The Emergence of Cooperation

Background

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- Tension between opportunistic behavior and cooperation is central to human, and animal, interaction

- Theory of infinitely repeated games has shown that the shadow of the future can limit opportunistic behavior

- Lots of theory and applications

- Problem of multiplicity of possible outcomes
  - Evolutionary theory
  - Experimental evidence

Plan for the morning:

- Prisoners’ dilemmas without a future
  - Nash equilibrium

- The shadow of the future
  - Subgame perfect equilibrium
  - Describe possible equilibrium outcomes and strategies
  - Problem of multiplicity

- Mention previous evolutionary research (focus in the afternoon)

- Experimental evidence

Social Dilemmas

- Tension between personal incentives and group welfare
  - Pollution – climate change
  - Contribution to public goods
  - Competition between oligopolies
  - Hunting in packs
  - Educational investments by cities and states
  - Cheating in trade

Prisoners' dilemma

Player 2

Player 1

	C	D
C	R, R	S, T
D	T, S	P, P

T>R>P>S and 2R>T+S

Prisoners' dilemma

Player 2

Player 1

	C	D
C	R, R	S, T
D	T, S	P, P

T>R>P>S and 2R>T+S

For both players D is a best response to any action of the other player

Prisoners' dilemma

Player 2

Player 1

	C	D
C	R, R	S, T
D	T, S	P, P

T>R>P>S and 2R>T+S

For both players D is a best response to any action of the other player

In equilibrium both players defect!!

Payoff is (P,P) when it could have been (R,R)

Equilibrium is inefficient

Nash equilibrium

- An outcome such that my action is a best response to yours and vice versa (a fixed point)

Prisoners' Dilemma

Player 2

Player 1

	C	D
C	4, 4	1, 5
D	5, 1	2, 2

Coordination game

Player 2

Player 1

	A	B
A	4, 4	0, 0
B	0, 0	1, 1

Multiple equilibria are possible

Back to Prisoners' dilemma

- How can cooperation be supported?
  - Altruism (change the game in the heads of the players)
  - Third party enforcement (i.e. global CO_2 emissions tax)
  - Repeated interaction: the shadow of the future

The shadow of the future

- Bad example: play the PD twice
- Plan: Play C in t=1, and play C in t=2 if both played C before

t=1

Player 2

Player 1		C	D
	C	R, R	S, T
	D	T, S	P, P

T>R>P>S and 2R>T+S

t=2 CC

Player 2

Player 1		C	D
	C	R, R	S, T
	D	T, S	P, P

t=2 ~CC

Player 2

Player 1		C	D
	C	R, R	S, T
	D	T, S	P, P

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Player 2

Player 1		C	D
	C	R, R	S, T
	D	T, S	P, P

T>R>P>S and 2R>T+S

C after CC is not credible!

t=2 CC

Player 2

Player 1		C	D
	C	R, R	S, T
	D	T, S	P, P

t=2 ~CC

Player 2

Player 1		C	D
	C	R, R	S, T
	D	T, S	P, P

The shadow of the future

- Bad example: play the PD twice
- Plan: Play C in t=1, and play C in t=2 if both played C before

t=1

Player 1 (rows), Player 2 (columns)

	C	D
C	R, R	S, T
D	T, S	P, P

T>R>P>S and 2R>T+S

C after CC is not credible!

t=2 CC

Player 1 (rows), Player 2 (columns)

	C	D
C	R, R	S, T
D	T, S	P, P

t=2 ~CC

Player 1 (rows), Player 2 (columns)

	C	D
C	R, R	S, T
D	T, S	P, P

The shadow of the future

- Bad example: play the PD twice

- Plan: Play C in t=1, and play C in t=2 if both played C before

- Not an equilibrium as playing C in the last period is not credible

- Selten’s subgame perfect equilibrium asks that plans (strategies) be optimal given the plans of other players after every possible contingency

The shadow of the future (toy example)

- Play PD first and coordination game second

Prisoners' Dilemma

Player 2

Player 1

	C	D
C	4, 4	1, 5
D	5, 1	2, 2

Coordination game

Player 2

Player 1

	A	B
A	4, 4	0, 0
B	0, 0	1, 1

The shadow of the future (toy example)

- Plan: play C in t=1, and play A in t=2 if CC in t=1, otherwise play B

t=1

Player 2 (columns), Player 1 (rows)

