Mechanism Design and Information Design

- Basic Mechanism Design:
  
  1. Fix an economic environment and information structure
  2. Design the rules of the game to get a desirable outcome
  
  Information Design:
  
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Information Design: Some Leading Cases

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... and this lecture
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This Lecture

- a general framework in two slides
- leading examples at length
- applications in brief
- various elaborations if time
Setup

- Maintained Environment: Fix players 1,...,I; payoff states $\Theta$; prior on states $\psi \in \Delta(\Theta)$
Setup

- **Maintained Environment**: Fix players 1,...,I; payoff states \( \Theta \); prior on states \( \psi \in \Delta(\Theta) \)
- **Basic Game** \( G : (A_i, u_i)_{i=1..I} \) where \( u_i : A \times \Theta \rightarrow \mathbb{R} \)
Setup

- Maintained Environment: Fix players $1, \ldots, l$; payoff states $\Theta$; prior on states $\psi \in \Delta(\Theta)$
- Basic Game $G: (A_i, u_i)_{i=1}^l$ where $u_i : A \times \Theta \to \mathbb{R}$
- Information Structure $S: (T_i)_{i=1}^l$ and $\pi: \Theta \to \Delta(T)$
Information Designer’s Problem

- *Decision rule* \( \sigma : T \times \Theta \rightarrow \Delta (A) \) is *obedient* for \((G, S)\) if, for all \(i, t_i, a_i\) and \(a'_i\),

\[
\sum_{a_{-i}, t_{-i}, \theta} u_i ((a_i, a_{-i}), \theta) \sigma (a | t, \theta) \pi (t | \theta) \psi (\theta) \\
\geq \sum_{a_{-i}, t_{-i}, \theta} u_i ((a'_i, a_{-i}), \theta) \sigma (a | t, \theta) \pi (t | \theta) \psi (\theta)
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Obedient decision rule \( \sigma \) is a *Bayes correlated equilibrium* (BCE). Characterizes implementability.
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Obedient decision rule \( \sigma \) is a **Bayes correlated equilibrium** (BCE). Characterizes implementability.

- Information designer with payoff \( \nu : A \times \Theta \rightarrow \mathbb{R} \) picks a Bayes correlated equilibrium \( \sigma \in BCE (G, S) \) to maximize

\[
V_S (\sigma) \equiv \sum_{a, t, \theta} \psi (\theta) \pi (t | \theta) \sigma (a | t, \theta) \nu (a, \theta).
\]
Information Design: Three Interpretations

1. Literal: actual information designer with ex ante commitment
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2. Metaphorical: e.g., adversarial / worst case
Information Design: Three Interpretations

1. Literal: actual information designer with ex ante commitment
2. Metaphorical: e.g., adversarial / worst case
3. Informational robustness: family of objectives characterize set of attainable outcomes
One Uninformed Player: Benchmark Investment Example

- A firm is deciding whether to invest or not:

   - Binary state: $\theta \in \{B, G\}$ (bad or good)
   - Binary action: $a \in \{Invest, Not Invest\}$
   - Payoffs:
     - Good state: $G$: Invest $x$, Not Invest $0$
     - Bad state: $B$: Invest $0$, Not Invest $0$

   - With $0 < x < 1$
   - Prior probability of each state is $\frac{1}{2}$

- The firm is uninformed (so one uninformed player)

- Information designer (government) seeks to maximize the probability of investment (independent of state)

- Leading example of Kamenica-Gentzkow 11
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- $p_\theta$ is probability of investment, conditional on being in state $\theta$

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- interpretation: firm observes signal = "action recommendation," drawn according to $(p_B, p_G)$
Obedience Constraints

- if "advised" to invest, invest has to be a best response:

\[-\frac{1}{2} p_B + \frac{1}{2} p_G x \geq 0 \iff \]

\[p_G \geq \frac{p_B}{x}\]
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- If "advised" to not invest, not invest has to be a best response.
- But because $x < 1$, investment constraint is binding one.
- Always invest ($p_B = 1$ and $p_G = 1$) is not a BCE.
- The "full information equilibrium" has invest only in good state ($p_B = 0$ and $p_G = 1$).
Bayes Correlated Equilibria

equilibrium outcomes \((p_B, p_G)\) for \(x = 0.9\)

- always invest \((p_B = 1 \text{ and } p_G = 1)\) is not a BCE
- the full information equilibrium has invest only in good state \((p_B = 0 \text{ and } p_G = 1)\)
Information Design

- recommendation maximizing the probability of investment:

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- Optimal for government to obfuscate, partially pooling good state and bad state
One Informed Player

- Firm receives a signal which is "correct" with probability $q > 1/2$. 
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Formally, the firm observes a signal \( g \) or \( b \), with signals \( g \) and \( b \) being observed with conditionally independent probability \( q \) when the true state is \( G \) or \( B \) respectively:

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A decision rule is then a quadruple \((p^b_B, p^b_G, p^g_B, p^g_G)\).

