

A Simple Mechanism-Design Approach to Informed-Principal Problems*

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Abstract

A principal who privately knows her type and designs a mechanism creates a signalling problem. Her choice of mechanism can reveal her information, often generating equilibrium multiplicity depending on beliefs. Informed-principal problems are therefore often avoided in applied work. I show that, with independent one-dimensional private values and quasilinear utility (allowing nonlinear preferences over allocations), the problem reduces to standard optimal mechanism design. Using BIC–DIC equivalence, I show that every principal type attains her full-information payoff, with no signalling analysis and no equilibrium construction. The solution is a Myerson strong solution and pins down the principal’s payoff in every perfect Bayesian equilibrium. It is also robust to beliefs, on and off the equilibrium path. Truthful reporting is a dominant strategy for agents and participation is optimal ex post, meaning no assumption about how agents interpret the principal’s choice of mechanism is needed.

Keywords: informed principal; mechanism design; private values; BIC–DIC equivalence; strong solution; robust implementation.

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1 Introduction

A principal with private information selects a mechanism for themselves and N agents. Because the principal’s private information affects their preferred mechanism, the chosen mechanism is informative about the principal’s private information. This introduces signalling into the standard mechanism design framework, leading to many equilibria arising depending on off-path beliefs. Such a situation is referred to as the *informed-principal problem*, and is widely considered a best-avoided difficulty in applied work. Loertscher and Marx (2022) remark that

“To avoid informed-principal problems, we model the mechanism-design problem as one in which a third party without private information ... organizes the exchange.”

Indeed, even though the informed-principal considerations have no material consequences on their environment they nevertheless write that “*it seems wise to circumvent the associated technicalities*”.

This paper identifies a collection of informed-principal problems where the technicalities are irrelevant and the problem reduces to a simple mechanism-design program. The main result (Theorem 1) uses results from robust implementation (Manelli and Vincent, 2010; Gershkov et al., 2013; Kushnir and Liu, 2019) to show that it is without loss to consider mechanisms whose implementation does not rely on the agents’ beliefs. I show one can restrict attention to mechanisms which are ex post incentive compatible (EPIC) and individually rational (EPIR) to the agents, and Bayesian incentive compatible (BIC) for the principal. As a corollary, I show the principal’s payoff is unique across all Perfect Bayesian Equilibria (PBE) (Corollary 1).

I focus on independent private value informed-principal problems with quasi-linear utility and potential non-linear dependence on allocations. The conditions required are standard. First, a generalised single-crossing condition ensures any Bayesian implementable mechanism can be rearranged into a dominant strategy one while preserving interim payoffs and total surplus. Second, I assume for every agent there exists a type which is worst-off under every allocation. The existence of a worst-off type allows me to construct a mechanism fully insuring this type against variation in their information rents at zero ex ante cost to the principal, ensuring participation in mechanism is ex post optimal.

Literature The informed-principal problem originates with Myerson (1983) and Crawford (1985). Myerson’s *strong solution* remains the strongest proposed solution concept in the informed principal literature and, loosely, says participation and reporting incentives should not depend on beliefs about the principal’s type. However, a strong solution may fail to exist. Nevertheless, when it does exist, it is a sequential equilibrium and hence a PBE refinement. My result proves that within the class of environments I consider, a strong solution exists and is the solution to a mechanism design problem.

Several results prove the existence of strong solutions and uniqueness of PBE principal payoffs in quasi-linear settings. Maskin and Tirole (1990) consider the dual of the informed principal problem, wherein different principal types trade in a Walrasian economy for slack in the agents’ incentive and participation constraints associated with pooling — trade in their dual space implies some principal types are pooling together. In the quasi-linear case, every principal type’s marginal substitution rate between transfers and slack on agent constraints is constant, implying no principals trade and hence can optimally separate, giving a strong solution. Mylovanov and Tröger (2012, 2014) reach the same conclusion by ironing the principal’s virtual surplus and showing there exists some agent type whose participation constraint is binding for every principal type.