	<u>C</u>	D
<u>C</u>	4, 4	1, 5
D	5, 1	2, 2

t=2 CC

Player 2 (columns), Player 1 (rows)

	<u>A</u>	B
<u>A</u>	4, 4	0, 0
B	0, 0	1, 1

t=2 ~CC

Player 2 (columns), Player 1 (rows)

	A	<u>B</u>
A	4, 4	0, 0
<u>B</u>	0, 0	1, 1

The shadow of the future (toy example)

- Plan: play C in t=1, and play A in t=2 if CC in t=1, otherwise play B

t=1

Player 2 (columns), Player 1 (rows)

	C	D
C	4, 4	1, 5
D	5, 1	2, 2

t=2 CC

Player 2 (columns), Player 1 (rows)

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A	4, 4	0, 0
B	0, 0	1, 1

t=2 ~CC

Player 2 (columns), Player 1 (rows)

	A	B
A	4, 4	0, 0
B	0, 0	1, 1

Is this an equilibrium?

The shadow of the future (toy example)

- Plan: play C in t=1, and play A in t=2 if CC in t=1, otherwise play B

t=1

Player 2

Player 1

	C	D
C	4, 4	1, 5
D	5, 1	2, 2

t=2 CC

Player 2

Player 1

	A	B
A	4, 4	0, 0
B	0, 0	1, 1

t=2 ~CC

Player 2

Player 1

	A	B
A	4, 4	0, 0
B	0, 0	1, 1

Is this an equilibrium?
Yes

The shadow of the future

- Infinitely repeated
  - t=1, 2, 3, 4…..
  - δ is discount factor or probability of continuation
  - Grim strategy: Cooperate in t=1, and cooperate in t>1 if no defection before

Player 2

Player 1		C	D
	C	R, R	S, T
	D	T, S	P, P

- If both players choose Grim then they cooperate for ever
- Can (Grim, Grim) be supported in equilibrium?

t=1

Player 2

Player 1

	C	D
C	R	S
D	T	P

t=2

CC	G	AD
G	$\frac{R}{1-\delta}$	$S+\frac{P\delta}{1-\delta}$
AD	$T+\frac{P\delta}{1-\delta}$	$\frac{P}{1-\delta}$

~CC	G	AD
G	$\frac{R}{1-\delta}$	$S+\frac{P\delta}{1-\delta}$
AD	$T+\frac{P\delta}{1-\delta}$	$\frac{P}{1-\delta}$

After a defection, G becomes AD

t=1

Player 2

Player 1

	<u>C</u>	D
<u>C</u>	R	S
D	T	P

t=2

CC	<u>G</u>	AD
<u>G</u>	$\frac{R}{1-\delta}$	$S+\frac{P\delta}{1-\delta}$
AD	$T+\frac{P\delta}{1-\delta}$	$\frac{P}{1-\delta}$

~CC	G	<u>AD</u>
G	$\frac{R}{1-\delta}$	$S+\frac{P\delta}{1-\delta}$
<u>AD</u>	$T+\frac{P\delta}{1-\delta}$	$\frac{P}{1-\delta}$

Recursivity: Incentives at t=1 coincide with those in any t without previous defections

t=1

Player 2

	<u>C</u>	D
Player 1 <u>C</u>	R	S
D	T	P

t=2

CC	<u>G</u>	AD
<u>G</u>	$\frac{R}{1-\delta}$	$S+\frac{P\delta}{1-\delta}$
AD	$T+\frac{P\delta}{1-\delta}$	$\frac{P}{1-\delta}$

~CC	G	<u>AD</u>
G	$\frac{R}{1-\delta}$	$S+\frac{P\delta}{1-\delta}$
<u>AD</u>	$T+\frac{P\delta}{1-\delta}$	$\frac{P}{1-\delta}$

C in t=1 is BR if $\frac{R}{1-\delta} \geq T + \frac{P\delta}{1-\delta}$ which holds if $\delta \geq \frac{T-R}{T-P}$

t=1

Player 2

	C	D
Player 1 C	R	S
D	T	P

t=2

CC	G	AD
G	$\frac{R}{1-\delta}$	$S+\frac{P\delta}{1-\delta}$
AD	$T+\frac{P\delta}{1-\delta}$	$\frac{P}{1-\delta}$

~CC	G	AD
G	$\frac{R}{1-\delta}$	$S+\frac{P\delta}{1-\delta}$
AD	$T+\frac{P\delta}{1-\delta}$	$\frac{P}{1-\delta}$

