Bounded Rationality in Keynesian Beauty Contests: A lesson for Central Bankers?

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Macro theory and experiments
Bank of Canada

Outline

- Keynes Beauty contest
- Original game and experiment: 2/3 average game
- Non-equilibrium behavior explained with “level-k model”
- Your Online experiments: variations
- Generalized BC: e.g. New Keynesian models, Expectation formation models and experiments.
- Level k in behavioral macro theories
- Does this have implications for central bankers?

Point of departure

Keynes's metaphor:
from complexity to simplicity

Keynes´s Beauty Contest metaphor for a complex world

(Keynes 1936, p.136)

Games and markets

Or, to change the metaphor slightly, professional investment *...competitors have to pick out the six prettiest faces from a hundred photographs, the prize being awarded to the competitor whose choice most nearly corresponds to the* ***AVERAGE PREFERENCES*** of the competitors ; ...

LEVEL K model

.....It is not a case of choosing those which, to the best of one's judgment, are really the prettiest, nor even those which average opinion genuinely thinks the prettiest. We have reached the third degree where we devote our intelligences to anticipating what average opinion expects the average opinion to be. And there are some, I believe, who practice the fourth, fifth and higher degrees.

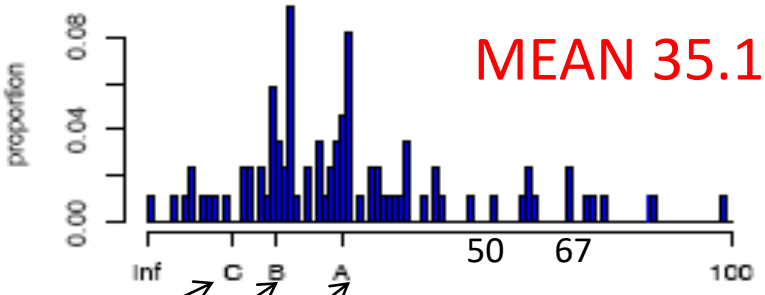
Basic rules of original game

- Choose a number between [0,100]
- Target: be closest to 2/3 average of choices of all players
- Winner: 10 Euros

- Unique Equilibrium: all play 0 (Fixed point 2/3*x=x => x=0)
  - Reached through iterated elimination of weakly dominant strategies: 100, 66.66, 44.44 ….0
  - Zero is a rationalizable strategy

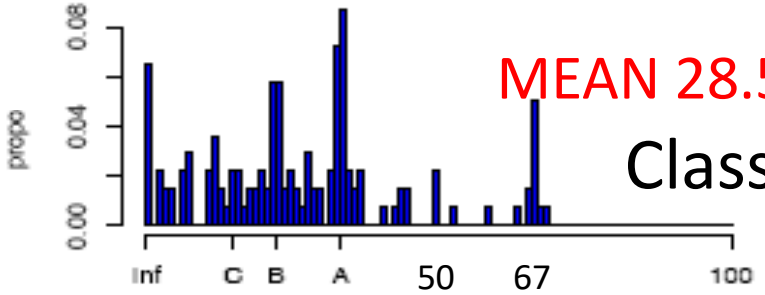
Note: if payoff according to distance: f(choice-target) then the equilibrium is unique and Pareto optimal STRONG

Nagel, AER 1995 Lab



MEAN 35.13

Bosch, Montalvo,Nagel, Satorra , AER 2002



MEAN 28.54

Class

Level k:

2/3 average; interval [0,100]

C = level 3 = 50*2/3*2/3*2/3=14.8

B = level 2 = 50*2/3*2/3=22.22

A = level 1 = 50*2/3=33.33

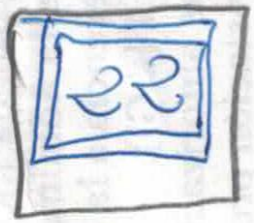
and noise NEWSPAPER

$\mu[0,100] \Rightarrow E(X) = \frac{a+b}{2} = \boxed{50} \rightarrow \$50 \cdot \frac{2}{3} = 33'33$

$E(\frac{2}{3}X) = \frac{2}{3}E(X) = \boxed{\frac{100}{3}} \Rightarrow 22'22$

$\frac{2}{3}$

Comments from participants of the newspaper experiments



My choice: 13

Theoretical highest all entries 67, highest winner 44.

Rough average winner: 22.

If all '22' entries: winner 15 (calculation repeatable etc)

People predict what the average is and multiply it by 2/3. This process continues until the average is approximately 1. And 2/3 of 1 is rounds up to 1.

I USED THE KEYNES "BEAUTY PARADE" ANALOGY. "LOGICAL" ANSWER IS ϕ; SUPERFICIAL THINKING GIVES 33 (50×0.66). ESTIMATING (50:50) $\Rightarrow$

$(50\% \times 33) + (50\% \times 0) = 16.5$

$16.5 \times 2/3 = 11$

Keynesian reasoning (level k model),

- **(Level -1: simplification of the situation)**

- **Level 0**: no game form recognition; **zero intelligence, - automatic choice; favorite number, salient number; focal point**
- **Level 1**: game form recognition, but **no theory of mind** as Playing against NATURE

- **Level 2**: model others as level 1 players => **theory of mind**
- **Level k: model others as level k-1 players**

…

- **Equilibrium**: Nash, **rational expectation, fixed points**

- **ADD NOISE TO ALL LEVELS;**

Variations: higher level players give best response to a distribution of lower level players; Poisson distribution; add cognitive cost.

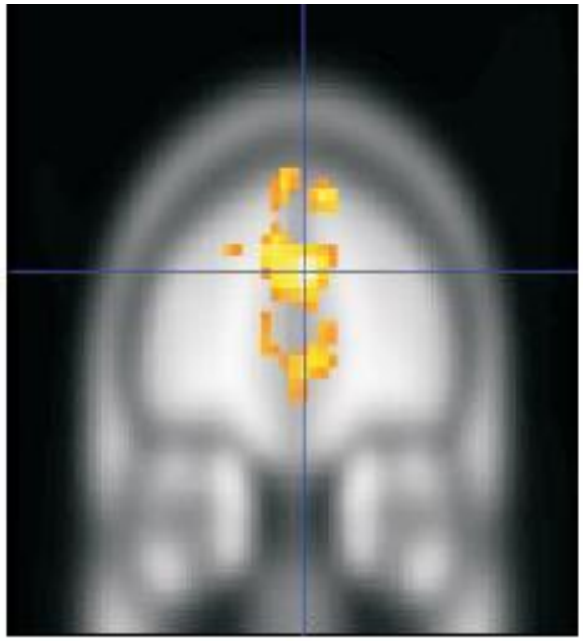
Introduced in Nagel (1995), Variations: Stahl Wilson (1995), Costa Gomes et al (2001); Camerer, Ho, Chong (2004); Alaoui, Penta (2017); survey Crawford et al. (2013)

