# Signaling

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# The Big Picture

- What have we learned up to now?
  - Camerer (BGT 2003) report Game Theory Experiments (test theory & inspire new theory)

1. Mixed-strategy Nash Equilibrium (MSE) 
2. Subgame Perfect Equilibrium (SPE) 
3. Bayesian Nash Equilibrium (BNE) 
4. Sequential Equilibrium (SE)  [today]

- Why theory works well in some situations?

# The Big Picture

- Why theory works well in simple situations?

1. Learning to play Nash?
2. Limited strategic reasoning
   - Backward Induction fails!
3. Initial response (level-k reasoning)
4. Cannot detect deviations
5. Coordination and pre-game Communication

# The Big Picture

- Camerer (BGT 2003) purposely reported different classes of game theory experiments

1. MSE (Ch. 3)
2. SPE and dominant solvable games (Ch. 5)
3. Learning (Ch. 6)
4. Coordination (Ch. 7)
5. SE and Signaling and Reputation (Ch. 8)
6. Games of Social Preferences (Ch. 2)

# The Big Picture

- We also saw Risk and Time Preferences...
- What about Market Behavior? Applications?

1. Auction (auction chapter in EL)
2. Cheap Talk Games (and Lying)
3. Voting Games (special case of MSE!)
4. Bargaining → Market Design
5. Field Experiments
6. Prediction Markets and Bubbles

# Signaling

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# What Makes a Signal Work?

- A Signal must be affordable by certain types of people
  - Cost $<$ Benefit (if receivers "decodes" it)
- A signal must be too expensive for players of the wrong type to afford
  - Cost $>$ Benefit (even if receivers "decodes" it)
- Separating Equilibrium: Those who buy and those who don't are of different types

# What Makes a Signal Work?

- Separating Equilibrium consists of a circular argument:
  - Signal senders buy the signal anticipating receivers decode it
  - Receivers get assurance about sender types from the signal and act different with/without it
  - This is a self-fulfilling prophecy
- Spence (Dissertation 1974)

# Applying for Economics Graduate School

## An Example of Signaling

# Questions

- What should I apply? MBA or Econ PhD?
- What's the most important factor if I apply?
- Are foreigners/females discriminated against?
- Is mathematics needed in graduate school?
- Is MA (at NTU) required before I enter PhD?
- How should I prepare myself now?

# What Program Should I Apply?

- MBA or Econ PhD?
- This depends on Your Career Interest
- However, MBA is NOT for "newly graduates"
  - MBA is designed for people who have worked for years and are heading for top management
- They teach undergraduate level Economics, but
  - tie it with actual working experience
  - Socializing with other CEO-to-be's is a bonus

# What Program Should I Apply?

- Econ PhD provides you the rigorous training to modern "economic analysis" techniques
- This is used by
  - Academics (Economics, Public Policy, Law, etc.)
  - Economics Consulting Firms
  - Public Policy Evaluation
  - Financial Companies (like Investment Banking)
  - International Organizations (APEC, IMF, etc.)

# Most Important Factor

- What is the Most Important Factor when I Apply for Graduate School?
- Petersons Guide surveyed both students and admission committee members (faculty)
- They find that both agree No.1 factor is:
  - Letter from someone the committee knows
- Why is this No.1?
- Credible Signaling!

# Most Important Factor

- No.1:
  - Letter from someone the committee knows
- Who are the people committees know?
- What if I cannot find someone to write?
- Find Other "Credible Signals"!
  - GPA?
  - GRE or TOEFL?
  - Other Distinct Features such as AWA 5.0 or higher?

# Discrimination and Gender

- Are Foreigners or Females Discriminated Against?
- Foreigners:
  - Different Programs have different policy
  - UCLA (8/35) vs. MIT (25/30)
- Women: Only 16% of the Faculty are Female
  - Does the market favor women? Maybe...
  - Comparison: 33% Math Professors are Female

# Is Mathematics Needed?

- Advice for Econ PhD Applicants:
  - Take a heavy dose of mathematics during undergraduate. ~ Peterson's Guide
- So, the answer is generally "yes."
  - There is a "gap" between undergrad & graduate...
- However, the ability to find economic intuition behind the math is even more essential
  - My first year micro comp. experience...
- They need Bilingual People!

