1 Applications

Application I: Public Goods
Application II: Prediction Markets
Application III: Contracting & Regulation
Application I: Designing Stable Mechanisms
Healy (2006)
Mathevet (2008)
Healy & Mathevet
Implementing Lindahl Equilibria

3. Healy & Mathevet
Previous Experiments

- **Chen & Plott 96**
  - GL100 ($\gamma = 100$) > GL1 ($\gamma = 1$)
  - High $\gamma \Rightarrow$ better convergence

- **Chen & Tang 98**
  - GL100 > GL1 $\gamma$ > Walker
  - Claims that supermodularity is sufficient for convergence

- **Arifovic & Ledyard 03**
  - GL50 > GL100 > GL150
  - GL50 is not supermodular, still converges
The Public Goods Environment

- $n$ agents
- 1 private good $x$, 1 public good $y$
- Endowed with private good only ($\omega_i$)
- Preferences: $u_i(x_i, y) = v_i(y) + x_i$
- Linear technology ($\kappa$)
- Mechanisms: $m_i \in M_i$
  
  $$y(m) = y(m_1, m_2, \ldots, m_n)$$
  $$t_i(m) = t_i(m_1, \ldots m_n)$$
  $$x_i = \omega_i - t_i(m)$$
Five Mechanisms

• “Efficient” $\Rightarrow g\circ\mu(e) \in PO(e)$

• Inefficient Mechanisms
  - Voluntary Contribution Mech. (VCM)
  - Proportional Tax Mech.

• (Outcome-) Efficient Mechanisms
  - Dominant Strategy Equilibrium
    - Vickrey, Clarke, Groves (VCG) (1961, 71, 73)
  - Nash Equilibrium
    - Groves-Ledyard (1977)
    - Walker (1981)
VCG Mechanism: Theory

\[ M_i = \Theta_i \quad m_i = \hat{\theta}_i = (\hat{a}_i, \hat{b}_i) \]

\[ y(\hat{\theta}) = \arg \max_{y \geq 0} \left[ \sum_j v_j(y | \hat{\theta}_j) - \kappa y \right] \]

\[ t_i(\hat{\theta}) = \frac{\kappa y(\hat{\theta})}{n} - \left( \sum_{j \neq i} v_j(y(\hat{\theta}) | \hat{\theta}_j) - \frac{n-1}{n} \kappa y(\hat{\theta}) \right) \]

\[ + \max_{y \geq 0} \left( \sum_{j \neq i} v_j(y | \hat{\theta}_j) - \frac{n-1}{n} \kappa y \right) \]

- Truth-telling is a dominant strategy
- Pareto optimal public good level
- Not budget balanced
- Not always individually rational
VCG Mechanism: Best Responses

- Truth-telling ($\hat{\theta}_i = \theta_i$) is a *weak* dominant strategy
- There is always a continuum of best responses:
  
  \[
  BR_i(\hat{\theta}_{-i}) = \{\hat{\theta}_i : y(\hat{\theta}_i, \hat{\theta}_{-i}) = y(\theta_i, \hat{\theta}_{-i})\}
  \]
VCG Mechanism: Previous Experiments

• Attiyeh, Franciosi & Isaac ’00
  – Binary public good: weak dominant strategy
  – Value revelation around 15%, no convergence

• Cason, Saijo, Sjostrom & Yamato ’03
  – Binary public good:
    • 50% revelation
    • Many pairings play dominated Nash equilibria
  – Continuous public good with single-peaked preferences (strict dominant strategy):
    • 81% revelation
VCG Experiment Results

- Demand revelation: 50 – 60%
  - NEVER observe the dominant strategy equilibrium

- 10/20 subjects fully reveal in 9/10 final periods
  - “Fully reveal” = both parameters

- 6/20 subjects fully reveal < 10% of time

- Outcomes very close to Pareto optimal
  - Announcements may be near non-revealing best responses
Summary of Experimental Results

- **VCM**: convergence to dominant strategies
- **Prop Tax**: non-equir., but near best response
- **Groves-Ledyard**: convergence to stable equil.
- **Walker**: no convergence to unstable equilibrium
- **VCG**: low revelation, but high efficiency

*Goal*: A simple model of behavior to explain/predict which mechanisms converge to equilibrium

*Observation*: Results are qualitatively similar to best response predictions
5-period B.R. vs. Nash Equilibrium

- Voluntary Contribution (strict dom. strats): \( EQ_i^t \approx BR_i^t \)

- Groves-Ledyard (stable Nash equil): \( EQ_i^t \approx BR_i^t \)

- Walker (unstable Nash equil): 73/81 tests reject \( H_0 \)
  - No apparent pattern of results across time

- Proportional Tax: 16/19 tests reject \( H_0 \)

- 5-period model beats *any* static prediction
Best Response in the VCG Mechanism

• Convert data to polar coordinates:
Best Response in the cVCG Mechanism

Origin = Truth-telling dominant strategy
0-degree Line = Best response to 5-period average
Efficiency

Efficiency Confidence Intervals - All 50 Periods

Mechanism
Walker    VC    PT    GL    VCG

No Pub Good
Conclusions

• Importance of **dynamics & stability**
  – Dynamic models outperform static models
• Strict vs. weak dominant strategies
• Applications for “real world” implementation
• Directions for theoretical work:
  – Developing stable mechanisms
• Open experimental questions:
  – Efficiency/equilibrium tension in VCG
  – Effect of the “What-If Scenario Analyzer”
• **Better** learning models
• Take any Bayesian mechanism
• Add ‘penalty term’ to make the game supermodular
• Penalty terms wash out (like d’AGV’s mechanism)
• This trick doesn’t work in general complete info settings
• Known mechanisms for public goods are eerily similar...
  **Theorem 1:** Green-Laffont-type characterization

