Iterated Revelation:

How to incentivize experts to reveal novel actions

Evan Piermont
Royal Holloway, University of London

University of Bristol --- February 2026

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- Almost always: expert provides *statistical* info about the resolution of uncertainty

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regulator	firm	cost structure
Ph.D student	supervisor	prob. of success

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regulator	firm	cost structure	feasible mergers
Ph.D student	supervisor	prob. of success	research ideas
homeowner	architect	???	house design

Project Choice

Armstrong and Vickers (2010), Guo and Shmaya (2023) study project choice:

- A manager (decision maker) is uncertain about which projects are feasible
- A subordinate (expert) makes recommendations
- The manager commits to a selection rule
    - how to choose a project from the subordinate's recommendations

But what if ex-ante commitment to a selection rule is infeasible?

- Unawareness: a student unaware of state-of-the-art research ideas
- Inexpressibility: impractical to express every possible house design
- Enforceability: A regulator may be unable to make reasonable commitments

Literature

- Delegation / Project Choice
  - Holmstrom (1980); Armstrong and Vickers (2010); Guo and Shmaya (2023)
- Incomplete Contracting / Unawareness in Contracting
  - Grossman and Hart (1986); Maskin and Tirole (1999); Tirole (2009); Hart (2017); Piermont (2017); Lei and Zhao (2021); Francetich and Schipper (2021)
- Strategic Information Transmission
  - Milgrom (1981), Crawford and Sobel (1982); Seidmann and Winter (1997); Aumann and Hart (2003); Chakraborty and Harbaugh (2010)
- Evidentiary disclosure
  - Dye, 1985; Green and Laffont, 1986; Grossman and Hart, 1986; Bull and Watson, 2007; Ben-Porath et al., 2019

Model

Environment

The environment is described by

$\mathcal{A}$ — a (compact) set of actions

(u_d, u_e) — (continuous) utility functions $\mathcal{A} \to \mathbb{R}$

$\mathcal{R}$ — a collection of non-empty (compact) subsets of $\mathcal{A}$ such that

- Exists $r^\dagger \in \mathcal{R}$ such that $r^\dagger \subseteq r$ for all $r \in \mathcal{R}$
- for $r \in \mathcal{R}$, there are a finite $r' \in \mathcal{R}$ with $r' \subseteq r$.

Revelation Types

- A revelation type $r \in \mathcal{R}$ is a set of actions / projects that an agent can express
- Say that r is more expressive than r', if $r' \subseteq r$
- $r^\dagger$ is the dm's type

Key Assumptions

Let the expert be of type $r \in \mathcal{R}$:

Voluntary Disclosure: the expert can always masquerade as a type $r' \subseteq r$

Information Spillover: Only subsets of actions $r' \in \mathcal{R}$ can be revealed

Hard Evidence: If the expert reveals r, then any $a \in r$ is ‘real’

Selection Rules

An selection rule is a function from types to actions:

$$\begin{array}{cccc} f: & r & \mapsto & a \\ & \pitchfork & & \pitchfork \\ & \mathcal{R} & \to & r \end{array}$$

- Selection rules are *direct mechanisms*
- These are the object of study in the project choice literature
- Inexpressibility precludes direct mechanisms / revelation principle

Call f monotone if ex's payoff is monotone in her type

$$u_e(f(r')) \leq u_e(f(r)) \tag{1}$$

whenever $r' \subseteq r$, and strongly monotone if in addition (2) holds strictly whenever $f(r) \neq f(r')$.

- If direct mechanisms existed, monotonicity is incentive compatibility
- Direct mechanisms don't exist: even with monotonicity, there need not be any 'strategic' way of enacting a selection rule.

Call f efficient if outcome is Pareto undominated:

for all $r \supseteq r_d$, is no $a \in r$ such that

$$u_d(a) \geq u_d(f(r)) \qquad \text{and} \qquad u_e(a) \geq u_e(f(r)), \tag{2}$$

with at least one inequality holding strictly.

So, what can we do without ex-ante commitment to a selection rule?