# Is Mathematics Needed?

- What Kind of Math is Needed?
- Advanced Calculus – Score A or A+
  - The thinking process required for you to score A/A+ is what's important
- Linear Algebra – Basic Tool for Econometrics
- Advance Statistical Inference (Mathematical Statistics) – Basic Tool for Econometrics
- The more the better, but mastering these three is better than being a jack of all traits...

# Is MA required before I enter PhD?

- No. Top-10 schools admit only PhD students.
  - Chicago: We'll give you a master if you can't finish.
- However, you might not be able to survive studying both math & economics in English...
- Hence, a MA might help since
  - MA classes are similar to PhD classes
  - You might not be sure if you want to go for PhD
- Condition on passing 1st year comp's, MA is unnecessary, but you may want to hedge...

# How Should I Prepare Myself Now?

- Create Credible Signals!
- Such As:
- GPA 4.0, ranked 1/160
- Good References
- A Published Research Paper
- Take a Heavy Dose of Mathematics
- Take Graduate Level Courses in Economics
- Take Economics Courses Taught in English

# What Makes a Signal Work?

- Exercise: Show which types of people can afford the following signals:
  - GPA 4.0, ranked 1/160
  - Good References
  - A Published Research Paper
  - Take a Heavy Dose of Mathematics
  - Take Graduate Level Courses in Economics
  - Take Economics Courses Taught in English
  - AWA 5.0+

# Theory of Signaling

- Harsanyi (MS 1967-68)
  - Types: Privately observe a move of "Nature"
- Bayesian-Nash Equilibrium (simultaneous) or Perfect-Bayesian Equilibrium (sequential)
  - Separating Equilibrium
  - Pooling Equilibrium
  - Semi-pooling Equilibrium
- Refinements: Sequential, Intuitive, Divine, Universal Divine, Never-Weak-BR, Stable

# Simple Signaling Game

- Brandts and Holt (AER 1992)
- Worker Types are H or L with (2/3, 1/3)
- Seeing own type, Workers can choose to S (skip) or I (invest in education)
- Seeing this action, Employer assign the worker to a D (dull) or C (chanlenging) job
- Employer payoffs are 125 if she assigns D to L types and C to H types

# Simple Signaling Game

- Workers get 100 doing C and 20 doing D
- L types get additional 40 for taking action S
- H types get 40 for taking action I, 20 for taking S