• Experimental results say ‘stability (supermodularity?) matters’
  **Theorem 2:** With one-dimensional strategy space, can’t guarantee supermodularity

**Theorem 3:** Show how to get stability by adding 2\textsuperscript{nd} dim.
Mechanisms

Real-message mechanisms:

- Strategy space: \( M_i = \mathbb{R}^k \ \forall i \)
- Outcome function: \((y(m), t_1(m), \ldots, t_n(m))\)

**Trivial Observation:**
Every mechanism’s tax functions can be written as

\[
t_i(m) = q_i(m_{-i}) y(m) + g_i(m) .
\]

Note: ‘Price-taking’ assumption
Existing Mechanisms

- Groves-Ledyard 1977
- Hurwicz 1979
- Walker 1981
- Kim 1993
- Chen 2002
- Others...
Conjecture

For any continuous mechanism implementing Lindahl allocations...

1. if $\mathcal{M}_i = \mathbb{R}^1$ then $g_i \equiv 0$, and
2. if $\mathcal{M}_i = \mathbb{R}^k$ for $k > 1$ then let $\mathcal{M}_i = S_i \times Z_i$ s.t.
   \[ y(m) \equiv y(s), \text{ then } g_i(m^*) \equiv 0 \text{ whenever } m^* \text{ is in equilibrium.} \]

**Interpretation:** $t_i(m) = q_i(m_{-i})y(m) + g_i(m)$

1. Agents solve Lindahl’s program (as price takers) given $z^*$
2. Additional dimensions can be used to provide desirable off-equilibrium properties
Proving The Conjecture: Assumptions

**A1: Rich Domain**

\[-\alpha y^2 + \beta y + x_i : \alpha \in \mathbb{R}_+, \beta \in \mathbb{R} \subseteq \{ u_i(\cdot|\theta_i) : \theta_i \in \Theta_i \} \]

\[\{-\alpha |y - \beta| + x_i : \alpha \in \mathbb{R}_+, \beta \in \mathbb{R} \subseteq \{ u_i(\cdot|\theta_i) : \theta_i \in \Theta_i \}\} \]

**A2: Differentiable Mechanisms**

\[y(m), t_i(m) \text{ are all twice continuously differentiable and } \frac{\partial y(m)}{\partial m_i} \text{ is bounded away from zero } \forall i.\]
Proving The Conjecture: Non-NE

Consider the 1-dimensional case:

- If \( m \) is a NE for some environment \( \phi(m) \in \Theta \) then we can derive restrictions from \( t_i(m) = p_i(\phi_i(m))y(m) \forall m \).
- No restrictions on \( t_i(m) \) for \( m \) that are never NE

**Lemma**

With a rich domain, \( m^* \) is a Nash equilibrium for some environment if \( \forall i, m \exists \gamma_i \) s.t. \( \forall m'_i \)

\[
|t_i(m^*) - t_i(m'_i, m^*_{-i})| \leq \gamma_i |y(m^*) - y(m'_i, m^*_{-i})| .
\]  

(1)

**A3:** All \( m \in \mathcal{M} \) are NE

\((\mathcal{M}, (y(m), t(m)))\) satisfies condition 1 a.e.
Proving the Conjecture: Multiple Prices

Non-unique Lindahl price \( \Rightarrow \) no useful restrictions on transfers.
Proving the Conjecture: Quadratic Prefs

Choose parameters to satisfy FOC, local SOC at $y(m^*)$. 
Proving the Conjecture: Check Deviations

Large changes in $y$ are not profitable.
Proving the Conjecture: Check Deviations

Tiny changes in $y$ are not profitable.

$\tilde{v}_i(y) > v_i(y|\phi_i(m^*)) > p_i(\phi_i(m^*))$
Proving the Conjecture: $\uparrow$ Concavity

Increase concavity of $v_i$, keep FOC & local SOC.
Proving the Conjecture: No Deviations

Eventually all deviations are unprofitable; $m^*$ is a NE.
All $m$ are NE and all NE give Lindahl allocations $\Rightarrow$

$$t_i(m) = q_i(m_{-i})y(m) + g_i(m) = p_i(\phi(m))y(m),$$

so

$$g_i(m) = [p_i(\phi(m)) - q_i(m_{-i})]y(m).$$

Differentiating gives

$$\frac{\partial g_i(m)}{\partial m_i} = \frac{\partial [p_i(\phi(m)) - q_i(m_{-i})]}{\partial m_i}y(m) + [p_i(\phi(m)) - q_i(m_{-i})] \frac{\partial y(m)}{\partial m_i} \quad (2)$$
Proving the Conjecture: Restriction #2

All \( m \) are NE implies FOC w.r.t. \( m_i \) holds at all \( m \):

\[
\frac{\partial v_i(y(m)|\phi_i(m))}{\partial y} y(m) \frac{\partial y(m)}{\partial m_i} = \frac{\partial t_i(m)}{\partial m_i} \\
= q_i(m_{-i}) \frac{\partial y(m)}{\partial m_i} + \frac{\partial g_i(m)}{\partial m_i}.
\]

