# Prices vs. Quantities: Robust Regulation

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**COVID-19 pandemic:**

- Many economists advocated paying individuals to get vaccinated.
- Many schools, employers, and governments instead imposed vaccine mandates.

## Prices vs. Quantities

This may seem like the "prices-versus-quantities" problem studied by Weitzman (1974)…

- **Rich information**: regulator knows full distribution of externalities (Bayesian uncertainty).
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…but it is different.

- **Simple information**: regulator knows only average externality (non-Bayesian uncertainty).
- **Rich instruments**: regulator designs a nonlinear pricing schedule (full mechanism design).

**This paper:** What is the **optimal regulation** with **simple information** and **rich instruments**?

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**Main result:** the **optimal policy** is a **quantity control** (*positive*: floor, *negative*: ceiling).

**Role for prices:** information about selection can justify **price regulation** (tax or subsidy).

# Framework

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  *Assumptions*: $\theta \sim F \in C^1$ with positive density $f$ on $\Theta$; $u_q > 0$, $u_{qq} < 0$ for $q \in [0, A]$;
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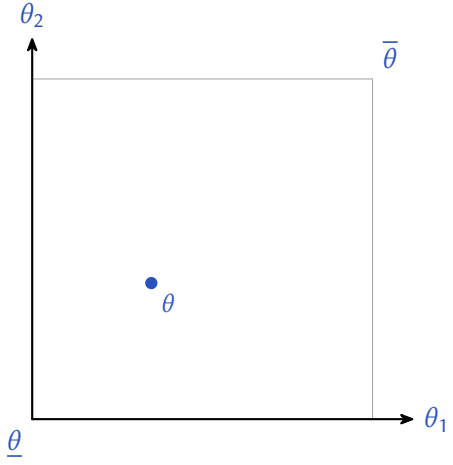
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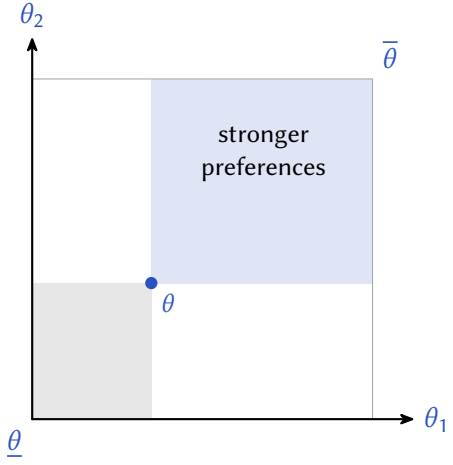
- Utility from own consumption $q(\theta, \xi)$, payment $t(\theta, \xi)$, aggregate externality $E(q)$:

$$u(q(\theta, \xi), \theta) - t(\theta, \xi) + E(q), \qquad \text{where } E(q) = \iint_{(\hat{\theta}, \hat{\xi}) \in \Theta \times \mathbb{R}_+} \hat{\xi} q(\hat{\theta}, \hat{\xi}) \, \mathrm{d}H(\hat{\theta}, \hat{\xi}).$$

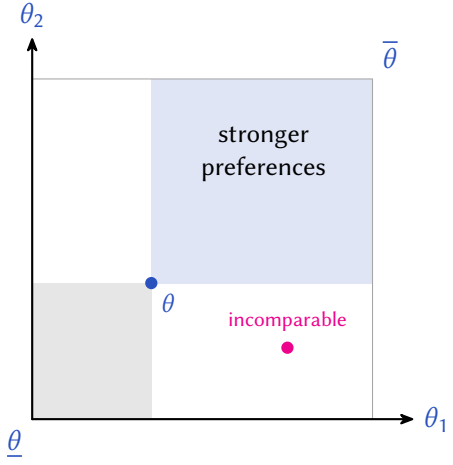
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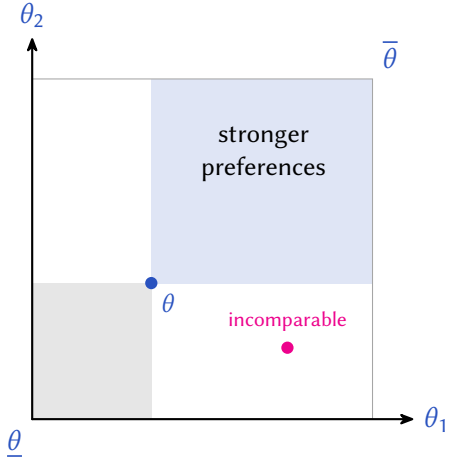
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Coordinates of $\theta$ may be correlated with each other and with $\xi$.