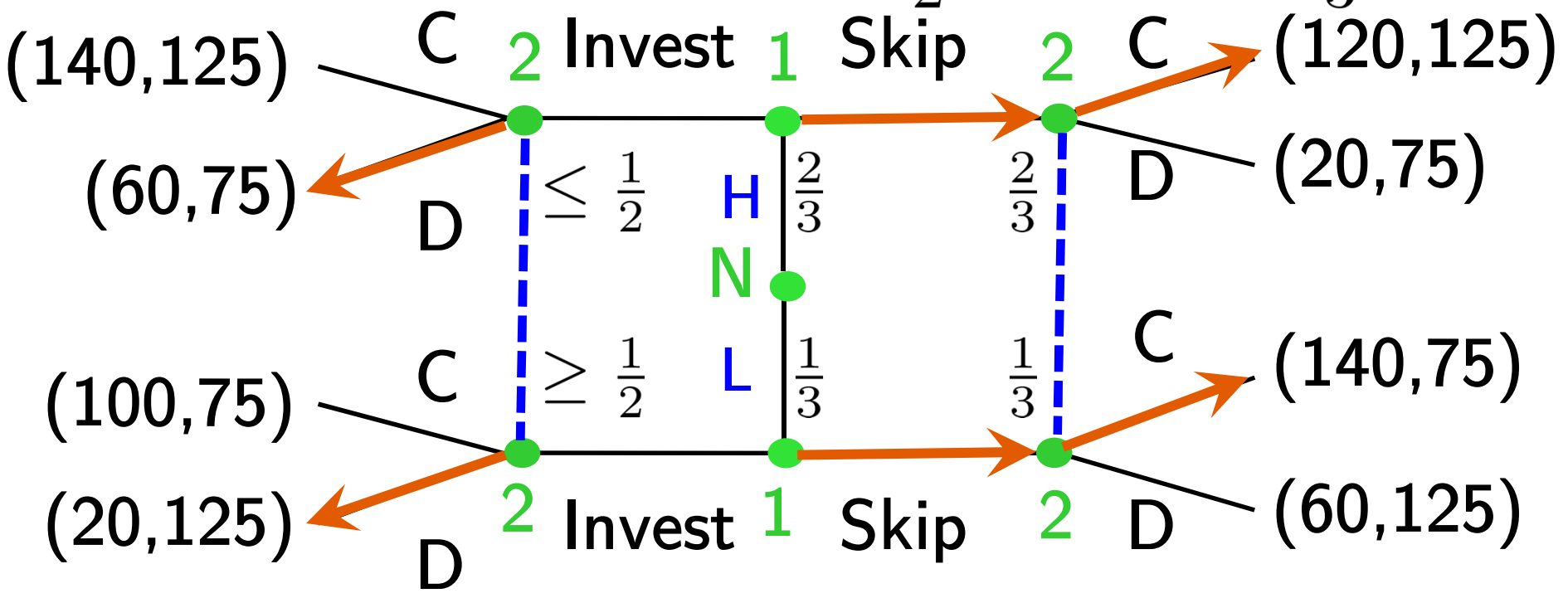
| | Action seeing S | | Action seeing I | |
|---|---|---|---|---|
| | $C^S$ | $D^S$ | $C^I$ | $D^I$ |
| Type L | 140, 75 | 60, 125 | 100, 75 | 20, 125 |
| Type H | 120, 125 | ~~20~~40, 75 | 140, 125 | 60,75 |

# Simple Signaling Game

- Two Pooling Equilibria:
- Sequential Equilibrium
  - Both Types choose S, Employers assign C
  - Out-of-equilibrium Belief: choosing I means L
  - Hence, Employers assign D if they see I
- Intuitive Equilibrium
  - Both Types choose I, Employers assign C
  - Out-of-equilibrium Belief: choosing S means L
  - Hence, Employers assign D if they see S