Example

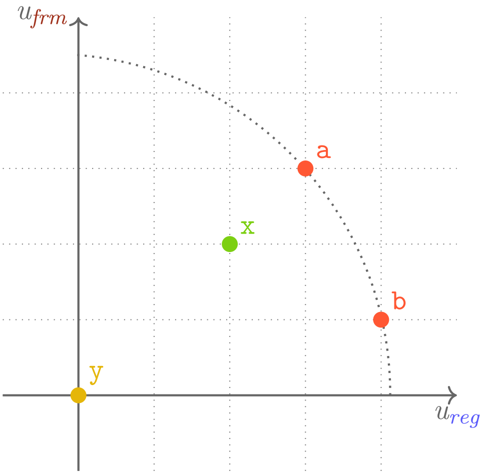
- A regulator (the decision maker) is evaluating mergers (i.e., projects) :
  - can only choose a merger structure it is aware of
- A firm (the expert) may be aware of novel ways of structuring a merger
- choice of merger structure determines payoffs for both players
  - the firm cares about producer welfare
  - the regulator cares about consumer welfare foremost, but
  - also cares about efficiency

Example

- Each merger yields (x_{reg}, x_{frm}):
  - x_{reg} is regulator's payoff (consumer welfare)
  - x_{frm} is firms's (producer welfare)
- There are four ways to structure the merger:

$$\mathtt{x} = (2,2) \qquad \mathtt{y} = (0,0)$$
$$\mathtt{a} = (3,3) \qquad \mathtt{b} = (4,1)$$

- a and b must be revealed together



u_{frm}
a
x
b
y
u_{reg}

Example

- Initially the regulator is aware of

$$\mathtt{x} = (2,2) \qquad \mathtt{y} = (0,0)$$

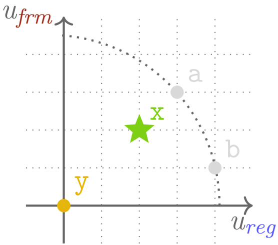
and the firm is also aware of

$$\mathtt{a} = (3,3) \qquad \mathtt{b} = (4,1)$$

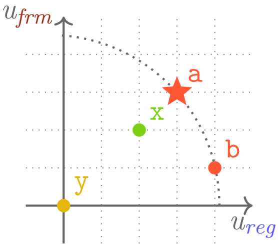
- Since $\mathtt{a}$ and $\mathtt{b}$ must be revealed together

$$\mathcal{R} = \{\{\mathtt{y},\mathtt{x}\},\{\mathtt{y},\mathtt{x},\mathtt{a},\mathtt{b}\}\}$$

A monotone and efficient selection rule:



$$f(\{y, x\}) = x$$

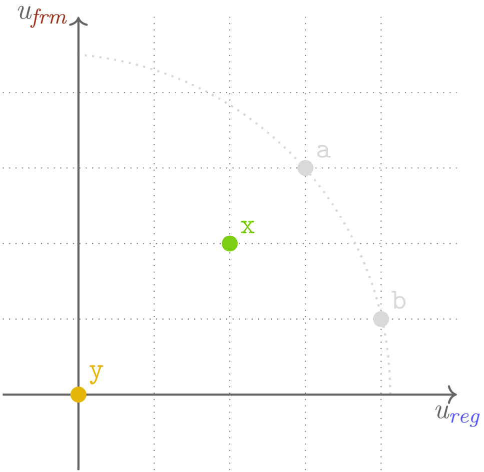


$$f(\{y, x, a, b\}) = a$$

Example A

- If the firm had full control over what to reveal: simply reveal $\texttt{a} = (3, 3)$
- However, not all mergers can be independently revealed:
  - Revealing one merger in a 'class' reveals the existence of the whole class, etc
- Regulator cannot commit to $\texttt{a}$ (or $\texttt{b}$) until it is revealed
  - Cannot express the direct selection rule above

Example A



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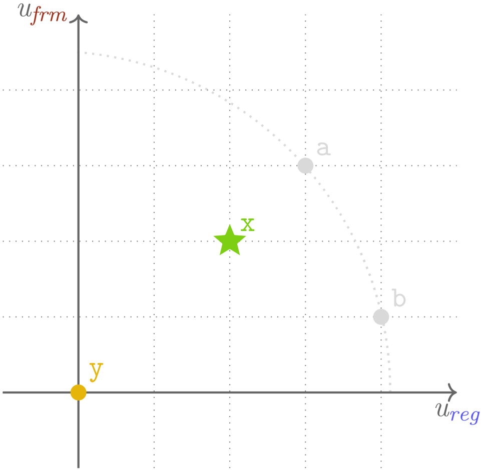

