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Procuring drugs while regulating the private market[☆]

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ABSTRACT

Public procurement mechanisms play a critical role in reducing drug costs and improving access to medicines. However, their competitive effects often fail to fully translate into private markets, where patient loyalty and physician preferences create quasi-monopolistic conditions for branded drugs. This paper proposes a novel mechanism that integrates public procurement and private market regulation. A branded-drug producer with market power competes with generic firms in a procurement auction, but it may opt out to retain unregulated monopoly profits. The optimal mechanism adjusts the allocation rule based on the firm's cost reports: For low-cost reports, it resembles a standard optimal auction. For high-cost reports, it favors the branded-drug producer in procurement while tightening price caps in the private market. This mechanism results in higher profits for all cost realizations, reflecting the role of higher informational rents driven by type-dependent outside option. Compared to standard practices, this mechanism yields significant welfare gains.

1. Introduction

Public and private health expenditures have increased significantly in OECD countries over recent decades, largely due to technological advancements, and the concentration of market power among pharmaceutical suppliers (García-Goñi, 2022). Procurement mechanisms play a critical role in reducing prices and securing cost-effective access to medicines. For example, tendering, which involves bulk purchases at fixed prices through confidential bids, is widely adopted for both generic and non-generic drugs, as well as for retail and hospital pharmaceuticals (Wouters et al., 2017).[1] However, competition introduced by public tendering does not fully extend to the private market, where patients remain loyal to specific brands prescribed by their physicians. This loyalty stems from the nature of pharmaceuticals as credence goods: since patients lack the expertise to assess drug quality, they rely on doctors' recommendations, which favor familiar brands (Dulleck and Kerschbamer, 2006; Kerschbamer and Sutter, 2017). As a result, firms with strong brand recognition enjoy market power. In contrast, firms producing generics, perceived as homogeneous substitutes, compete in a fringe where they behave competitively. Private market regulation typically relies on laissez-faire policies or light interventions, such as mandatory generic substitution policies, price caps, or reference prices (OECD, 2008).

We analyze a regulator who simultaneously engages in bulk procurement for public needs and regulates the private market. Firms are privately informed about costs, and one of them – the branded drug producer – also sells in a monopoly market.[2] The latter can choose not to participate in the procurement, and still enjoy unregulated monopoly profits. By participating in the mechanism, it accepts both the procurement rules and cap price in the private market. The regulator designs a mechanism that maximizes expected social welfare.

We characterize the optimal mechanism that integrates public procurement and private market regulation. A central feature of the mechanism is its potential bias in favor of the branded-drug producer. For low-cost reports, all firms are treated based on inflated virtual costs, following standard procurement. However, for high-cost reports, the mechanism adjusts to provide the branded-drug producer a competitive advantage in procurement while imposing stricter price regulation in the private market. This nuanced approach ensures that even high-costs firms remain competitive in the auction while balancing their market power in the private market. Crucially, transfers to participating firms are determined not only by their own cost reports but

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[1] Tendering is extensively used in European countries, especially in hospitals. In the United States, Group Purchasing Organizations (GPOs) consolidate hospital demand to negotiate lower prices; in Chile, Cenabast is responsible for open contracting in public procurement to lower medicine prices and improve accessibility (Raventos and Zolezzi, 2015).

[2] More precisely, all firms participate in the private market, but only the branded producer enjoys market power. This reflects that brand loyalty and physician prescribing habits prevent direct competition between branded and generic drugs.

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also by the broader allocation rule, which accounts for all possible cost realizations. This interdependence ensures that even the most competitive firms receive higher benefits than they would in the absence of regulatory oversight. By strategically linking procurement and price regulation, the mechanism enhances efficiency while addressing informational asymmetries and mitigating market power.