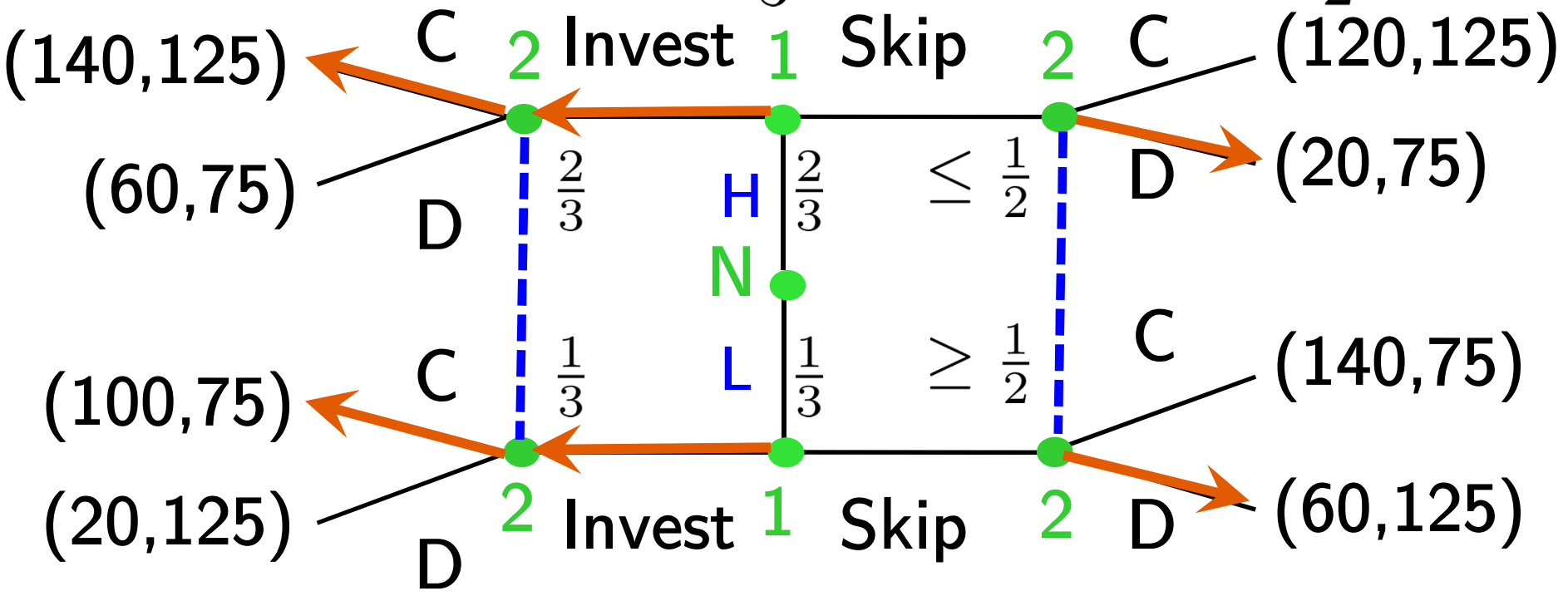
# Simple Signaling Game: Extensive Form

- Sequential Equilibrium: $\Big((S|H, S|L), (D|I, C|S)\Big)$
- Beliefs: $\Pr(H|I) \leq p_1 = \frac{1}{2}, \Pr(H|S) = \frac{2}{3}$



# Simple Signaling Game: Extensive Form

- Intuitive Equilibrium: $\Big((I|H, I|L), (C|I, D|S)\Big)$
- Beliefs: $\Pr(H|I) = \frac{2}{3}, \Pr(H|S) \leq p_1 = \frac{1}{2}$



# Simple Signaling Game

| Periods | Message \| Type | | Action \| Type | | Equilibrium Predictions | |
|---|---|---|---|---|---|---|
| | I \| H | I \| L | C \| I | D \| S | Intuit. | Seq. |
| 1-4 | 100 | 25 | 100 | 74 | 100 | 0 |
| 5-8 | 100 | 58 | 100 | 100 | 100 | 0 |
| 9-12 | 100 | 75 | 98 | 60 | 100 | 0 |
| Suggest Actions: "C \| S, D \| I" | | | | | | |
| 1-4 | 50 | 13 | 60 | 46 | 100 | 0 |
| 5-8 | 75 | 33 | 33 | 67 | 100 | 0 |

# Follow-up Studies

- Banks, Camerer and Porter (GEB 1994)
- Design 7 games, separating:
  - Nash vs. non-Nash
  - Sequential vs. Nash
  - Intuitive vs. Sequential
  - Divine vs. Intuitive
  - Universal Divine vs. Divine
  - NWBR vs. Universal Divine
  - Stable vs. NWBR

# Follow-up Studies

- Results show that subjects do converge to the more refined equilibrium up to intuitive
- After that, subjects conform to neither
  - Except for possibly Stable vs. NWBR
- Is this a test of refinements, or a test of equilibrium selection?
- Exercise: Show how equilibria in Table 8.3 (BCP94') satisfy corresponding refinements

# Follow-up Studies

- In game 2-6, different types send different messages
  - No simple decision rule explains this
  - But weak dominance and 1 round IEDS hold
- Are people just level-1?
- Also, how does the convergence work?