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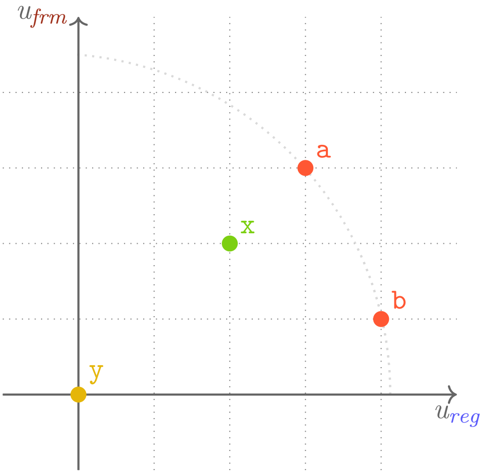

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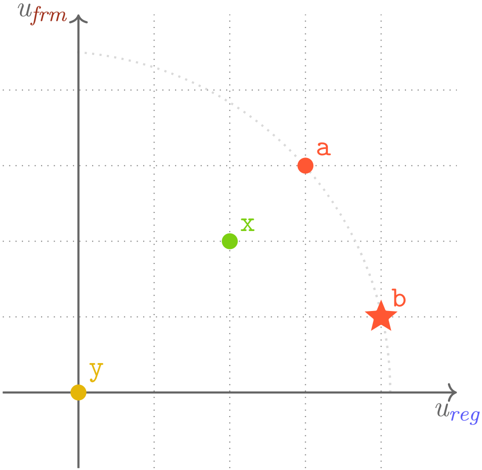
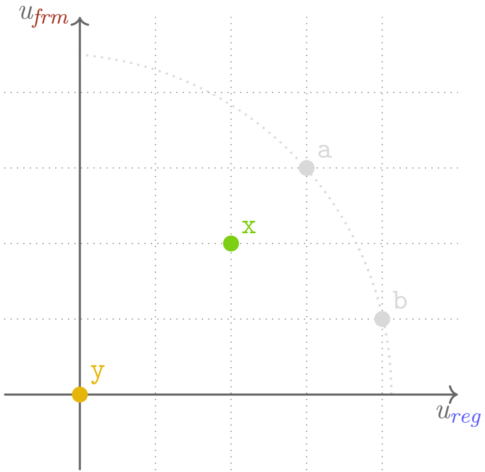


Example A

- Since the firm prefers x to b, she would choose not to reveal.
- This is Pareto Inefficient: a dominates x
- What if regulator and firm can create the following contract (before revelation):
  - shortlist an ‘outside option’ (that the regulator is aware of)
  - this can be re-negotiated after revelation
  - the regulator can propose a new merger, but the firm can veto (therefore implement outside option)

Example A



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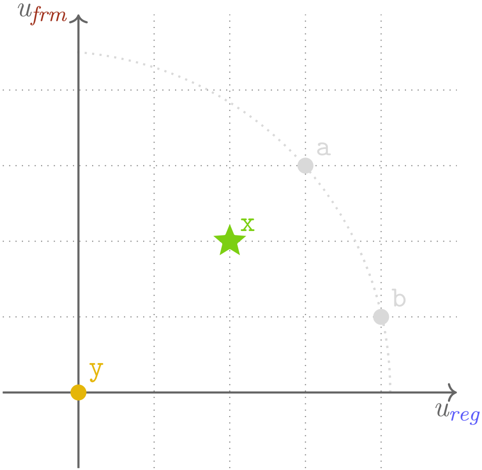

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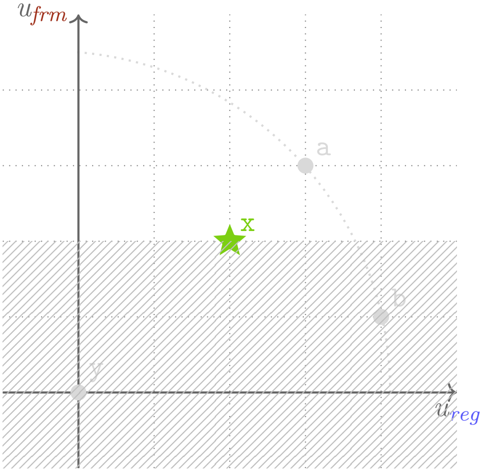

