$p_z D_z(p_z) \leq U_z \quad \perp \quad \mu_z \leq 1$$

When binding, p^*_x equates price to average utility per unit:

$$p^*_x = \frac{(1-\theta)\, u_x(\bar{d}_x) + \theta\, u_x(d^*_x)}{(1-\theta)\, \bar{d}_x + \theta\, d^*_x}$$

Proposition 2. The cap p^*_x depends only on demand; supply determines whether it binds and the rationing level $\mu^*_z = S_y(p^*_x)/D_x(p^*_x)$.

Illustrations: Semi-log case

Semi-log demand: $d(p) = \exp\left(\frac{\alpha - p}{\beta}\right)$

Iterative algorithm from $p_0^* = \bar{p}, \quad d_0^* = \bar{d}$:

$$p_{k+1}^* = \frac{(1-\theta)\, u(\bar{d}) + \theta\, u(d_k^*)}{(1-\theta)\, \bar{d} + \theta\, d_k^*}, \qquad d_k^* = d(p_k^*)$$

Sequence $\{p_k^*\}$ is monotone increasing, converges for any $\theta < 1$.

> **Proposition 3.** The optimal price cap satisfies
>
> $$p^* = \lambda(\theta)\, \beta + \bar{p}$$
>
> where $\lambda(\theta)$ solves $(\lambda - 1)\, e^{\lambda} = \frac{\theta}{1-\theta}$

- Cap rises one-to-one with reference price $\bar{p}$
- Cap increases with θ: more responsive demand $\rightarrow$ higher threshold
- Non-sticky demand falls by at least 63% before cap binds: $d^* = e^{-\lambda(\theta)}\bar{d}$

Extensions: roadmap

1. **Incentive payments for supply**
   - VCG mechanism induces truthful bidding as dominant strategy
   - Key result: *when the cap binds, required transfers are zero*
2. **Investment efficiency**
   - Firms internalize marginal contributions $\Rightarrow$ efficient investment ex ante
   - *No separate capacity payments needed*
3. **Endogenous selection into stickiness**
   - Consumers choose responsiveness at private cost c
   - Equilibrium $\theta = H(\Delta)$ coincides with planner's optimum
4. **Inequality-aware welfare weights**
   - Welfare weights $\bar{\omega}_s, \bar{\omega}_r$ shift the cap: $\bar{\omega}_s > \bar{\omega}_r \Rightarrow$ lower p^*
   - Price-cap rule unchanged when same weights apply to selection cost

Incentive payments for truthful supply

Idea: Clear the market $n+1$ times — once with all firms, once removing each firm i.

- Market clears at $\hat{p}$ with all firms; counterfactual price $\hat{p}_{-i}$ without firm i
- Firm i receives market revenue plus a side transfer:

$$T_i = \int_{\hat{p}}^{\hat{p}_{-i}} D_i(p')\,dp'$$

  where D_i is residual demand facing firm i

Properties:

1. Truthful bidding ($C_i' = p$) is a dominant strategy
2. Allocation is efficient
3. Each firm's payoff = its marginal contribution to welfare: $\pi_i = W - W_{-i}$

> **With the price cap:** When p^* binds, $\hat{p}_{-i}$ is also capped $\Rightarrow$ $T_i = 0$.
> Firms are fully compensated through market revenue at p^* alone.

Investment efficiency

Firms choose investment K_i at cost $G_i(K_i)$ before the market state is realized.

Under the mechanism (p_x^*, μ_z^*, T_i):

- Each firm's profit equals its marginal contribution: $\pi_{i,z} = W_z - W_{z,-i}$
- Firm i invests until private marginal benefit = marginal cost:

$$\frac{\partial}{\partial K_i}\mathbb{E}[W_z - W_{z,-i}] = G_i'(K_i)$$

- This coincides with the planner's first-order condition

$\Rightarrow$ No separate capacity payments needed: the price cap + VCG mechanism aligns private and social investment incentives.