# Follow-up Studies

- More studies on learning:
- Brands and Holt (IJGT 1993)
  - Subjects lead to play less refined equilibrium
  - Why? Initial random play produces history that supports the non-intuitive equilibrium
- Anderson and Camerer (ET 2000)
  - EWA yields $\delta$=$0.54$ ($0.05$);
  - Does better than choice reinforcement ($\delta$=$0$) and weighted fictitious play ($\delta$=$1$)

# Specialized Signaling Games

- Potters and van Winden (IJGT 1996)
  - Lobbying
- Cadsby, Frank & Maksimovic (RFS 1990)
  - Corporate Finance
- Cooper, Kagel, Lo and Gu (AER 1999)
  - Ratchet Effect
- Cooper, Garvin and Kagel (Rand/EJ 1997)
  - Belief Learning in Limit Pricing Signaling Games

# Lobbying: Potters & van Winden (IJGT96)

- Lobby group is type $t_1$ or $t_2$ with ($1$-$p$, $p$)
- Lobby group can send a signal (cost $c$)
- Politician chooses action $x_1$ or $x_2$ (match type)

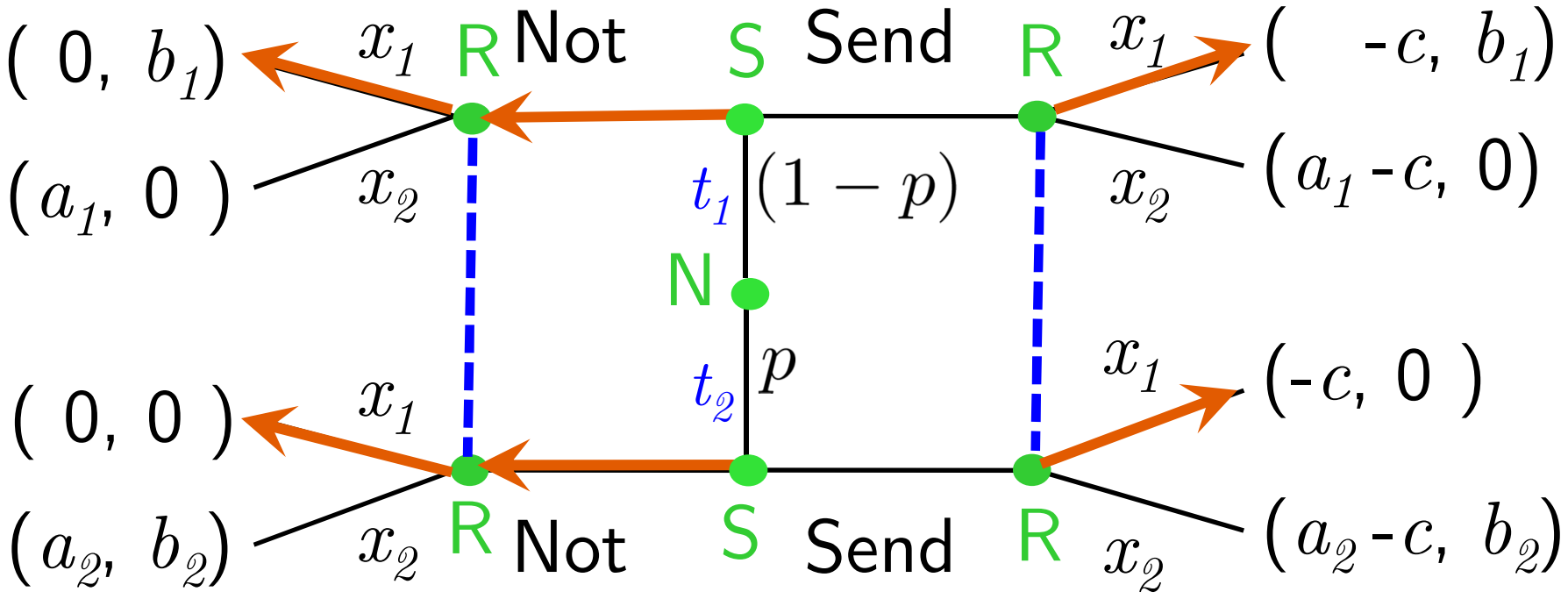
| Type | No signal | | Costly Signal | |
|---|---|---|---|---|
| | $x_1$ | $x_2$ | $x_1$ | $x_2$ |
| $t_1$ ($1$-$p$) | 0, $b_1$ | $a_1$, 0 | -$c$, $b_1$ | $a_1$-$c$, 0 |
| $t_2$ ($p$) | 0, 0 | $a_2$, $b_2$ | -$c$, 0 | $a_2$-$c$, $b_2$ |