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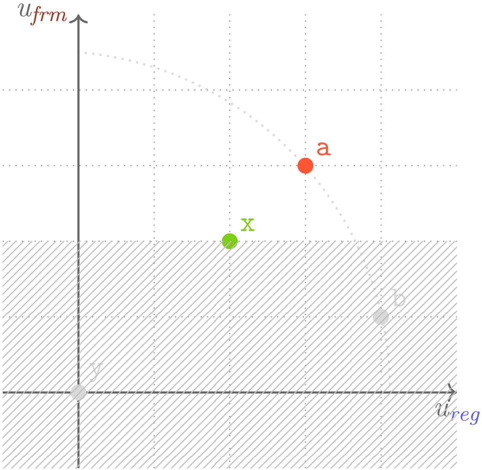

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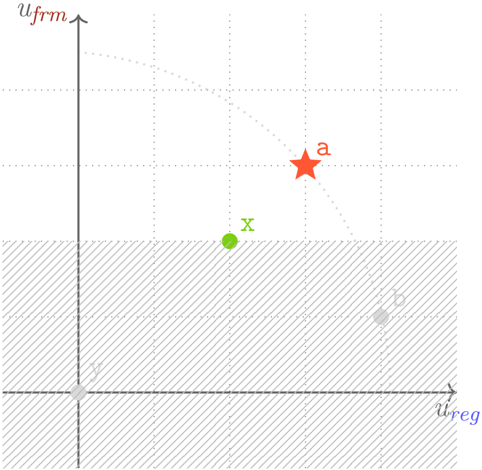

So a two stage game with commitment to not revoke the prior proposal resulted in

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Does this always work?

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- full revelation
- an efficient contract

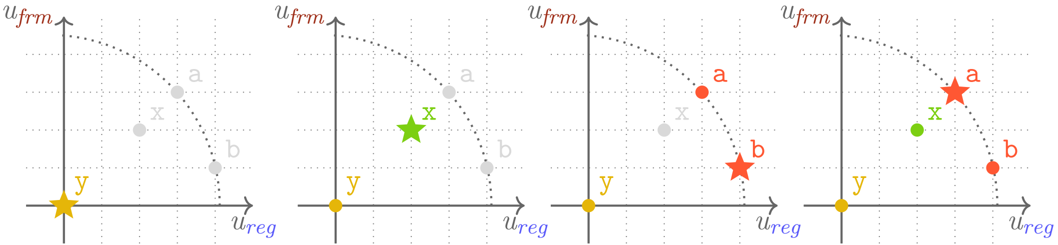
Does this always work? No

Example B

- What if the regulator was also initially unaware of $\mathtt{x}$
- $\mathtt{x}$ and $\{\mathtt{a}, \mathtt{b}\}$ can be revealed independently:

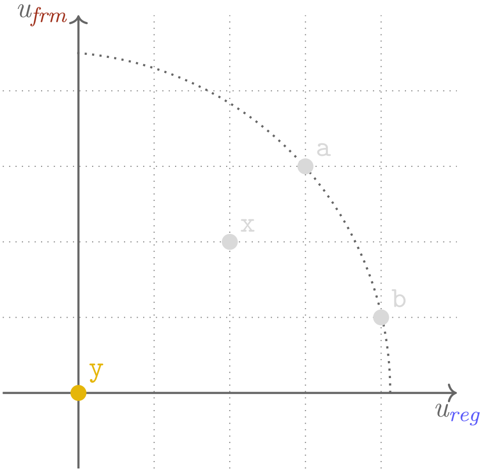
$$\mathcal{R} = \{\{\mathtt{y}\}, \{\mathtt{y}, \mathtt{x}\}, \{\mathtt{y}, \mathtt{a}, \mathtt{b}\}, \{\mathtt{y}, \mathtt{x}, \mathtt{a}, \mathtt{b}\}\}$$

A monotone and efficient selection rule:



$$f(\{y\}) = y \qquad f(\{y, x\}) = x \qquad f(\{y, a, b\}) = b \qquad f(\{y, x, a, b\}) = a$$