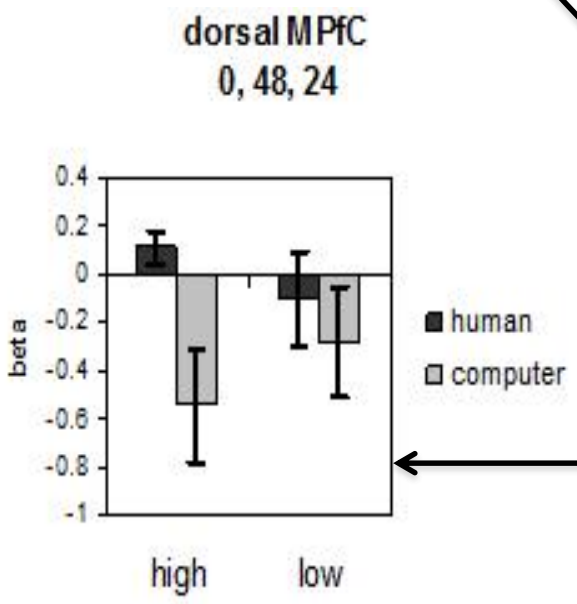
Objective of design: Link between stimulus (model, rules), behavior, physiological data (e.g. brain activity), to understand thought processes

Stimulus: Rules of the BC game

e.g. target 2/3-average

Behavior against humans and computer

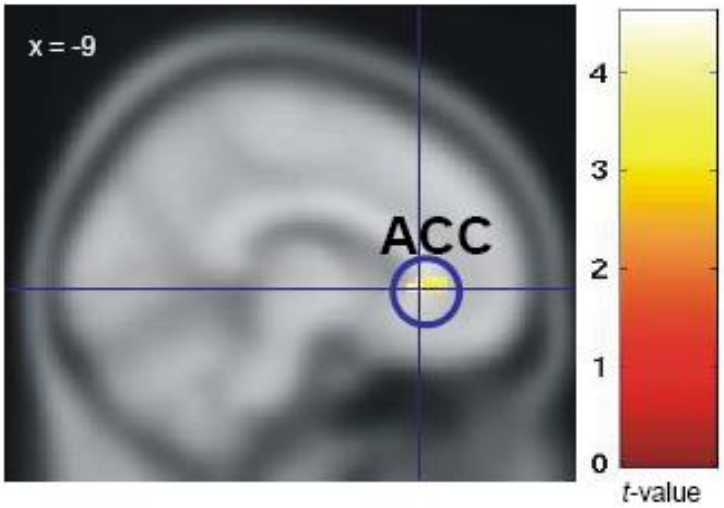




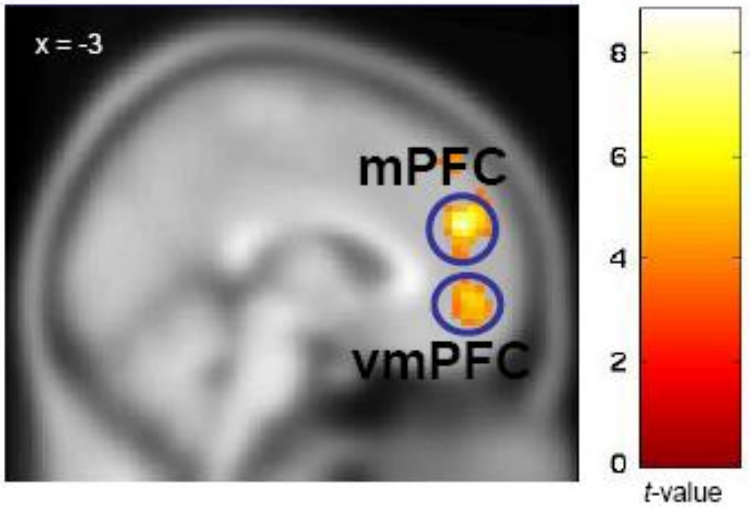
Level k model: HIGH vs LOW

High vs. low level of reasoning

Low level of reasoning



High level of reasoning



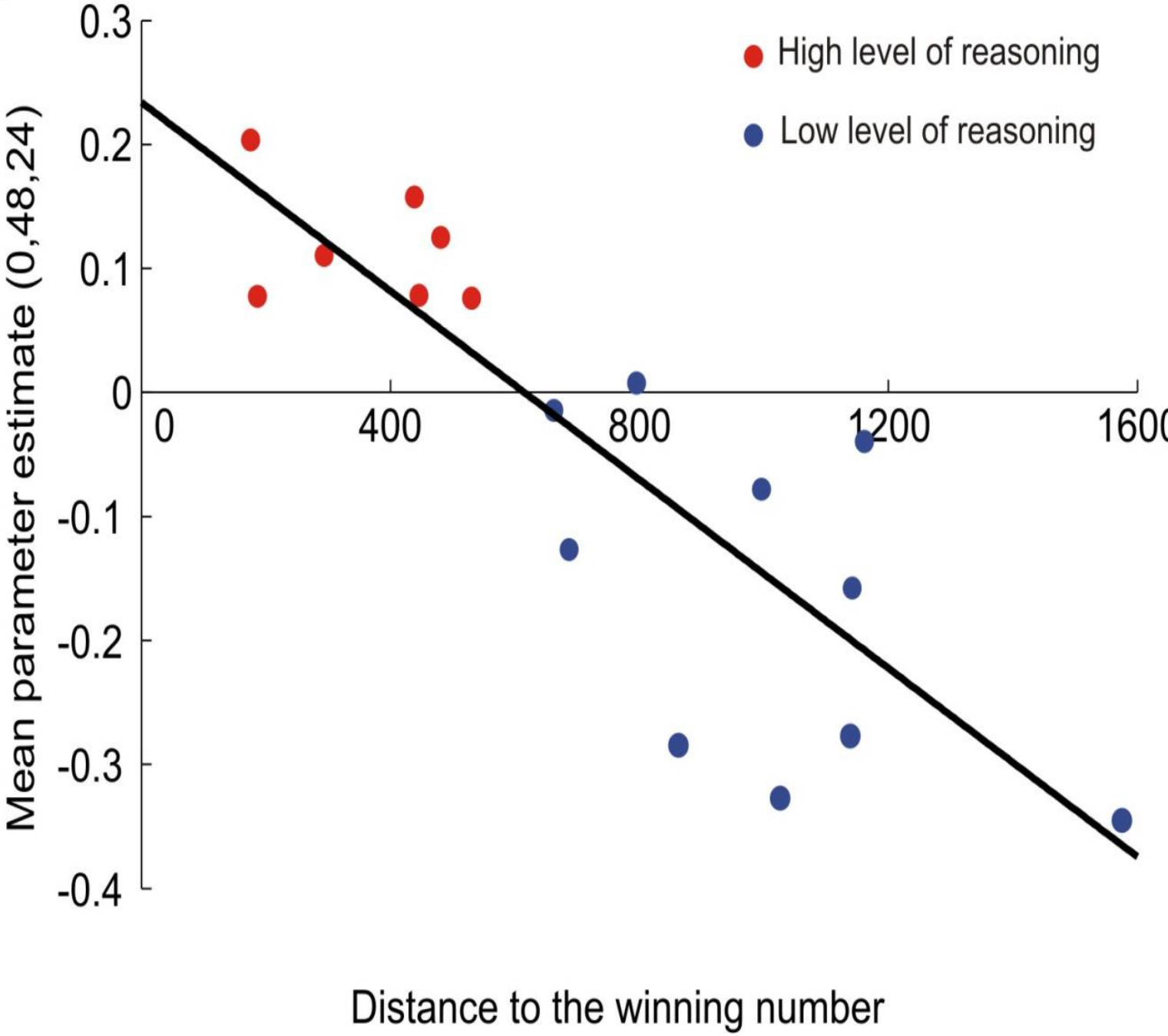
"CHOOSING 33"