# Lobbying

- For $\beta = \frac{pb_2}{(1-p)b_1} < 1$; there are 2 equilibrium:
- Pooling: Lobby groups both don't send signal
- Politician ignores signal and chooses $x_1$
  - Intuitive, divine, but not universally divine
- Semi-pooling: type $t_2$ always send signal
- Politicians mix $x_1$, $x_2$ with $(1\text{-}c/a_1,\ c/a_1)$ if signal
- type $t_1$ mixes by sending signal with prob. $\beta$
  - Universally divine

# Lobbying: Pooling Equilibrium

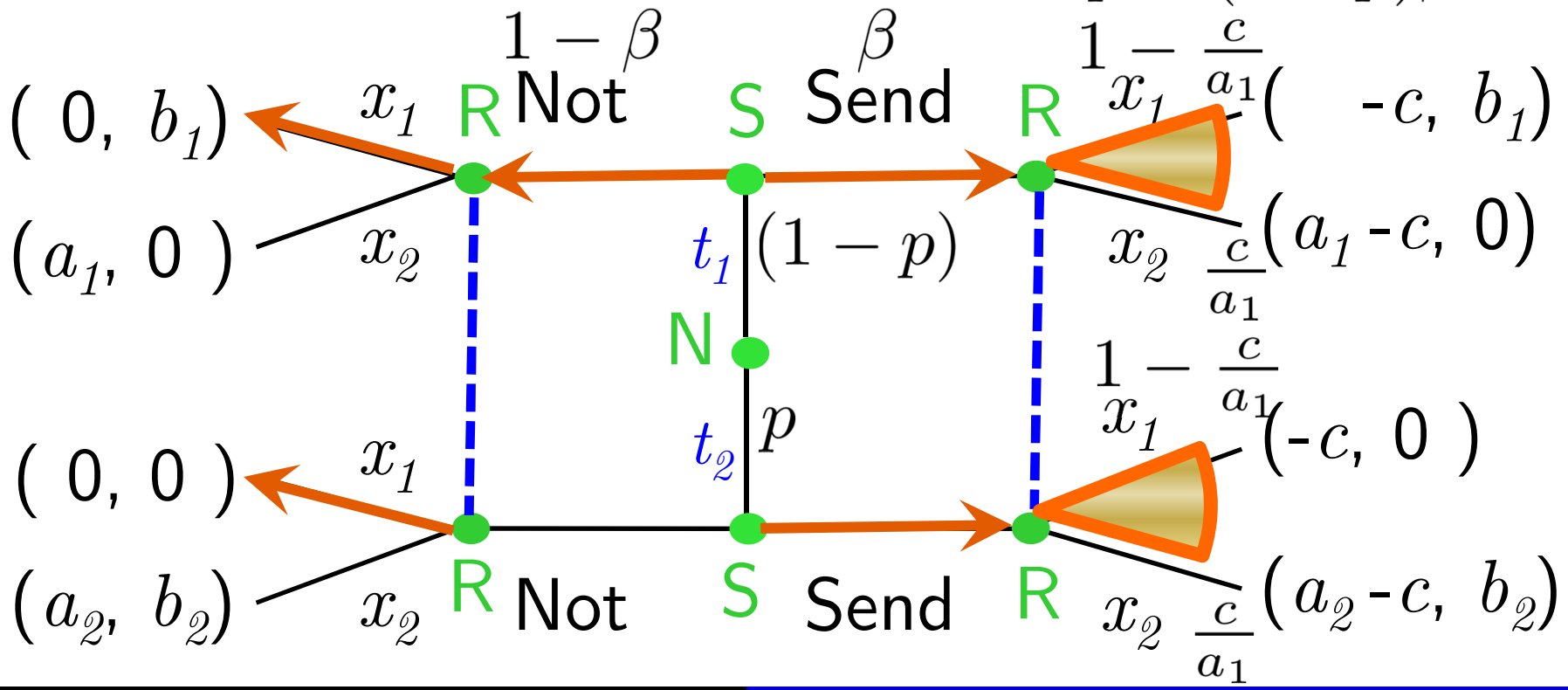
- Equilibrium: $\Big((Not|t_1, Not|t_2), (x_1|Send, x_1|Not)\Big)$
- Beliefs: $\Pr(t_2|Not) = p = \Pr(t_2|Send)$