1.1. Related literature

The paper is related to the literature on monopoly regulation, based on Baron and Myerson's (1982) and Laffont and Tirole's (1993) models, as well as to the literature on standard procurement when participants have private information about costs (Myerson, 1981; Riley and Samuelson, 1981; Maskin and Riley, 1984). We extend these works by examining a setting where the regulated firm also participates in the procurement. Finally the article is related to the literature on mechanism design under type-dependent outside option (Maggi and Rodriguez-Clare, 1995; Jullien, 2000; Picard, 2001; Laffont and Martimort, 2002), which explores how firms' outside option influences their participation in regulatory or contractual agreements. In our model, indeed, participating in the procurement involves type-dependent individual rationality constraint. Vislie's (2000) paper provides a related perspective in the context of environmental regulation, by showing how regulators adjust policy to account for firms' potential relocation, balancing the need to control pollution with the firms' external opportunities. Finally, the paper closest to ours is Auriol and Picard (2009), who analyze the trade-off governments face between regulating a natural monopoly and outsourcing it with the possibility of ex-post contracts. Outsourcing gives monoply profits to a firm, which become its (type-dependent) outside option at the moment of recontracting. They show that, under certain conditions, outsourcing can enhance welfare compared to direct regulation. Our model similarly examines how type-dependent outside options shape regulatory and procurement decisions, particularly when the government must balance market competition with welfare maximization.

2. The model

A single buyer (e.g. a government) is procuring one unit of a good from $N \geq 2$ firms. We assume that public demand is price-inelastic, capturing standard practices where central buyers (aggregating the demand of public hospitals) purchase medicines based on fixed budgets and predetermined needs.[3] Firm i's constant marginal cost c_i is private information, and independently distributed according to the twice continuously differentiable cdf $F_i(\cdot)$, with positive density f_i on $C_i := [\underline{c}_i, \overline{c}_i]$. As usual we write $c = (c_1, \dots, c_N)$, $C = \prod_{i=1}^N C_i$, and $f(c) = \prod_{i=1}^N f_i(c_i)$.

While firms $i = 2, \dots, N$ only participate in the procurement, firm $i = 1$ also sells in a market where it enjoys market power. Firm 1 can choose not to participate in the mechanism, and still enjoy monopoly profits $H(c_1) := (P^M(c_1) - c_1)D(P^M(c_1))$, where $P^M(c_1)$ denotes the unregulated monopoly price. On the other hand, firms $i = 2, \dots, N$ do not have access to that market, so we normalize their outside option to 0. To simplify the exposition, we assume that the cross-price elasticity between firm 1's product and the other firms' is zero.[4] By participating in the mechanism, firm 1 accepts both the rules for the procurement and the price at which it must sell in the private market.

Without loss of generality, we consider a direct and incentive compatible mechanism (q, P, t), where $q : C \to \Delta_N$ determines the probability of each firm winning the procurement, $P : C \to \mathbb{R}_+$ is the regulated price at which firm 1 must sell in the monopoly market and $t : C \to \mathbb{R}^N$ represents the transfers.

We denote by $Q_i(z_i) = \int_{C_{-i}} q_i(z_i, c_{-i}) f_{-i}(c_{-i})\, dc_{-i}$ firm i's expected probability of winning the procurement when it reports z_i, while other firms reporting truthfully, and by $T_i(z_i) = \int_{c_{-i}} t_i(z_i, c_{-i}) f_{-i}(c_{-i})\, dc_{-i}$ its expected transfer when it reports z_i. The expected payoff of firm i when its true cost is c_i and it reports z_i is

$$\pi_i(z_i, c_i) = \begin{cases} -Q_i(z_i) c_i + T_i(z_i) + \mathbb{E}_{c_{-1}}\left[\left(P(z_1, c_{-1}) - c_1\right) D\left(P(z_1, c_{-1})\right)\right] & if \quad i = 1 \\ -Q_i(z_i) c_i + T_i(z_i) & if \quad i \neq 1 \end{cases}$$

Definition 1. We denote firm i's equilibrium payoff by $\Pi_i(c_i) := \max_{z_i} \pi_i(z_i, c_i)$.

Definition 2. A mechanism satisfies

- Incentive compatibity (IC) if, for all i and c_i, $\Pi_i(c_i) = \pi_i(c_i, c_i)$.
- Voluntary participation (VP) if, $\Pi_1(c_1) \geq H(c_1)$ and $\Pi_i(c_i) \geq 0$ for $i \neq 1$.

