Screening in digital monopolies

Pietro Dall'Ara   Elia Sartori
CSEF & University of Naples Federico II

1st European Economic Theory Conference

Free damaging and replication

Several goods exhibit:

1. Free replication;

Free damaging and replication

Several goods exhibit:

1. Free replication;
2. Free damaging.

Free damaging and replication

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taste heterogeneity

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This paper studies monopoly provision of goods whose production structure exhibits free replication and free damaging.

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Examples of **digital goods**:

1. Software goods;
2. Digital audio content;
3. Data.

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Up to 32,767 variables	-	✔	✔	✔	✔
Up to 120,000 variables	-	-	✔	✔	✔
Maximum number of observations					
Up to 2.14 billion	✔	✔	✔	✔	✔
Up to 20 billion	-	-	✔	✔	✔

Plan

1. Model;
2. Efficiency benchmark;
3. Monopoly allocation and inefficiencies;
4. No-damaging constraint, extensions, and interpretations.

Model

A unit mass of buyers, each drawing a **type** $\theta \in [0,1] = \Theta$, interacts with a seller.

Type θ is privately informed about $\theta \sim F$, for twice diff. F on $(0,1)$;
$\hookrightarrow$ F is regular in these slides, $\mathbb{E}\{\cdot\}$ refers to the r.v. θ.

Type θ has payoff from **quality** $q \in \mathbb{R}_+$ and transfer $t \in \mathbb{R}$:

$$\underbrace{g(q) + \theta q}_{\text{utility } u(q,\theta)} \quad -t,$$

for a strictly concave, increasing, and twice diff. g (Chade-Swinkels '21.)

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The cost of **allocation** $\boldsymbol{q}\colon \Theta \to \mathbb{R}_+$ is

$$C(\boldsymbol{q}) = c(\sup \boldsymbol{q}(\Theta)),$$

for a **production cost** c, increasing, strictly convex, twice diff., with $c'(0) = 0$ and $\lim_{q\to\infty} c'(q) = \infty$.

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for a strictly concave, increasing, and twice diff. g (Chade-Swinkels '21.)

With *separable* costs, the cost of $\boldsymbol{q}$ is

$$C(\boldsymbol{q}) = \mathbb{E}\{k(\boldsymbol{q}(\theta))\},$$

for some k (Mussa-Rosen '78.)

Efficiency

The *surplus* induced by allocation $\boldsymbol{q}$ is

$$\mathbb{E}\{u(\boldsymbol{q}(\theta), \theta)\} - c(\sup \boldsymbol{q}(\Theta)).$$

The *efficient* quality allocation $\boldsymbol{q}^\star$ maximizes surplus.

Proposition 1
The efficient allocation is given by $\boldsymbol{q}^\star(\theta) = q^\star$ for all θ, in which $q^\star$ is the unique quality q such that

$$g'(q) + \mathbb{E}\{\theta\} = c'(q).$$

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1. Damaging is inefficient: $\mathbb{E}\{u(\sup \boldsymbol{q}(\Theta), \theta)\} \geq \mathbb{E}\{u(\boldsymbol{q}(\theta), \theta)\}$;
2. Average marginal utility equals marginal production costs.

Efficiency

The *surplus* induced by allocation $\theta \mapsto q$ is

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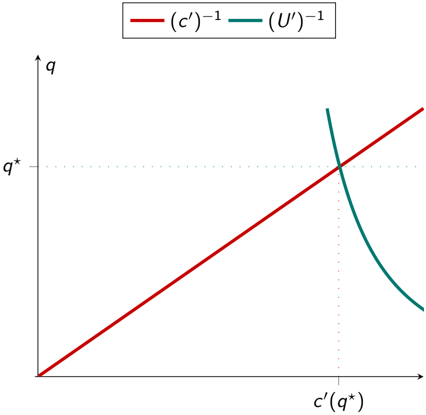

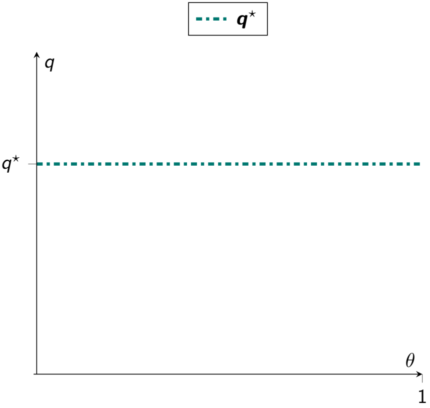

Define $U(q) = g(q) + \int_\Theta \theta \,\mathrm{d}F(\theta) q$.

Monopoly

The monopolist problem is:

$$(\mathcal{P}^M) \qquad \max_{\boldsymbol{q},\, t(\cdot)} \int_\Theta t(\theta)\,\mathrm{d}F(\theta) - c(\sup \boldsymbol{q}(\Theta)) \text{ subject to:}$$

$$\begin{aligned} u(\boldsymbol{q}(\theta), \theta) - t(\theta) &\geq u(\boldsymbol{q}(\hat{\theta}), \theta) - t(\hat{\theta}), \text{ for all } (\theta, \hat{\theta}), \\ u(\boldsymbol{q}(\theta), \theta) - t(\theta) &\geq 0, \text{ for all } \theta. \end{aligned}$$

- The *monopolist* allocation $\boldsymbol{q}^M$ solves $\mathcal{P}^M$ for some $t(\cdot)$.

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- The *monopolist* allocation $\boldsymbol{q}^M$ solves $\mathcal{P}^M$ for some $t(\cdot)$.
- Without separable costs: the monopolist problem cannot be solved via "pointwise maximization".

Monopoly

The q *constrained problem* and its value $V(q)$ are:

$$(\mathcal{P}(q)) \qquad V(q) := \max_{\boldsymbol{q},\, t(\cdot)} \int_{\Theta} t(\theta)\,\mathrm{d}F(\theta) - \cancel{c(\sup \boldsymbol{q}(\Theta))} \text{ subject to:}$$

$$\boldsymbol{q}(\theta) \leq q, \text{ for all } \theta,$$

$$u(\boldsymbol{q}(\theta), \theta) - t(\theta) \geq u(\boldsymbol{q}(\hat{\theta}), \theta) - t(\hat{\theta}), \text{ for all } (\theta, \hat{\theta}),$$

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Lemma 1 (Invest then distribute)

The allocation $\boldsymbol{q}$ solves $\mathcal{P}^M$ if and only if:

1. $\boldsymbol{q}$ solves $\mathcal{P}(q^M)$,
2. q^M solves $\max_q V(q) - c(q)$.