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  **Examples:**

  - **price regulation**: $T(q) = (c - s)\, q$ implements a uniform subsidy $s$;
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- Equivalently (Myerson, 1979), she chooses a direct mechanism $(q, t)$, consisting of:
  - the **allocation function** $q : \Theta \times \mathbb{R}_+ \longrightarrow [0, A]$ denoting consumption by each agent;
  - the **payment function** $t : \Theta \times \mathbb{R}_+ \longrightarrow \mathbb{R}$ denoting payment by each agent.

# Mechanism Design

- By the revelation principle, restrict attention to **incentive-compatible** $(q, t)$ WLOG:

$$(\theta, \xi) \in \arg\max_{(\hat{\theta}, \hat{\xi})} \left[ u(q(\hat{\theta}, \hat{\xi}), \theta) - t(\hat{\theta}, \hat{\xi}) + E(q) \right]. \tag{IC}$$

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  Following Myerson (1981), one can show that $(q, t)$ satisfies (IC) for some $t$ only if

$$q(\hat{\theta}, \hat{\xi}) \overset{a.e.}{=} \hat{q}(\hat{\theta}), \qquad \text{where } \hat{q} \in Q := \{\hat{q} : \Theta \to [0, A] \text{ is nondecreasing}\}.$$

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- Henceforth, consider the **relaxed** feasible set $Q$ (will show solution is implementable).

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  **#2. positive selection**—regulator considers **#1.** and also requires $m$ to be "nondecreasing";

  **#3. negative selection**—regulator considers **#1.** and also requires $m$ to be "nonincreasing."

  Denote the respective corresponding feasible sets of $m : \Theta \to \mathbb{R}_+$ by $\mathcal{M}_0$, $\mathcal{M}_+$, and $\mathcal{M}_-$.

## Positive and Negative Selection

Let $m(\theta) \coloneqq \mathbf{E}_H[\xi \mid \theta]$ and $\mu \coloneqq \mathbf{E}_F[m(\theta)]$. For any measurable set of types $B \subset \Theta$, define

$$F(B) \coloneqq \int_B \mathrm{d}F(\theta) \quad \text{and} \quad F^m(B) \coloneqq \frac{1}{\mu} \int_B m(\theta)\, \mathrm{d}F(\theta).$$

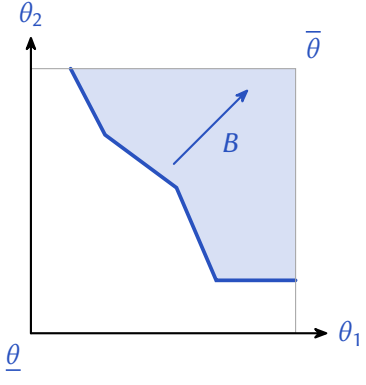
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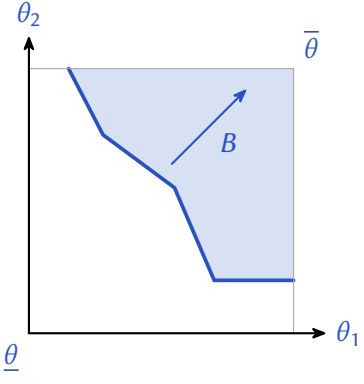


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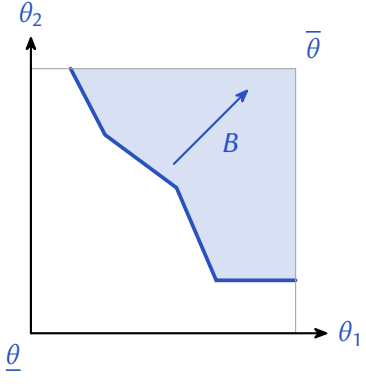