Lindahl pricing implies \( \partial v_i / \partial y = p_i \), so

\[
p_i(\phi(m)) \frac{y(m)}{\partial m_i} = q_i(m_{-i}) \frac{\partial y(m)}{\partial m_i} + \frac{\partial g_i(m)}{\partial m_i}
\]

or

\[
\frac{\partial g_i(m)}{\partial m_i} = [p_i(\phi(m)) - q_i(m_{-i})] \frac{\partial y(m)}{\partial m_i} \quad (3)
\]
Proving the Conjecture: Conclusion

We have
\[
\frac{\partial g_i(m)}{\partial m_i} = \frac{\partial [p_i(\phi(m)) - q_i(m_{-i})]}{\partial m_i} y(m) + [p_i(\phi(m)) - q_i(m_{-i})] \frac{\partial y(m)}{\partial m_i}
\]

\[
\frac{\partial g_i(m)}{\partial m_i} = [p_i(\phi(m)) - q_i(m_{-i})] \frac{\partial y(m)}{\partial m_i}.
\]

Thus, \(p_i(\phi(m))\) doesn’t depend on \(m_i\).

\[
g_i(m) = \underbrace{[p_i(\phi(m)) - q_i(m_{-i})] y(m)}_{h_i(m_{-i})}
\]

\[
t_i(m) = q_i(m_{-i}) y(m) + h_i(m_{-i}) y(m)
= \tilde{q}_i(m_{-i}) y(m)
= p_i(\phi(m)) y(m)
\]
Theorem 1

Assume all quasilinear-quadratic preferences are admissible. If a mechanism \((\mathbb{R}^n, (y, t))\) Nash implements the Lindahl allocations and on some open set \(M^* \subseteq M\) the mechanism is twice continuously differentiable, has \(\partial y / \partial m_i\) bounded away from zero, and satisfies the relative Lipschitz condition, then the transfers must be of the form

\[
t_i(m) = q_i(m_{-i})y(m)
\]

for all \(m \in M^*\).

- See Brock 1980 (and G-L 1987)
- Sufficiency
Let \( m_i = (s_i, z_i) \) but \( y(m) = y(s) \).

- \( \tilde{z}_i(s_i, m_{-i}) \): transfer-minimizing \( z_i \) (\( \exists ? \))
- Not all \( m \) may be NE - only characterize on NE set
- Relative Lipschitz condition:

\[
\left| t_i(s_i, \tilde{z}_i(s_i, m_{-i}), m_{-i}) - t_i(s'_i, \tilde{z}_i(s'_i, m_{-i}, m_{-i})) \right| \\
\leq \gamma_i |y(s) - y(s'_i, s_{-i})|
\]

- In FOC: \( \frac{\partial g_i}{\partial z_i} \frac{\partial \tilde{z}_i}{\partial s_i} = 0 \), so same proof
- Thus, \( g_i = 0 \) in equilibrium
Walrasian Equilibria

- Proof is nearly identical
- Characterization result extends
Supermodular Games: Definition

A game \( G = (N, \{(S_i \times Z_i)\}, u) \) with twice-differentiable \( u_i \) is supermodular if for all \( i \),

- Each \( u_i \) is supermodular in \( m_i \):
  \[
  \frac{\partial^2 u_i}{\partial s_i \partial z_i} \geq 0
  \]

- Each \( u_i \) has increasing differences in \( (m_i, m_{-i}) \): \( \forall j \)
  \[
  \frac{\partial^2 u_i}{\partial s_i \partial s_j} \geq 0 \quad \frac{\partial^2 u_i}{\partial s_i \partial z_j} \geq 0
  \]
  \[
  \frac{\partial^2 u_i}{\partial z_i \partial s_j} \geq 0 \quad \frac{\partial^2 u_i}{\partial z_i \partial z_j} \geq 0
  \]

- \( u_i \) is upper-semicontinuous in \( m_i \) and continuous in \( m_{-i} \).
- Each \( S_i \times Z_i \) is compact
Supermodular Implementation: Definition

- **Definition**: The mechanism $\Gamma$ supermodularly Nash implements the Lindahl allocations if for all $\theta$,
  
  1. Equilibrium outcomes $= \text{Lindahl allocations}$
  2. The game induced by $\Gamma$ is supermodular for all $\theta$.

- If there exists such a $\Gamma$ then the Lindahl (social choice) correspondence is said to be (Nash) supermodular implementable.
Theorem 2

- **Definition**: The outcome function $y$ is symmetric if 
  \[ y(m_i, m_j, m_{-ij}) = y(m_j, m_i, m_{-ij}) \]
  for all $m, i, j$.

**Theorem**

*Under the above assumptions, there can be no one-dimensional mechanism with a symmetric outcome function that supermodularly implements the Lindahl correspondence.*

Theorem 3

- Impossibility result points to more dimensions.

A4: Q-L with bounded concavity

\[ u_i(x_i, y|\theta_i) = v_i(y|\theta_i) + x_i \] and \( \partial^2 v_i / \partial y^2 \) is negative & bounded.