3. Optimal mechanism

The regulator designs a mechanism to maximize social welfare, which consists of three components: (i) consumer surplus, (ii) the net benefit of public procurement, and (iii) firms' profits in the private market. We assume that there is no direct interaction between public procurement and private demand, as publicly procured drugs do not involve direct patient copayments, and firms cannot manipulate government demand through price-setting. The regulator then solves

$$\begin{aligned} \max_{q,P,t} \quad & \mathbb{E}_c \left\{ CS(P(c)) + V - \sum_{i=1}^N t_i(c) + \lambda \left[\sum_{i=1}^N t_i(c) - \sum_{i=1}^N q_i(c) c_i \right.\right. \\ & \left.\left. + \left(P(c) - c_1\right) D(P(c)) \right] \right\} \\ s.t. \quad & IC \quad and \quad VP \end{aligned}$$

where $CS(P) = \int_P^{D^{-1}(0)} D(s) ds$ denotes consumer surplus in the private market, V denotes the gross benefit from public procurement, and λ determines the regulator's relative weight on firm profits in the social welfare function. Following Baron and Myerson (1982) and Laffont and Tirole (1993), we assume $\lambda \leq 1$, reflecting a regulator primarily concerned with consumer welfare but who also takes into account producer surplus to ensure efficiency and long-term market stability.

In our setting, the branded-drug producer (firm 1) has a type-dependent outside option that decreases in c, which introduces countervailing incentives, leading to modified virtual costs and making the participation constraint binding for a set of types with positive measure. On the one hand, firm 1 has the standard incentive to mimic higher-cost types in order to sell at higher prices; on the other hand, it has incentives to mimic lower-cost types, which have a better outside option, to be better compensated for participation. This affects the regulator's incentives to distort the allocation in order to control informational rents: (i) To deter the incentives to overstate costs, the regulator imposes downwards distortions, restricting sales for low-cost firms if they deviate, leading to inflated virtual costs; (ii) To deter the incentives to understate costs, the regulator applies upwards distortions, forcing firms to sell larger quantities at lower prices, which is reflected in deflated virtual costs.

The relative strength of these opposing forces is endogenously determined by the allocation rule (q, P). Intuitively, for lower-cost types,

[3] This is a crucial segment of pharmaceutical revenues, as centralized procurement represents a substantial share of drug purchases in many countries. IQVIA (2022) data show that in several European countries this accounts for close to 50% up as much as 70% of the total pharmaceutical market.

[4] If cross-price elasticity were nonzero, the monopoly profits would be $H(c_1, c_2, \dots, c_N)$. From an interim perspective, firm 1 would consider its outside option as $\overline{H}(c_1) = \mathbb{E}_{c_2,\dots,c_N}\left[H(c_1, c_2, \dots, c_N)\right]$, which would become the primitive of the model.

the first effect dominates, as the quantities sold (in the procurement mechanism and the monopoly market) are the relevant force. The second effect becomes more important for higher-cost types, leading the regulator to upwardly distort the allocation. This, in turn, makes the voluntary participation constraint binding, as the regulator aims to make the participation payoff steeper than the outside option. To determine the optimal allocation we follow Jullien (2000), and introduce a shadow value for the participation constraint, modifying the virtual cost structure to account for these countervailing incentives. The regulator's problem can be rewritten as:

$$\begin{aligned}\max_{q,P,\gamma}\quad & \mathbb{E}_c\left\{CS\left(P\left(c\right)\right)-\sum_{i=1}^{N}q_i\left(c\right)J_i\left(c_i\right)+\left(P\left(c\right)-J_1\left(c_1\right)\right)D(P(c))\right\}\\ s.t.\quad & Q_i\left(c_i\right)\text{ nonincreasing for all } i\geq 2\\ & Q_1\left(c_1\right)+\mathbb{E}_{c_{-1}}D(P(c))\text{ nonincreasing}\\ & \gamma(c_1)\text{ nondecreasing}\\ & \gamma(0)=0,\gamma(1)=1\end{aligned}$$

where

$$J_i\left(c_i\right)=\begin{cases}c_i+(1-\lambda)\frac{F_i(c_i)}{f_i(c_i)} & \text{if } i\geq 2\\ c_1+(1-\lambda)\frac{F_1(c_1)-\gamma(c_1)}{f_1(c_1)} & \text{if } i=1\end{cases}$$

are firm i's virtual costs, and $\gamma\left(c_1\right)$ represents the shadow value associated with a uniform (marginal) reduction of the outside option $H(c_1)$ for all types between $\underline{c}_1$ and c_1. The fact that as c_1 increases, virtual costs become more deflated, is captured by the increasing function $\gamma\left(c_1\right)$.