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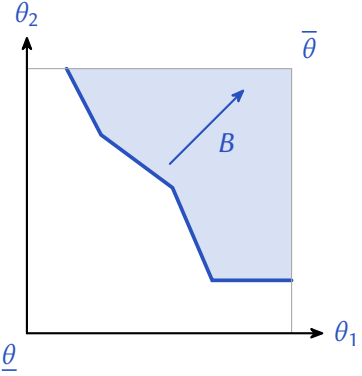
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# Robust Mechanism Design

- The regulator evaluates policies by their **worst-case welfare performance**.
- If the joint distribution $H$ were known, then total surplus would be

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- Under the three informational benchmarks $* \in \{0, +, -\}$, the regulator solves

$$\sup_{q \text{ is implementable}} \inf_{m \in \mathcal{M}_*} \int_{\Theta} \left[ u(q(\theta), \theta) + \left[ m(\theta) - c \right] q(\theta) \right] \, \mathrm{d}F(\theta);$$

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# Main Results

# Main Result #1: Unknown Selection

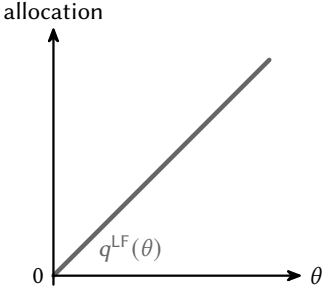
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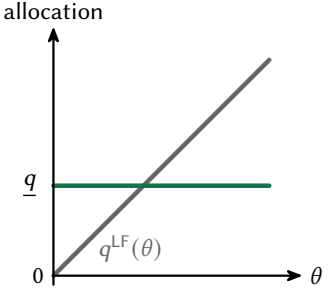
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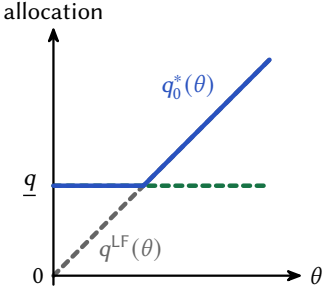
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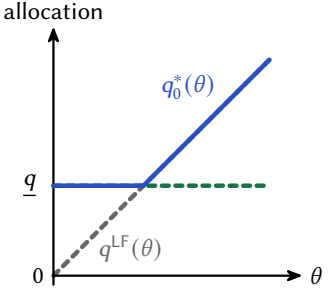
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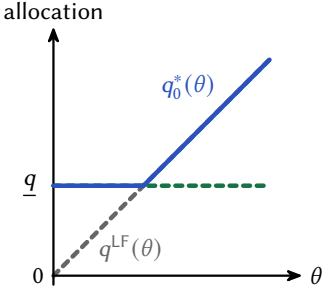

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**#2.** There is **no intervention** above $\underline{q}$.

Intervention leads to unnecessary distortion in worst case.

# Remark: Choosing the Optimal Floor

Raising the floor changes consumption only where $q^{\mathrm{LF}}(\theta) < \underline{q}$.

An interior optimum therefore satisfies

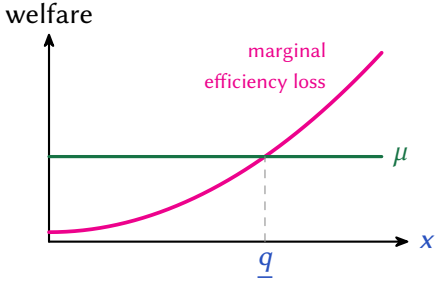
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This is **one-dimensional optimization**, even with multidimensional preferences.

- $F$ affects the level of the floor through aggregate efficiency losses.
- Greater $\mu$ raises the optimal floor.

# Main Result #2: Known Selection

**Theorem 2.** Let $D(p, \theta)$ be the demand function of an agent of type $\theta$.

Under positive selection, the **unique** optimal allocation can be implemented by a **uniform per-unit subsidy equal to** $\mu$:

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- By Theorem 2, there is nevertheless still a role for **price regulation**.

  Nature can no longer concentrate high MB on low types; worst case changes.

- The worst case under negative selection coincides with unknown selection.

  It remains to show that a uniform subsidy is optimal under positive selection.