Monopoly

The q *constrained problem* and its value $V(q)$ are:

$$(\mathcal{P}(q)) \qquad V(q) := \max_{\boldsymbol{q}} \int_{[0,1]} \underbrace{g(\boldsymbol{q}(\theta)) + \varphi(\theta)\boldsymbol{q}(\theta)}_{\text{Virtual surplus}} \mathrm{d}F(\theta) \text{ subject to:}$$

$$\boldsymbol{q}(\theta) \leq q, \text{ for all } \theta \in \Theta,$$

$$\boldsymbol{q} \text{ is nondecreasing;}$$

in which $\varphi(\theta) := \theta - \frac{1-F(\theta)}{F'(\theta)}$.

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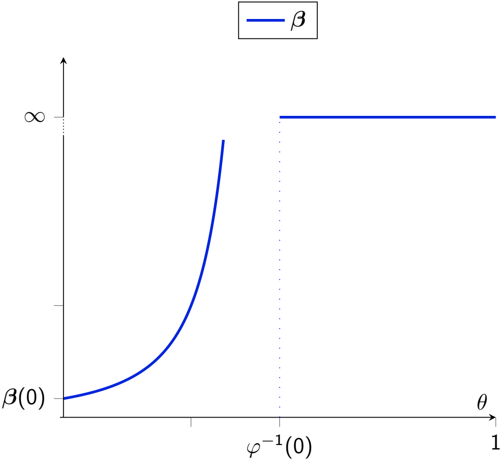
Virtual surplus maximization

The *virtual-surplus maximizer*

$$\boldsymbol{\beta}(\theta) \in \operatorname*{Argmax}_{q}\, g(q) + \varphi(\theta)q$$

is such that:

1. $\boldsymbol{\beta}(\theta) = \infty$ if $\theta \geq \varphi^{-1}(0)$;
2. $\boldsymbol{\beta}$ is increasing;
3. $\boldsymbol{\beta}(0) > 0$ ("Inada" g).



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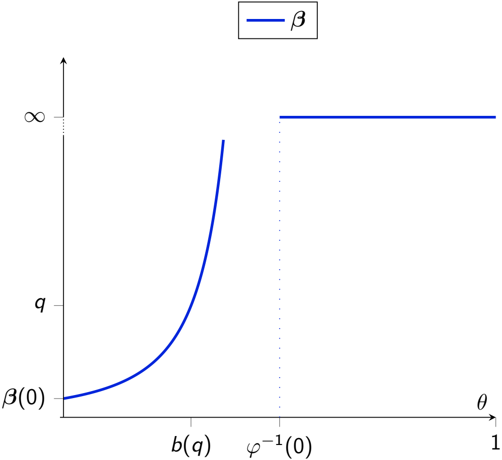
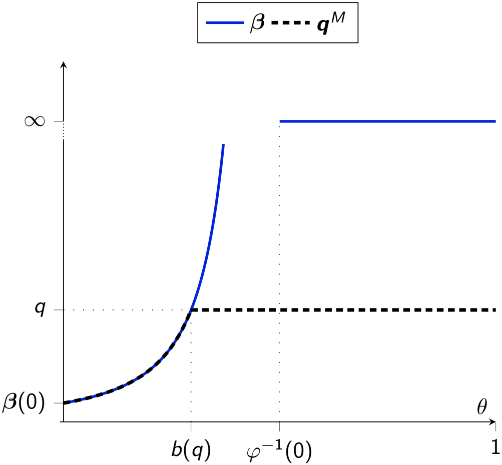
b is the inverse of $\boldsymbol{\beta}$.



Virtual surplus maximization

Lemma 2
Allocation $\boldsymbol{q}$ solves $\mathcal{P}(q)$ iff:

$$\boldsymbol{q}(\theta) = \min\{\boldsymbol{\beta}(\theta), q\}, \text{ for all } \theta.$$



Virtual surplus maximization

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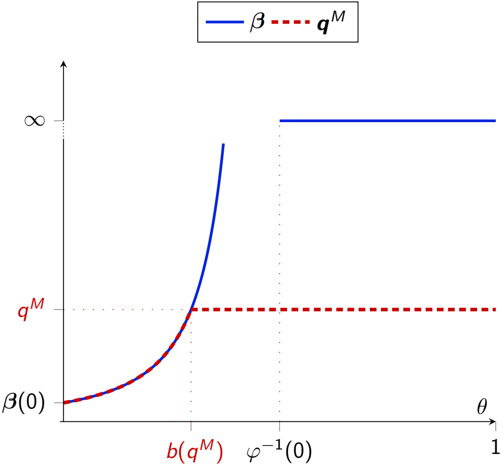
Distributive properties of $\boldsymbol{q}^M$:

1. Bunching at the top;
2. Distributional inefficiency at the bottom or full bunching;
3. No exclusion.



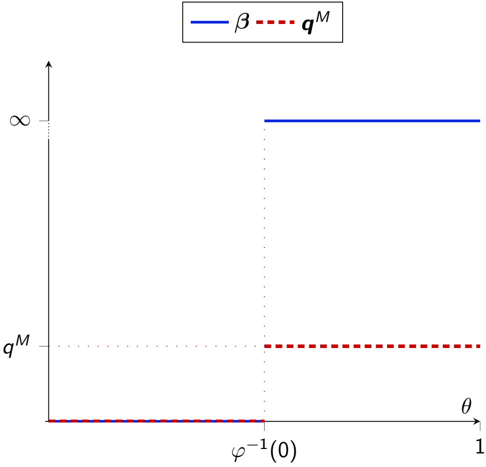
Linear preferences

Distributive properties if $g(q) = 0$:

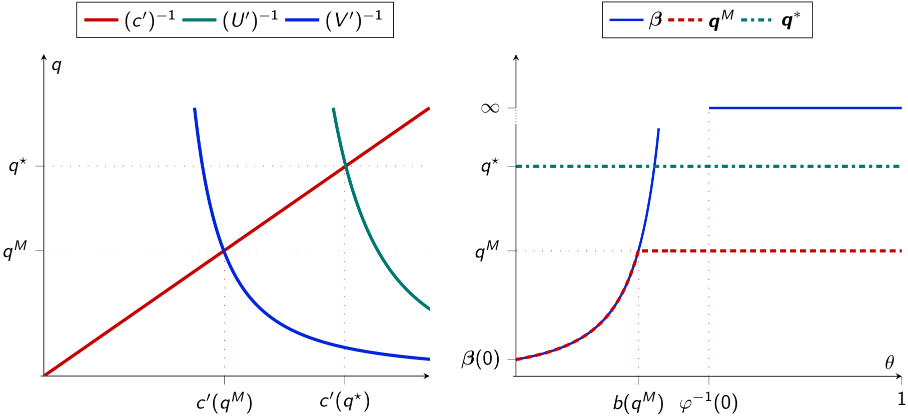
1. Bunching at the top; $\beta(\theta) = \infty$ for $\theta \geq \varphi^{-1}(0)$
2. Exclusion at the bottom; $\beta(\theta) = 0$ for $\theta < \varphi^{-1}(0)$

$\Longrightarrow$ **Single-quality menu**.

Richness in digital markets is due solely to preferences.



The monopolist allocation



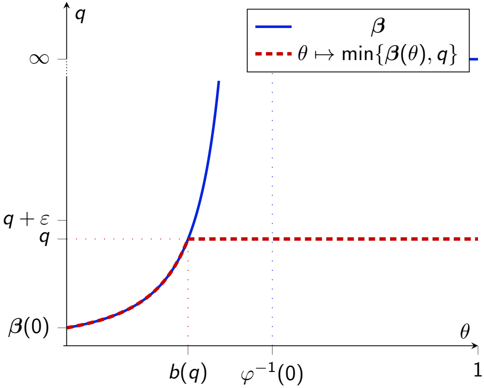
Marginal revenues

$V'(q)$ is the marginal return from increasing the cap of the q-constrained allocation $\theta \mapsto \min\{\boldsymbol{\beta}(\theta), q\}$:

$$V'(q) = \underbrace{(1 - F(b(q)))}_{\text{bunched types}} \underbrace{(g'(q) + b(q))}_{u_q \text{ of } b(q)}.$$

The change from q to $q + \varepsilon$ leads to:

1. same revenues from $q' < q$: q' sold to the same θ, and θ gets the same **rent**;
2. higher quality for bunched types;
3. higher price by $u_q(q, b(q))\varepsilon$.



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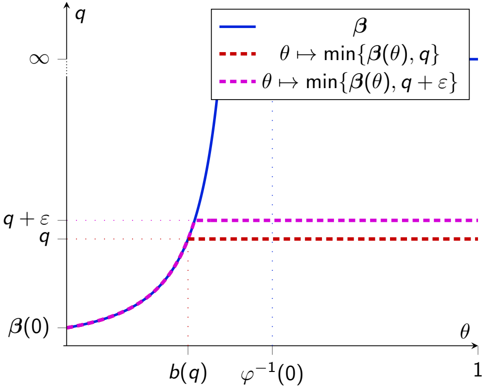

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1. By Markov's inequality:

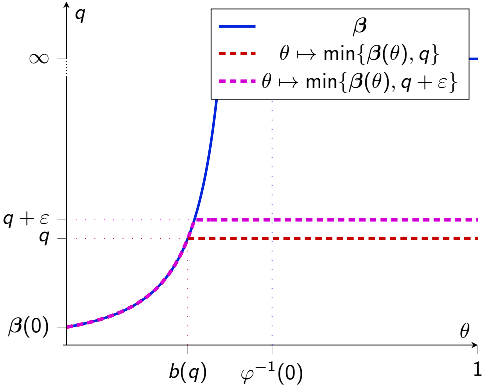
   $$(1 - F(b(q)))b(q) \leq \mathbb{E}\{\theta\};$$

2. By the distributive properties

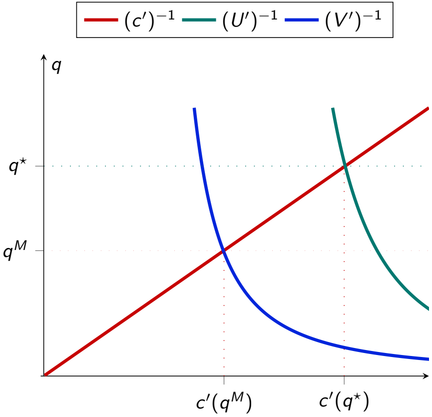
   $$b(q) < 1,$$

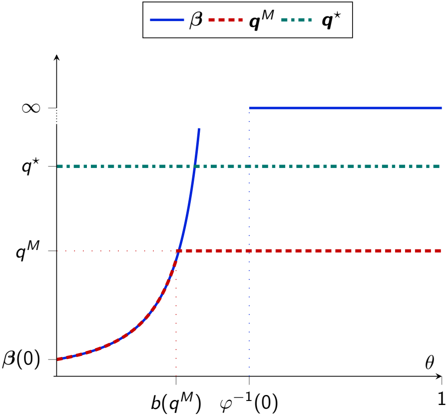
So:

$$V'(q) < g'(q) + \mathbb{E}\{\theta\}.$$



Productive inefficiency





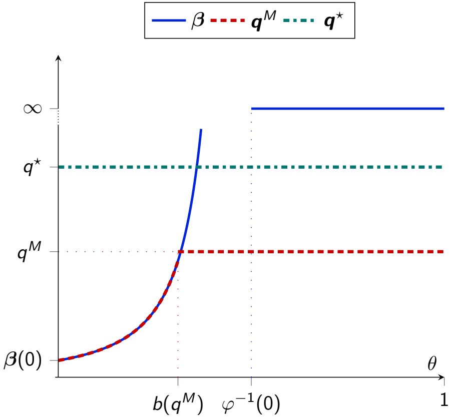
Productive inefficiency

Proposition 2

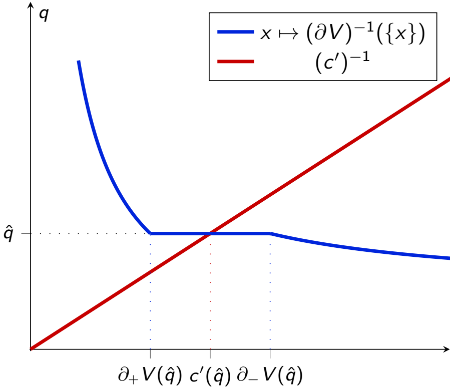
The monopolist allocation is given by $\boldsymbol{q}^M(\theta) = \min\{\boldsymbol{\beta}(\theta), q\}$ for all θ, in which q^M is the unique q solving

$$V'(q) = c'(q).$$

Moreover, it holds that: $q^M < q^\star$.

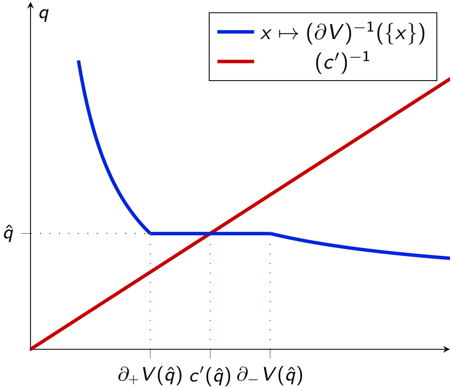


Non-regular distribution



- $\boldsymbol{\beta}$ is ironed to obtain $\overline{\boldsymbol{\beta}}$;
- By Lemma 1,
  $\theta \mapsto \min\{\overline{\boldsymbol{\beta}}(\theta), q\}$ solves $\mathcal{P}(q)$;

Non-regular distribution



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  $\theta \mapsto \min\{\overline{\beta}(\theta), q\}$ solves $\mathcal{P}(q)$;
- If types in (θ', θ'') are bunched "at" $\hat{q} \in (0, q)$,

  $$\partial_- V(\hat{q}) > \partial_+ V(\hat{q}),$$

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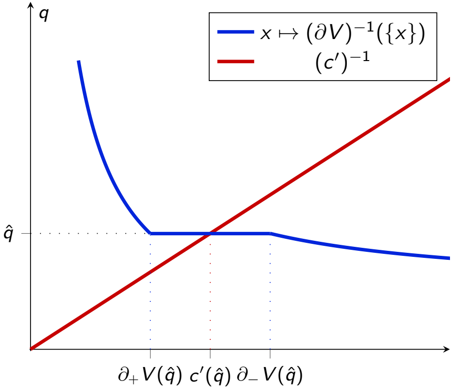

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V is concave by concavity of u in q, and productive inefficiency holds.

Proposition 3

Without regularity, the monopolist allocation is $\boldsymbol{q}^M(\theta) = \min\{\overline{\boldsymbol{\beta}}(\theta), q^M\}$, in which q^M is the unique q with $c'(q) \in \partial V(q)$. Moreover, it holds that $q^M < q^\star$.

No damaging

Without damaging, the q constrained problem is:

$$V_N(q) := \max_{\boldsymbol{q},\, t(\cdot)} \int_{\Theta} t(\theta)\,\mathrm{d}F(\theta) \text{ subject to:}$$

$$\text{IC, IR, } \boldsymbol{q}(\theta) \in \{0, q\}, \text{ for all } \theta.$$

The constraint is irrelevant under:
1. Full bunching by $\boldsymbol{q}^M$;
2. Linear preferences.

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The monopolist chooses a **marginally excluded** type $n(q)$, so

$$V_N(q) = (1 - F(n(q)))(g(q) + n(q)q), \quad \text{for } g(q) + \varphi(n(q))q = 0.$$

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$$V_N'(q) = (1 - F(n(q)))(g'(q) + n(q)), \quad \text{for} \quad g(q) + \varphi(n(q))q = 0.$$

$$\text{(Recall:} \quad V'(q) = (1 - F(b(q)))(g'(q) + b(q)), \quad \text{for} \quad g'(q) + \varphi(b(q)) = 0.)$$

- Intuitively: damaging ban $\implies n(q) \leq b(q)$, strictly if $b(q) > 0$,
- so productive inefficiency is worse:

$$V_N'(q) - V'(q) = \int_{[n(q), b(q)]} (1 - F(\theta))(g'(q) + \theta)\,\mathrm{d}\theta \geq 0,$$

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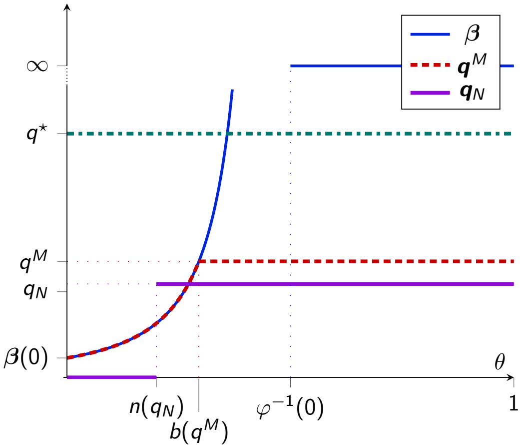
No damaging

The no-damaging allocation $\boldsymbol{q}_N$ features:

- Less production;
- No damaging;
- (Possibility of) exclusion.

The welfare comparison is type specific and ambiguous.



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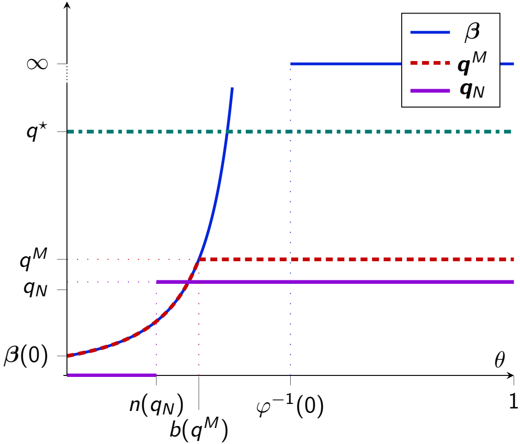

Proposition 4

Without damaging, the monopolist allocation is $\boldsymbol{q}_N(\theta) = \mathbf{1}_{[b_N(q_N),1]}(\theta)q_N$, in which q_N is the unique q solving $V_N'(q) = c'(q)$. Moreover, we have $q_N \leq q^M$, strictly if $b(q^M) > 0$.