Endogenous selection into stickiness

Consumers draw private cost $c \geq 0$ from CDF H for becoming responsive. Choose before z is realized.

- Surplus gain from responsiveness:

$$\Delta = \mathbb{E}\big[\varphi_x(p_z)\big] - \mathbb{E}\big[\varphi_x(\bar{p}_x)\big]$$

- Consumer becomes responsive iff $c \leq \Delta$, so $\theta = H(\Delta)$
- Planner's FOC: increase θ until marginal social benefit = cost of marginal type $H^{-1}(\theta)$
- By the envelope theorem, these coincide:

$$\frac{d}{d\theta}\mathbb{E}[W_z(\theta)] = \Delta = H^{-1}(\theta)$$

> Stickiness is rational here, not a behavioral bias. The equilibrium θ is efficient under the optimal cap.

Inequality-aware welfare weights

Planner observes average welfare weights $\bar{\omega}_s$ (sticky) and $\bar{\omega}_r$ (responsive).

Weighted aggregate utility:

$$U_z^{\omega} = \mu_z \Big[(1-\theta)\,\bar{\omega}_s\,u_x(\bar{d}_x) + \theta\,\bar{\omega}_r\,u_x(d_x)\Big]$$

- Optimal cap becomes:

$$p_x^{*,\omega} = \frac{(1-\theta)\,\bar{\omega}_s\,u_x(\bar{d}_x) + \theta\,\bar{\omega}_r\,u_x(d_x^*)}{(1-\theta)\,\bar{d}_x + \theta\,d_x^*}$$

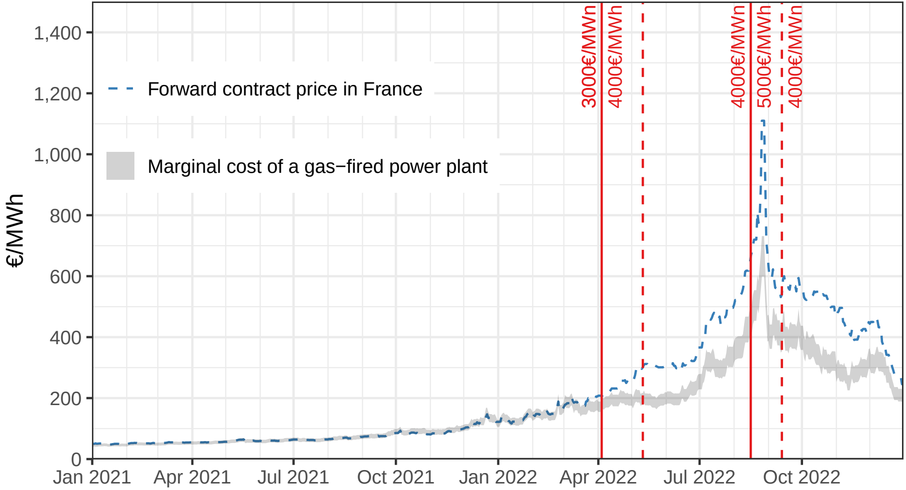
- $\bar{\omega}_s > \bar{\omega}_r \Rightarrow$ cap is lower: more protection for vulnerable sticky consumers

> Distributional concerns shift the cap but preserve the structure of the mechanism.

The European energy crisis: France 2022–2023

- War in Ukraine $\rightarrow$ surge in fossil fuel prices, especially natural gas
- France's nuclear fleet: stress corrosion problem took out $\sim$40% of capacity in 2022
- EU wholesale price cap protocol: automatic escalation rule
  - Cap at €3,000/MWh at start of 2022
  - Raised to €4,000 after French price hit threshold (April 2022)
  - Raised to €5,000 after Baltic prices hit ceiling (August 2022)
- 2023 electricity forward prices rose $\sim 10\times$ by August 2022
- Collateral demands across EU energy markets exceeded €1 trillion
- Governments committed tens of billions in loans and guarantees to avert systemic collapse

Forward prices for 2023 delivery



Counterfactual analysis: design

Question: Which factors can rationalize the $10\times$ price surge?

