Robust Monopoly Regulation

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Regulating monopolies is challenging

- Cooper et al. (2018): prices at monopoly hospitals are 12% higher than those in markets with four or five rivals

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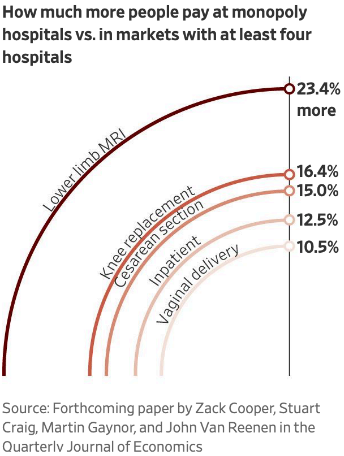

Source: wsj

Regulating monopolies is challenging

- A regulator may want to constrain a monopolistic firm's price
- Price-constrained firm may fail to cover its fixed cost, ending up not producing
- Protect consumer well-being *versus* not distort production

Regulating monopolies is challenging

- The challenge could be solved if the regulator had complete information
  - let the firm produce the efficient quantity and price at marginal cost
  - subsidize the firm for its other costs

- What shall the regulator do when he knows much less about the industry than the firm does?

- If he wants a policy that works “fairly well” in all circumstances, what shall this policy look like?

What we do

- Regulator's payoff

$$\text{consumer surplus} \; + \; \alpha \; \text{firm's profit}, \; \alpha \in [0,1]$$

- He can regulate firm's price and quantity, give a subsidy, charge a tax

- Given a demand and cost, regret to the regulator:

$$\textbf{regret} \; = \; \text{payoff if he had complete information} \; - \; \text{what he gets}$$

"money left on the table"

- Optimal policy:

$$\underset{\text{policy}}{\textbf{minimize}} \; \underbrace{\max_{\text{demand,cost}} \; \text{regret}}_{\text{worst-case regret}}$$

What we find

$\alpha = 0$

consumer surplus

(consumer well-being)

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loss from underproduction

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$\alpha = 1$

consumer surplus
$+$ firm's profit

(efficiency)

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What we find

$\alpha = 0$	$\alpha = 1$
consumer surplus	consumer surplus $+$ firm's profit
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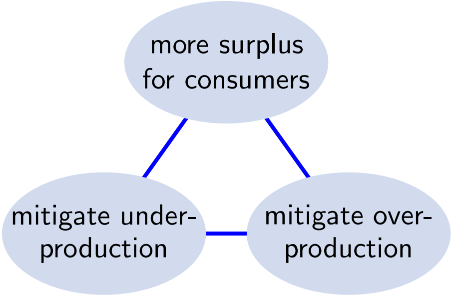
← $\alpha \in (0, 1)$ →

combination of price cap and subsidy rule

What we find



$\alpha \in (0, 1)$

combination of price cap and subsidy rule

Closest literature

- Monopoly regulation:
  Baron and Myerson (1982), Lewis and Sappington (1988a,b), Armstrong (1999), Armstrong and Sappington (2007)

- Mechanism design with worst-case regret:
  Hurwicz and Shapiro (1978), Bergemann and Schlag (2008, 2011), Manski (2011), Renou and Schlag (2011), Beviá and Corchón (2019), Kasberger and Schlag (2020), Malladi (2020)

  Robust mechanism design:
  Garrett (2014), Carroll (2019)

- Delegation:
  Holmström (1977, 1984), Alonso and Matouschek (2008), Ambrus and Egorov (2017), Kolotilin and Zapechelnyuk (2019), Amador and Bagwell (2021)

Roadmap

- Environment
- Main result
- Extensions
- Conclusion

Environment

- A monopolistic firm and a mass one of consumers
- $V : [0,1] \to [0,\bar{v}]$: a decreasing u.s.c. inverse demand function
  - (q,p) is feasible if $p \leqslant V(q)$
- $C : [0,1] \to \mathbf{R}_+$ with $C(0) = 0$: an increasing l.s.c. cost function