For example, if firm’s own information is sufficiently noisy, or \( q \leq \frac{1}{1+x} \), there is still a binding investment constraint for each signal, e.g.,

\[
p^g_G \geq \frac{1 - q p^g_B}{q} x.
\]

(if the good signal is good enough, can get investment with probability 1)
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$$p_G^g \geq \frac{1 - q \, p_B^g}{q}.$$  

(if the good signal is good enough, can get investment with probability 1)

the interesting question: what if we project $\left(p_B^b, p_G^b, p_B^g, p_G^g\right)$ back into ex ante behavior $\left(p_B^b, p_G^b, p_B^g, p_G^g\right)$? e.g.

$$p_G = q p_G^g + (1 - q) \, p_G^b$$
One Informed Player: Bayes Correlated Equilibrium

equilibrium set (for $x = 0.9$ and $q = 0.5, 0.575, 0.7$ and $0.875$)
Two Firms

- payoffs almost as before....

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\[
\begin{array}{|c|c|c|}
\hline
\theta = B & I & N \\
\hline
I & -1 + \epsilon & -1 \\
N & 0 & 0 \\
\hline
\end{array}
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- ...up to $\epsilon$ term
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- assume that information designer (government) wants to maximize the sum of probabilities that firms invest....
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<td>I</td>
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- ...up to $\varepsilon$ term

- assume that information designer (government) wants to maximize the sum of probabilities that firms invest....

- if $\varepsilon = 0$, problem is exactly as before firm by firm; doesn’t matter if and how firms’ signals are correlated
Two Firms

▶ payoffs almost as before....

\[
\begin{array}{c|cc}
\theta = B & I & N \\
\hline
I & -1 + \varepsilon & -1 \\
N & 0 & 0 \\
\end{array}
\]

\[
\begin{array}{c|cc}
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\hline
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\end{array}
\]

▶ ...up to \( \varepsilon \) term

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▶ we will consider what happens when \( |\varepsilon| \approx 0 \) (so the analysis cannot change very much)
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- will now have profile of action recommendations depending on the state
Two Firms: Strategic Complementarities

- If $\varepsilon > 0$, optimal rule is

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- the probability of any one firm investing is still about $x$.
Two Firms: Strategic Complementarities

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- binding constraints are still investment constraints, slackened by having simultaneous investment...

$$
\frac{x + \varepsilon}{1 - \varepsilon} (1 - 1 + \varepsilon) + x + \varepsilon \geq 0
$$
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\[\frac{x + \varepsilon}{1 - \varepsilon} (-1 + \varepsilon) + x + \varepsilon \geq 0\]

- ....so signals are public
Two Firms: Strategic Substitutes

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....and signals are private
Application 1 - Information Sharing: Strategic Substitutes

- Classic Question: are firms better off if they share their information?
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Consider quantity competition when firms uncertain about level of demand (intercept of linear demand curve) with symmetry, normality and linear best response; two effects in conflict:
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Consider quantity competition when firms uncertain about level of demand (intercept of linear demand curve) with symmetry, normality and linear best response; two effects in conflict:

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2. Strategic Effect: Firms would like to be as uncorrelated with each other as possible
Application 1 - Information Sharing

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- Consider quantity competition when firms uncertain about level of demand: individual and strategic effects in conflict
- Resolution:
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Resolution:

- For large enough price sensitivity (and thus strategic substitutability), strategic effect wins and no information is optimal
- For low enough price sensitivity (and thus strategic substitutability), individual choice effect wins and full information is optimal
- For intermediate price sensitivity, there is a non-trivial trade-off and it is optimal to have firms observe noisy signals of demand, but with uncorrelated noise and thus conditionally independent signals, and thus signals which are as uncorrelated as possible conditional on their accuracy
Objective

- Classic Question: can informational frictions explain aggregate volatility?
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- Consider a setting where each agent sets his output equal to his productivity which has a common component and an idiosyncratic component.
Application 2 - Aggregate Volatility: Wacky Designer

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- Which information structure maximizes variance of average action?
What information structure maximizes variance of average action?

- critical information structure has a confounding (c.f., Lucas 72) signal $s_i = \lambda x_i + (1 - \lambda) y$ \textit{without noise}...