- Use hourly bid data from the French day-ahead market (2023): $\sim$4.3 million bids, $\sim$500 per hour
- Hold demand schedules as observed in the data
- Construct supply curves from engineering estimates of 57 fossil-fuel plants
- Replicate actual 2023 equilibrium outcomes (mean price €96/MWh)
- Construct counterfactual equilibria by varying three factors:
  1. Input costs (gas, coal, oil) set to August 2022 forward prices
  2. Nuclear availability scaled from 100% to 60% of realized 2023 output
  3. Price cap level varied from €3,000 to €7,000/MWh
- Ask: which combination reproduces the observed futures prices?

EU price cap: counterfactual mean prices in 2023

Nuclear availability	Price cap (€/MWh)					Share of hours rationing
	3,000	4,000	5,000	6,000	7,000	
100%	174	174	174	174	174	0
90%	215	219	222	226	230	0.004
80%	304	323	342	360	379	0.019
70%	486	540	595	650	705	0.055
60%	847	1,001	1,156	1,310	1,465	0.155

Input prices fixed at 25 August 2022 levels. Nuclear availability relative to realized 2023 output. All prices in €/MWh.

First row: higher gas prices alone raise mean price to €174/MWh (+60%), but the cap never binds. Cannot explain the 10× surge.

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Input prices fixed at 25 August 2022 levels. Nuclear availability relative to realized 2023 output. All prices in €/MWh.

Central scenario: 70% nuclear + €7,000 cap → €705/MWh, consistent with August 2022 futures. Nuclear shortfall + EU cap protocol explains the crisis.

Computing the optimal price cap

For each hour, estimate demand from bid data:

$$D_x(p) = \underbrace{\gamma_x}_{\text{sticky}} + \underbrace{\eta_x \exp\left(-\frac{p}{\beta_x}\right)}_{\text{responsive}}$$

- Mean estimates: $\gamma \approx 46$ GW, $\eta \approx 8$ GW, $\beta \approx 140$ €/MWh
- Responsive share: $\theta \approx 0.026$
- Reference price $\bar{p}$: rolling one-year average of realized prices
- Apply Proposition 3: $p^* = \lambda(\theta)\,\beta + \bar{p}$ for each hour
- If p^* binds: activate supply below p^*, ration demand pro rata

Note: The parametric form illustrates the mechanism. Final results are computed directly from the raw bid curves, minimizing $\Delta ABC = (1-\theta)\Delta CEF$ hour by hour.

Optimal price cap: counterfactual mean prices in 2023

Nuclear availability	Optimal price cap (€/MWh)	Market price (€/MWh)	Share of hours rationing
100%	584	172	0.010
90%	604	202	0.029
80%	629	249	0.082
70%	661	334	0.201
60%	722	446	0.388

Input prices fixed at 25 August 2022 levels. Nuclear availability relative to realized 2023 output.
Central scenario: optimal cap €661/MWh $\rightarrow$ mean price €334/MWh vs. €705 under EU protocol. Rationing more frequent (20% of hours) but quantities modest ($\sim$7% of load).

Central scenario (70%): mean price €334 vs. €705 under EU protocol.
Total expenditures: €135bn vs. €334bn $\rightarrow$ savings of $\sim$€200bn (two-thirds).

Concluding remarks

Electricity market design debates center on three concerns:

- **Consumer protection:** ad hoc price caps distort markets
- **Investment incentives:** caps suppress scarcity rents $\rightarrow$ capacity payments needed
- **Demand response:** consumers should be nudged into price responsiveness

Our mechanism addresses all three at the root:

- The optimal cap follows from demand primitives $\rightarrow$ optimal protection of consumer
- VCG payments align private and social investment incentives $\rightarrow$ no separate capacity market
- Equilibrium stickiness can be efficient $\rightarrow$ potential behavioral biases is a separate issue

The underlying logic extends beyond electricity: any uniform-price market pooling committed and flexible demand faces the same tension.