# Summary: What Information Changes

| selection | worst-case external benefit | optimal instrument |
|---|---|---|
| unknown | $\mu \operatorname{ess\,inf}_{\theta \in \Theta} q(\theta)$ | quantity floor |
| negative | $\mu \operatorname{ess\,inf}_{\theta \in \Theta} q(\theta)$ | quantity floor |
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- Robustness makes a simple statistic of consumption sufficient for external benefit.
- With known heterogeneous $m$, even the optimal uniform subsidy is generally a weighted average (by demand response), rather than $\mu$.

  In fact, Diamond (1973) and subsequent authors caution against this "naïve" subsidy.

# Prices vs. Quantities

| | positive externality | negative externality |
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| unknown selection | quantity floor | quantity ceiling |
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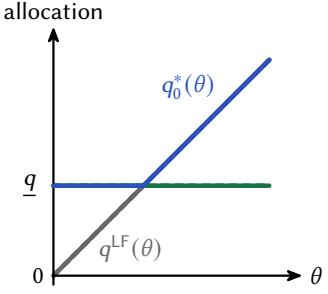
**Price regulation:** optimal when information on selection rules out that concentration.

# Proofs of Main Results

# Main Result #1: Unknown Selection

**Theorem 1.** Let $q^{\mathsf{LF}}$ denote the laissez-faire allocation function. Under unknown selection, there exists a **quantity floor** $\underline{q} \in [0, A]$ such that the **unique** optimal allocation is

$$q_0^*(\theta) = \max\left\{q^{\mathsf{LF}}(\theta), \underline{q}\right\}.$$




**#1.** There is a **quantity floor** of $\underline{q}$.

This maximally lower-bounds MB generated, subject to IC.

**#2.** There is **no intervention** above $\underline{q}$.

Intervention leads to unnecessary distortion in the worst case.

# Proof Overview

The proof of Theorem 1 proceeds in three steps:

**#1. Solving Nature's problem.**

Nature concentrates marginal benefit among types consuming the least.

Given any allocation function $q$, the worst-case external benefit is $\mu \operatorname{ess\,inf}_{\theta \in \Theta} q(\theta)$.

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**#3. Showing implementability.**

The allocation $q_0^*(\theta) = \max\{q^{\mathrm{LF}}(\theta), \underline{q}\}$ can be implemented by a quantity floor.

## Step #1: Solving Nature's Problem

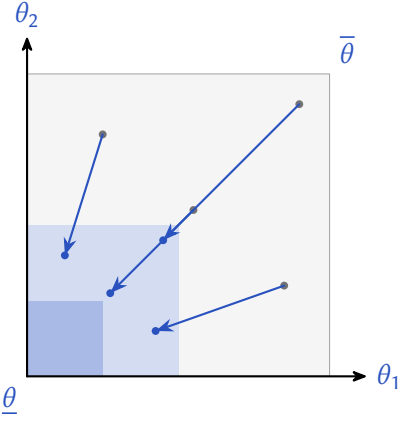
For any allocation function $q \in Q$, the **worst-case external benefit** satisfies

$$\inf_{m \in \mathcal{M}_0} \mathbf{E}_F[m(\theta)q(\theta)] \geq \inf_{m \in \mathcal{M}_0} \mathbf{E}_F[m(\theta)] \cdot \operatorname*{ess\,inf}_{\theta \in \Theta} q(\theta) = \mu \operatorname*{ess\,inf}_{\theta \in \Theta} q(\theta).$$

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Contract externalities into the lower corner:

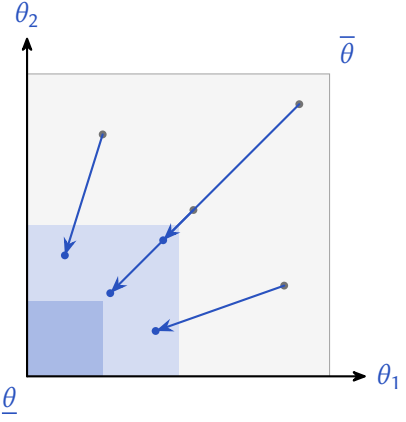
$$\phi_n : \theta \mapsto \underline{\theta} + \frac{\theta - \underline{\theta}}{n}.$$

This preserves the mean externality $\mu$.