The contribution of this paper is a simple proof that makes the implementation and its agent-side robustness explicit. Unlike the previous literature, I proceed via a direct mechanism design approach that circumvents the need to consider PBEs entirely. Bayesian-dominant-strategy equivalence (Manelli and Vincent, 2010; Gershkov et al., 2013; Kushnir and Liu, 2019) first removes agents’ Bayesian reporting constraints. A transfer adjustment independent of an agent’s report then makes the utility of his uniformly worst type constant across others’ reports. This preserves incentives and expected payments while strengthening interim participation to ex-post participation. Letting the principal absorb transfer adjustments is related to the budget-balancing arguments of Crémer and Riordan (1985) and Börgers and Norman (2009). Finally, each principal type selects its preferred continuation mechanism from a common feasible set, making the principal’s reporting constraint immediate.

2 Environment

There are $n + 1$ players $\mathcal{I} = \{0, 1, \dots, n\}$, where player 0 is the *principal* (she) and $N := \{1, \dots, n\}$ are the *agents* (he/they).

Each player $i \in \mathcal{I}$ has a one-dimensional type $\theta_i \in \Theta_i := [\underline{\theta}_i, \bar{\theta}_i] \subset \mathbb{R}$ drawn independently according to a CDF F_i with full support on Θ_i . I write $\boldsymbol{\theta} = (\theta_0, \dots, \theta_n)$, $\mathbf{F} = \prod_{j=0}^n F_j$, and $\boldsymbol{\theta}_{-i} = (\theta_0, \dots, \theta_{i-1}, \theta_{i+1}, \dots, \theta_n)$, $\mathbf{F}_{-i} = \prod_{j=1, i \neq j}^n F_j$. The principal privately observes θ_0 before choosing a mechanism and each agent i observes only θ_i .

An outcome consists of a physical allocation $a \in A$, where $A \subseteq \mathbb{R}^k$ is compact, together with payments $\mathbf{p} = (p_1, \dots, p_n) \in \mathbb{R}^n$, where p_i is the payment made by agent i . The principal is the residual claimant, so her monetary payoff from $\mathbf{p}$ is $\sum_{i \in N} t_i$. Given outcome $(a, \mathbf{p})$, agent $i \in N$ receives utility $u_i(a, p_i; \theta_i) = v_i(a, \theta_i) - p_i$ while the principal receives $u_0(a, \mathbf{t}; \theta_0) = v_0(a, \theta_0) + \sum_{i \in N} p_i$.

After observing θ_0 , the principal chooses a *direct* mechanism $M = (q^M, t^M)$ where

$$(q^M, t^M) : \Theta_0 \times \Theta_1 \times \dots \times \Theta_n \rightarrow \Delta(A) \times \mathbb{R}^n$$

is the outcome rule. Let $\mathcal{M}$ denote the class of measurable direct mechanisms.

Agents observe the mechanism chosen by the principal, but not her type. Each agent then decide whether to participate, with outside option normalised to zero, and, conditional on participation, sends a message into the mechanism.

A strategy for the principal is a mechanism selection map $\sigma_0 : \Theta_0 \rightarrow \mathcal{M}$ and reporting strategy $\rho_0 : \Theta_0 \times \mathcal{M} \rightarrow \Theta_0$. A strategy for agent i is a pair $(\pi_i, \rho_i) : \Theta_i \times \mathcal{M} \rightarrow \Delta(\{0, 1\}) \times \Delta(\Theta_i)$ where $\pi_i(\theta_i, M) \in \Delta(\{0, 1\})$ is their participation decision and $\rho_i(\theta_i, M) \in \Delta(\Theta_i)$ is their reporting strategy.

After observing a mechanism $M \in \mathcal{M}$, each agent forms a posterior belief about the principal's type. Let $\mu^M \in \Delta(\Theta_0)$ denote this posterior. Since types are independent, observing M conveys information only about θ_0 ; conditional on his own type θ_i , agent i continues to hold the prior $\mathbf{F}_{-0,i}$ over the types of the remaining agents. On the support of the induced distribution over mechanisms, μ^M is determined by Bayes' rule; off the support it is unrestricted.

3 Preliminaries

This section recalls the definitions and strong solution concept proposed by Myerson (1983). Readers familiar with the solution concept can move on to Section 4.

An *outcome* is a pair of functions $(Q, T) : \Theta \rightarrow \Delta(A) \times \mathbb{R}^n$ describing the realised distribution over alternatives $Q(\theta)$ and the transfers of agents $T(\theta)$.