Cost interpretation

For separable costs: $\Pi^{\text{M-R}}(\boldsymbol{q}) = \underbrace{\int_\Theta t(\theta)\,\mathrm{d}F(\theta)}_{\text{per-agent revenues}} - \underbrace{\int_\Theta k(\boldsymbol{q}(\theta))\,\mathrm{d}F(\theta)}_{\text{per-agent costs}},$

1. Payment $t(\theta)$ and production cost $k(\boldsymbol{q}(\theta))$ are comparable;
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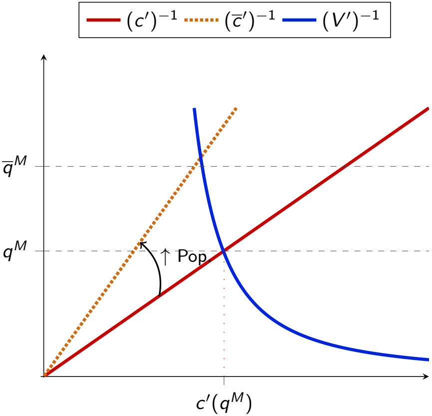
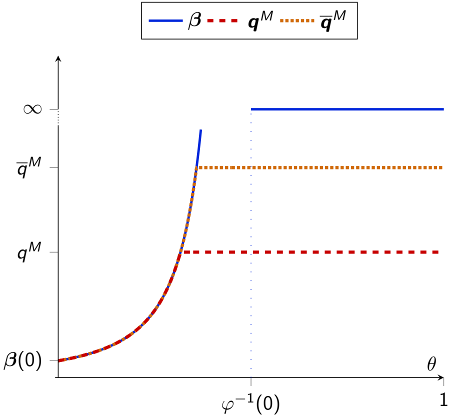
For digital goods: $\Pi(\boldsymbol{q}) = \underbrace{\int_\Theta t(\theta)\,\mathrm{d}F(\theta)}_{\text{per-agent revenues}} - \underbrace{c(\sup \boldsymbol{q}(\Theta))}_{\text{per-agent costs}},$

1. Payment $t(\theta)$ and production cost $c(q^M)$ are of different sizes;
2. Population size impacts q^M;

In general: $C(\boldsymbol{q}) = \int_\Theta k(\boldsymbol{q}(\theta))\,\mathrm{d}F(\theta) + c(\sup \boldsymbol{q}(\Theta))$.

Population size





Separable interpretation

For a separable interpretation (with a continuum of buyers:)

$$\Pi(\boldsymbol{q}) = \int_{\Theta} t(\theta) - \underbrace{c(\sup \boldsymbol{q}(\Theta))}_{\substack{\text{same magnitude} \\ \text{as } t(\theta)}} \,\mathrm{d}F(\theta),$$

under which production exhibits:

1. costly replication;
2. free damaging;
3. impossibility or high costs of producing $q' < \sup \boldsymbol{q}(\Theta)$.

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In the damaged-goods model of Deneckere and McAfee (1996):

1. Costs are purely-separable **damaging** costs k, with $k'(q) \leq 0$;

$\hookrightarrow$ identify gains from screening

2. The cost of the undamaged good is fixed.

$\hookrightarrow$ if damaging is free, our separable interpretation

Single buyer

$$\Pi^{\text{M-R}}(\boldsymbol{q}) = \underbrace{\int_\Theta t(\theta)\,\mathrm{d}F(\theta)}_{\text{expected revenues}} - \underbrace{\int_\Theta c(\boldsymbol{q}(\theta))\,\mathrm{d}F(\theta)}_{\text{expected costs}},$$

1. Payment $t(\theta)$ and production cost $k(\boldsymbol{q}(\theta))$ are comparable;
2. Production occurs after type is elicited;
3. Damaging and replication costs do not bite.

$$\Pi(\boldsymbol{q}) = \underbrace{\int_\Theta t(\theta)\,\mathrm{d}F(\theta)}_{\text{expected revenues}} - \underbrace{c(\sup \boldsymbol{q}(\Theta))}_{\text{costs}}.$$

1. Payment $t(\theta)$ and production cost $c(\sup \boldsymbol{q}(\Theta))$ are comparable;
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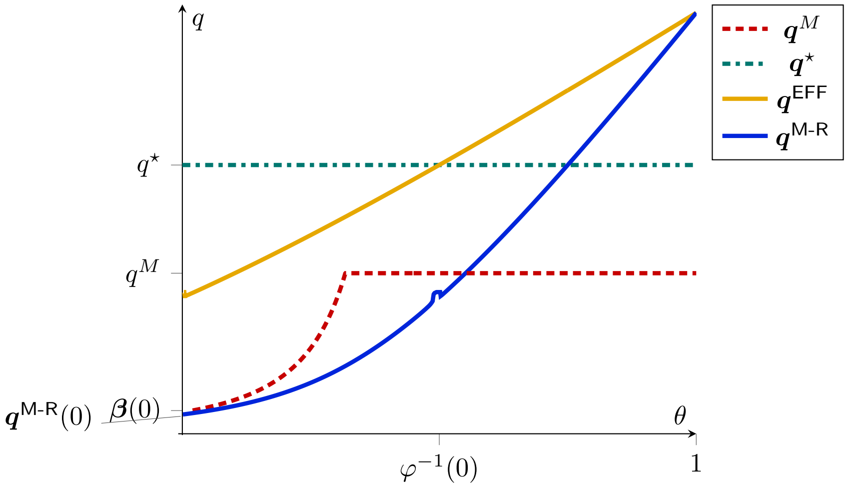
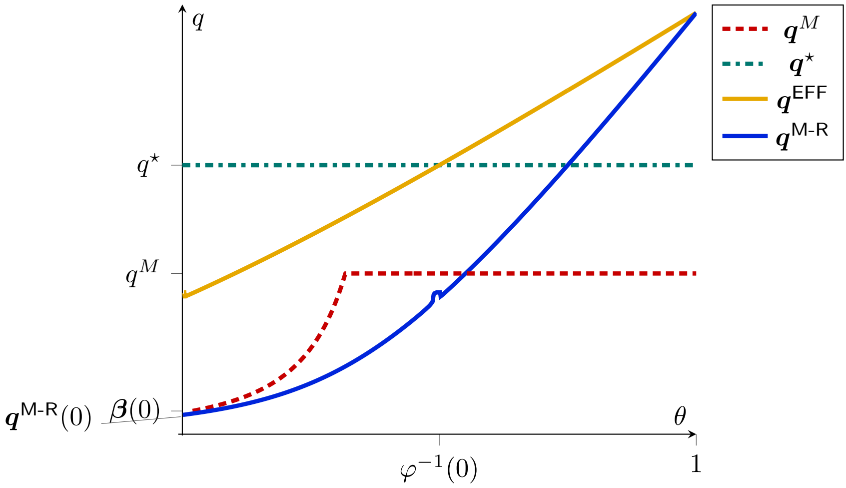
Single buyer