We make a standard regularity assumption to guarantee that the solution to the relaxed problem (which ignores incentive compatibility constraints) is indeed feasible.

Assumption 1. The distribution functions F_i satisfy that $\frac{F_i(c_i)}{f_i(c_i)}$ is increasing in c_i and $\frac{1-F_i(c_i)}{f_i(c_i)}$ is decreasing in c_i.

We make a second regularity assumption to ensure the tractability of the regulator's problem. Specifically, we impose an upper bound on the convexity of the outside option, which guarantees that once the participation constraint becomes binding at $\hat{c}_1$, it remains so for all higher-cost types, and that $\gamma\left(c_1\right)$ is strictly increasing for $c_1\geq\hat{c}_1$. Intuitively, this implies that for low-cost types, the incentive to mimic higher-cost types dominates. However, for high-cost types, the incentive to extract rent through participation becomes the driving force, making upward distortions more important.

Assumption 2. Let define firm 1's virtual cost for a fixed γ by $J_1^{\gamma}(c_1)=c_1+(1-\lambda)\frac{F_1(c_1)-\gamma}{f_1(c_1)}$. Then[5]

$$-D'(J_1^{\gamma}(c_1))\frac{\partial J_1^{\gamma}(c_1)}{\partial c_1}\geq -D'(P^M(c_1))\frac{\partial P^M(c_1)}{\partial c_1}=H''(c_1).$$

With these assumptions, we characterize the optimal mechanism, which exhibits a simple structure.

Theorem 1. *The allocation rule (q,P) is such that the government buys from the firm with the lowest virtual cost, while allowing firm 1 to charge its virtual cost in the monopoly market. Moreover, there exists a threshold $\hat{c}_1$ such that:*

1. *If $c_1\leq\hat{c}_1$, firm 1's virtual cost is the standard one: $J_1(c_1)=c_1+(1-\lambda)\frac{F_1(c_1)}{f_1(c_1)}$.*
2. *If $c_1\geq\hat{c}_1$, firm 1's virtual cost is reduced, $J_1(c_1)=c_1+(1-\lambda)\frac{F_1(c_1)-\gamma(c_1)}{f_1(c_1)}$. Therefore firm 1 is given an advantage in the procurement, but it is forced to charge a lower price in the monopoly market.*

Finally, firm 1 always receives higher transfers compared to scenarios without a type-dependent outside option, while other firms receive reduced transfers.

The optimal mechanism adjusts the allocation rule based on firm 1's cost reports, ensuring a balance between competitive procurement and price regulation. For low-cost types, the participation constraint does not bind, and the mechanism resembles a standard optimal auction. However, due to countervailing incentives, high-cost types face a binding participation constraint, and stronger incentives to mimic lower-cost types. As a result, the mechanism favors firm 1 in the procurement while simultaneously tightening price caps in the private market. Notably, this does not involve pooling; instead, each cost type receives a combination of gradually increasing advantages in procurement and progressively stricter price caps. Furthermore, firm 1 receives higher transfers than in a standard auction, even at lower cost realizations, since the distortions imposed on higher-cost types must be offset by transfers to lower-cost types. The opposite happens for other firms, where lower expected quantities sold further decrease their informational rents and therefore their transfers.