"CHOOSING 22"

Heterogeneity is visible in the brain

Coricelli Nagel (PNAS 2009)

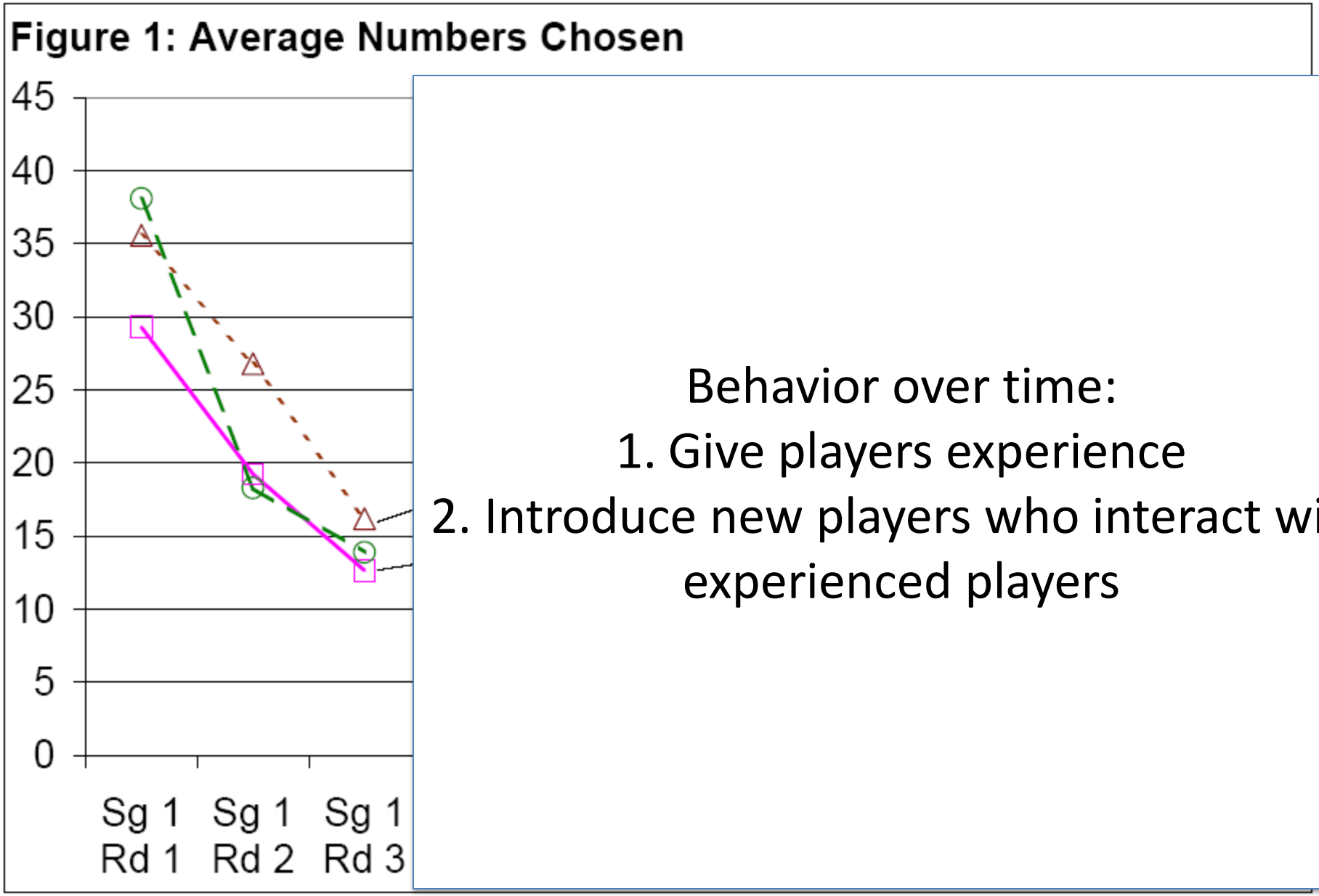
MNI x=0, y=48, z=24



New Questions

- How to manipulate level k reasoning
  - especially when behavior is far away from a (unique) Pareto optimal equilibrium
    - Allowing learning over time, team reasoning, etc.
    - ONE SHOT: Turning level k reasoning "on and off"
      - Depending on the game structure
      - Depending on the subject pool
- A generalized Beauty contest spans a class of aggregative games and markets
  - what common structure is there in such a class of games and markets