# Lobbying: Semi-Pooling Equilibrium

$$\Big((\beta S + (1-\beta)N | t_1, S | t_2), ((1-\alpha)x_1 + \alpha x_2 | S, x_1 | N)\Big)$$

- Beliefs: $\Pr(t_2|N) = 0; \Pr(t_2|S) = \dfrac{p}{p + (1-p)\beta}$



# Lobbying

| Treatment | Signal Freq. $(t_1, t_2)$ | | | $x_2$ Freq. (no sig., sig) | | |
|---|---|---|---|---|---|---|
| | β | Actual | Pred. | $c/a_1$ | Actual | Pred. |
| 1 | 0.25 | 38, 76 | 25,100 | 0.25 | 2, 5 | 0,25 |
| 2(2c) | 0.75 | 46,100 | 75,100 | 0.25 | 3, 79 | 0,25 |
| 2a(6c) | 0.75 | 83, 93 | 75,100 | 0.25 | 11, 54 | 0,25 |
| 3 | 0.25 | 16, 85 | 25,100 | 0.75 | 0, 53 | 0,75 |
| 4 | 0.75 | 22, 83 | 75,100 | 0.75 | 5, 80 | 0,75 |
| Aver. | 0.25 | 27, 81 | 25,100 | 0.25 | 5, 46 | 0,25 |
| | 0.75 | 50, 92 | 75,100 | 0.75 | 2, 66 | 0,75 |

# Lobbying

- Supporting universally divine equilibrium
- Fictitious Play Learning:
  - Past frequency of $x_2$ after signal is $r(m)_{t\text{-}1}$
- Should signal if $r(m)_{t\text{-}1}\ a_1$ - $c > 0$
  - Subjects signal 46% if >0, 28% if <0
  - Politicians choose $x_2$ 77% if >0, 37% if <0
- Potters and van Winden (JEBO 2000)
  - Similar results; little difference between students and professionals

# Corporate Finance

- Cadsby, Frank & Maksimovic (RFS 1990)
- Firms are either H or L with (50%, 50%)
  - Worth $B_H$, $B_L$ if carry project; worth $A_H$, $A_L$ if pass
- Need capital $I$ to finance the project
- Investors can put up $I$ and get $S$ shares
- Exercise: When will there be pooling, separating, and semi-separating equilibria?

- Example:
- L types worth 375, 50 (with/without project)
- H types worth 625, 200 (with/without project)
- Capital $I = 300$
- Separating equilibrium: $S$=0.80
- Pooling equilibrium: $S$=0.60
- Semi-pooling equilibrium: $S$=0.68
- Exercise: Show that these are equilibria!

# Corporate Finance

- Cadsby et al. ran 10 sessions (Table 8.11)
- Results support equilibrium (pooling if multi.)
  - When unique pooling: all firms offer shares
  - When unique separating: Initially, both offer (pool), but H types learn not to offer (separate)
  - When multiple: Converge to pooling equilibrium
- Cadsby, Frank and Maksimovic (RFS 1998)
  - Add costly signals (see Table 8.12 for results)

# Ratchet Effect

- Cooper, Kagel, Lo and Gu (AER 1999)
- Firms are either H or L with (50%, 50%)
- Choose output level 1-7
- Planner choose "easy" or "tough" target
  - Set "easy" if Pr( L | output ) > 0.325
- Pooling Eq: L chooses 1 or 2; H pools with L
- Myopic K firms: Naively pick 5 (& get "tough")
  - Exercise: Prove these with payoffs in Table 8.13.