Example

We present an example that quantifies the benefits of implementing a mechanism that optimally combines procurement and regulation. Consider 2 firms, with $c_i\sim U[0,1]$. Firm 1 also sells in a monopoly market facing linear demand $D(P)=A-P$, so that $P^M\left(c_1\right)=\frac{A+c_1}{2}$, $H(c_1)=\frac{(A-c_1)^2}{4}$ and $CS(P)=\frac{(A-P)^2}{2}$.[6] We assume $A\geq 2$ to guarantee production in the monopoly market. Then: $\hat{c}_1=\frac{2+A}{5-2\lambda}$, $J_2(c_2)=(2-\lambda)c_2$, and

$$J_1(c_1)=\begin{cases}(2-\lambda)c_1 & \text{if}\quad c_1\leq\hat{c}_1\\ (2-\lambda)c_1-\frac{(c_1(5-2\lambda)-2-A)(2-\lambda)}{2(3-\lambda)} & \text{if}\quad c_1\geq\hat{c}_1.\end{cases}$$

Note that $\hat{c}_1$, the cost at which the participation constraint begins to bind due to countervailing incentives, increases with market size (A). As the private market expands, firms face stronger incentives to inflate costs to secure higher regulated prices. Consequently, the mechanism increasingly resembles a standard combination of procurement and regulation mechanisms.

We compare this mechanism against two benchmarks that treat procurement and regulation as independent problems. In Benchmark 1 the government is unable to make transfers to the firm in exchange for price caps. Since firm 1 can always bypass the mechanism and earn monopoly profits, the mechanism reduces to a second-price auction with laissez-faire in the private market. Benchmark 2 involves monopoly regulation, while considering firm 1's outside option as $H(c_1)$. Procurement is handled separately through a second price auction, where firms' outside option is 0. Here, the government fails to link the outside options of both problems effectively, resulting in limited informational rents.

The main welfare gain comes from the introduction of transfers (Benchmark 1), which improves welfare by up to 30%. However, the additional gains from optimally linking procurement and regulation are significant, reaching nearly 8%. This underscores the importance of designing integrated mechanisms that go beyond standard approaches to fully exploit the complementarities between firms' incentives in both mechanisms. Relative gains increase with market size (A) and the

[5] For a linear demand $D(P)=A-BP$, and a uniform distribution this assumption is satisfied.

[6] It is easy to see that Assumptions 1 and 2 are satisfied (see Appendix).

Table 1
Welfare gains of the optimal mechanism with respect to benchmarks 1 and 2.

Comparison benchmark 1	$\lambda = 1/4$	$\lambda = 1/2$	$\lambda = 3/4$
$A = 3$	25,25%	26,70%	29,56%
$A = 4$	25,07%	27,71%	30,90%
Comparison benchmark 2	$\lambda = 1/4$	$\lambda = 1/2$	$\lambda = 3/4$
$A = 3$	0,63%	1,62%	4,05%
$A = 4$	2,85%	4,97%	7,69%

weight placed on firms' profits in the social welfare function (λ): as the private market expands, the regulator can better leverage firms' incentives to sell there to reduce costs in procurement. Additionally, as λ grows, substituting price caps with transfers becomes less costly, allowing the optimal mechanism to fully exploit this flexibility for improved welfare outcomes.

4. Conclusion

This paper introduces a novel mechanism that integrates public procurement and private market regulation, addressing the tension between competitive bidding and the market power of branded-drug producers. By leveraging bulk purchasing power, the mechanism not only ensures cost-effective access to medicines but also limits market power.

Our results demonstrate that this integrated approach outperforms traditional mechanisms that treat procurement and price regulation separately, achieving greater welfare by aligning bidding competition with private market discipline. Beyond pharmaceuticals, these insights extend to industries where firms operate in both regulated and unregulated markets, such as energy, telecommunications, and transportation.

Appendix

Proof of Theorem 1. We follow the standard approach of relaxing incentive compatibility constraints and then solving through pointwise maximization, which now requires finding the multiplier $\gamma(c_1)$.

(1) From pointwise maximization firm 1's optimal price only depends on its marginal cost, that is $P\left(c_1, c_{-1}\right) \equiv P\left(c_1\right)$.

(2) Consider now $\hat{c}_1$, defined by the smallest solution to

$$Q_1^0(\hat{c}_1) + D(J^0(\hat{c}_1)) = D(P^M(c_1)),$$

where $Q_1^\gamma(c_1) := Pr(J_1^\gamma(c_1) \leq \min_k J_k(c_k))$. Following Jullien (2000), we conjecture a solution where $\gamma(c_1) = 0$ for $c_1 \leq \hat{c}_1$. In this region, pointwise maximization dictates $P(c_1) = J_1^0(c_1)$, and $Q_1(c_1) = Q_1^0(c_1)$. Moreover $Q_1^0(c_1)+D(J_1^0(c_1)) \geq D(P^M(c_1))$ and therefore the firm's payoff is steeper than the outside option.