Example B



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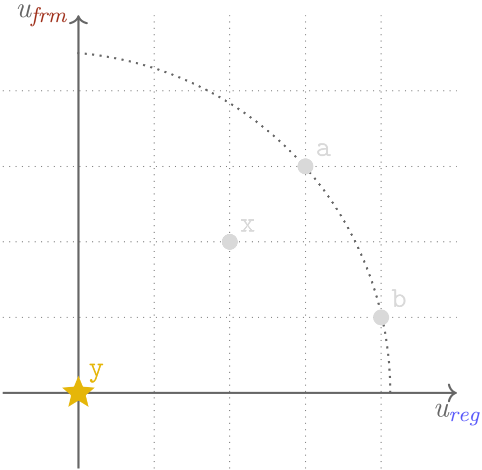

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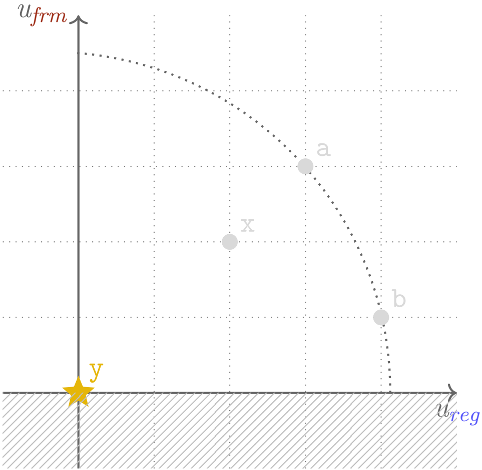

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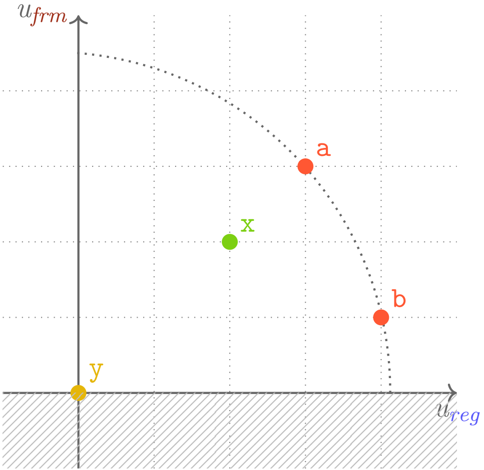

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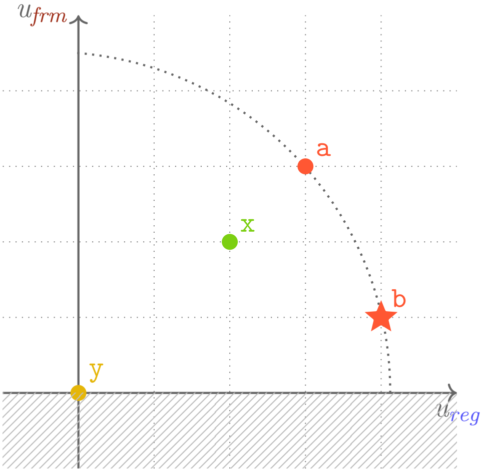
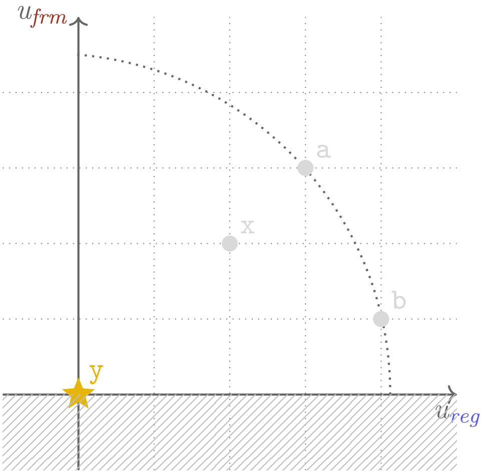


But the firm does not have to reveal everything! Instead, reveal only `x`

Example B



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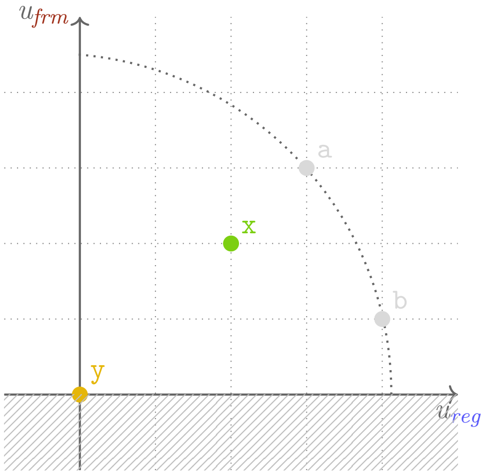