Slonim, Experimental Economics 2005: Experienced vs Inexperienced players

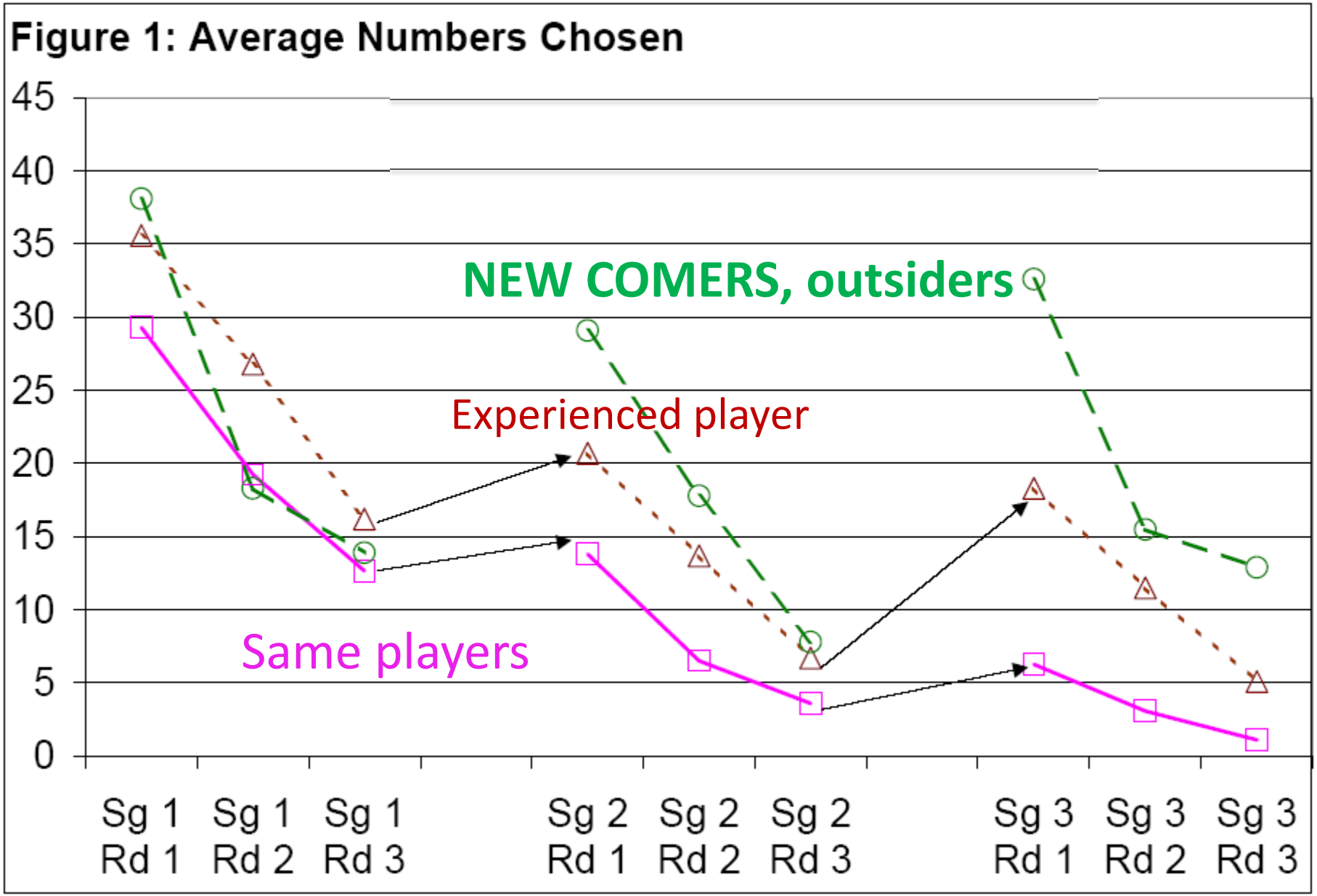


Behavior over time:

1. Give players experience
2. Introduce new players who interact with experienced players

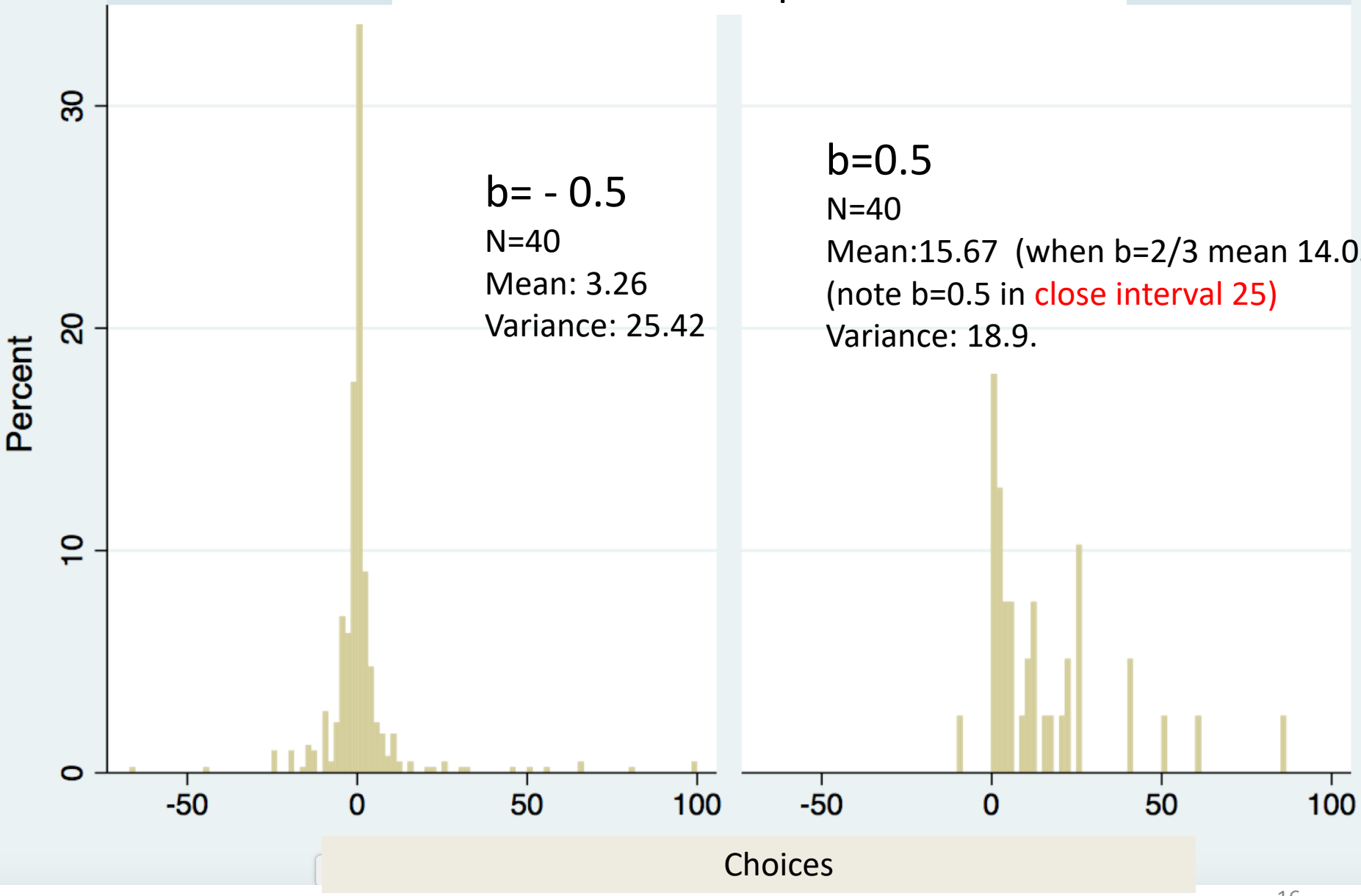
A series of super games: some subjects are newly introduced to mimic new entrants

Slonim, Experimental Economics 2005



A series of super games: some subjects are newly introduced to mimic new entrants