Environment

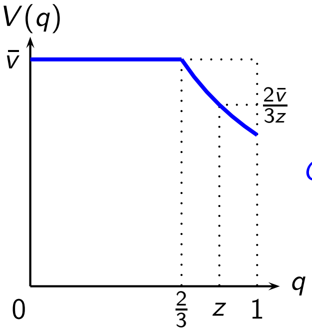
- Maximal total surplus is

$$\mathrm{OPT} = \max_{q\in[0,1]} \underbrace{\int_0^q V(z)\,\mathrm{d}z}_{\text{total value to consumers}} - C(q)$$

- If the firm produces q, the distortion is

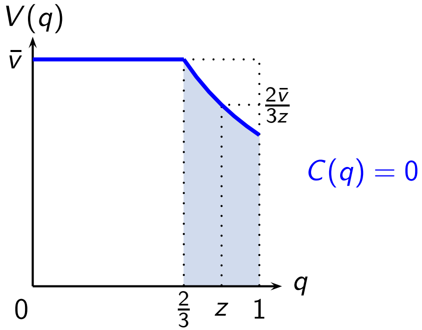
$$\mathrm{DSTR} = \mathrm{OPT} - \left(\int_0^q V(z)\,\mathrm{d}z - C(q)\right)$$

Environment: an example of demand and cost scenario



$C(q) = 0$

Environment: an example of demand and cost scenario

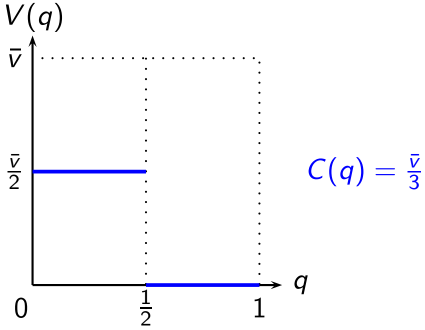


- If the firm produces $q = \frac{2}{3}$,

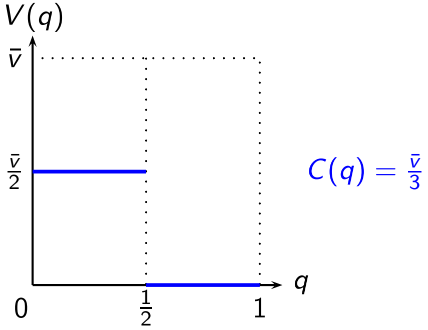
$$\mathrm{DSTR} = \frac{2\bar{v}}{3} \int_{\frac{2}{3}}^{1} \frac{1}{z} \, \mathrm{d}z = -\frac{2\bar{v}}{3} \log \frac{2}{3} > 0$$

- The firm underproduces

Environment: an example of demand and cost scenario



Environment: an example of demand and cost scenario



- If the firm produces $q = \frac{1}{2}$,

$$\mathrm{DSTR} = 0 - \left(\frac{\bar{v}}{4} - \frac{\bar{v}}{3}\right) = \frac{\bar{v}}{3} - \frac{\bar{v}}{4} > 0$$

- The firm overproduces

Regulatory policy

- A policy is an u.s.c. function

$$\rho : [0,1] \times [0,\bar{v}] \to \mathbf{R}$$

  - if the firm sells q at price p, then it receives $\rho(q,p)$
  - if $\rho(q,p) > qp$, a subsidy of $\rho(q,p) - qp$
  - if $\rho(q,p) = qp, \forall q, p$, the firm is unregulated
- The firm can stay out of business with a profit of zero

Regulatory policy: examples

- A lump-sum subsidy $w > 0$ if quantity exceeds $\tilde{q}$:

$$\rho(q,p) = \begin{cases} qp, & \text{if } q < \tilde{q} \\ qp + w, & \text{if } q \geqslant \tilde{q} \end{cases}$$

- A price cap of k:

$$\rho(q,p) = \begin{cases} qp, & \text{if } p \leqslant k \\ -\infty, & \text{if } p > k \end{cases}$$

- A cap of k on the revenue per unit: $\rho(q,p) = \min\{qp, qk\}$
- A proportional tax: $\rho(q,p) = (1-\tau)qp,$ for some $\tau \in (0,1)$
- A lump-sum tax: $\rho(q,p) = qp - w,$ for some $w > 0$