I shall say a strategy profile $(\sigma_0, \rho_0; \{(\pi_i, \rho_i)\}_{i \in N})$ *induces* outcome (Q, T) if

$$Q(\theta) = \mathbb{E}[q^{\sigma_0(\theta_0)}(\rho(\theta))], \quad (1)$$

$$T_i(\theta) = \mathbb{E}[t_i^{\sigma_0(\theta_0)}(\rho(\theta))], \quad i \in N, \quad (2)$$

where the expectation is taken with respect to the mechanism randomisation.

The game is complicated by the possibility that the principal's choice of mechanism conveys information about her type. Rather than characterising equilibria of this mechanism-selection game directly, I follow Myerson (1983) and study *strong solutions*.

I begin by invoking the inscrutability principle, which permits restriction to principal strategies where every type offers the same mechanism.

I define what inscrutability means.

Definition 1 (Inscrutable mechanism selection) *A mechanism-selection strategy $\sigma_0 : \Theta_0 \rightarrow \Delta(\mathcal{M})$ is inscrutable if there exists some $M \in \mathcal{M}$ such that*

$$\sigma_0(M \mid \theta_0) = 1 \quad \text{for every } \theta_0 \in \Theta_0.$$

I refer to M as an inscrutable mechanism.

Given a posterior $\mu \in \Delta(\Theta_0)$, define the agents' expected payoff in mechanism M as

$$U_i^M(r_i \mid \theta_i; \mu) = \int_{\Theta_{-0,i}} \int_{\Theta_0} [v_i(q^M(\theta_0, r_i, \theta_{-0,i}) - t_i^M(\theta_0, r_i, \theta_{-0,i}))] d\mu d\mathbf{F}_{-0,i}$$

Likewise, for each principal type $\theta_0 \in \Delta(\theta_0)$, define their payoff from reporting

r_0 in mechanism M as

$$\Pi_0^M(r_0; \theta_0) = \int_{\Theta_{-0}} \left[v_0(q^M(r_0, \theta_{-0}), \theta_0) + \sum_{i \in N} t_i^M(r_0, \theta_{-0}) \right] dF_{-0}$$

I shall say a mechanism M is *incentive feasible* given a posterior belief $\mu \in \Delta(\Theta_0)$ if

$$U_i^M(\theta_i | \theta_i, \mu) \geq \max\{U_i^M(r_i | \theta_i, \mu), 0\}, \quad \forall \theta_i, r_i \quad (3)$$

$$\Pi_i^M(\theta_0 | \theta_0) \geq \Pi_i^M(r_0 | \theta_0), \quad \forall r_0 \quad (4)$$

For any mechanism M that is incentive feasible given the prior F_0 , write $\Pi_0^M(\theta_0) := \Pi_0^M(\theta_0; \theta_0)$ for the interim payoff of principal type θ_0 under truthful reporting. We say that a principal strategy σ_0 is *incentive compatible* if $\sigma_0(\theta_0)$ is an incentive feasible mechanism given the posterior $\mu^{\sigma_0(\theta_0)}$ and

$$\Pi_0^{\sigma_0(\theta_0)}(\theta_0) \geq \Pi_0^{\sigma_0(r_0)}(\theta_0) \quad \forall \theta_0, r_0 \in \Theta_0 \quad (5)$$

I may now state Myerson's inscrutability result.

Proposition 1 (Inscrutability principle) *Suppose incentive compatible principal strategy σ_0 that induces outcome (Q, T) given truthful reporting. Then there exists an inscrutable and incentive compatible principal strategy σ_0^* which also induces (Q, T) under truthful reporting.*

By [Proposition 1](#), I henceforth restrict attention to inscrutable mechanism selection. I identify an inscrutable mechanism-selection strategy with the common direct mechanism M selected by every type of the principal.

Definition 2 (Strong solution) *An incentive-feasible mechanism M is a strong solution for the principal if it is both safe and undominated, where:*

- (i) *M is safe if it is incentive feasible given δ_{θ_0} for every $\theta_0 \in \Theta_0$, where δ_{θ_0} denotes the degenerate belief assigning probability one to θ_0 ;*
- (ii) *M is undominated if there exists no mechanism M' that is incentive feasible given the prior F_0 such that $\Pi_0^{M'}(\theta_0) \geq \Pi_0^M(\theta_0)$, for every $\theta_0 \in \Theta_0$ with strict inequality for some $\theta_0 \in \Theta_0$.*

4 Analysis

I impose some assumptions on the utility function, coming from Kushnir and Liu (2019).