Substitutes vs Complements

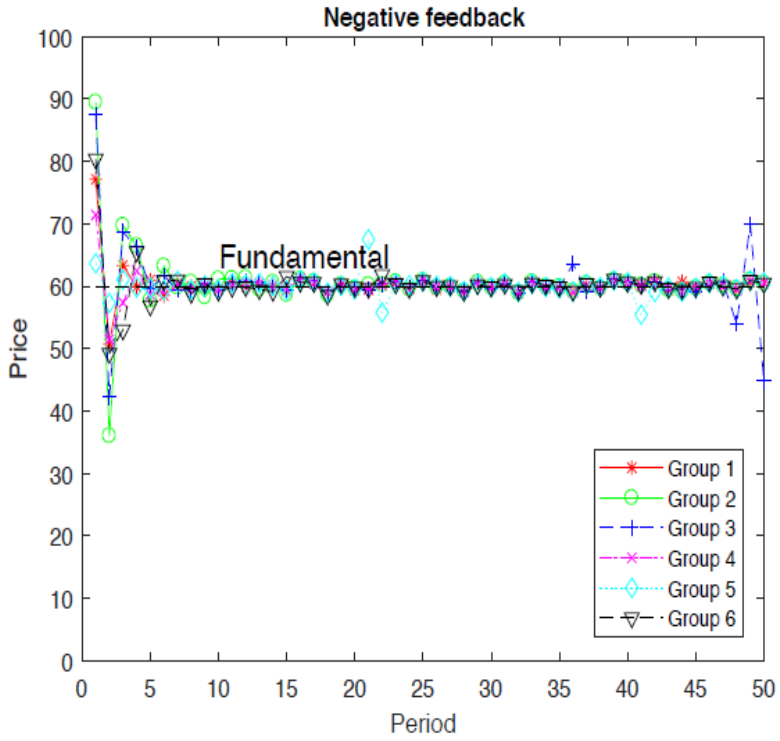


Datasets Behavior over time, no knowledge of parameters

Markets of strategic substitutes

$$p_t = \frac{20}{21}(123 - \bar{p}_t^e) + \varepsilon_t,$$

negative feedback

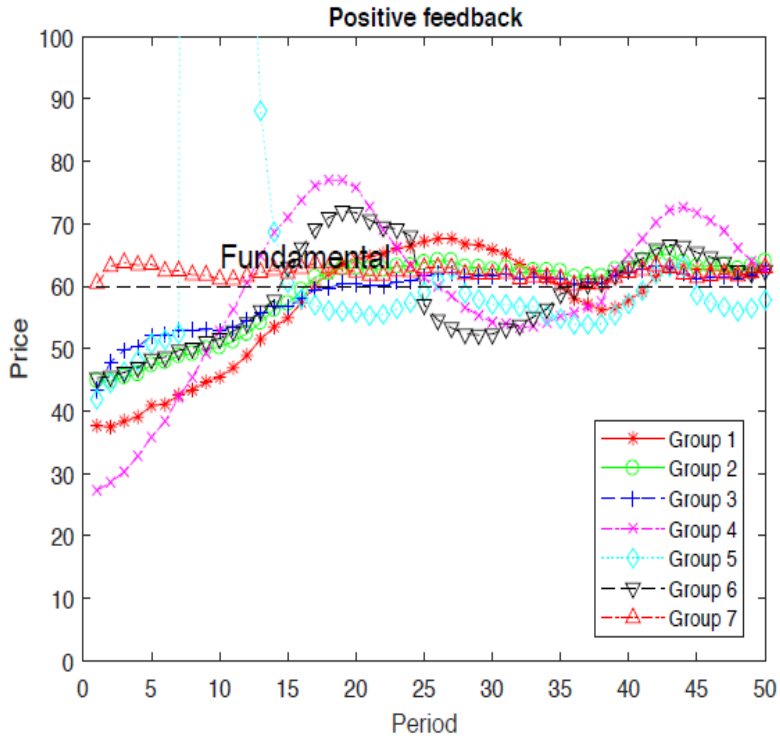


REE 60

Markets of strat.complements

$$p_t = \frac{20}{21}(\bar{p}_t^e + 3) + \varepsilon_t.$$

positive feedback



Heemeijer et al. (2009); figure from Mauersberger (2018)

Importance of level 0 through changes of rules

2/3average+10

choice from [0,100]

or choice from any number

Equilibrium: 2/3x+10=x => x=30

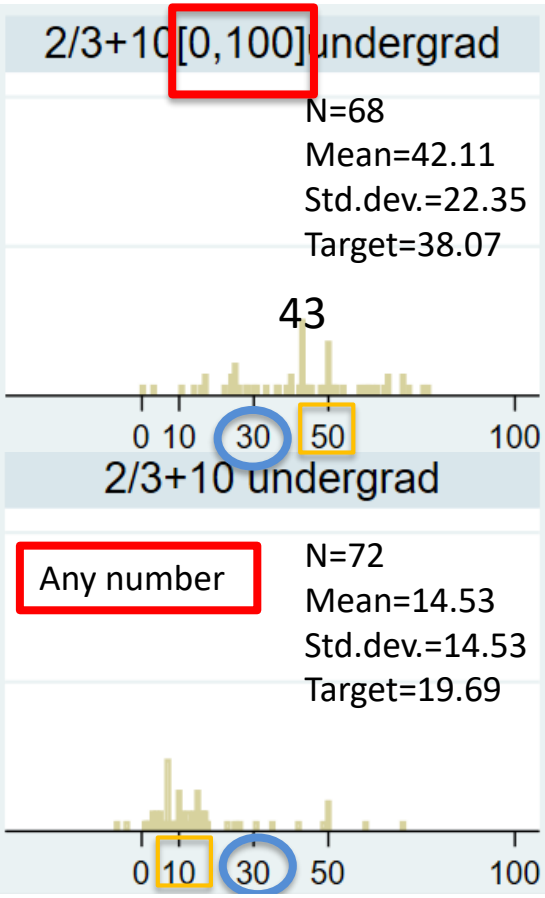
10 represents e.g. fundamental value or preannoucemnt

Online experiments with ECB members and undergraduates

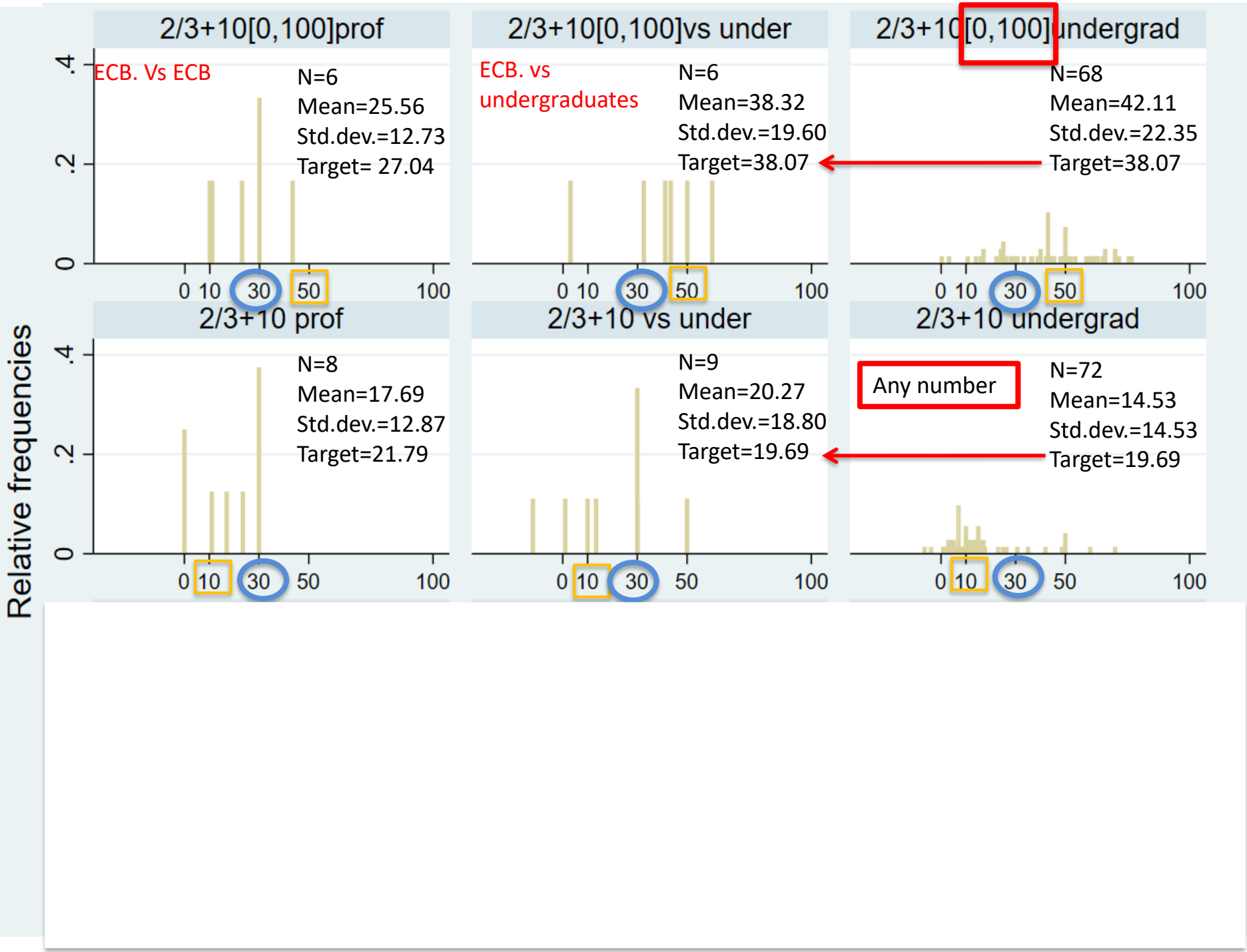
Games: 2/3average+10
choice from [0,100] (Top graph)