  Alibaba faces record $2.8 billion antitrust fine in China

Timing of the game

- The regulator chooses and commits to a policy ρ
- The firm privately observes (V, C); it chooses (q, p) and obtains the market revenue qp
- The regulator transfers $\rho(q, p) - qp$ to the firm

Firm's best response and regulator's payoff

Fix a policy ρ and a demand and cost scenario (V, C):

- If the firm sells q at price p,
  the firm's profit and consumer surplus are:

$$\mathrm{FP} = \rho(q, p) - C(q), \quad \mathrm{CS} = \int_0^q V(z)\, \mathrm{d}z - \rho(q, p)$$

- (q, p) is a best response to (V, C) under ρ if it maximizes FP among all feasible (q, p)

- The regulator's payoff is

$$\mathrm{CS} + \alpha \mathrm{FP}, \ \alpha \in [0, 1]$$

The regulator's complete-information payoff is OPT

Claim

Suppose that the regulator knows (V, C). Then

$$\max\left(\mathrm{CS} + \alpha\mathrm{FP}\right) = \mathrm{OPT},$$

where the maximum is over all policies ρ and all firm's best responses (q, p) to (V, C) under ρ.

- Let q^* denote the socially optimal quantity
- Let $\rho(q^*, V(q^*)) = C(q^*)$

  $\rho(q, p) = 0$ for $(q, p) \neq (q^*, V(q^*))$

The regulator's complete-information payoff is OPT

Claim

Suppose that the regulator knows (V, C). Then

$$\max\left(\mathrm{CS} + \alpha \mathrm{FP}\right) = \mathrm{OPT},$$

where the maximum is over all policies ρ and all firm's best responses (q, p) to (V, C) under ρ.

- The regulator's complete-information payoff is independent of α

Simplifying regret

Fix a policy ρ and a demand and cost scenario (V, C):

The firm chooses (q, p). Then

$$\begin{aligned}\mathrm{RGRT} &= \text{Complete-info payoff} - \text{Incomplete-info payoff} \\ &= \mathrm{OPT} - (\mathrm{CS} + \alpha \mathrm{FP}) \\ &= \mathrm{OPT} - (\mathrm{CS} + \mathrm{FP}) + (1-\alpha)\mathrm{FP} \\ &= \underbrace{\mathrm{DSTR}} + \underbrace{(1-\alpha)\mathrm{FP}}\end{aligned}$$

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Worst-case regret approach

The regulator's problem is

$$\underset{\rho}{\textbf{minimize}} \max_{V,C} \mathrm{RGRT}$$

where

- maximum is over all (V, C)
  - talk: the firm breaks ties against the regulator
- minimization is over all policies ρ

Roadmap

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- Main result
  - Lower bound on worst-case regret
  - Upper bound on worst-case regret by optimal policy
- Extensions
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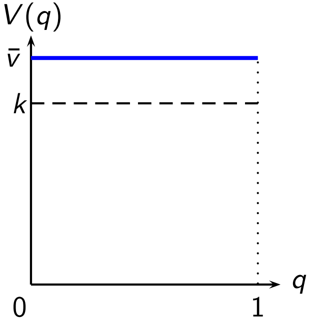
Suppose regulator imposes a price cap k



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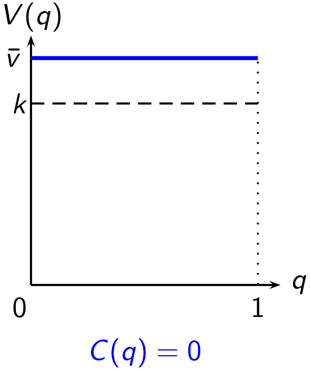

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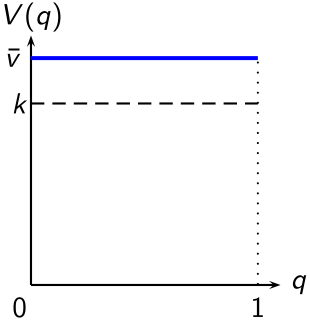