Theorem

Under Assumptions 1–4, any one-dimensional mechanism \( \Gamma = (M, (y, t)) \) that implements Lindahl allocations can be converted into a supermodular two-dimensional mechanism that implements Lindahl allocations.
Intuition for the Result

- Add a function $g_i(s, z)$ to the transfers
  
  \[ t_i^{SM} = t_i(m) + \rho_i g_i(z_i, m) \]

  such that
  
  - $g_i$ does not alter the $m$ component of NE
  - $g_i = 0$ at any equilibrium (same tax)
  - Cross-partials of $g_i$ are bounded above zero, $\rho_i$ ramps up cross-partials

- Exactly how Chen’s 2002 mechanism is constructed

- Similar in spirit to Mathevet 2007: Add complementarities that vanish in equilibrium.
Summary

- Experimental results suggest stability matters
- Characterization theorem answers an open question
- For Lindahl implementation, supermodularity can be added
- Requires slightly larger strategy space
- Ultimate goal: practical mechanism design
Application II: Prediction Markets

“Prediction Market Alternatives for Complex Environments”
Healy, Ledyard, Linardi & Lowery (2008)
The Success of Prediction Markets

- Wall St. market: 1848–1940 (Rhode & Strumpf 2004)
  - 11/15 correct in mid-October, only 1 very wrong (Wilson 1916)

- Iowa Electronic Markets (Berg et al. 2003)
  - See figure...
The Success of Prediction Markets

Avg. Error: 1.5% vs. 2.1%. Source: Berg, Forsythe, Nelson & Rietz (2003)
The Success of Prediction Markets

- Wall St. market: 1848–1940 (Rhode & Strumpf 2004)
  - 11/15 correct in mid-October, only 1 wrong (W. Wilson)

- Iowa Electronic Markets (Berg et al. 2003)
  - See figure...
  - But... Erikson & Wlezien use trends in polls

- TradeSports (Tetlock, Wolfers, Zitzewitz, others...)
  - Trade volume during Davidson vs. Kansas $\approx 7,700$ $10$ tickets

- NewsFutures, Hollywood Stock Exchange (Pennock et al. 2001)
  - See figure...
Figure 3
Predicting Movie Success

Source: Data from 489 movies, 2000–2003 ([http://www.hsx.com]).


The Success of Prediction Markets
Corporate Applications

- Predicting printer sales at Hewlett-Packard (K-Y Chen & Plott 2002)
- Companies claiming to use prediction markets:
  
  Abbot Labs  
  Corning  
  General Electric  
  InterContinental Hotels  
  Nokia  
  TNT  
  Arcelor Mittal  
  Electronic Arts  
  Google  
  Masterfoods  
  Pfizer  
  Best Buy  
  Eli Lilly  
  Hewlett-Packard  
  Microsoft  
  Qualcomm  
  Chrysler  
  Frito Lay  
  Intel  
  Motorola  
  Siemens  

- Are they doing it ‘right’? Volume? Complexity??
The Policy Analysis Market (PAM)

- 2001–2003 DARPA (DoD) \(\Rightarrow\) NetExchange (Ledyard, Polk, Hanson)
- Goal: Predict events the DoD might care about
- NetExchange focus: political instability in Middle East
- A subset of the issues:
  - Correlation blows up the state space
  - Manipulation? (Camerer 98, Strumpf & Rhode 07)
  - Moral Hazard? (Hanson et. al 07)
  - Moral repugnance & P.R. (Roth 07, Hanson 07)
- Aug 03: Shut Down, DARPA audited, Poindexter ‘retired’
Questions:

1. Can markets actually work when the environment gets complicated?
2. Would other mechanisms do better?

Answers:
Test markets vs. 3 other mechs in complex lab environments

1. Market falls apart, simple iterated polls perform better
2. Why the poll seems to do better in this environment
Easy vs. Hard Environments

Example similar to our experiment:

1. **Simple:** Will Rays beat Red Sox?
   - Two states: \{Rays, Red Sox\}, one security

2. **Hard:** Who will win each of the last 3 series (2 pennants and World Series)?
   - Three events, not independent
   - Eight states: \{Rays, Red Sox\} × \{Phillies, Dodgers\} × \{AL, NL\}
   - “AL Champion wins” is correlated with other 2 events
   - Incomplete set of securities is typically used
     - TradeSports offers 6 securities (1+1+4)
   - We will use a complete set of 8
The Mechanisms

1. Double Auction (prediction market)
2. Pari-mutuel (horse track)
3. Iterated Poll (‘Delphi method’: RAND/USAF)
Alternative Mechanisms: Pari-Mutuel

- Bettors buy tickets on each event
  - \( n_j \) = \# of tickets purchased on event \( j \)
- Payoff odds of event-\( j \) tickets = \( (n_j / \sum_k n_k)^{-1} \)
- Still need \( 2^k \) securities
- Still have a no-trade theorem
Players announce a belief distribution $P^i$ over the 8 events

$$\bar{P} = \frac{1}{n} \sum_i P^i$$

Repeat 5 times

Everyone paid based on final average distribution $\bar{P}$

Incentive compatible scoring rule:
- Everyone receives $\left( \ln [\bar{P}_j] - \ln [1/8] \right)$ event-$j$ securities
- If event $k$ is true, event-$k$ security pays $1$.