D after some D is BR regardless of δ

(Grim, Grim) is a subgame perfect equilibrium if players are sufficiently patient

The shadow of the future and multiple equilibria

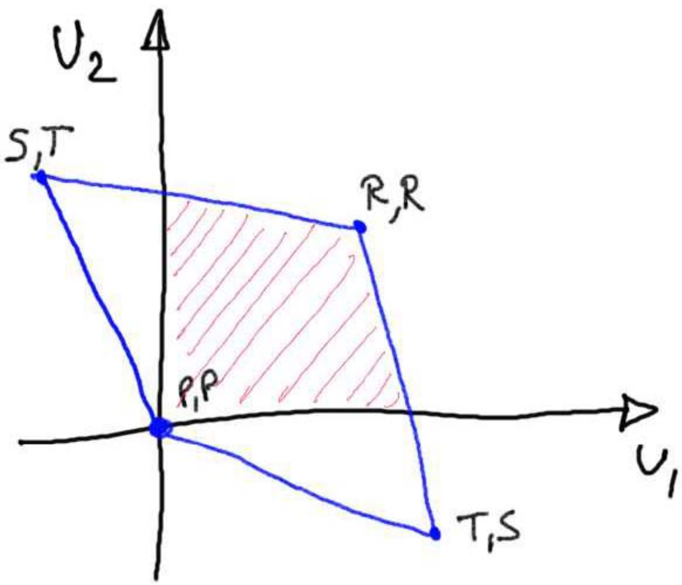
- (Grim, Grim) is an equilibrium

- But so is (Always Defect, Always Defect)

- There are many equilibria

The folk theorem

- Friedman, Aumann and Shapley, Rubinstein, Fudenberg and Maskin and others
- Any feasible and individually rational payoff can be supported in equilibrium if players are sufficiently patient



Multiplicity

- In equilibrium payoffs and in strategies

- “The multiplicity of equilibria is an embarrassment of riches” Tirole (1988)

- “The theory of repeated games has been somewhat disappointing. ... the theory does not make sharp predictions” Fudenberg and Maskin (1993)

- While multiplicity is essential to support cooperation, there is a demand for more precise predictions

Solutions to multiplicity

- Applications of evolutionary processes
- Experimental evidence

Evolution and Repeated Games

- Evolutionary Stable Strategies (ESS): Axelrod and Hamilton (1981), Boyd and Lorberbaum (1987), Bendor and Swistak (1997)
- ESS+ trembles: Boyd (1989) and Kim (1994)
- Uniform stability + trembles + finite complexity: Fudenberg and Maskin (1990, 1993)
- Finite Automata + LCC: Rubinstein (1986) and Abreu and Rubinstein (1988)
- … + Evolutionary stability: Binmore and Samuelson (1992), Cooper (1996) and Volij (2002)
- Memory 1 strategies with trembles and mutants: Nowak and Sigmund (1993)
- Stochastic Stability and gift giving: Johnson, Levine and Pesendorfer (2001).
- Risk dominance (evolutionary motivated): Blonski and Spagnolo (2000)

Risk dominance

- Checking subgame perfection assumes perfect knowledge about the strategy of other player
- If δ is sufficiently large both (G,G) and (AD,AD) are SPE

	G	AD
G	$\frac{R}{1-\delta}$	$S+\frac{P\delta}{1-\delta}$
AD	$T+\frac{P\delta}{1-\delta}$	$\frac{P}{1-\delta}$