$C(q) = 0$

$\mathrm{DSTR} = 0,\ \mathrm{FP} = k$

$\mathrm{RGRT} = (1 - \alpha)k$

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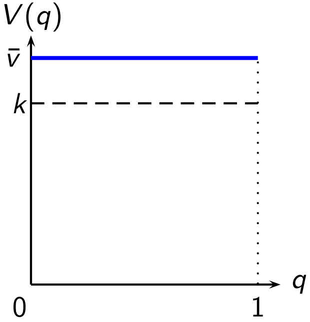

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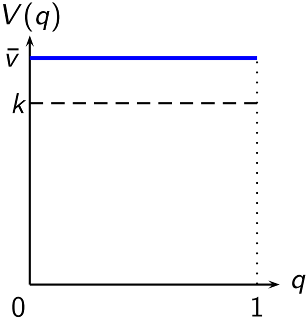

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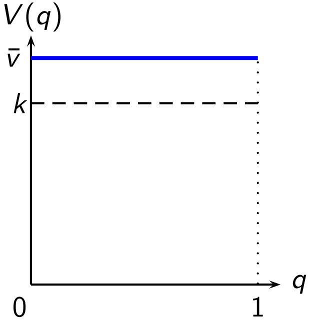

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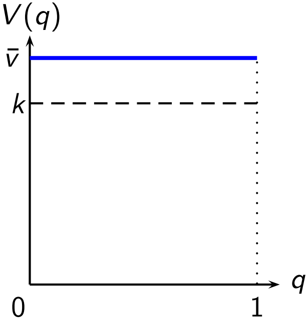

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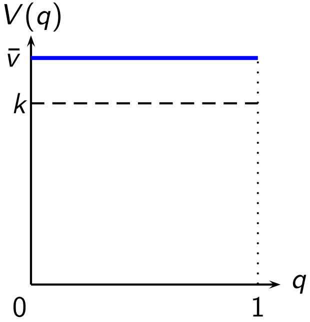

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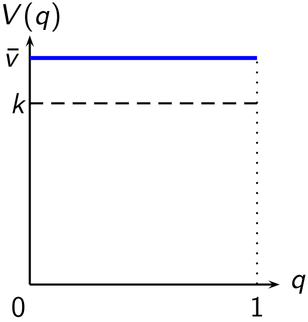

$C(q) = k$

$\mathrm{DSTR} = \bar{v} - k,\ \mathrm{FP} = 0$

$\mathrm{RGRT} = \bar{v} - k$

Suppose regulator imposes a price cap k

$$\text{Let } (1-\alpha)k_\alpha = \bar{v} - k_\alpha \implies k_\alpha = \frac{\bar{v}}{2-\alpha}$$

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Claim

The worst-case regret under any policy is at least $(1-\alpha)k_\alpha$.

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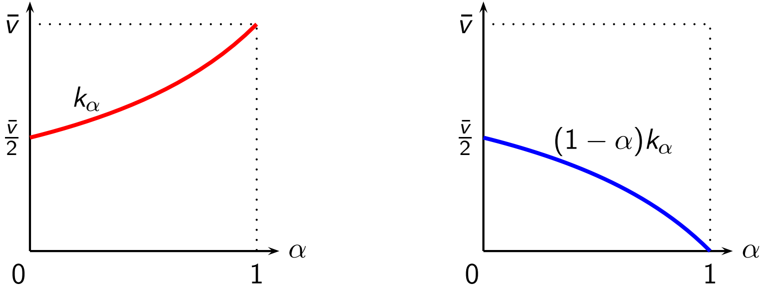


Lower bound on worst-case regret

Theorem

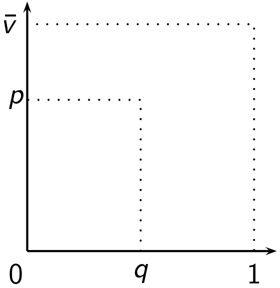
Let

$$\mathrm{LB}(q,p) = \min \left\{ (1-\alpha) q k_\alpha - qp \log q, \; q(k_\alpha - p) \right\}.$$

The worst-case regret under any policy is at least

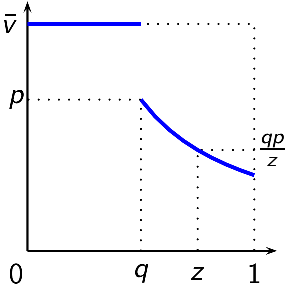
$$\max_{q \in [0,1], \; p \in [0, k_\alpha]} \mathrm{LB}(q,p).$$

Proof of lower bound



Fix a policy ρ. Pick any (q, p).