Definition 3 (Kushnir and Liu (2019)) *The game satisfies Generalised Single-Crossing (GSC) if for every $i \in \mathcal{I}$, $v_i(a, \theta_i) = f_i(a)M_i(\theta_i) + m_i(\theta_i) + g_i(a)$, where*

1. $f_i, g_i : A \rightarrow \mathbb{R}$ are continuous;
2. $M_i, m_i : \Theta_i \rightarrow \mathbb{R}$ are continuously differentiable, and M_i is strictly increasing;
3. Letting $f(a) := (f_i(a))_{i \in \mathcal{I}}$ and $g(a) := (g_i(a))_{i \in \mathcal{I}}$, I have that $f(A)$ is convex and $g(a) = Bf(a)$ for some matrix B .

GSC ensures for any Bayesian incentive compatible mechanism there exists an interim outcome equivalent one that is dominant strategy compatible for all players.

I also require that there exists a uniformly worst-type for every agent.

Definition 4 *The game has the worse-type property if every agent $i \in N$ has a uniformly worst type $\theta_i^w \in \Theta_i$, in the sense that*

$$v_i(a, \theta_i) \geq v_i(a, \theta_i^w) \quad \text{for every } (a, \theta_i) \in A \times \Theta_i. \quad (\text{W})$$

Property (W) holds in many cases of interest. In particular, whenever payoffs are monotone in type, (W) holds, but the condition extends beyond this case. The uniform worst-type property is what lets ex-post IR for a single benchmark type propagate, via EPIC, to ex-post IR for every type after we flatten that worst type's realised rent across states. Property (W) may fail in environments with countervailing incentives where incentive constraints bind in multiple directions.

I next show there exists a strong solution which solves a simple mechanism-design problem.

Theorem 1 *Suppose the game satisfies GSC and property (W).*

Then, there exists a strong solution M^ which solves*

$$\max_{M \in \mathcal{M}} \mathbb{E}_{\theta_0} [\Pi_0^M(\theta_0)] \quad (\text{P})$$

subject to

- M is BIC for the principal,
- M is EPIC for every agent $i \in N$,
- M is EPIR for every agent $i \in N$,

[Theorem 1](#) is appealing for applied work for two reasons. First, it is straightforward to solve program (P) using known techniques. Second, the solution is robust to agents' beliefs and so is in line with the Wilson doctrine. Furthermore, as a corollary we show that if, as is standard in mechanism design, agents who are indifferent choose to participate and report truthfully, then program (P) identifies the *unique* interim payoff of the principal in any PBE.

Corollary 1 *Suppose GSC and property (W) hold, and agents who are indifferent choose to participate and report truthfully. Then the principal's payoff is almost-surely unique in any PBE and is identified by program (P).*

Proof. Let $\Pi_0^{\text{PBE}}(\theta_0)$ be the principal's interim payoff in a given PBE. Any principal type could deviate to offering their preferred EPIC and EPIR mechanism to agents, so $\Pi_0^{\text{PBE}}(\theta_0) \geq \sup_{M \text{ EPIC+EPIR}} \Pi_0^M(\theta_0)$. But the best EPIR and EPIC mechanism is ex ante optimal by [Theorem 1](#). Hence, $\Pi_0^{\text{PBE}}(\theta_0) = \sup_{M \text{ EPIC+EPIR}} \Pi_0^M(\theta_0)$ F_0 -almost-surely. $\square$

Consequently, not only is the strong solution of [Theorem 1](#) robust to agent beliefs on-path, but it is further robust to off-path beliefs. As a result, once GSC and property (W) are verified in a particular model, the straightforward mechanism design program (P) in [Theorem 1](#) is sufficient to capture the full range of equilibria possible. Hence, although the problem is one of an informed principal, one can dispense with any reference to signalling or beliefs.

A Appendix

A.1 Proof of Theorem 1

We identify mechanisms that agree F -almost surely.