There exist many seq. equil. with full info aggregation

There exist babbling seq. equil. with “almost” no aggregation
Alternative Mechanisms: Market Scoring Rule (Hanson)

- A public distribution is shown: \((1/8, \ldots, 1/8)\)
- Individuals may ‘move’ the distribution to \((P_1^i, \ldots, P_8^i)\)
- Move from \((Q_1, \ldots, Q_8)\) to \((P_1^i, \ldots, P_8^i)\) \(\implies\)
  - Receive \(\left(\ln \left[ P_j^i \right] - \ln \left[ Q_j^i \right] \right)\) event-\(j\) securities for each \(j\)
  - Moving \(P_j^i\) up means buying, down means selling
  - If event \(k\) is true, event-\(k\) security pays $1
  - Incentive compatible: you should move to your best guess

- Subsidized \(\implies\) avoids no-trade theorem
- Incentive compatible \(\implies\) myopic players reveal truthfully
- Incentive to misrepresent? Depends on move timing...
• Run experiments using Caltech undergrads paid ≈ $35
• No experience
• Crossover design: DA-Poll, Poll-DA, MSR-Pari, Pari-MSR
• 3 subjects per group
• 8 periods with each mechanism
• No rematching
Period & Order Effects

No significant period or order effects (good!)
Comparison of $l_2$ distances with 2 states:

<table>
<thead>
<tr>
<th></th>
<th>Avg Dist.</th>
<th>DblAuctn</th>
<th>MSR</th>
<th>Parimutuel</th>
<th>Poll</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg Dist.</td>
<td>—</td>
<td>0.262</td>
<td>0.419</td>
<td>0.295</td>
<td>0.266</td>
</tr>
<tr>
<td>DblAuctn</td>
<td>0.262</td>
<td>—</td>
<td><strong>0.092</strong></td>
<td>0.646</td>
<td>0.663</td>
</tr>
<tr>
<td>MSR</td>
<td>0.419</td>
<td>—</td>
<td>—</td>
<td><strong>0.098</strong></td>
<td>—</td>
</tr>
<tr>
<td>Parimutuel</td>
<td>0.295</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.519</td>
</tr>
<tr>
<td>Poll</td>
<td>0.266</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

MSR $\geq$ Parimutuel $\geq$ Poll $\geq$ DblAuctn
MSR $>$ Poll $\geq$ DblAuctn
## 2 States: Catastrophes

Periods with catastrophes:

<table>
<thead>
<tr>
<th></th>
<th>DblAuc</th>
<th>MSR</th>
<th>Pari</th>
<th>Poll</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Trade</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Confusion</td>
<td>5</td>
<td>7</td>
<td>6</td>
<td><strong>11</strong></td>
</tr>
<tr>
<td>Mirage</td>
<td>13</td>
<td><strong>14</strong></td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Confused Mirage</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td><strong>3</strong></td>
</tr>
<tr>
<td>None</td>
<td><strong>14</strong></td>
<td>12</td>
<td>13</td>
<td>12</td>
</tr>
</tbody>
</table>
## 2 States: Summary of Results

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>2 States</th>
<th>8 States</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Err</td>
<td>NoTrd</td>
</tr>
<tr>
<td>DblAuc</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>MSR</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Pari</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>Poll</td>
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</tr>
</tbody>
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<th>Parimutuel</th>
<th>Poll</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg $l_2$ Dist.</td>
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<td>0.696</td>
<td>0.527</td>
<td>0.605</td>
<td>0.418</td>
</tr>
<tr>
<td>DblAuc</td>
<td>0.696</td>
<td>—</td>
<td>0.002</td>
<td>0.093</td>
<td>$&lt; 0.001$</td>
</tr>
<tr>
<td>MSR</td>
<td>0.527</td>
<td>—</td>
<td>—</td>
<td>0.083</td>
<td>0.324</td>
</tr>
<tr>
<td>Parimutuel</td>
<td>0.605</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>$0.001$</td>
</tr>
<tr>
<td>Poll</td>
<td>0.418</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

$\text{DblAuc} > \text{Parimutuel} > \text{MSR} \geq \text{Poll}$
8 States: Catastrophes: No Trade

<table>
<thead>
<tr>
<th>Periods w/ No Trade</th>
<th>DblAuc</th>
<th>MSR</th>
<th>Parimutuel</th>
<th>Poll</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>9/32</td>
<td>0</td>
</tr>
</tbody>
</table>
8 States: Catastrophes: Confusion

\(l_2\) distance to convex hull, conditional on trade occurring:

<table>
<thead>
<tr>
<th>Avg. Dist.</th>
<th>DblAuc</th>
<th>MSR</th>
<th>Pari.</th>
<th>Poll</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. Dist.</td>
<td>0.447</td>
<td>0.362</td>
<td>0.398</td>
<td>0.312</td>
</tr>
<tr>
<td># Trade Pers.</td>
<td>32</td>
<td>32</td>
<td>23</td>
<td>32</td>
</tr>
</tbody>
</table>

\begin{align*}
\text{DblAuc} & \geq \text{Pari} \geq \text{MSR} \geq \text{Poll} \\
\text{DblAuc} & > \text{MSR} \geq \text{Poll} \\
\text{DblAuc} & \geq \text{Pari} > \text{Poll}
\end{align*}
8 States: Catastrophes: Mirages

Frequency of Mirages:

<table>
<thead>
<tr>
<th></th>
<th>Pers. w/</th>
<th>No. of</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trade</td>
<td>Mirages</td>
<td></td>
</tr>
<tr>
<td>DblAuc</td>
<td>32</td>
<td>13</td>
<td>0.406</td>
</tr>
<tr>
<td>MSR</td>
<td>32</td>
<td>7</td>
<td>0.219</td>
</tr>
<tr>
<td>Pari.</td>
<td>23</td>
<td>7</td>
<td>0.304</td>
</tr>
<tr>
<td>Poll</td>
<td>32</td>
<td>3</td>
<td>0.094</td>
</tr>
</tbody>
</table>