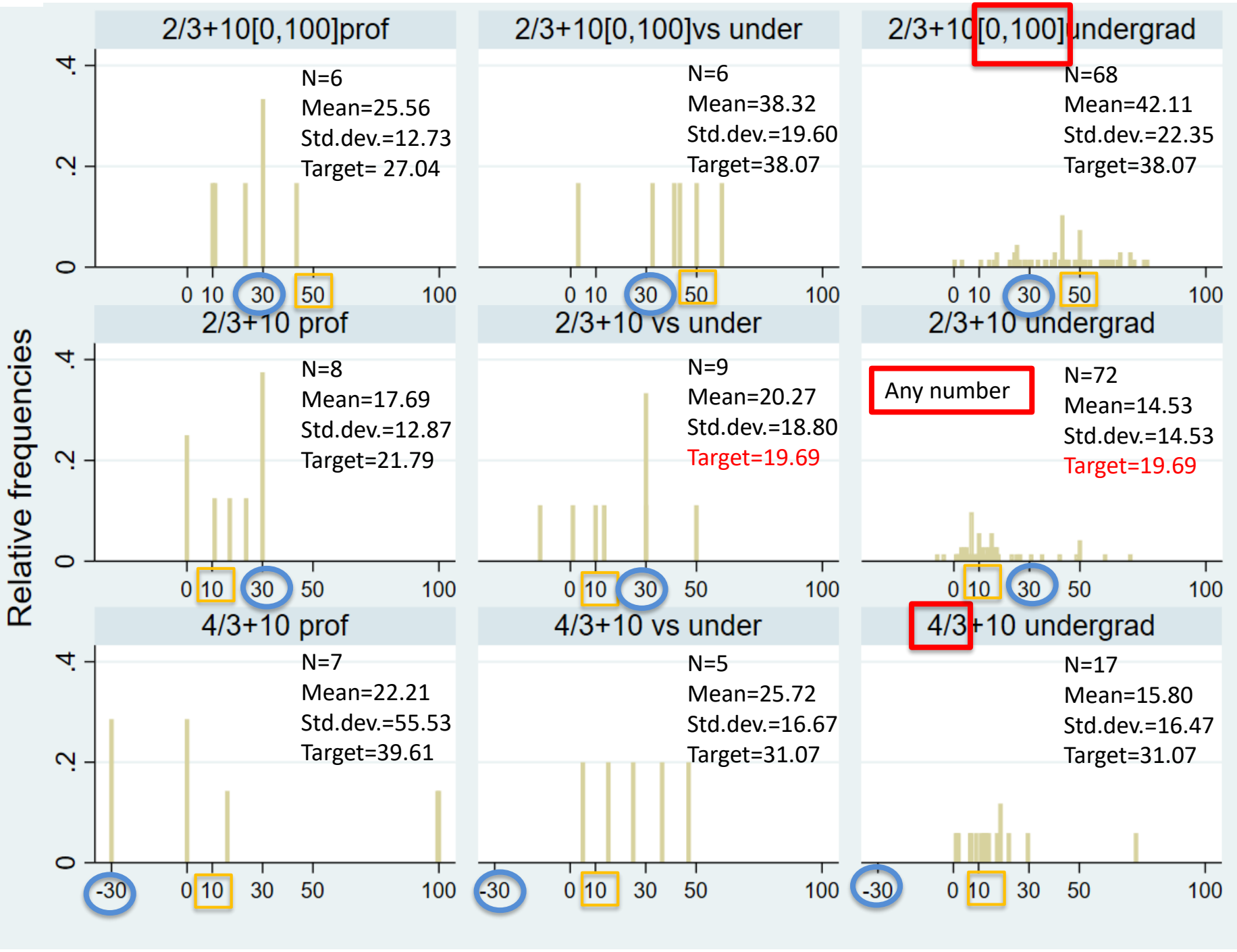
choice from any number (Bottom graph)

Level 0 varies from 50 (Top) to 10 (Bottom)
Equilibrium: 30 fixed point= 2/3x+10=x



Relative frequencies


2/3+10[0,100]prof
ECB. Vs ECB
N=6
Mean=25.56
Std.dev.=12.73
Target= 27.04
2/3+10[0,100]vs under
ECB. vs undergraduates
N=6
Mean=38.32
Std.dev.=19.60
Target=38.07
2/3+10[0,100]undergrad
N=68
Mean=42.11
Std.dev.=22.35
Target=38.07
2/3+10 prof
N=8
Mean=17.69
Std.dev.=12.87
Target=21.79
2/3+10 vs under
N=9
Mean=20.27
Std.dev.=18.80
Target=19.69
2/3+10 undergrad
Any number
N=72
Mean=14.53
Std.dev.=14.53
Target=19.69
Relative frequencies
0
.2
.4
0 10 30 50 100