Single buyer



$\Pi^{\text{M-R}}(\boldsymbol{q}^{\text{M-R}}) - \Pi(\boldsymbol{q}^M) =$ gains from "interim" damaging wrt ex-ante damaging.

Hybrid costs

With more general costs: $C(\boldsymbol{q}) = \int_\Theta \hat{c}(\boldsymbol{q}(\theta), \sup \boldsymbol{q}(\Theta))\,\mathrm{d}F(\theta)$,
the seller pays:

1. Development / production costs: $c(\sup \boldsymbol{q}(\Theta))$;
2. Distribution / replication costs: $k(\boldsymbol{q}(\theta))$;
3. Damaging costs.

Lemma 1 holds, but the characterization of $\boldsymbol{q}^M$ has two complications:

1. Distribution: the solution to $\mathcal{P}(q)$ does not depends on q solely through capping;
2. Production: the marginal return $V'(q)$ depends on: (i) bunching region, and (ii) damaging.

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If $C(\boldsymbol{q}) = c(\sup \boldsymbol{q}(\Theta)) + \kappa \log\left(\frac{\sup \boldsymbol{q}(\Theta)}{\boldsymbol{q}(\theta)}\right)$, then **1.** is turned off.

Damaging costs

If $C(\boldsymbol{q}) = c(\sup \boldsymbol{q}(\Theta)) + \kappa \log\left(\frac{\sup \boldsymbol{q}(\Theta)}{\boldsymbol{q}(\theta)}\right)$, then:

- Production costs + pure-damaging replication / distribution costs;

Damaging costs

If $C(\boldsymbol{q}) = c(\sup \boldsymbol{q}(\Theta)) + \kappa \log\left(\frac{\sup \boldsymbol{q}(\Theta)}{\boldsymbol{q}(\theta)}\right)$, then:

- Production costs + pure-damaging replication / distribution costs;
- The efficient allocation is flat: damaging decreases utility and increases costs;
- The solution to $\mathcal{P}(q)$ is $\theta \mapsto \min\{\boldsymbol{\beta}_\kappa(\theta), q\}$.

1. $\kappa > 0$ acts as a preference shift ($\uparrow g$) at the distribution stage:
   - $\uparrow \boldsymbol{\beta}_\kappa$ and $\downarrow b_\kappa(q)$;

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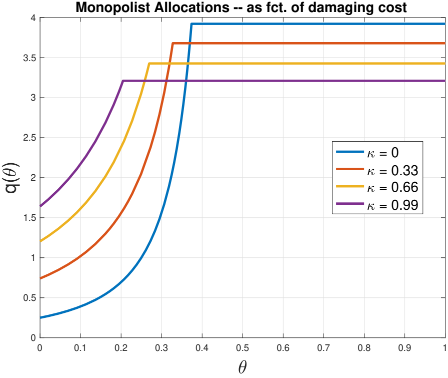
1. $\kappa > 0$ acts as a preference shift ($\uparrow g$) at the distribution stage:
   - $\uparrow \boldsymbol{\beta}_\kappa$ and $\downarrow b_\kappa(q)$;
2. $\kappa > 0$ impacts production directly:
   - $V'(q) = (1 - F(b_\kappa(q))(g'(q) + b_\kappa(q)) - \kappa \frac{b_\kappa(q)}{q}$.

Damaging costs

$\kappa > 0$ implies

1. Less damaging;
2. Lower production.



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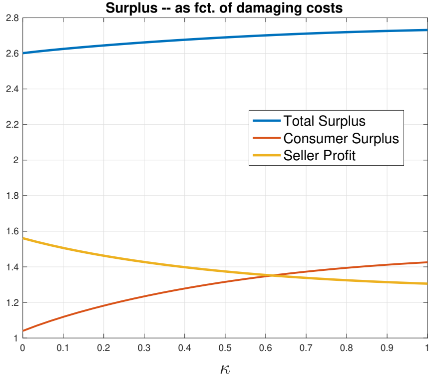

Conclusion

1. With digital goods, two interdependent inefficiencies arise: **productive and damaging**.
2. The *efficiency at the top* insight is revisited: '**distributional efficiency** for **high types**.'

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$$\underbrace{\int_{\Theta} t(\theta)\,\mathrm{d}F(\theta) - c(\sup \boldsymbol{q}(\Theta))}_{\text{Magnitude gap}} \quad \text{v.} \quad \underbrace{\int_{\Theta} t(\theta) - c(\sup \boldsymbol{q}(\Theta))\,\mathrm{d}F(\theta)}_{\text{Costly replication}}.$$

- Free-replication–and-damaging technology for mass of buyers; (plus a timing mismatch for a single buyer;)
- Costly-replication technology for mass of buyers.

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4. The results extend to: $C(\boldsymbol{q}) = c(\sup \boldsymbol{q}(\Theta)) + \int_{\Theta} k(\boldsymbol{q}(\theta))\,\mathrm{d}F(\theta)$, general u (damaging costs), and nonregular F.