DblAuc > MSR > Poll
Pari > Poll
## 8 States: Summary

<table>
<thead>
<tr>
<th>Mech</th>
<th>2 States</th>
<th>8 States</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Err</td>
<td>NoTrd</td>
</tr>
<tr>
<td>DblAuc</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>MSR</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Pari</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>Poll</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

**Increased complexity:** Double auction fails, MSR & Poll work
Declaring a Winner?

Poll’s only failing: confusion in 2-states. How bad is it?
Beating the Prior

Percentage of periods where mechanism outperformed the “informed” prior:

<table>
<thead>
<tr>
<th></th>
<th>2 States</th>
<th>8 States</th>
</tr>
</thead>
<tbody>
<tr>
<td>DblAuc</td>
<td>0.375</td>
<td>0.000</td>
</tr>
<tr>
<td>MSR</td>
<td>0.355</td>
<td>0.250</td>
</tr>
<tr>
<td>Pari</td>
<td>0.393</td>
<td>0.044</td>
</tr>
<tr>
<td>Poll</td>
<td><strong>0.406</strong></td>
<td><strong>0.313</strong></td>
</tr>
</tbody>
</table>

Poll looks good (relatively)...
Observations

• Why does the poll out-perform the market?
• Observation 1: Preferences are aligned in the poll, so traders have no incentive to misrepresent
• ‘Misrepresenter’: Move away from full info, then move toward
• Number of misrepresenterors per mechanism:

<table>
<thead>
<tr>
<th>DblAuc</th>
<th>MSR</th>
<th>Pari</th>
<th>Poll</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>5</td>
<td>12</td>
<td>3</td>
</tr>
</tbody>
</table>
Observations

- **Observation 2**: Traders have an incentive to participate in the poll
- No-trade theorem in DblAuc and Parimutuel
- MSR and poll are subsidized
  - 25.9 cents/trader/period in 2-state
  - 35.0 cents/trader/period in 8-state
- Pari-mutuel no trade: 4/32 and 9/32 pers.
- DblAuc: 1 inactive trader in 4/64 periods
- MSR: 1 period of no trade (1st period confusion?)
Observations

• **Observation 3:** Attention is ‘spread thin’ in the DblAuc


<table>
<thead>
<tr>
<th>States</th>
<th>Txns/Min.</th>
<th>Vol./Min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>5.00</td>
<td>6.48</td>
</tr>
<tr>
<td>8</td>
<td>2.60</td>
<td>14.47</td>
</tr>
</tbody>
</table>

• % of txns on 2 most active securities: 46%
• % of txns on 2 least active securities: 8%
• Low-hanging fruit is missed:
  • \( p(TTT) = 24/75 \) and \( p(HHH) = 4/75 \) regardless of pvt info
  • \( \text{Avg} \ |p(TTT) - 24/75| \) and \( \text{Avg} \ |p(HHH) - 4/75| \) are greater than any other mechanism
  • Significantly greater than MSR and Poll
Observations

- **Observation 4:** Poll averages traders’ announcements, mitigating effects of a single aberrant trader
- Frequency of worse-than-average final reports & predictions

<table>
<thead>
<tr>
<th>Mech</th>
<th>2 States</th>
<th></th>
<th>8 States</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Last Report</td>
<td>Prediction</td>
<td>Last Report</td>
<td>Prediction</td>
</tr>
<tr>
<td>DblAuc</td>
<td>11</td>
<td>11</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>MSR</td>
<td>18</td>
<td>18</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Pari-mutuel</td>
<td>11</td>
<td>11</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Poll</td>
<td><strong>28</strong></td>
<td><strong>8</strong></td>
<td><strong>21</strong></td>
<td><strong>8</strong></td>
</tr>
</tbody>
</table>
Summary

- Double auction works fine with 2 states, not 8
  - Observation: think markets problem (focus on 2 securities)
  - Note: not market power problem
- Pari-mutuel hurt by delay and no trade
- MSR helps ‘unfocus’ attention, but prone to bad outcomes
  - Single ‘bad’ player can damage performance
- Poll performs best
  - Aligned incentives, participation incentives, averaging smooths behavior, completely ‘unfocused’
Application III:
Optimal Contracting within NASA
Healy, Ledyard, Noussair,
Thronson, Ulrich & Varsi
Mars Climate Orbiter

- Launched: 12/11/98
- Lost: 9/23/99 (orbit entry)
- English-to-Metric problem

Mars Polar Lander

- Launched: 1/3/99
- Lost: 12/3/99 (landing)
- Landing software glitch?

Total Cost: $327 Million

Deeper issue: Cost overruns
NASA Mission Acquisition

OMB

Politicians

HQ

IC1

IC2

Space Scientists

Private contractors, etc.

HQ = Principal

ICs = Agents
Budget Allocation: Cost Caps

1. HQ: Menu of missions for near future
2. ICs: Review menu, provide cost estimates*
3. HQ: Assigns missions to ICs*
4. ICs: Refine cost estimates
5. HQ: Assign cost caps for each mission
6. ICs: Build mission**
7. HQ: Fund mission up to cost cap**

*Adverse Selection    **Moral Hazard
IC Realizes a Cost Overrun

**IC:**
- Descope Mission (Less Science)
- Increase Risk (Fewer Tests)
- Cancel Mission
- Request $$ From HQ

**HQ:**
- Reject Request
- Cancel Mission Reallocate $$
- Reallocate $$ From Other Missions
- Ask Congress For $$

Congress Approval (Damages Reputation)
Mars Orbiter & Lander

- **Review Board:**
  
  “Program was under-funded by 30%.”
  