Proof of lower bound



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Let $V(z) = \bar{v}, \forall z \leqslant q; \frac{qp}{z}, \forall z > q$

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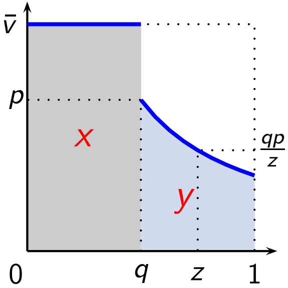

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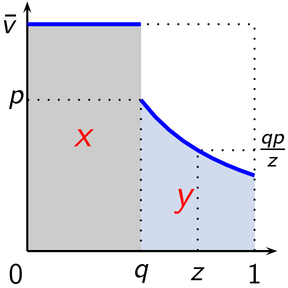
Let $V(z) = \bar{v}, \forall z \leqslant q; \frac{qp}{z}, \forall z > q$

Let $x = \max_{q' \leqslant q} \rho(q', p')$

$y = \max_{q' \geqslant q, q'p' \leqslant qp} \rho(q', p')$

Proof of lower bound



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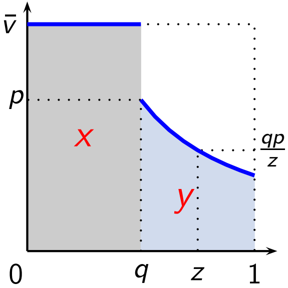
Let $x = \max_{q' \leqslant q} \rho(q', p')$

$y = \max_{q' \geqslant q, q'p' \leqslant qp} \rho(q', p')$

1. If $\max\{x, y\} \leqslant qk_\alpha$, a firm with fixed cost qk_α won't produce:

$$\mathrm{RGRT} = \mathrm{DSTR} = q(\bar{v} - k_\alpha) + \int_q^1 \frac{qp}{z}\, \mathrm{d}z$$
$$= q(1-\alpha)k_\alpha - qp\log(q) \geqslant \mathrm{LB}(q, p)$$

Proof of lower bound



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$y = \max_{q' \geqslant q, q'p' \leqslant qp} \rho(q', p')$

2. If $\max\{x, y\} \geqslant qk_\alpha$ and $x \geqslant y$, a firm with zero cost has $\mathrm{FP} \geqslant qk_\alpha$ and produces less than q:

$$\mathrm{RGRT} \geqslant (1-\alpha)qk_\alpha + \mathrm{DSTR} \geqslant (1-\alpha)qk_\alpha + \int_q^1 \frac{qp}{z}\,\mathrm{d}z$$
$$= q(1-\alpha)k_\alpha - qp\log(q) \geqslant \mathrm{LB}(q,p)$$

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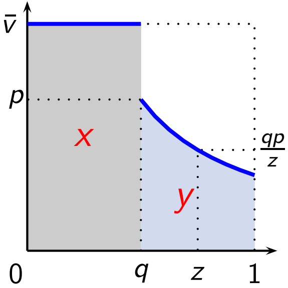

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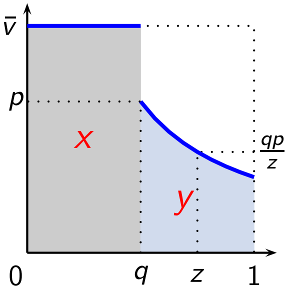
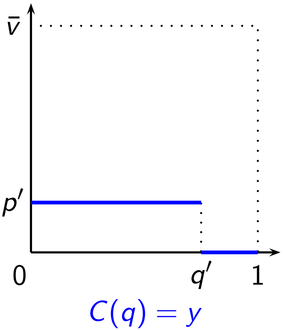
Let $x = \max_{q' \leqslant q} \rho(q', p')$

$y = \max_{q' \geqslant q, q'p' \leqslant qp} \rho(q', p')$

3. If $\max\{x, y\} \geqslant qk_\alpha$ and $y \geqslant x$, there exists q', p' in light-blue area such that $\rho(q', p') = y \geqslant qk_\alpha$