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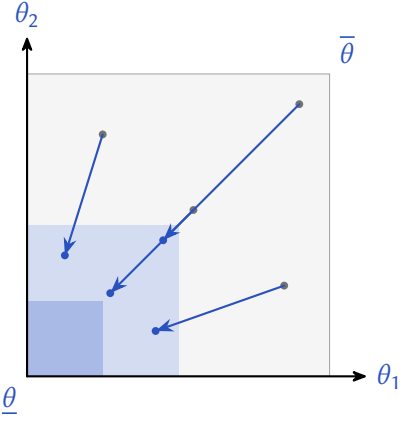
The external benefit is then

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So $\inf_{m \in \mathcal{M}_0} \mathbf{E}_F[m(\theta)q(\theta)] = \mu \operatorname{ess\,inf}_{\theta \in \Theta} q(\theta)$.

## Step #2: Solving the Regulator's Relaxed Problem

Given Nature's worst-case external benefit, the regulator's relaxed problem becomes

$$\sup_{q \in Q} \left\{ \mathbf{E}_F[u(q(\theta), \theta) - cq(\theta)] + \mu \operatorname*{ess\,inf}_{\theta \in \Theta} q(\theta) \right\}.$$

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For each $\underline{q} \in [0, A]$ and $\theta \in \Theta$, strict concavity implies

$$\arg\max_{q \in [\underline{q}, A]} [u(q, \theta) - cq] = \max\left\{ D(c, \theta), \underline{q} \right\}.$$

This pointwise maximizer is nondecreasing, so it belongs to $Q$.

## Step #3: Showing Implementability

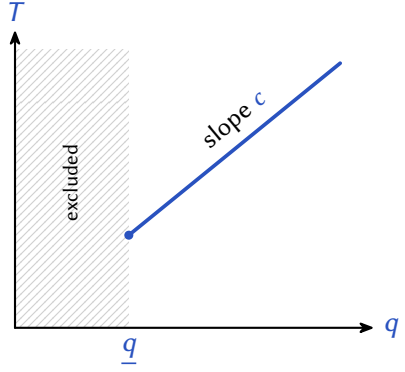
Choose a maximizer $\underline{q}$ of the outer problem and set

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Every type chooses

$$\arg\max_{q \in [\underline{q}, A]} [u(q, \theta) - cq] = \max\{q^{\mathrm{LF}}(\theta), \underline{q}\}.$$

The relaxed optimum is **implementable**.

The optimal allocation is $q_0^*(\theta) = \max\left\{q^{\mathrm{LF}}(\theta), \underline{q}\right\}$.

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**Theorem 2.** Let $D(p, \theta)$ be the demand function of an agent of type $\theta$.

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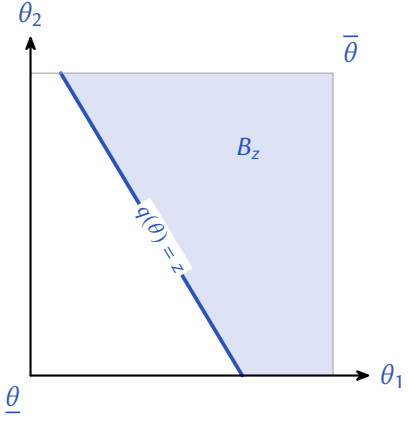
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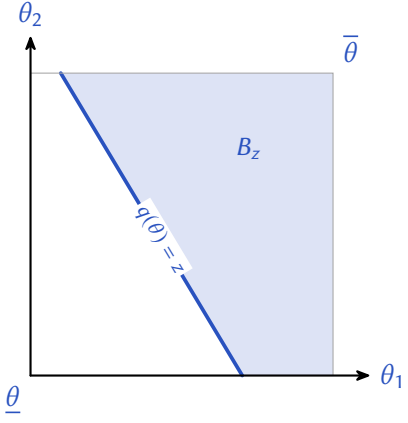



For each $z$, the following is an upper set:

$$B_z = \{\theta : q(\theta) > z\}.$$

Positive selection requires $F^m(B_z) \geq F(B_z)$.