  JPL requested additional $19 million: rejected.

- **Ed Weiler:**
  
  “[Poor] engineering decisions were made because people were trying to emphasize keeping within the cost cap.”
  
  HQ should have a reserve of money for overruns.

- **Dan Goldin:**
  
  “The Lockheed Martin team was overly aggressive, because their focus was on winning [the contract].”
Theory: A Fixed Project

• Agent
  Luck: \( L \)   Effort: \( e \)
  Cost: \( C(e) = L - e \)   Disutility: \( f(e) \) \((f' > 0, f'' > 0)\)
  Payment from Principal: \( T \)
  Payoff: \( U(T,e) = T - C(e) - f(e) \)

• Principal
  Observes \( C \), not \( L \) or \( e \).   Payment to agent: \( T \)
  Benefit of project: \( S \)   Cost of capital: \( \lambda \)
  Payoff: \( V(T,e) = S + U(T,e) - (1 + \lambda)T \)
Mechanism Design Problem:
What’s the right $T$ when $L$ is unknown?
Cost Cap: Low type reduces effort, gets higher transfer
High type earns $<0$ if he participates
Agent: Announce $C^E$  \hspace{1cm} Principal: Pay $T = T^*(C^E, C)$

Cost caps are *backwards!*
Optimal Contract Features

- High cost types get enough money
- Low cost types don’t misrepresent (Strong cost saving incentives)

- Multiple agents:
  - Use cost estimates as bids
  - Solves adverse selection problem

- Second best: some distortion occurs
Theory vs. Reality

- IC’s cost estimates sharpen in time
  Luck + innovation while building
- Project size, complexity can vary (*S not fixed*)
- IC also cares about outcome (*S*)
- Project is a lottery
- Failure is worse than cancellation
- Interaction is repeated
- *f(e)* and *C(e)* are not known, not observable
- Common knowledge priors, utility maximizing…
Proposal: MCCS

1. IC & HQ negotiate cost “baseline” $C_B$
2. 3 linear contracts: Hi, Base, Low
   (Each is a function of $C_B$)
3. IC begins building, innovating
   (Costs change, partly due to luck)
4. IC picks a contract
5. HQ pays IC based on contract, cost
6. IC & HQ can keep savings for future
Proposal: MCCS
Hypothesis

• MCCS outperforms cost caps
  \(\uparrow\) payoffs \(\downarrow\) delays \(\uparrow\) innovations

• Why?
  – Low types have cost-saving incentive
  – High types get enough money
  – Risk sharing \(\rightarrow\) more innovation \(\rightarrow\) lower cost
  – Intertemporal budgets \(\rightarrow\) insurance
Experiment

• 1HQ + {1 or 2} ICs
• Static menu of 2 missions, 3 levels each
• HQ has annual budget of 1500 francs
• HQ allocates budget via {Cost Cap or MCCS}
  – Money earmarked for IC and mission and level
• IC Innovation
  – Spend more → higher prob. of big cost reductions
• IC Building
  – Chooses Science (S) and Reliability (R)
  – Mission crashes with probability 1-R
  – Payout: S if succeeds, -F if fails, 0 if cancelled
  – Don’t care about money: unspent funds are wasted
Timing

1. HQ/IC negotiate cost caps/baselines
2. ICs attempt 1st innovation
3. Renegotiation (cost caps only)
4. 2nd Innovation attempt
5. IC Builds: Science (S) + Reliability (R)
   (Receive transfer, pay $C(S,R)$)
6. Project launched: success/fail
   HQ Expected Payoff: $R*S - (1-R)*F$
Luck + Bonus

- IC’s cost is changed by 3 luck “shocks”
  - 1st: Before negotiation
  - 2nd: During innovation
  - 3rd: Pre-build

- IC gets a bonus if a “level 1” mission flies
  - Only difference between IC and HQ.
PERIOD 0

The following information is known by all players:

<table>
<thead>
<tr>
<th>Number of Centers</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headquarter's Budget</td>
<td>1500 M$</td>
</tr>
</tbody>
</table>

Bogeys are known by all players, Internal Information Costs are known only by you.

<table>
<thead>
<tr>
<th>TABLE OF &quot;BOGEYS&quot;</th>
<th>Center 1</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Project A1:</strong></td>
<td><strong>Bogey:</strong> 979.74 M$</td>
<td><strong>Bogey:</strong> 759.91 M$</td>
</tr>
<tr>
<td>Planned Science Content</td>
<td>500 pts</td>
<td><strong>Internal Info:</strong> 60.19 M$</td>
</tr>
<tr>
<td>Min. Science Content</td>
<td>500 pts</td>
<td><strong>Est Cost:</strong> 1039.93 M$</td>
</tr>
<tr>
<td>Failure Cost</td>
<td>1500 pts</td>
<td></td>
</tr>
</tbody>
</table>

| **Project A2:**   | |
| Planned Science Content | 400 pts |
| Min. Science Content  | 400 pts |

Login: IC1  Session: sample1  Period: 0  Winnings: pts
Allocating a Fixed Cost (Cost Cap) of 0 indicates that a Center is not assigned a mission.