Proof of lower bound





3. If $\max\{x, y\} \geqslant qk_\alpha$ and $y \geqslant x$, there exists q', p' in light-blue area such that $\rho(q', p') = y \geqslant qk_\alpha$

Consider RHS firm:

$$\mathrm{RGRT} = \mathrm{DSTR} \geqslant qk_\alpha - q'p' \geqslant q(k_\alpha - p) \geqslant \mathrm{LB}(q, p)$$

Lower bound on worst-case regret

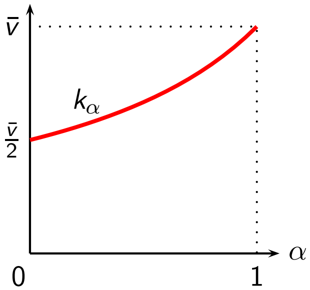
Theorem

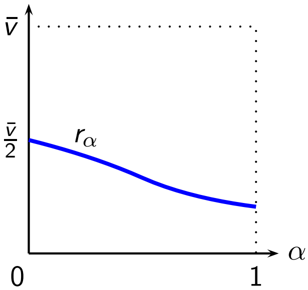
Let

$$\mathrm{LB}(q,p) = \min\{\,(1-\alpha)qk_\alpha - qp\log q,\; q(k_\alpha - p)\,\}\,.$$

The worst-case regret under any policy is at least

$$r_\alpha := \max_{q\in[0,1],\, p\in[0,k_\alpha]} \mathrm{LB}(q,p).$$





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- Main result
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  - Lower bound on worst-case regret
  - Upper bound on worst-case regret by optimal policy
- Extensions
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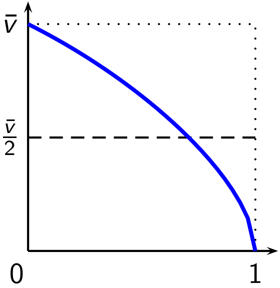
$\alpha = 0$: regulator's payoff is consumer surplus

Theorem ($\alpha = 0$)

The worst-case regret is at most $r_0 = \frac{\bar{v}}{2}$ given the price cap $k_0 = \frac{\bar{v}}{2}$.

$\alpha = 0$: regulator's payoff is consumer surplus

Proof idea:



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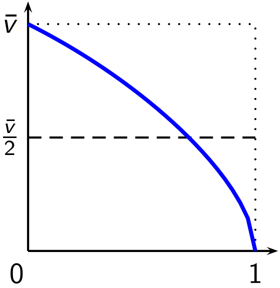

if $q = 0$, for consumers with value $\leqslant \frac{\bar{v}}{2}$
each adds $\leqslant \frac{\bar{v}}{2}$ to total surplus;
for consumers with value $\geqslant \frac{\bar{v}}{2}$,
average cost is $\geqslant \frac{\bar{v}}{2}$, so each adds $\leqslant \frac{\bar{v}}{2}$.

$\alpha = 0$: regulator's payoff is consumer surplus

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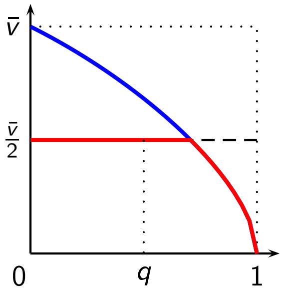

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average cost is $\geqslant \frac{\bar{v}}{2}$, so each adds $\leqslant \frac{\bar{v}}{2}$.

if $q > 0$, for consumers who are served,
regulator loses at most $p \leqslant \frac{\bar{v}}{2}$ each;
for consumers who are not served,
regulator loses $\leqslant \frac{\bar{v}}{2}$ each.