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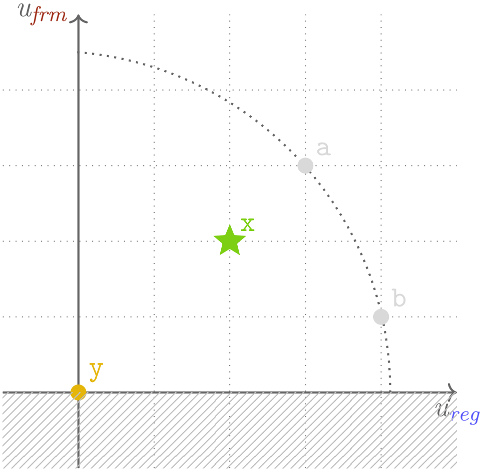

The firm prefers `x` to `b`:

- it will only partially reveal
- again, this is inefficient: `a` dominates `x`

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But, we can repeat!

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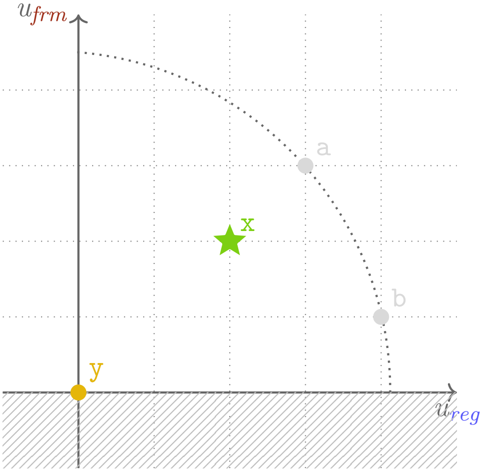

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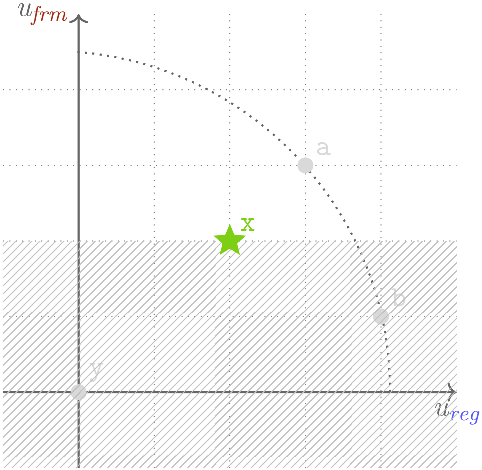

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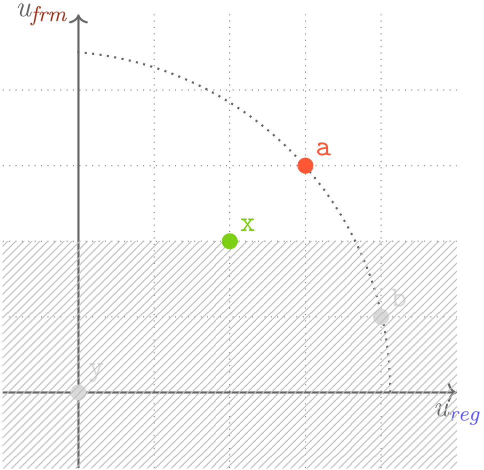

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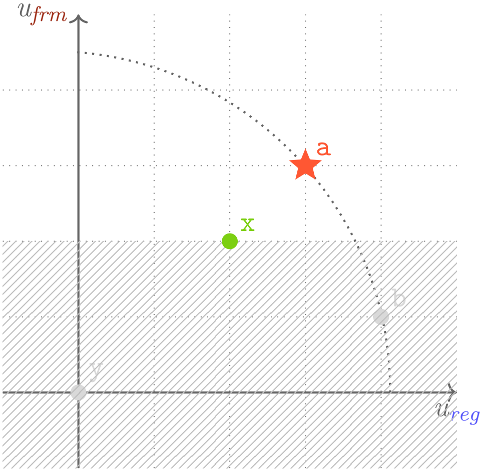

Iterated Revelation Protocol

Iterated Revelation Protocol

INITIAL STEP — The decision maker announces $r_0 = r^\dagger$, and shortlists $a_0 \in r_0$.