<table>
<thead>
<tr>
<th>Project</th>
<th>Center</th>
<th>Bogey</th>
<th>Requested Fixed Cost (Cost Cap)</th>
<th>Your Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Center1</td>
<td>979.74 mf</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>Center1</td>
<td>759.91 mf</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>A3</td>
<td>Center1</td>
<td>539.87 mf</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>Center1</td>
<td>1579.74 mf</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>B2</td>
<td>Center1</td>
<td>659.91 mf</td>
<td>678</td>
<td></td>
</tr>
<tr>
<td>B3</td>
<td>Center1</td>
<td>389.87 mf</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Total Requested: 1678

Total Planned Response: 1500

Total Budget: 1500
You Are Center 1

Innovation Opportunity - 1st of 2

Note: Total costs for a project are $a (S^2) + b \log[1/(1-R)] + \text{Innovation Funding Spent} + \text{Luck Costs}$

Where $S = \text{Total Science Content}$ and $R = \text{Total Reliability}$

Successful innovation decreases the value of $a$ by $1/3$, and the money spent ("funding") adds directly to your final cost.

<table>
<thead>
<tr>
<th>Project</th>
<th>Your Cost Estimate</th>
<th>Fixed Cost (Cost Cap)</th>
<th>Cost Coefficient (a)</th>
<th>Innovation Funding</th>
<th>Prob. of Innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project A1</td>
<td>1039.93</td>
<td>950</td>
<td>0.0032</td>
<td>100 M$</td>
<td>63.0%</td>
</tr>
<tr>
<td>Project B2</td>
<td>673.32</td>
<td>550</td>
<td>0.0024</td>
<td>0 M$</td>
<td>0%</td>
</tr>
</tbody>
</table>

Spend This Amount & See if Innovation Occurs

Login: IC1  Session: sample1  Period: 0  Winnings: pts
You are Center 1

Building - Phase D only

Choose the amount of Science Content and Reliability to build in Phase D only.

Total Science Content = Science Content from Phase A-C + Science Content from Phase D
Total Reliability = Reliability from Phase A-C + Reliability from Phase D

<table>
<thead>
<tr>
<th>Project</th>
<th>DON'T DELIVER THIS PROJECT</th>
<th>Science Content from Phase A-C</th>
<th>Science Content for Phase D</th>
<th>Total Science Content</th>
<th>Min. Science Content for All Phases</th>
<th>Reliability for Phase A-C</th>
<th>Reliability for Phase D</th>
<th>Final Reliability for All Phases</th>
<th>Total Innovation Funding Spent</th>
<th>Cost from Phase A-C</th>
<th>Second Luck Cost</th>
<th>Final Total Cost</th>
<th>Total Fixed Cost (Cost Cap)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project A1</td>
<td>x</td>
<td>260 (52% of Min.)</td>
<td>[260][82%] of Min.</td>
<td>[520][104%] of Min.</td>
<td>500</td>
<td>46%</td>
<td>46%</td>
<td>52%</td>
<td>300 MS</td>
<td>318.63</td>
<td>71.52</td>
<td>841.7</td>
<td>850</td>
</tr>
<tr>
<td>Project B2</td>
<td>x</td>
<td>225 (45% of Min.)</td>
<td>[284][56.8%] of Min.</td>
<td>[509][101.1%] of Min.</td>
<td>500</td>
<td>44%</td>
<td>47.5%</td>
<td>51.5%</td>
<td>150 MS</td>
<td>138.96</td>
<td>29.73</td>
<td>649.42</td>
<td>650</td>
</tr>
</tbody>
</table>

Build and Launch This Project
## Treatments & No. of Periods

<table>
<thead>
<tr>
<th>Number of Centers</th>
<th>Variance of Cost Shocks</th>
<th>Cost Caps</th>
<th>MCCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>Low</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>75</strong></td>
<td><strong>40</strong></td>
</tr>
</tbody>
</table>
Results: Total Earnings

<table>
<thead>
<tr>
<th># of Centers</th>
<th>Cost Variance</th>
<th>Cost Caps</th>
<th>MCCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>1 Low</td>
<td>748</td>
<td>768</td>
</tr>
<tr>
<td>HQ</td>
<td>High</td>
<td>730</td>
<td>778</td>
</tr>
<tr>
<td>Payoff</td>
<td>2 Low</td>
<td>746</td>
<td>524</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>767</td>
<td>777</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>745</td>
<td>744</td>
</tr>
<tr>
<td>Average</td>
<td>1 Low</td>
<td>1111</td>
<td>950</td>
</tr>
<tr>
<td>IC</td>
<td>High</td>
<td>1021</td>
<td>963</td>
</tr>
<tr>
<td>Payoff</td>
<td>2 Low</td>
<td>908</td>
<td>777</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>997</td>
<td>1007</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>991</td>
<td>948</td>
</tr>
</tbody>
</table>

- HQ + IC earn more under MCCS
- MCCS with experienced subjects > benchmarks
- (MCCS – Cost Cap) > (C.B. – N.C.B)
Results Cont’d

• MCCS vs. Cost Cap:
  – More innovation
  – Lower final costs
  – Fewer missions cancelled
  – Experience increases payouts

• Issues with MCCS:
  – Overinvest in innovation effort
  – Overinvest in science
  – “Fair” distribution of missions
Summary

• NASA Project: Ongoing
  – Single contract cost sharing
  – Different parameters, functional forms

• Bending theory to fit the problem
• Lab as a “Testbed”
• Results/Design feedback loop