$\alpha = 1$: regulator's payoff is total surplus

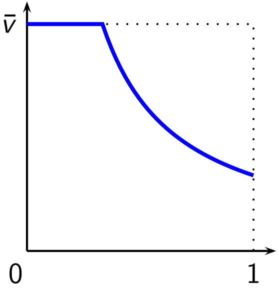
Theorem ($\alpha = 1$)

The worst-case regret is at most r_1 given the policy:

$$\rho(q, p) = \min\{\ q\ \bar{v}\ ,\ qp + r_1\ \}.$$

$\alpha = 1$: regulator's payoff is total surplus

Proof idea:



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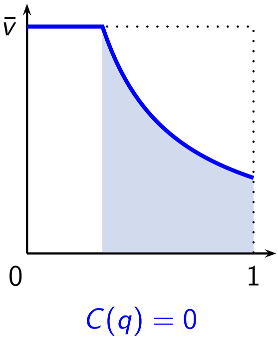

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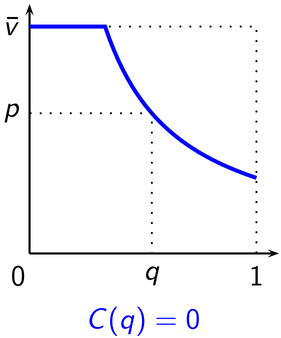

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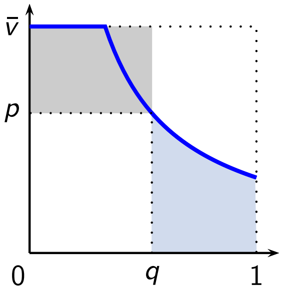

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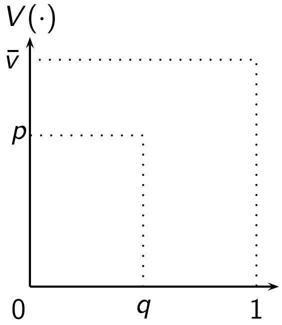
but, subsidy $(\bar{v} - p)q$
might incentivize overproduction;
regulator loses $(\bar{v} - p)q$ in light-gray

How much additional surplus?

Question: an unregulated firm sells q at price p and doesn't want to produce more. How much additional surplus?

Lemma

The maximal additional surplus is $-qp \log q$.



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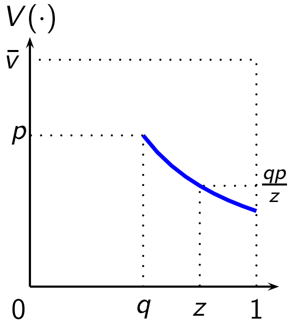

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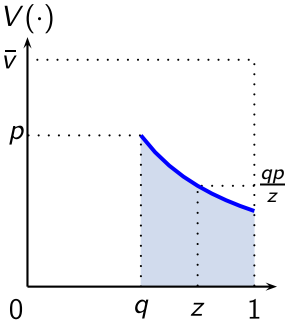

$0 \leqslant \alpha \leqslant 1$: optimal policy

Theorem ($0 \leqslant \alpha \leqslant 1$)

The worst-case regret is at most r_α given the policy:

$$\rho(q,p) = \min\{\ q\ k_\alpha\ ,\ qp + s\ \},$$

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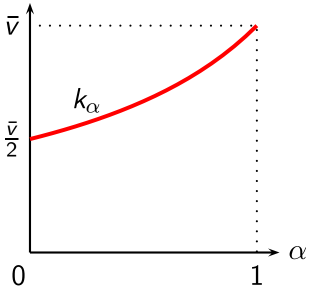

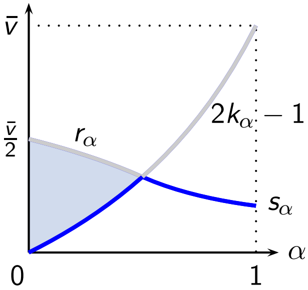

How our policy addresses three objectives simultaneously

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  overproduction induced by subsidy is under control

Regulation in practice

Price cap regulation:

- British Telecom (Littlechild 1983), gas, airports, water, electricity and the railways (Cowan 2002)
- U.S. telecommunications industry (Ai and Sappington 2002)