Risk dominance

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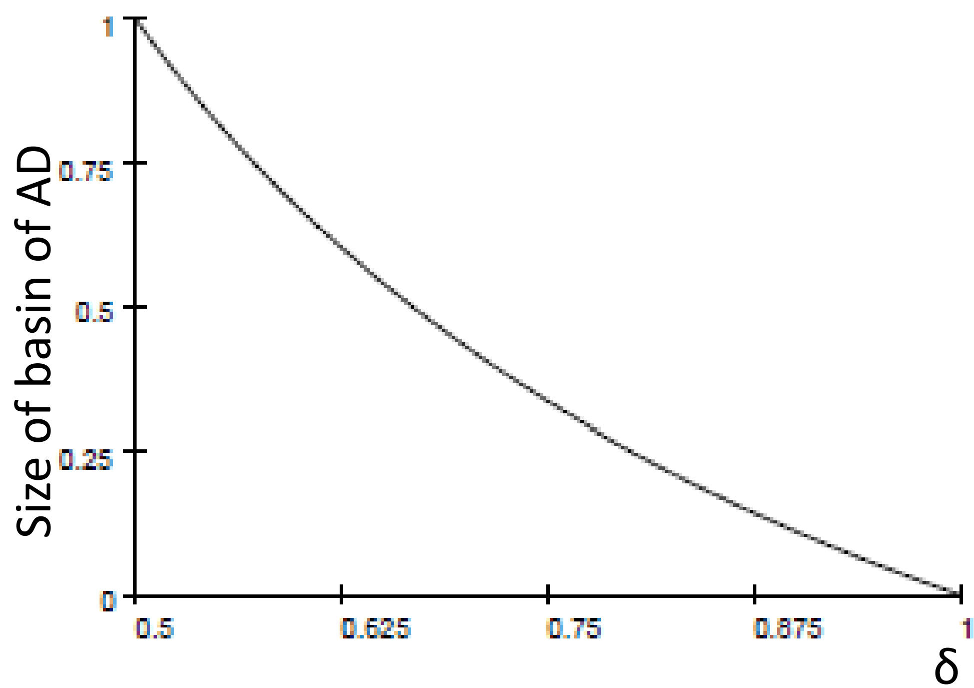
- Risk dominance selects the equilibrium action that is best response to other randomizing 50-50
- In other words, which equilibrium is most robust to invasions/mutations

Size of the basin of attraction of AD vs. G

		Player 2	
		C	D
Player 1	C	2, 2	0, 3
	D	3, 0	1, 1



Experiments on repeated games

- Based on a survey written with Guillaume Frechette (NYU)

- Experimental economics
  - Generate in computer lab the environment under study
  - Pay subjects
  - No deception

Questions?

- Does the shadow of the future matter?
- Does it matter as theory predicts?
- What equilibrium will people choose to play when there are multiple ones?
- What strategies do they use to support cooperation?

Perfect Monitoring with Fixed Pairs

- Infinitely repeated games induced by having a random continuation rule - Roth and Murnighan (1978)
- δ is the probability of continuation
- Induces same preferences under the assumption of risk neutral preferences

First Wave of Results

Percentage of cooperation in round 1

	Probability of Continuation		
	0.105	0.5	0.895
Roth and Murnighan (1978)	19	29.75	36.36
Murnighan and Roth (1983)	17.83	37.48	29.07

First Wave of Experiments

- “So the results remain equivocal.” Roth (HEE 1995)
- “True enough it does – but not by much.” Palfrey and Rosenthal (1994)
- Only one supergame

New Wave of Experiments

- Prisoners' dilemma, fixed pairs and perfect monitoring
- Meta-data: to check robustness of results
- 15 articles on infinitely repeated games + 2 with one-shot games
  - 141 sessions
  - 32 treatments (combinations of δ, T, R, P, and S)
  - 2415 subjects
  - 157k actions