For $c_1 \geq \hat{c}_1$, it is not possible to continue at $\gamma(c_1) = 0$, since firm 1's payoff would become flatter than the outside option, which would require $\gamma(c_1) = 1$. Noting that $J_1^1(c_1) < c_1$, this would imply a steeper payoff function, and therefore a contradiction. We then consider $\gamma(c_1)$ such that the slope of the payoff function and the outside option are equal. Then $\gamma(c_1)$ is implicitly characterized by

$$Q_1^\gamma(c_1) + D(J_1^\gamma(c_1)) = D(P^M(c_1)) \tag{1}$$

and the virtual cost of firm 1 is

$$J_1(c_1) = c_1 + (1-\lambda)\frac{F_1(c_1) - \gamma(c_1)}{f_1(c_1)} < J_1^0(c_1)$$

Pointwise maximization then delivers the solution: $P(c_1) = J_1(c_1)$ and $Q_1(c_1) = Q_1^{\gamma(c_1)}(c_1)$. It is still left to check that $\gamma(c_1)$ is increasing, and IC constraints are satisfied. Using implicit differentiation in (1), we obtain

$$D'(P^M(c_1))\frac{\partial P^M(c_1)}{\partial c_1} = Q_1^{\gamma'}(J_1^\gamma(c_1))\left[\frac{\partial J_1^\gamma}{\partial c_1} + \frac{\partial J_1^\gamma}{\partial \gamma}\frac{\partial \gamma(c_1)}{\partial c_1}\right] + D'(J_1^\gamma(c_1)) \times \left[\frac{\partial J_1^\gamma}{\partial c_1} + \frac{\partial J_1^\gamma}{\partial \gamma}\frac{\partial \gamma(c_1)}{\partial c_1}\right]$$

From here, we obtain

$$\frac{\partial \gamma(c_1)}{\partial c_1} = \frac{-[Q_1^{\gamma'}(J_1^\gamma(c_1)) + D'(J_1^\gamma(c_1))]\frac{\partial J_1^\gamma}{\partial c_1} + D'(P^M(c_1))\frac{\partial P^M(c_1)}{\partial c_1}}{[Q_1^{\gamma'}(J_1^\gamma(c_1)) + D'(J_1^\gamma(c_1))]\frac{\partial J_1^\gamma}{\partial \gamma}} \geq \frac{-D'(J_1^\gamma(c_1))\frac{\partial J_1^\gamma}{\partial c_1} + D'(P^M(c_1))\frac{\partial P^M(c_1)}{\partial c_1}}{[Q_1^{\gamma'}(J_1^\gamma(c_1)) + D'(J_1^\gamma(c_1))]\frac{\partial J_1^\gamma}{\partial \gamma}}$$

with a positive denominator and numerator (because of Assumption 2). Moreover, IC constraints are satisfied since, by Assumption 1, virtual costs are increasing.

In conclusion, for all c_1, the optimal allocation is characterized by $P\left(c_1\right) = J_1\left(c_1\right)$ and

$$q_i\left(c_i, c_{-i}\right) = \begin{cases} 1 & if \quad J_i\left(c_i\right) = \min_k J_k\left(c_k\right) \\ 0 & otherwise \end{cases}$$

Finally, firm 1 always receives higher transfers compared to scenarios without a type-dependent outside option: Note that transfers from the procurement and the regulated monopoly market are given by:

$$T_1^P\left(c_1\right) = c_1 + \int_{c_1}^{\bar{c}_1} Q(s)ds$$

$$T_1^R\left(c_1\right) = -(P\left(c_1\right) - c_1)D\left(P\left(c_1\right)\right) + \int_{c_1}^{\bar{c}_1} D\left(P(s)\right)ds$$

Since the firm is treated weakly better than others given the type-dependent outside option, and is forced to charge a lower price in the monopoly market, then its total transfers are higher. □