2/3+10[0,100]prof
N=6
Mean=25.56
Std.dev.=12.73
Target= 27.04
2/3+10[0,100]vs under
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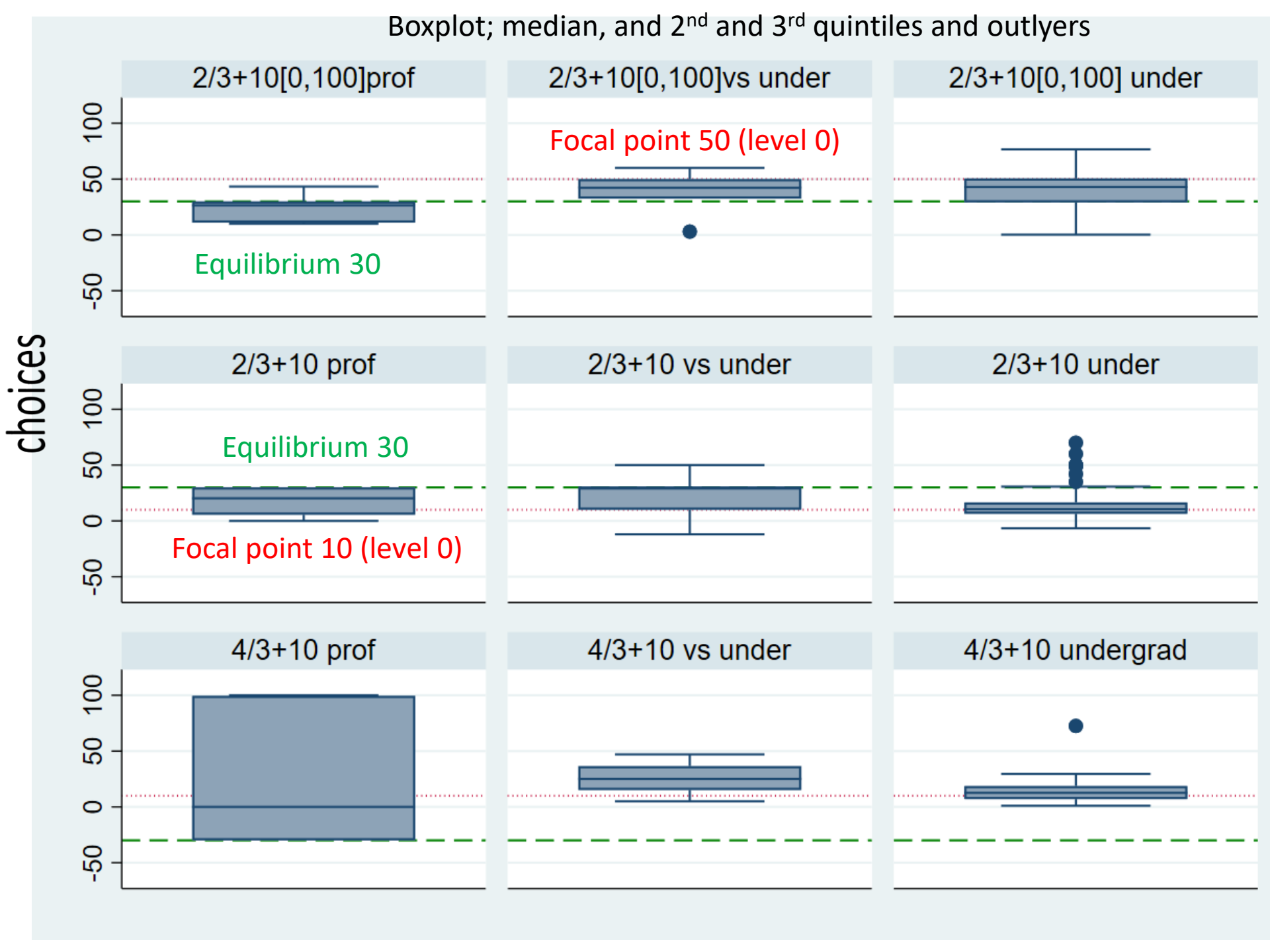
2/3+10 vs under
N=9
Mean=20.27
Std.dev.=18.80
Target=19.69
2/3+10 undergrad
Any number
N=72
Mean=14.53
Std.dev.=14.53
Target=19.69
4/3+10 prof
N=7
Mean=22.21
Std.dev.=55.53
Target=39.61
4/3+10 vs under
N=5
Mean=25.72
Std.dev.=16.67
Target=31.07
4/3+10 undergrad
N=17
Mean=15.80
Std.dev.=16.47
Target=31.07
Relative frequencies
0
.2
.4
-30
0
10
30
50
100


Boxplot; median, and 2nd and 3rd quintiles and outlyers
2/3+10[0,100]prof
2/3+10[0,100]vs under
2/3+10[0,100] under
Focal point 50 (level 0)
Equilibrium 30
2/3+10 prof
2/3+10 vs under
2/3+10 under
Equilibrium 30
Focal point 10 (level 0)
4/3+10 prof
4/3+10 vs under
4/3+10 undergrad
choices
100
50
0
-50

Generalized Beauty Contest

(Selten (1970), Benhabib et al. Eco'trica (2015), Benhabib et al. (2018), Angeletos and Lian (2018)

Optimal choice (best response) for player i:

$$y_t^i = \hat{E}_t^i(c_t + b\, f(y_t^1, \ldots, y_t^N) + d\, f(y_{t+1}^1, \ldots, y_{t+1}^N) + \varepsilon_t^i)$$

10 + 2/3 average +e(i), where e(i) ϵ N(0, 10)

- E: Expectation
- f(.): (aggregated) behavior of all players
  - E.g. average, median, sum, max, min
- c: constant, e.g. fundamental value
- b,d =parameters:
  - b,d<0 strategic substitutes
  - b,d>0 strategic complements
- ε(i): exogenous idiosyncratic (noisy) variable, N(λ, σ^2)

Examples for "Beauty contest games"

- New-Keynesian models (Woodford, 2003; Galí, 2008; Walsh, 2010)

$$y_t = \bar{y}^e_{t+1} - \sigma(i_t - \bar{\pi}^e_{t+1} - \rho) + g_t$$

$$\pi_t = \kappa y_t + \beta \bar{\pi}^e_{t+1} + u_t$$

$$i_t = \rho + \phi_\pi(\pi_t - \pi)$$

  - Inflation prediction reduced (under a certain belief formation for the output gap) to:

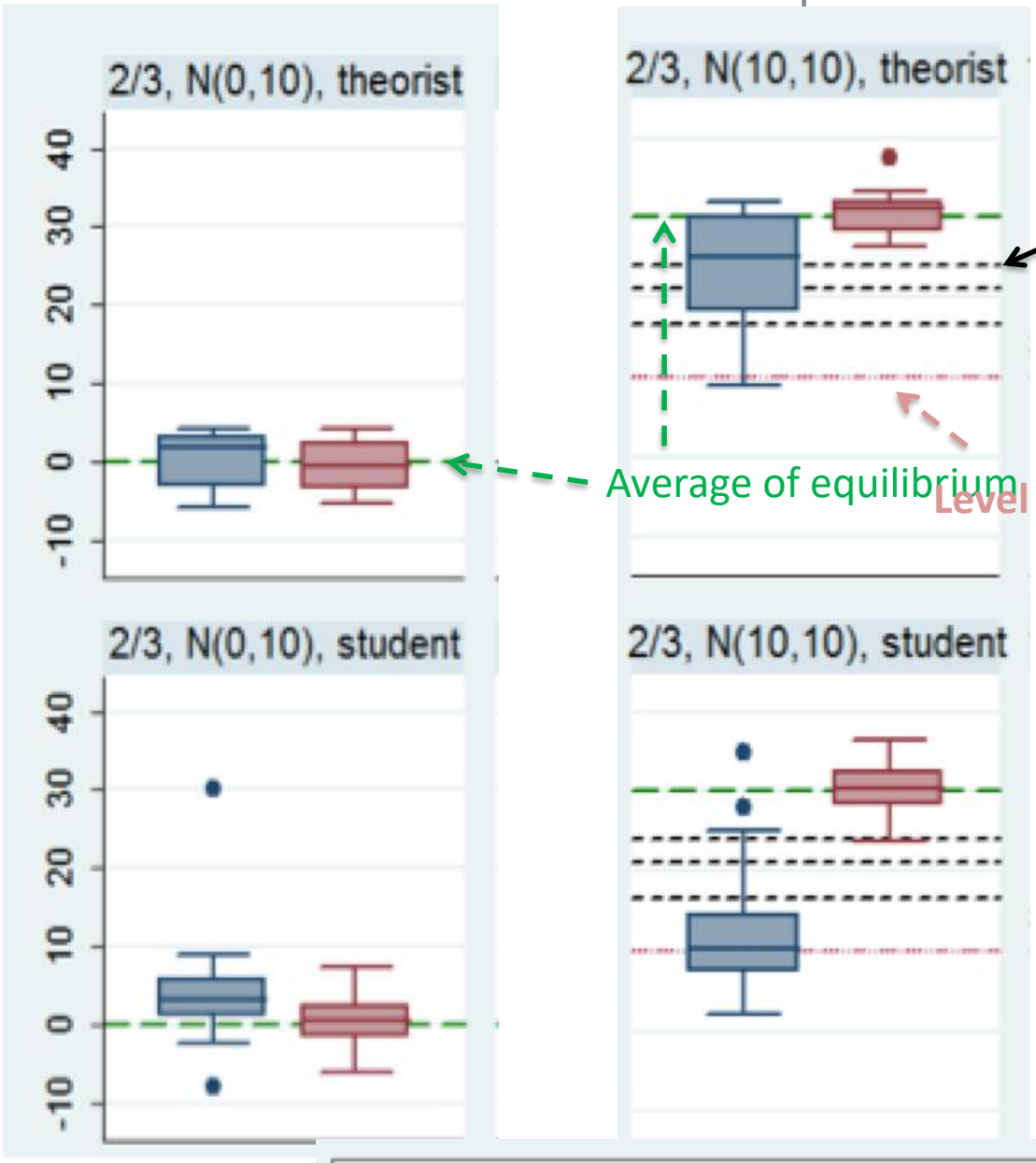
$$\pi_t = c + b\bar{\pi}^e_{t+1} + \upsilon_t \qquad \hat{E}^i_{t-1}\pi_t = \pi_t$$