Let $\mathcal{S}$ be the set of inscrutable mechanisms which are EPIR and EPIC for agents. Also, let $\mathcal{B}$ be the collection of inscrutable mechanisms which are BIC for all players (agents and principal) and interim IR for agents. We prove the theorem by first upper bounding revenue over all incentive feasible inscrutable mechanisms by the revenue achievable from mechanisms lying in a compact subset of $\mathcal{S}$. Then, after showing that $\Pi_0^M(\theta_0)$ is a Carothéodory function we show there exists an optimal mechanism within $\mathcal{S}$. Finally, applying the measurable selection theorem of Aliprantis and Border (2006) (Theorem 18.19), we show that the optimal mechanism within $\mathcal{S}$ is incentive feasible and is a Myerson strong solution.

We proceed by several lemmata.

Lemma A.1 *The principal's expected ex ante profit in any mechanism in $\mathcal{B}$ is bounded above by each type θ_0 picking their optimal mechanism in $\mathcal{S}$. That is*

$$\sup_{M \in \mathcal{S}} \mathbb{E}_{\theta_0} [\Pi_0^M(\theta_0)] \geq \sup_{M \in \mathcal{B}} \mathbb{E}_{\theta_0} [\Pi_0^M(\theta_0)]$$

Proof. Fix any mechanism $M \in \mathcal{B}$. By the GSC condition, Kushnir and Liu (2019) implies there exists an ex ante budget balanced mechanism $\tilde{M}$ such that interim payoffs of all players are equal those under M but which is EPIC for all agents. We restore ex post budget balancedness by making principal absorb the violation of ex post budget balancedness and making them residual claimant. Call this new mechanism $\hat{M}$. The agents remain EPIC under this change, but the principal may no longer be. Nevertheless, as the mechanism is ex ante budget balanced, the principal's ex ante payoff remains the same. Hence, $\mathbb{E}_{\theta_0} [\Pi_0^M(\theta_0)] = \mathbb{E}_{\theta_0} [\Pi_0^{\hat{M}}(\theta_0)]$.

The mechanism $\hat{M}$ is EPIC and interim IR for agents. We now strengthen the agents' participation constraints to EPIR. Suppose agent transfers are $\{\hat{t}_i\}_{i \in N}$ and the allocation rule is $\hat{q}$ under $\hat{M}$. By property (W), there exists a worst type w_i for each agent. Define

$$h_i(\theta_{-i}) := v_i(\hat{q}(w_i, \theta_{-i}), w_i) - \hat{t}_i(w_i, \theta_{-i})$$

Define new agent transfers $\bar{t}_i(\theta_i, \boldsymbol{\theta}_{-i}) = \hat{t}_i(\theta_i, \boldsymbol{\theta}_{-i}) + h_i(\boldsymbol{\theta}_{-i})$. Under these transfers, for every agent i , the worst type's ex post payoff is 0 for certain. By EPIC, this implies all other types ex post payoff is non-negative as they could mimic the worst off types. Hence, the new mechanism $\bar{M} = (\hat{q}, \bar{t}_i)$ is EPIC and EPIR for agents. Further, because $\hat{M}$ was interim IR for the agents, $\mathbb{E}_{\boldsymbol{\theta}_{-i}}[h_i(\boldsymbol{\theta}_{-i})] \geq 0$. Consequently, the principal's ex ante payoff in $\bar{M}$ is weakly higher than in $\hat{M}$. Therefore,

$$\mathbb{E}_{\theta_0}[\Pi_0^M(\theta_0)] = \mathbb{E}_{\theta_0}[\Pi_0^{\hat{M}}(\theta_0)] \leq \mathbb{E}_{\theta_0}[\Pi_0^{\bar{M}}(\theta_0)]$$

Because $\bar{M} \in \mathcal{S}$, $\mathbb{E}_{\theta_0}[\Pi_0^{\bar{M}}(\theta_0)] \leq \sup_{M \in \mathcal{S}} \mathbb{E}_{\theta_0}[\Pi_0^M(\theta_0)]$. And so, for any $M \in \mathcal{B}$,

$$\mathbb{E}_{\theta_0}[\Pi_0^M(\theta_0)] \leq \sup_{M' \in \mathcal{S}} \mathbb{E}_{\theta_0}[\Pi_0^{M'}(\theta_0)]$$