ITERATIVE STEP — Given $(r_0, \dots, r_{n-1})$ distinct prior revelations, the expert reveals $r_n \in \mathcal{R}$.

- If $r_{n-1} \subsetneq r_n$, the dm shortlists $a_n \in r_n$, and the ITERATIVE STEP is repeated
- Otherwise, the protocol moves to the FINAL STEP

FINAL STEP — Given $(r_0, \dots, r_n)$ distinct revelations, the expert chooses an action $a \in \{a_0, \dots, a_n\}$.

Importantly:

- This protocol can be explained / contracted to without having to express any specific actions/outcomes
- Specifically, the only contractual obligations in an IRP are actions that *have already been* revealed.

Strategies

Given the IRP, a strategy

- for the dm is a function from *sequences of revelations* to actions:

$$s : (r_0 \dots r_n) \mapsto a_n \in r_n$$

- for the ex is a function from *sequences of shortlisted actions* to revelations:

$$\sigma : (a_0 \dots a_{n-1}) \mapsto r_n \in \mathcal{R}$$

(and a choice out of the final shortlist)

Implementation

Let $a(s, \sigma)$ denote the action enacted by playing strategies s and σ.

Say that s implements the selection rule f if for all $r \in \mathcal{R}$

$$f(r) = a(s, \sigma) \quad \text{for some best response for type } r$$

and fully implements f if

$$f(r) = a(s, \sigma) \quad \text{for every best response for type } r$$

Theorem

The following are equivalent for a selection rule f

(1) f is monotone (resp. strongly monotone)

(2) there exists some s that implements f, (resp. fully implements)

Greedy Strategies & Efficiency

Each shortlist proposal in an IRP specifies:

(1) The outcome should the game end
   - ◇ dm wants to maximize his own payoff

(2) The implicit incentive constraint should the game continue
   - ◇ dm wants to minimize ex's payoff

In the examples, IRPs solved (1) ignoring (2)

Definition

Call a strategy s (for the decision maker) mostly greedy if for all $(r_0 \dots r_n)$, there is no $a \in r_n$ such that $V_e(s(r_0 \dots r_{n-1})) \leq V_e(a)$ and

$$u_d(a) > u_d(s(r_0 \dots r_n))$$

or such that

$$u_d(a) = u_d(s(r_0 \dots r_n)) \text{ and } u_e(a) > u_e(s(r_0 \dots r_n))$$

A mostly greedy strategy:

- maximizes the dm's payoff myopically (subject to IC constraint)
- does not account for effect on future incentive constraints
- breaks ties in favor of the expert (hence only *mostly* greedy)

Theorem

Let s be mostly greedy. Then s implements the decision maker's preferred efficient selection rule, $f^\star$.

- If f is any other monotone and efficient selection rule, then for all $r \supseteq r_d$

$$u_d(f^\star(r)) \geq u_d(f(r))$$

Comparative Statics: Information Spillover

- Let $\mathcal{R}$ and $\mathcal{Q}$ be two different type spaces over the same set of actions:

$$\mathcal{R} \subseteq \mathcal{Q} \subseteq 2^{\mathcal{A}}$$

- Let $r^\dagger, r \in \mathcal{R}$ and $q^\dagger, q \in \mathcal{Q}$ be such that

$$r^\dagger = q^\dagger \subseteq r = q$$

Let $f^{\mathcal{R}}$ and $f^{\mathcal{Q}}$ denote the efficient, monotone selection rule induced by the mostly greedy strategy, then:

$$u_d(f^{\mathcal{Q}}(q)) \leq u_d(f^{\mathcal{R}}(r))$$

Comparative Statics: Information Spillover

- In the limit $\mathcal{R} = \{\mathcal{A} - r^\dagger\}$ (all actions reveal all other actions)
  - As if dm maximizes subject to individual rationality constraint
- In the limit $\mathcal{R} = 2^{\mathcal{A}}$ (all actions can be revealed independently)
  - As if expert maximizes subject to individual rationality constraint
  - This coincides with the expert preferred efficient selection rule
  - Corollary: efficient selection rule is unique

General Strategic Analysis

Definition

Call a strategy s greedy if for all $(r_0 \dots r_n)$, there is no $a \in r_n$ such that

$$V_e(s(r_0 \dots r_{n-1})) \leq V_e(a) \quad \text{and} \quad V_d(s(r_0 \dots r_n)) < V_d(a)$$