- variance of average action is maximized when

$$\lambda = \frac{\sigma}{2\sigma + \sqrt{\sigma^2 + \tau^2}}$$

and maximum variance of average action is

$$\left(\frac{\sigma + \sqrt{\sigma^2 + \tau^2}}{2}\right)^2$$
Application 2 - Aggregate Volatility

What information structure maximizes variance of average action?

- "optimal" information structure has a confounding (c.f., Lucas 72) signal $s_i = \lambda x_i + (1 - \lambda) y$ without noise...

- as $\sigma \to 0$:...
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- can then be embedded in a richer setting (Angeletos La’O 13)
Example: Two bidders and valuations independently and uniformly distributed on the interval $[0, 1]$

Plot: (expected bidders’ surplus, expected revenue) pairs
- green = feasible pairs, blue = unknown value pairs, red = known value pairs
Application 3 - First Price Auction

1. Known value case (red region) is subset of unknown value case (blue region)
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2. Robust Prediction:

   2.1 revenue has lower bound $\frac{1}{10}$

   2.2 lower bound (w.r.t. first order stochastic dominance) on bids

3. Partial Identification: Winning bid distribution $\leq$ Lower bound on Value Distribution (w/o identifying private vs. common values)
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Designer Access to Players’ Information

- We want to assume that information designer knows the state \( \theta \)...
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...but what should we assume about what information designer knows about players’ information? Consider three scenarios:
Designer Access to Players’ Information

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2. Communicating Designer: the designer can condition his announcements about the state only on players’ reports of their types
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1. Omniscient Designer: the designer knows all players’ information too...[**maintained assumption so far**]
2. Communicating Designer: the designer can condition his announcements about the state only on players’ reports of their types
3. Non-Communicating Designer: the designer can tell players about the state but without conditioning on players’ information
as before, firm observes a signal $t \in T$ and government makes a recommendation to invest $p^t_\theta$ as a function of reported signal $t$ and state $\theta$
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incentive constraint: add truth-telling to obedience
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incentive constraint: add truth-telling to obedience

to insure truth-telling, differences in recommendations must be bounded across states
Communicating Designer

- adding truth-telling constraints... ($x = 0.9$, $q = 0.7$)
Communicating Designer

- adding truth-telling constraints... ($x = 0.9, q = 0.7$)

- communicating (red), omniscient (pink)
if there is a large discrepancy in recommendations, then firm has an incentive to misreport his signal
Communicating Designer

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- e.g., at maximum investment BCE (top right), firm with good signal is always told to invest;
Communicating Designer

- if there is a large discrepancy in recommendations, then firm has an incentive to misreport his signal
- e.g., at maximum investment BCE (top right), firm with good signal is always told to invest; might as well mis-report good signal as bad signal to get
Non-communicating designer

- firm observes his signal
Non-communicating designer

- firm observes his signal
- government offers a recommendation, independent of the signal, depending on the true state
Non-communicating designer

- firm observes his signal
- government offers a recommendation, independent of the signal, depending on the true state
- In our example, communicating and non-communicating designer can attain the same set of outcomes; Kotolin et al show this in a more general - but still restrictive - class of environments
<table>
<thead>
<tr>
<th>Taxonomy</th>
<th>Single Agent</th>
<th>Many Agent Uninformed Designer</th>
<th>Many Agent Informed Designer</th>
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<tr>
<td>Omniscient</td>
<td>·</td>
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<td>BCE</td>
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Elaborations

1. Other Objectives
   - Ely 15, Arieli 15, Taneva 16

2. Comparing Information
   - many player Blackwell order generalization

3. Concavification and its many player generalizations
   - Kamenica-Gentzkow 11 get a lot of action out of "concavification" (Aumann-Maschler 95); many player generalization harder - Mathevet, Perego and Taneva 16

4. Adversarial Information Design
   - Carroll 15, Taneva et al 16, Kajii-Morris 97

5. Incomplete information correlated equilibrium literature
   - Forges 93

6. Relation to Mechanism Design
   - Myerson 82, 87, 91
Literature

- Our methodology papers:
  - "Robust Predictions in Incomplete Information Games," Ecta 13 (includes Cournot results)
  - "Bayes Correlated Equilibrium and The Comparison of Information Structures," TE 16
  - "Information Design, Bayesian Persuasion and Bayes Correlated Equilibrium," AER P&P 2016
  - Full paper on material in lecture in preparation

- Examples
  - Kamenica-Gentzkow 11 and Bergemann Morris 16 (see also Taneva 16)
  - "Information and Volatility" (with Tibor Heumann) JET; see also "Information and Market Power" (working paper)
  - "First Price Auctions with General Information Structures: Implications for Bidding and Revenue" (with Ben Brooks) Ecta forthcoming; see also "The Limits of Price Discrimination" AER
1. Other Objectives

- Suppose the government was interested in maximizing the probability of at least one firm investing
- (Assuming $x > 1/2$) This can always be achieved with probability 1.