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Thanks!

Extra slides

Literature

Multi-product monopoly
Mussa and Rosen (1978); Maskin and Riley (1984); Wilson (1993) . . .
Costs are separable.

Damaged goods
Deneckere and McAfee (1996); McAfee (2007); Grubb (2009); Corrao, Flynn, and Sastry (2023).
Costs are separable, and consumers can damage the good.

Pricing of information with buyer's private information
Bergemann, Bonatti, and Smolin (2018); Bergemann and Ottaviani (2021); Yang (2022); Bergemann, Cai, Velegkas, and Zhao (2022); Rodríguez Olivera (2024); Bonatti, Dahleh, Horel, and Nouripour (2024) . . .
Information is sold to strategic buyers, without production.

Kolotilin, Mylovanov, Zapechelnyuk, and Li (2017) . . .
Information is allocated without production.

Mechanism & information design
Bergemann, Heumann, and Morris (2025); Mensch and Ravid (2025); Thereze (2025).

Efficiency with general u and k

Proposition 5

The allocation $\boldsymbol{q}^\star$ is efficient iff $\boldsymbol{q}^\star(\theta) = \min\{\boldsymbol{\gamma}(\theta), q^\star\}$ for all θ, in which: $q^\star$ is the unique quality q such that $\int_{[a(q),1]} u_1(q,\theta) - k'(q)\,\mathrm{d}F(\theta) = c'(q)$, and $\boldsymbol{\gamma}$ is a nondecreasing allocation such that $\boldsymbol{\gamma}(\theta) = \boldsymbol{\alpha}(\theta)$ almost everywhere.

In general, $q \in [0, \overline{q}]$, and:

$$J(q,\theta) := u(q,\theta) - \frac{1}{h(\theta)} u_2(q,\theta) - k(q),$$

$\boldsymbol{\beta}(\theta)$ is the largest element of

$$\operatorname*{Argmax}_q J(q,\theta),$$

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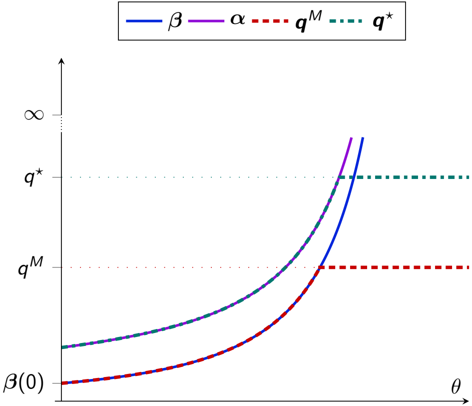
u and J satisfy incr. differences, and are: twice diff., concave in q for all θ, str. quasiconcave in q a.e. on Θ; k is Inada.



Monopoly with general u and k

Proposition 6

The allocation $\boldsymbol{q}^M$ is monopolist iff $\boldsymbol{q}^M(\theta) = \min\{\boldsymbol{\gamma}(\theta), q^M\}$ for all θ, in which: q^M is the unique quality q such that $\int_{[b(q),1]} J_1(q,\theta)\,\mathrm{d}F(\theta) = c'(q)$, and $\boldsymbol{\gamma}$ is a nondecreasing allocation such that $\boldsymbol{\gamma}(\theta) = \boldsymbol{\beta}(\theta)$ almost everywhere. Moreover, $0 < q^M < q^\star$.

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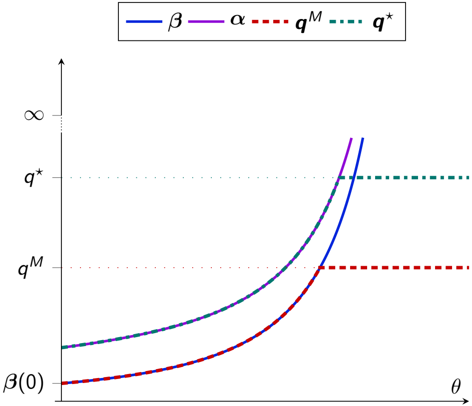

No-damaging monopoly with general u and k

Assumption: $J(0,\theta) = 0$ for all θ and $J(q,\cdot)$ is increasing for all $q > 0$.

Proposition 7

The allocation $\boldsymbol{q}_N$ is no screening iff $\boldsymbol{q}_N(\theta) = [\theta \geq b_N(q_N)]q_N$ for all $\theta \in \Theta \setminus \{b_N(q)\}$ and $\boldsymbol{q}_N(b_N(q_N)) \in \{0, q_N\}$, in which q_N is the unique quality q such that: $\int_{[b_N(q),1]} J_1(q,\theta)\,\mathrm{d}F(\theta) = c'(q)$. Moreover, it holds that:

1. $0 < q_N \leq q^M$;
2. $q_N < q^M$ if $b(q^M) > b_N(q^M)$.

We use Iverson brackets: $[P] = 1$ if P is true, and $[P] = 0$ otherwise.

Productive inefficiency addendum 1/3

Productive inefficiency arises if:

$$\underbrace{V'(q)}_{\substack{\text{Marginal revenues}\\ \text{given } \theta \mapsto \min\{\boldsymbol{\beta}(\theta),\, q\}}} \quad < \quad \underbrace{g'(q) + \mathbb{E}\{\theta\}}_{\substack{\text{Marginal total utility}\\ \text{given } \theta \mapsto q}} \ .$$

1. The q constrained allocation $\theta \mapsto \min\{\boldsymbol{\beta}(\theta), q\}$ induces total utility

$$U(q) \coloneqq \mathbb{E}\{u(\min\{\boldsymbol{\beta}(\theta), q\}, \theta)\};$$

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$$U(q) \coloneqq \mathbb{E}\{u(\min\{\boldsymbol{\beta}(\theta), q\}, \theta)\};$$

2. $U'(q) <$ marginal total utility given $\theta \mapsto q$, because

$$U'(q) = \int_{[b(q),1]} g'(q) + \theta \, \mathrm{d}F(\theta) \leq g'(q) + \mathbb{E}\{\theta\};$$

3. It holds that

$$V'(q) < V'(q) + \mathrm{Rents}'(q) = U'(q).$$

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Productive inefficiency addendum 2/3

Productive inefficiency arises because:

$$V'(q) < g'(q) + \mathbb{E}\{\theta\}.$$

The monopoly that produces quality q implies total surplus

$$V(q) + U(q) - c(q),$$

with $U(q) = \int_{[0,1]} \int_{[0,\theta]} \min\{\beta(\theta'), \overline{q}\} \, \mathrm{d}\theta' \, \mathrm{d}F(\theta)$ (Envelope Theorem).