- There is no way to for the dm to increase his own payoff
- Generalization of mostly greedy strategy

Theorem

A selection rule f is implemented by a greedy s

if and only if

for all $r \in \mathcal{R}$, there is no other monotone selection rule f' such that

$$\inf_{r' \supseteq r} V_d(f(r')) < \inf_{r' \supseteq r} V_d(f'(r'))$$

Definition

Call a strategy s locally rational if for all $(r_0 \dots r_n)$, there is no $a \in r_n$ such that

$$V_e(s(r_0 \dots r_{n-1})) \leq V_e(a) < V_e(s(r_0 \dots r_n)) \quad \text{and} \quad V_d(s(r_0 \dots r_n)) < V_d(a)$$

- There is no way to simultaneously for the dm to
  - increase his own payoff
  - decrease the expert's payoff

Theorem

A selection rule f is implemented by a locally rational s

if and only if

for all $r \in \mathcal{R}$, there is no other monotone selection rule f' such that

$$
\begin{aligned}
V_d(f(r')) &\leq V_d(f'(r')) \qquad \text{for all } r' \supseteq r, \\
V_d(f(r')) &< V_d(f'(r')) \qquad \text{for some } r' \supseteq r
\end{aligned}
$$

- 'if' direction requires a richness condition on $\mathcal{R}$

Payoff Uncertainty

- The implementation above presupposes dm can anticipate ex’s acceptance / rejection

- What happens with private information:
  - Actions are state-dependent $u : \mathcal{A} \times \Omega \to \mathbb{R}$
  - assume ex knows the state, $\omega \in \Omega$
  - dm does not

Example C

- $\Omega = \{\omega_L, \omega_R\}$, ex knows the state, dm believes equally likely
  - Each action is therefore given by $(\langle x_{d,L}, x_{d,R}\rangle, \langle x_{e,L}, x_{e,R}\rangle)$.
- The dm is initially aware of one action:

$$x = (\langle 0, 0\rangle, \langle 0, 0\rangle)$$

- The ex is also aware of:

$$a_L = (\langle 3, -1\rangle, \langle 3, -1\rangle) \qquad a_R = (\langle -1, 3\rangle, \langle -1, 3\rangle) \qquad b = (\langle 2, 2\rangle, \langle 2, 2\rangle)$$

- The only revelation type is $\{a_L, a_R, b\}$.

Example C

$$*x = \langle 0, 0\rangle, \langle 0, 0\rangle*$$

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$$\downarrow$$

$$\begin{aligned} x &= (\langle \mathbf{0}, 0\rangle, \langle \mathbf{0}, 0\rangle) \\ b &= (\langle \mathbf{2}, 2\rangle, \langle \mathbf{2}, 2\rangle) \\ a_L &= (\langle \mathbf{3}, -1\rangle, \langle \mathbf{3}, -1\rangle) \\ a_R &= (\langle -\mathbf{1}, 3\rangle, \langle -\mathbf{1}, 3\rangle) \end{aligned}$$

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$$a_R = (\langle -1, \mathbf{3}\rangle, \langle -1, \mathbf{3}\rangle)$$

Example C

- Preferences are completely aligned, but IRP does not allow delegation

- the protocol cannot use ex's private info.
  - this *creates* inefficiency

- Instead, dm chooses a set of actions $p_1 \subseteq r$. After revelation, propose

$$p_1 = \{a_L, a_R\}$$

  and let the ex choose.

- A generalized IRP allows the dm to choose a set of actions at each step:
    - At each $(r_0 \dots r_n)$, $s(r_0 \dots r_n) \subseteq r_n$
- A generalized selection rule is a function $f : \Omega \times \mathcal{R} \to \mathcal{A}$
    - For each $r \in \mathcal{R}$, $w \in \Omega$, we have $f(\omega, t) \in t$

Theorem

The following are equivalent for a gen. selection rule f

(1) f can be implemented by a gen. IRP

(2) f is monotone: for all $\omega, r \in \Omega \times \mathcal{R}$

$$u_e(f(\omega', r'), \omega) \leq u_e(f(\omega, t), \omega)$$

for any other $\omega' \in \Omega$ and $r' \subseteq r$.

Thank You