The effect of the shadow of the future increases with experience

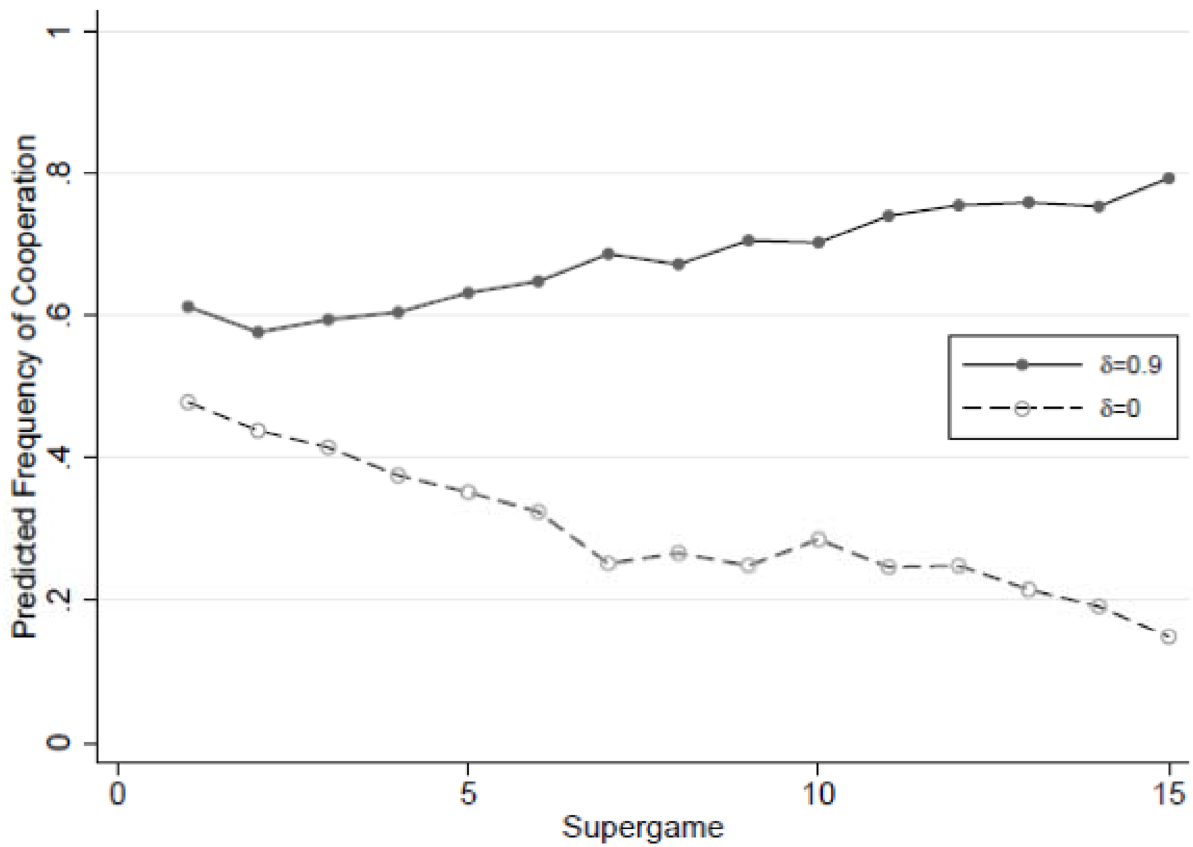


Figure 1: The Impact of δ on Round 1 Cooperation by Supergame

Result 1: Cooperation is increasing in the shadow of the future (especially for experienced subjects)

The predictive power of theory

Is cooperation greater when it can be supported in equilibrium?

	Not SPE	SPE	Difference
Supergame 1	34.34	51.23	16.89***
Supergame 7	13.86	48.83	34.97***
Supergame 15	16.67	53.05	36.38***

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Result 2: Cooperation is greater when SPE but being SPE is not enough for subjects to reach high cooperation levels

Importance: The usual assumption that people will coordinate in the best equilibrium is wrong.

For example: “One natural method (to select from the multiplicity of equilibria) is to assume that the firms coordinate on an equilibrium that yields a Pareto-optimal point in the set of the firms' equilibrium points.” Tirole (1988)

Other tests of theory:

- Dal Bó (2005)
  - Compares finitely with infinitely repeated games
  - Compares payoff matrices with different predictions
  - Both comparisons are roughly consistent with theory

If SPE is not enough, then what? Risk Dominance?

	Not RD	RD	Difference
Supergame 1	35.64	54.22	18.57***
Supergame 7	16.10	55.88	39.79***
Supergame 15	20.33	63.06	42.73***