Example

The regulator's problem can be written as:

$$\max_{q,P,\gamma} \quad \mathbb{E}_c\left\{\frac{(A-P(c_1))^2}{2} - \sum_{i=1}^N q_i(c)J_i\left(c_i\right) + \left(P\left(c_1\right) - J_1\left(c_1\right)\right) \times \left(A - P(c_1)\right)\right\}$$

$$\begin{aligned} \text{s.t.} \quad & Q_2\left(c_2\right) \text{ nonincreasing} \\ & Q_1\left(c_1\right) + \mathbb{E}_{c_2}\left(A - P(c_1)\right) \text{ nonincreasing} \\ & \gamma(c_1) \text{ nondecreasing} \\ & \gamma(0) = 0,\ \gamma(1) = 1 \end{aligned}$$

where $\hat{c}_1 = \frac{2+A}{5-2\lambda}$, $J_2(c_2) = (2-\lambda)c_2$, and

$$J_1(c_1) = \begin{cases} (2-\lambda)c_1 & \text{if} \quad c_1 \leq \hat{c}_1 \\ (2-\lambda)c_1 - (1-\lambda)\gamma\left(c_1\right) & \text{if} \quad c_1 \geq \hat{c}_1 \end{cases}$$

and $\gamma\left(c_1\right) = \frac{(5c_1-2-A-2\lambda c_1)(2-\lambda)}{2(1-\lambda)(3-\lambda)}$. Note that in this case Assumption 2 is satisfied as it becomes:

$$(2-\lambda) - \frac{1}{2} \geq 0.$$

We calculate the performance of the optimal mechanism by solving the following integral:

$$U = \int_{c_1=0}^1 \int_{c_2=0}^1 \left\{\frac{\left(A - J_1\left(c_1\right)\right)^2}{2} - q_1\left(c_1c_2\right)J_1\left(c_1\right) - q_2\left(c_1c_2\right)J_2\left(c_2\right)\right\} \times dc_2dc_1$$

Similarly, we calculate the performance of the alternative mechanisms, Benchmark 1 and 2, by solving:

$$U_{B_1} = \int_{c_1=0}^1 \left[\frac{\left(A - c_1\right)^2}{8} + \left(\frac{A + c_1}{2} - c_1\left(2-\lambda\right)\right)\left(\frac{A - c_1}{2}\right)\right.$$

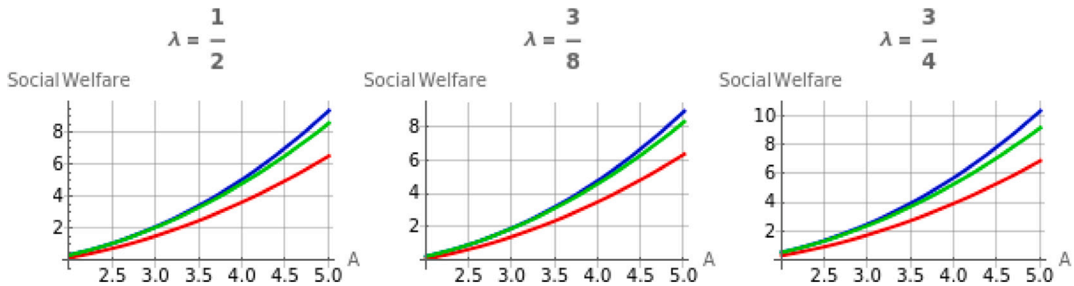

Fig. 1. Social welfare generated by the optimal mechanism (blue line) and benchmarks (red and green line). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

$$- \int_{c_2=c_1}^{1} c_1 (2-\lambda)\, dc_2 - \int_{c_2=0}^{c_1} c_2 (2-\lambda)\, dc_2 \Bigg] dc_1$$

$$U_{B_2} = \int_{c_1=0}^{1} \Bigg[\frac{\left(A - c_1 (2-\lambda)\right)^2}{2} - \int_{c_2=c_1}^{1} c_1 (2-\lambda)\, dc_2$$

$$- \int_{c_2=0}^{c_1} c_2 (2-\lambda)\, dc_2 \Bigg] dc_1$$

We then evaluate the integrals at differente values of λ and A, and show the results in Table 1 and Fig. 1.

Data availability

No data was used for the research described in the article.

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