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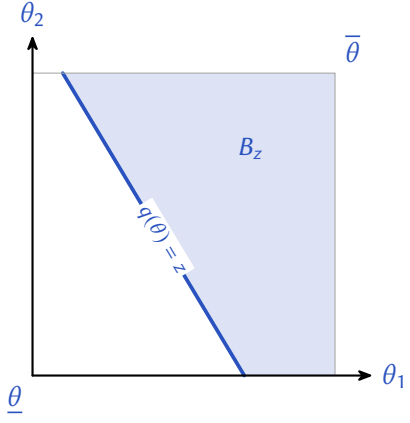
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Integrating over all $z$, external benefit is:

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Equality is attained by **no selection**: $m(\theta) \equiv \mu$. Thus, $\inf_{m \in \mathcal{M}_+} \mathbf{E}_F[m(\theta)q(\theta)] = \mu\,\mathbf{E}_F[q(\theta)]$.

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The regulator's relaxed problem is

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**Remark:** The optimal subsidy is $\mu$ and does not require information about $F$.

# Discussion

# Extension #1: Unit Demand

Consider linear utility $u(q, \theta) = v(\theta)q$ for some increasing $v : \Theta \to \mathbb{R}$, with $q \in [0, 1]$.

**Proposition 1.** Under unknown or negative selection, an optimal allocation is

$$q_0^*(\theta) = q_-^*(\theta) = \begin{cases} 1, & \text{if } \mu \geq \mathbf{E}_F[[c - v(\theta)]_+], \\ q^{\mathsf{LF}}(\theta) = \mathbf{1}_{v(\theta) > c}, & \text{if } \mu < \mathbf{E}_F[[c - v(\theta)]_+]. \end{cases}$$

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- By Proposition 1, there are three candidates: **mandate**, **no intervention**, **subsidy**.
  - Under unknown or negative selection, either a **mandate** or **no intervention** is optimal.
  - Under positive selection, a **subsidy** is optimal.

# Application to Vaccination

**Unknown/negative selection.** How to choose between a mandate and no intervention?

$$\underbrace{\mu}_{\text{benefit guaranteed by a mandate}} \gtreqless \underbrace{\mathbf{E}_F[[c - v(\theta)]_+]}_{\text{allocative loss from a mandate}} .$$

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With a sufficiently high average MB $\mu$, a vaccination mandate can be justified.

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**HPV/mpox**: Individuals anticipating greater exposure may have higher willingness to pay.

## Extension #2: Revenue Concerns

The regulator maximizes worst-case external benefit plus $\lambda \, \mathbf{E}_F[t(\theta) - cq(\theta)]$, subject to

$$\mathbf{E}_F[u(q(\theta), \theta) - t(\theta)] \geq \underline{U}, \qquad \lambda > 0.$$

This constraint limits the burden on agents as a group: **aggregate direct utility** $\geq \underline{U}$.

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**Proposition 2** (informal). The allocation problem is unchanged after replacing $\mu$ by $\mu/\lambda$.

- Under unknown or negative selection, a **quantity floor** is uniquely optimal.
- Under positive selection, a **uniform subsidy** of $\mu/\lambda$ is uniquely optimal.

## Extension #3: Bounded Marginal Externalities

Suppose $\xi \in [\underline{\xi}, \overline{\xi}]$ is known, where $0 \leq \underline{\xi} \leq \mu \leq \overline{\xi}$.

Nature can no longer concentrate all marginal benefit on an arbitrarily small set of agents.

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**Proposition 3.** Under unknown selection, there exists a threshold quantity $\underline{q} \in [0, A]$ such that the unique optimal allocation is

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- Above $\underline{q}$: consume $D(c - \underline{\xi}, \theta)$ (these are agents with strong consumption preferences).
- Below $\underline{q}$: consume $D(c - \overline{\xi}, \theta)$ (these are agents with weak consumption preferences).