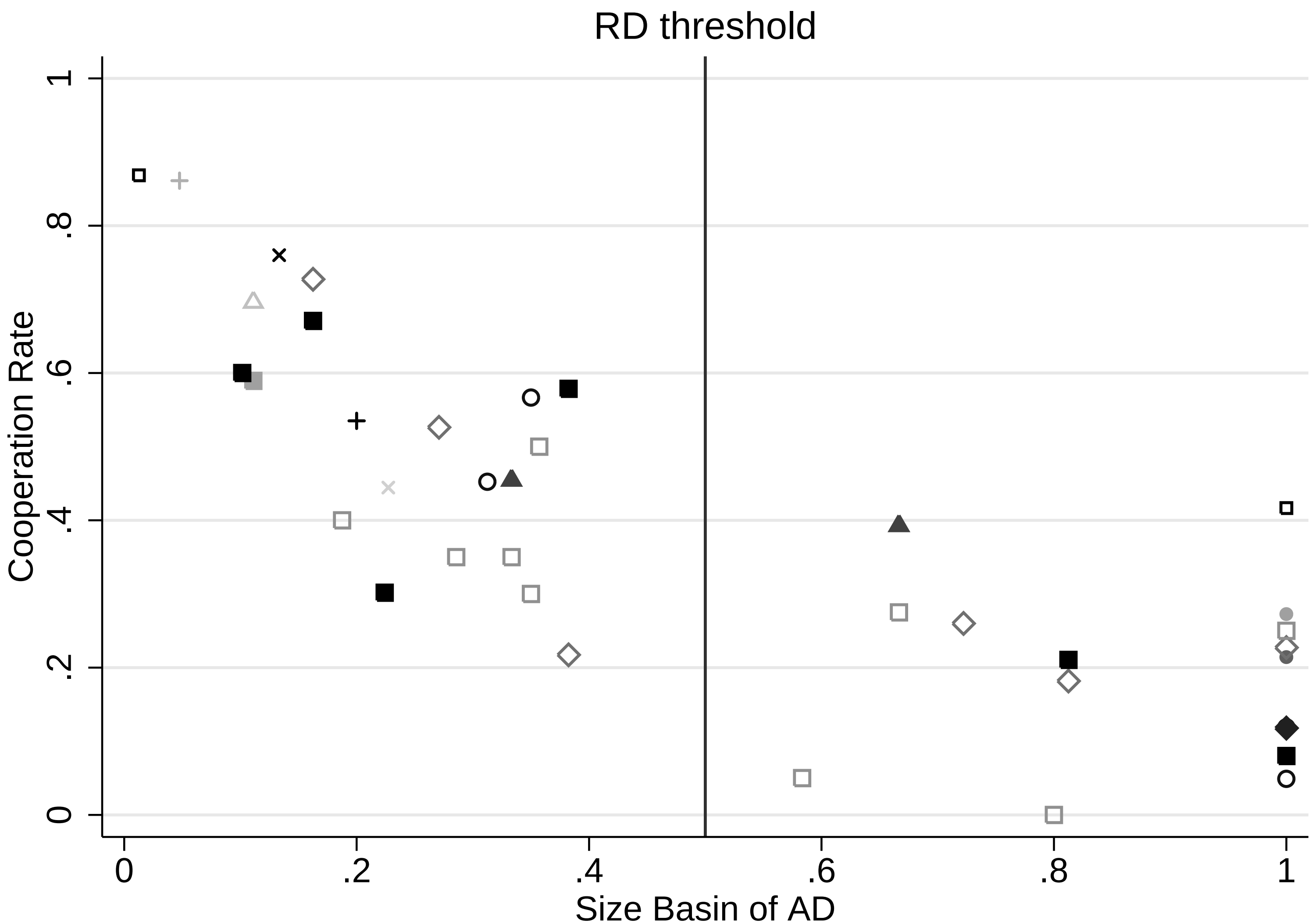
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Result 3: Cooperation is greater when risk-dominant but it is not enough for subjects to reach high cooperation levels

Importance: Coordination in the best equilibrium is difficult

When will people cooperate?

- Dichotomic indexes were not enough
- Study continuous indexes
  - Dal Bó and Fréchette (2011)
  - Blonski et al (2011)
- Focus on the size of the basin of attraction of AD



RD threshold
Cooperation Rate
Size Basin of AD
0
.2
.4
.6
.8
1

Result 4: Cooperation rates are increasing in how robust cooperation is to strategic uncertainty, especially when cooperation is risk-dominant

Strategies

- A strategy is a contingent plan
- How can we learn about strategies?
- Elicitation – Axelrod (1980s) and Dal Bó and Fréchette (2013)
- Estimation from choices – problems:
  - Infinite number of strategies
  - Finite realizations of histories
  - Lack of variation in equilibrium

Result 5: Three simple strategies (AD, Grim, TFT) account for most of the data

Importance: under perfect monitoring simplicity seems important but credibility of punishments is not

Can personal characteristics explain heterogeneity of behavior?

- No robust relationship found
  - Murnighan and Roth (1983), Sabater-Grande and Georgantzis (2002), Dal Bó (2005), Sherstyuk et al (2013), Dreber et al (2014), Proto (2014), Davis et al (2014)
  - Gender
  - Risk aversion
  - Altruism
  - Economic training
  - Psychological traits (big 5)
  - Patience
- Cooperation motivated by strategic considerations
  - Dreber et al (2012), Reuben and Suetens (2012) and Cabral et al (2014)

Conclusions

- Theory has shown how repetition can result in cooperation
- Demand for sharper predictions
- Experiments
  - the shadow of the future affects behavior
  - SPE is not enough
  - Robustness to invasion or strategic uncertainty help explain cooperation