# Ratchet Effect

- 70-90% L firms choose 2
- Most H firms choose 2 or 5
- Period 1-12: 54-76% myopic →80% tough
- Period 13-36: Convergence to pooling
- Big context effect only for Chinese manager
  - Provides language to folster learning from exp.
- Cooper, Garvin and Kagel (Rand/EJ 1997)
  - Belief Learning in Limit Pricing Signaling Games

# Reputation Formation

- Camerer and Weigelt (Econometrica 1988)
- 8 period trust game
- Borrower: "normal" (X) or "nice" (Y)
- (New) Lender each period: Lend or Don't
- Borrower chooses to Default or Repay
  - Normal types default; nice types repay

# Reputation Formation

| Lender Strategy | Borrower Strategy | Lender Payoff | Borrower Payoff | |
|---|---|---|---|---|
| | | | Normal | Nice (Y) |
| Lend | Default | -100 | 150 | 0 |
| | Repay | 40 | 60 | 60 |
| Don't | - | 10 | 10 | 10 |

# Reputation Formation

- What does the equilibrium look like?
- Last Period: Lend if $P_8(\text{nice}) > \tau = 0.79$
  - "normal" borrowers default; "nice" ones repay
- Period 7:
  - "normal" borrowers weigh between default now (and reveal) and default later

# Conditional Frequency of Lending

| Round | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| 3-5 | Predict | 100 | 100 | 100 | 100 | 64 | 64 | 64 | 64 |
| | Actual | | | | | | | | |
| 6-8 | Predict | 100 | 100 | 100 | 64 | 64 | 64 | 64 | 64 |
| | Actual | | | | | | | | |
| 9-10 | Predict | 100 | 100 | 100 | 64 | 64 | 64 | 64 | 64 |
| | Actual | | | | | | | | |

# Conditional Frequency of Lending

| Round | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| 3-5 | Predict | 100 | 100 | 100 | 100 | 64 | 64 | 64 | 64 |
| | Actual | 94 | 96 | 96 | 91 | 72 | 59 | 38* | 67 |
| 6-8 | Predict | 100 | 100 | 100 | 64 | 64 | 64 | 64 | 64 |
| | Actual | 96 | 99 | 100 | 95* | 85* | 72 | 58 | 47 |
| 9-10 | Predict | 100 | 100 | 100 | 64 | 64 | 64 | 64 | 64 |
| | Actual | 93 | 92 | 83 | 70 | 63 | 72 | 77 | 33 |

# Conditional Frequency of Repay (by X)

| Round | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| 3-5 | Predict | 100 | 100 | 100 | 81 | 65 | 59 | 44 | 0 |
| | Actual | | | | | | | | |
| 6-8 | Predict | 100 | 100 | 73 | 68 | 58 | 53 | 40 | 0 |
| | Actual | | | | | | | | |
| 9-10 | Predict | 100 | 100 | 73 | 67 | 63 | 56 | 42 | 0 |
| | Actual | | | | | | | | |

# Conditional Frequency of Repay (by X)

| Round | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| 3-5 | Predict | 100 | 100 | 100 | 81 | 65 | 59 | 44 | 0 |
| | Actual | 95 | 97 | 98 | 95* | 86* | 72 | 47 | 14 |
| 6-8 | Predict | 100 | 100 | 73 | 68 | 58 | 53 | 40 | 0 |
| | Actual | 97 | 95 | 97* | 92* | 85* | 70* | 48 | 0 |
| 9-10 | Predict | 100 | 100 | 73 | 67 | 63 | 56 | 42 | 0 |
| | Actual | 91 | 89 | 80 | 77 | 84* | 79* | 48 | 29 |

# Follow-up Studies

- Neral and Ochs (Econometrica 1992)
  - Similar repeated trust games
- Jung, Kagel and Levin (Rand 1994)
  - Entry deterrence in "chain-store paradox"
- Camerer, Ho and Chong (JET 2002)
  - Sophisticated EWA (strategic teaching!)

# Conclusion

- Cooper, Garvin and Kagel (EJ 1997)
  - "We do not suggest that game theory be abandoned, but rather as a descriptive model that it needs to incorporate more fully how people actually behave."
- Possible improvements:
- QRE, level-k or Cognitive Hierarchy
- Learning (EWA or belief learning)