## Extension #3: Bounded Marginal Externalities

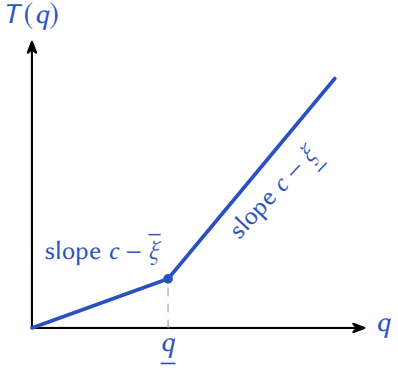
The optimal allocation is implemented by a **two-tier subsidy**:

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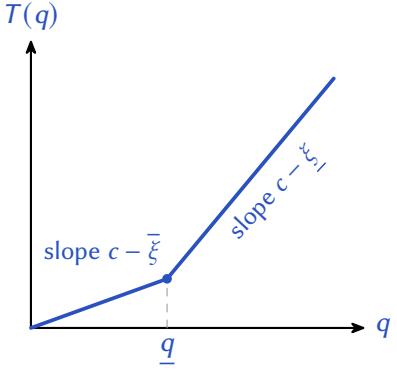
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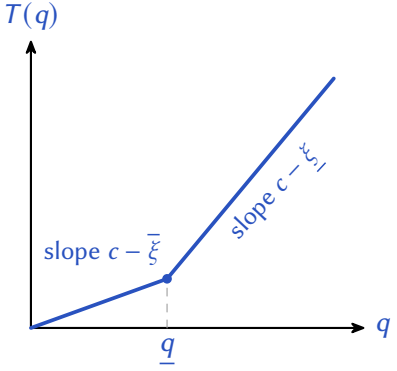

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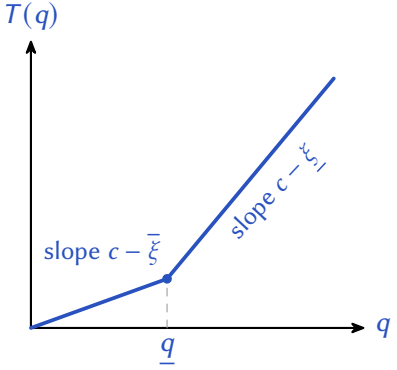
- Additional units: subsidize $\underline{\xi}$ per unit.

  If $\underline{\xi} = 0$, we recover **laissez-faire** above $\underline{q}$.

# Extension #3: Bounded Marginal Externalities

The optimal allocation is implemented by a **two-tier subsidy**:

$$T_0^*(q; \underline{\xi}, \overline{\xi}) = \left(c - \underline{\xi}\right) q - \left(\overline{\xi} - \underline{\xi}\right) \min\{q, \underline{q}\}.$$




- First $\underline{q}$ units: subsidize $\overline{\xi}$ per unit.

  If $\overline{\xi} \geq c$, we recover a **quantity floor** of $\underline{q}$.

- Additional units: subsidize $\underline{\xi}$ per unit.

  If $\underline{\xi} = 0$, we recover **laissez-faire** above $\underline{q}$.

- The kink creates **bunching** at $\underline{q}$.

# Other Applications

As the Supplemental Appendix shows, the logic extends beyond consumption externalities.

- **Regulatory uncertainty** *à la* Weitzman (1974).

  Regulator knows average marginal benefit, but not its dependence on abatement costs.

  Even with nonlinear payment schedules, a **quantity control** is robustly optimal.

# Other Applications

As the Supplemental Appendix shows, the logic extends beyond consumption externalities.

- **Regulatory uncertainty** *à la* Weitzman (1974).

  Regulator knows average marginal benefit, but not its dependence on abatement costs.

  Even with nonlinear payment schedules, a **quantity control** is robustly optimal.

- **Costly screening** (e.g., for redistribution).

  Regulator knows MRS distribution and average waiting cost, but not joint distribution.

  Robustness can favor **randomization**: a uniform lottery with no costly screening.

  This complements a growing literature on Bayesian redistributive mechanism design.

# Conclusion

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# Conclusion

Much of the prices vs. quantities debate considers **simple instruments**, **rich information**.

As a subsequent literature shows, richer price instruments can dominate quantity controls.

This paper differs along both dimensions: **rich instruments**, **simple information**.

- Heterogeneity + robustness provide a welfare-based rationale for **quantity controls**.
- Information about the direction of selection can justify a **uniform tax** or **subsidy**.

$\rightsquigarrow$ Instrument choice (prices vs. quantities) turns on what is known about **selection**.

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