Therefore, taking the supremum over $M \in \mathcal{B}$ we obtain

$$\sup_{M \in \mathcal{B}} \mathbb{E}_{\theta_0}[\Pi_0^M(\theta_0)] \leq \sup_{M' \in \mathcal{S}} \mathbb{E}_{\theta_0}[\Pi_0^{M'}(\theta_0)]$$

□

Next we show that $\sup_{M \in \mathcal{S}} \mathbb{E}_{\theta_0}[\Pi_0^M(\theta_0)]$ is achieved over a compact subset of $\mathcal{S}$. We equip the space of mechanisms with the weak topology.

Lemma A.2 *There exists a compact subset $\mathcal{S}_L \subseteq \mathcal{S}$ such that $\sup_{M \in \mathcal{S}} \mathbb{E}_{\theta_0}[\Pi_0^M(\theta_0)] = \sup_{M \in \mathcal{S}_L} \mathbb{E}_{\theta_0}[\Pi_0^M(\theta_0)]$.*

Proof. Set

$$K_i := \max_{a \in A, \theta_i \in \Theta_i} \{v_i(a, \theta_i) - v_i(a, w_i)\}, \quad L_i := \|v_i\|_\infty + K_i$$

Take any $M \in \mathcal{S}$. By EPIR of agents $v_i(q(\boldsymbol{\theta}), \theta_i) - t_i(\boldsymbol{\theta}) \geq 0$. As Θ is compact and v_i is compact, this implies $\sup_{\boldsymbol{\theta} \in \Theta} t_i(\boldsymbol{\theta}) \leq \bar{n} < \infty$. Further, suppose transfers are unbounded below. Then, as agent utility is bounded, the principal can instead make the transfers bounded without affecting agent incentives or participation ex post but strictly increasing the principal's ex ante revenue. Therefore, defining $\mathcal{S}_L$ as the set of mechanisms with suitably bounded transfers we have

$$\sup_{M \in \mathcal{S}} \mathbb{E}_{\theta_0}[\Pi_0^M(\theta_0)] = \sup_{M \in \mathcal{S}_L} \mathbb{E}_{\theta_0}[\Pi_0^M(\theta_0)]$$

Further, I claim $\mathcal{S}_L$ is compact. Indeed, it is defined as an intersection of

closed bounded sets and hence is compact. $\square$

Our next Lemma proves that $\Pi_0^M(\theta_0)$ is a Carathéodory function. That is, it is continuous in the mechanism M and measurable in θ_0 .

Lemma A.3 *The principal's profit $\Pi_0^M(\theta_0)$ is a Carathéodory function.*

Proof. Because we equipped the mechanism space with the weak topology. The principal's profit converges under a sequence of types and mechanisms. Therefore, $\Pi_0^M(\theta_0)$ is jointly continuous and hence a Carathéodory function. $\square$

Using these Lemmata we prove [Theorem 1](#)

Proof. Since it is optimising a continuous function over a compact set, by Weierstrass theorem $\sup_{M \in \mathcal{S}_L} \Pi_0^M(\theta_0)$ is achieved by some mechanism for every θ_0 . Additionally, by [Lemma A.3](#) and the measurable maximum theorem (Theorem 18.19, Aliprantis and Border (2006)) there exists a measurable selection $\sigma_0^* : \Theta_0 \rightarrow \mathcal{M}$ such that $\Pi_0^{\sigma_0^*(\theta_0)}(\theta_0) = \sup_{M \in \mathcal{S}_L} \Pi_0^M(\theta_0)$ for all θ_0 .

Consequently, using [Lemma A.1](#) we have

$$\mathbb{E}_{\theta_0}[\Pi_0^{\sigma_0^*(\theta_0)}(\theta_0)] \geq \sup_{M \in \mathcal{B}} \mathbb{E}_{\theta_0}[\Pi_0^M(\theta_0)]$$

The inscrutable mechanism associated with each θ_0 picking mechanisms according to σ_0^* is therefore ex ante optimal, incentive feasible, and since it is EPIC and EPIR to agents it is safe. Therefore, it is a strong solution. $\square$

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