The marginal surplus is $V'(q) + U'(q)$ and satisfies

$$V'(q) < V'(q) + U'(q) \leq g'(q) + \mathbb{E}\{\theta\}.$$

1. Monopolist does not internalize buyer surplus;
2. Damaging inefficiency.

Productive inefficiency addendum 3/3

WTS: $V'(q) + U'(q) \leq g'(q) + \mathbb{E}\{\theta\}$.

1. $U'(q) = \int_{[b(q),1]} \theta - b(q)\,\mathrm{d}F(\theta)$,
because the marginal $u(\boldsymbol{q}(\theta), \theta)$ increases at rate $g'(q) + \theta$ and the marginal transfer at rate $g'(q) + b(q)$, for $\theta > b(q)$ and $\boldsymbol{q}(\cdot) = \min\{\beta(\cdot), q\}$;

2. Using $V'(q) = (1 - F(b(q)))(g'(q) + b(q))$, we have

$$V'(q) + U'(q) = (1 - F(b(q)))g'(q) + \int_{[b(q),1]} \theta\,\mathrm{d}F(\theta).$$

Note that $U'(q) > 0$ for all $q > 0$, because $b(q) \leq \varphi^{-1}(0) < 1$ for all $q \geq 0$.)

Competition

The game among N firms has two stages:

1. Every firm i simultaneously chooses a quality q_i.
2. Every firm i, observing all stage-1 qualities, simultaneously chooses a pricing function $p_i \colon \mathbb{R}_+ \to \mathbb{R}$, with $p_i(q) = \infty$ if $q > q_i$.

Then: each type buys a good from a firm i, or does not buy any good for a payoff of 0.

Firms play a subgame-perfect Nash equilibrium.

Definition 1
An *n equilibrium* is an equilibrium in which exactly n firms are active; an n equilibrium is *symmetric* if active firms play the same strategy.

The game

Type θ buys quality $D_p(\theta)$ from firm $\iota_p(\theta)$, given the pricing functions in $(p_1, \dots, p_N) = p$.

The revenues of i given the pricing functions in $(p_1, \dots, p_N) = p$ are

$$R_i(p_1, \dots, p_N) \coloneqq \int_{\{\theta \mid \iota_p(\theta) = i\}} p_i(D_p(\theta))\, \mathrm{d}F(\theta).$$

The set of strategies for firm i is $S_i \coloneqq Q \times \boldsymbol{P}_i$, letting $\boldsymbol{P}_i \subseteq (\mathbb{R}^Q)^{Q^N}$ be the set of "conditional" pricing functions of firm i.

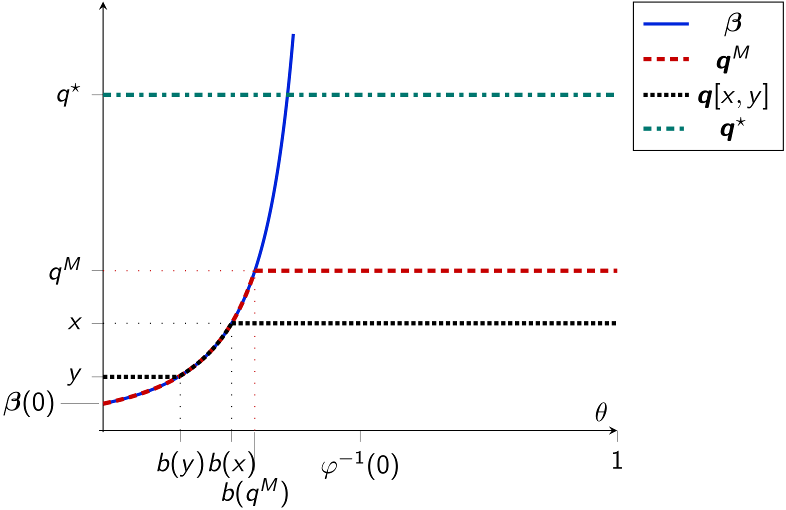
The *payoff* of firm i from the profile $s \coloneqq (\dots, (\overline{q}_i^s, P_i^s), \dots) \in \times_{i=1}^N S_i$ is

$$\Pi_i(s) \coloneqq R_i(P_1^s[\overline{q}^s], \dots, P_N^s[\overline{q}^s]) - c(\overline{q}_i^s).$$

Competitive allocations

Let's order qualities $(q_1, \ldots, q_N)$ so that: $x > y > \cdots$

Every quality below y comes at zero price.



Competitive equilibria

Lemma 3
In any pure-strategy equilibrium: one firm produces q^M and other firms are idle.

$\Longrightarrow$ Every symmetric n equilibrium is mixed if $n \geq 2$ (*competitive*.)

Proposition 8

1. For all $n \leq N$, there exists a symmetric n equilibrium.
2. Every symmetric and competitive n equilibrium induces the random allocation $\boldsymbol{q}[\hat{x}, \hat{y}]$, letting $\hat{x}$ and $\hat{y}$ be, resp., the first and second order statistics of the n i.i.d. draws $[0, q^M]$ with CDF

$$H_n(q) = \sqrt[n-1]{\frac{c'(q)}{V'(q)}}.$$

Properties of competitive equilibria

Corollary 1

Every symmetric competitive equilibrium leads to an allocation such that, with probability one:

1. The lowest quality is positive and free;
2. The highest quality is strictly lower than q^M.

In the paper:

1. Equilibrium welfare with $n \geq 2$ active firms decreases in n.
2. Monopoly dominates duopoly if monopoly fully bunches.
3. Duopoly dominates monopoly if: full bunching does not occur and costs are approximately fixed.

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