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This is true for $\varepsilon = 0$ and by continuity for $|\varepsilon|$ independent of the sign...

- Compare Ely 15, Arieli 15, Taneva 16
Other Objectives and a Benevolent Information Designer

- In one firm case, if government had the same objective as the firm, he would always give them full information...
- But in the two firm case, a benevolent government maximizing the (joint) profits of the two firms might still manipulate information in order to correct for externalities and coordinate behavior
- In game

\[
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\[
\begin{array}{ccc}
\theta = G & \text{I} & \text{N} \\
\text{I} & x + \varepsilon + z & x \\
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\]

benevolent government will behave as an investment maximizing government if $z$ is large enough
2. Ordering Information

- Intuition: more information for the player imposes more constraints on the information designer and reduces the set of outcomes she can induce.

- Recall Auction Example

- Say that information structure $S$ "is more incentive constrained than" ($= \) more informed than) $S'$ if it gives rise to a smaller set of BCE outcomes than $S'$ in all games.
  
  - in one player case, this ordering corresponds to Blackwell’s sufficiency ordering
  - in many player case, corresponds to "individual sufficiency" ordering

- Bergemann-Morris 16, see also Lehrer et al 10 and 11
Nice Properties of Individual Sufficiency Ordering

- Reduces to Blackwell in one player case
- Transitive
- Neither implies nor implied by Blackwell on join of players’ information
- Two information structures are each individually sufficient for each other if and only if they share the same higher order beliefs about $\Theta$
- $S$ is individually sufficient for $S'$ if and only if giving extra signals to $S'$ equals $S$ plus an appropriate correlation device
3. Concavification

- We described two step procedure for solving information design problem (with one or many players):
  1. Characterize all implementable decision rules
  2. Pick the designer’s favorite

- Concavification procedure (with one player)
  [Aumann-Maschler 95 and Kamenica-Gentzkow 11]
    - Identify information designer’s utility for every belief of the single player
    - Identify utility from optimal design by concavification, identifying information design only implicitly

- Many player generalization: Mathevet al 16

- Always nice interpretation, sometimes (but not always) useful in solving information design problem
4. Adversarial Equilibrium Selection

- Suppose that an information designer gets to make a communication $\Phi : T \times \Theta \rightarrow \Delta (M)$; new game of incomplete information $(G, S, \Phi)$
- Write $E (G, S, \Phi)$ for the set of Bayes Nash equilibria of $(G, S, \Phi)$ and write $V^*_S (\Phi, \beta)$ for the information designer’s utility
- We have been studying the maxmax problem

$$\max_C \max_{\beta} V^*_S (\Phi, \beta)$$

using a revelation principle argument to show that this equals

$$\max_{\sigma \in BCE(G, S)} V_S (\sigma)$$

- The maxmin problem

$$\max_C \min_{\beta} V^* (S, \Phi, \beta)$$

does not have a revelation principle characterization
- Carroll 15, Taneva et al 16, Kajii-Morris 97
5. Incomplete Information Correlated Equilibrium

- Decision rule $\sigma : T \times \Theta \rightarrow A$ is incentive compatible for $(G, S)$ if, for each $i$, $t_i$ and $a_i$, we have

$$\sum_{a_{-i}, t_{-i}, \theta} u_i ((a_i, a_{-i}), \theta) \sigma (a | t, \theta) \pi (t | \theta) \psi (\theta)$$

$$\geq \sum_{a_{-i}, t_{-i}, \theta} u_i ((\delta (a_i), a_{-i}), \theta) \sigma (a | (t_i', t_{-i}), \theta) \pi (t | \theta) \psi (\theta);$$

for all $t_i'$ and $\delta_i : A_i \rightarrow A_i$.

- Decision rule $\sigma : T \times \Theta \rightarrow A$ is join feasible for $(G, S)$ if $\sigma (a | t, \theta)$ is independent of $\theta$, i.e., $\sigma (a | t, \theta) = \sigma (a | t, \theta')$ for each $t \in T$, $a \in A$, and $\theta, \theta' \in \Theta$.

- Solution Concepts:
  - Bayes correlated equilibrium = obedience
  - Communication equilibrium = incentive compatibility (and thus obedience) and join feasibility
  - etc...
6. Mechanism Design and Information Design

- Myerson Mechanism Design:
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  - both combined in Myerson (1982, 1987)
- Truth-telling (honesty) and obedience constraints always maintained
- "information design" = "Bayesian games with communication" − truth-telling + informed information designer/mediator
- compare also informed principal literature