Table 1. Number of States Employing the Identified Form of Regulation*

Year	Rate of Return Regulation	Rate Case Moratoria	Earnings Sharing Regulation	Price Cap Regulation	Other
1985	50	0	0	0	0
1986	45	5	0	0	0
1987	36	10	3	0	1
1988	35	10	4	0	1
1989	31	10	8	0	1
1990	25	9	14	1	1
1991	21	8	19	1	1
1992	20	6	20	3	1
1993	19	5	22	3	1
1994	22	2	19	6	1
1995	20	3	17	9	1
1996	15	4	5	25	1
1997	13	4	4	28	1
1998	14	3	2	30	1
1999	12	1	1	35	1

**Sources*. BellSouth (1987–1995); Kirchhoff (1994–1999); Abel and Clements (1998).

Regulation in practice

Piece-rate subsidy:

- Feed-in tariffs:

  "FiTs usually take the form of a fixed price or constant premium. A fixed-price FiT removes investor exposure to low market prices and transfers the associated risk to the policymaker as a risk of excessive subsidy cost."

Roadmap

- Environment
- Main result
- Extensions
- Conclusion

Incorporating additional knowledge

- We made no assumptions on (V, C), except for monotonicity, semicontinuity, and the range of consumers' values
- The regulator may know more than this
- The regulator's problem is

$$\mathop{\textbf{minimize}}_{\rho} \max_{(V,C)\in\mathcal{E}} \mathrm{RGRT}$$

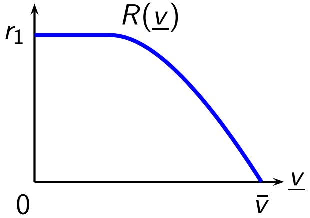
Incorporating knowledge on cost

- Suppose the regulator knows that the firm has a fixed cost plus constant marginal cost: $C(q) = a + bq$
- But he doesn't know the cost levels: a, b
- Our lower bound theorem still holds, since the proof uses only fixed cost functions
- Hence, our policy remains optimal

Incorporating knowledge on demand

- Suppose that the regulator knows that $\underline{v} \leqslant V(q) \leqslant \bar{v}$
- For $\alpha \leqslant \frac{1}{2}$, the worst-case regret is independent of $\underline{v}$
- For $\alpha = 1$, the worst-case regret is $R(\underline{v})$, which is achieved by:

$$\rho(q,p) = \min\{q\bar{v}, qp + R(\underline{v})\}$$



Price cap optimality for sufficiently homogeneous consumers

- Suppose that the regulator knows that $\underline{v} \leqslant V(q) \leqslant \bar{v}$

Proposition (price cap optimality)

If $\underline{v} \geqslant \frac{1}{2-\alpha}\bar{v}$, it is optimal to impose a price cap k_α.

Roadmap

- Environment
- Main result
- Extensions
- Conclusion

Conclusion: our advocate for non-Bayesian approach

Armstrong and Sappington (2007):

1. Relevant information asymmetries can be difficult to characterize precisely; not clear how to formulate a prior
2. Multi-dimensional screening problems are typically difficult to solve

Conclusion: our advocate for worst-case regret

1. Regret has a natural interpretation:

$$\text{regret} = \underbrace{\text{distortion}}_{\text{efficiency}} + \underbrace{(1-\alpha)\ \text{firm's profit}}_{\text{redistribution}}$$

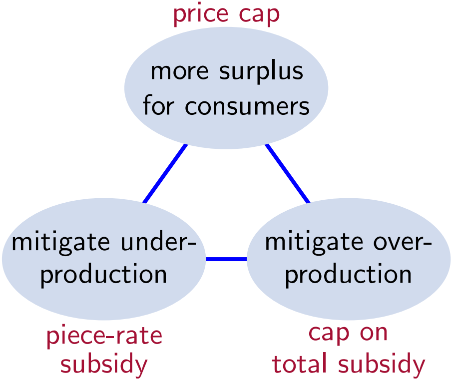
2. Worst-case regret is more relevant than worst-case payoff

Conclusion: our advocate for worst-case regret

3. Savage offers another interpretation, as observed by Linhart and Radner (1989):

   Suppose the [regulator] must justify his [policy] for a group of persons who have widely varying "subjective" probability distributions. In this case, the [regulator] might want to [regulate] in such a way as to minimize the maximum "outrage" felt in the group; here "outrage" is equated to regret.

Conclusion: three objectives and three instruments



Thank you!