Learning to forecast game

	Strategic substitutes	Strategic complements
dominant strategy	Neither substitutes, nor complements: public goods, prisoner's* dilemma, harmony game, second-price auctions,	
Level 1	Ultimatum game (proposer)	BC p=1 Stag hunt game * Battle of Sexes*
Level 2 or higher	BC game with p < 0¶ global game (congestion) Cournot game Entry (chicken) game Cobbweb markets	BC game with p > 0¶ Global game (attack or not) Ultimatum game with responder or proposer competition Bertrand game First-price auctions Neo Keynesian Asset markets BC with fundamentals
Strategic heterogeneity:	(hide and seek), fashion cycles, matching pennies	

Y(i) = 2/3 avg + e(i), e(i) from $N(\lambda, \sigma^2)$

Now with signals

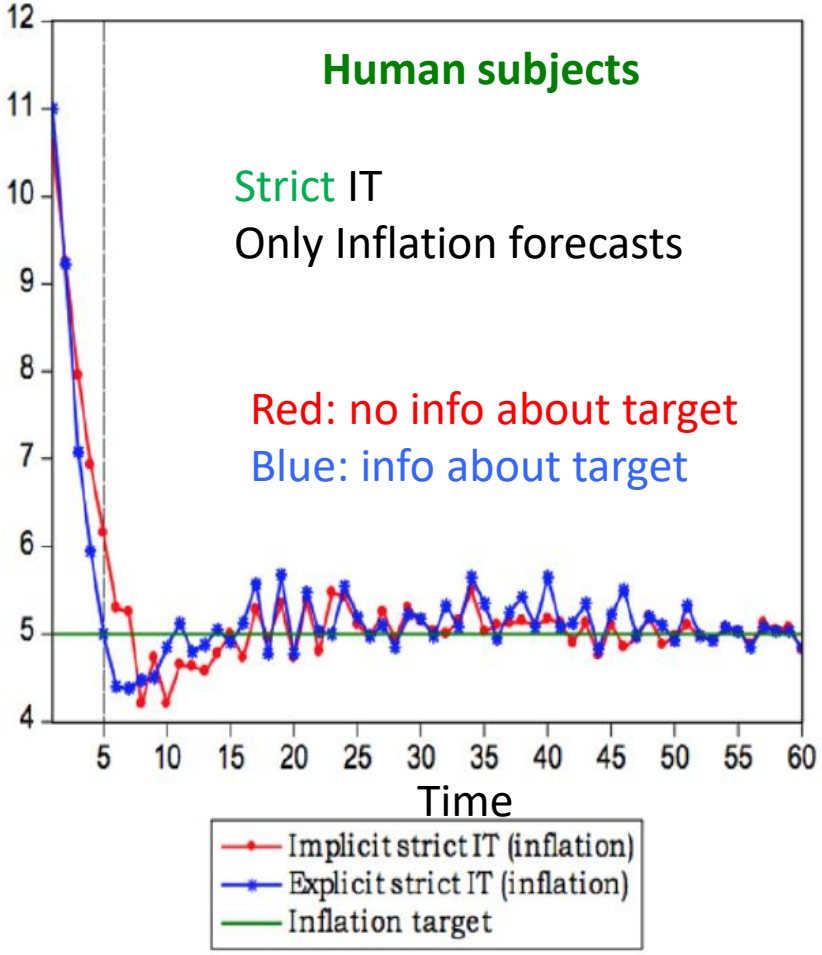


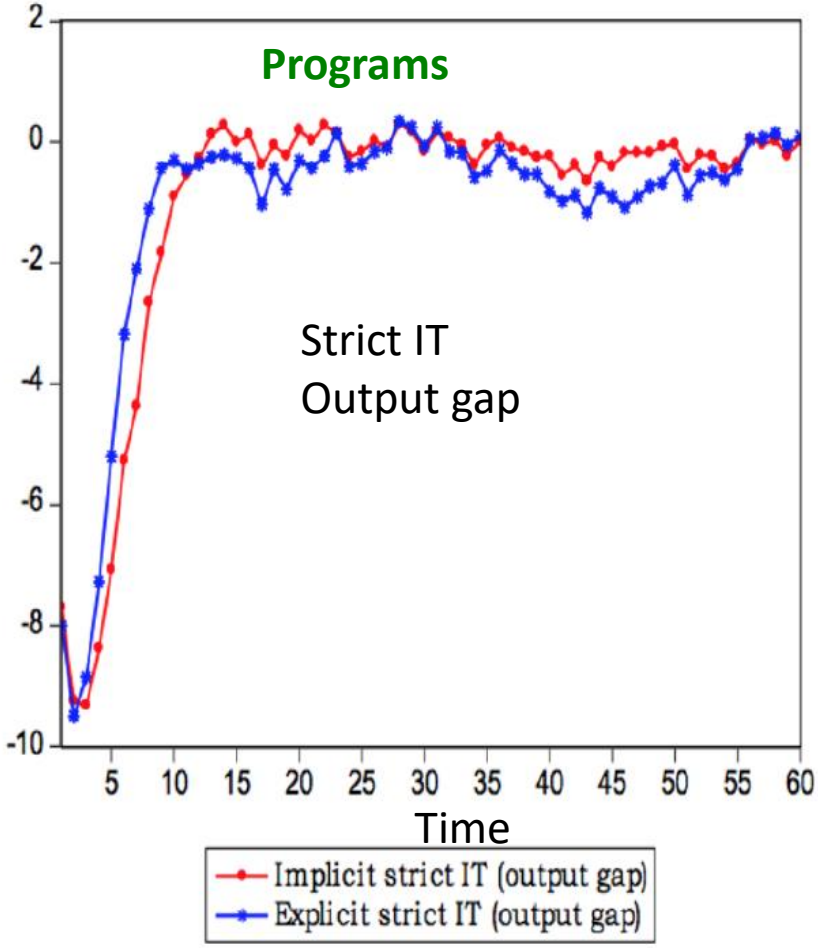
Benhabib, Duffy, Nagel (2018)
Buehren, Duffy, Nagel (2018)

Central bank communication

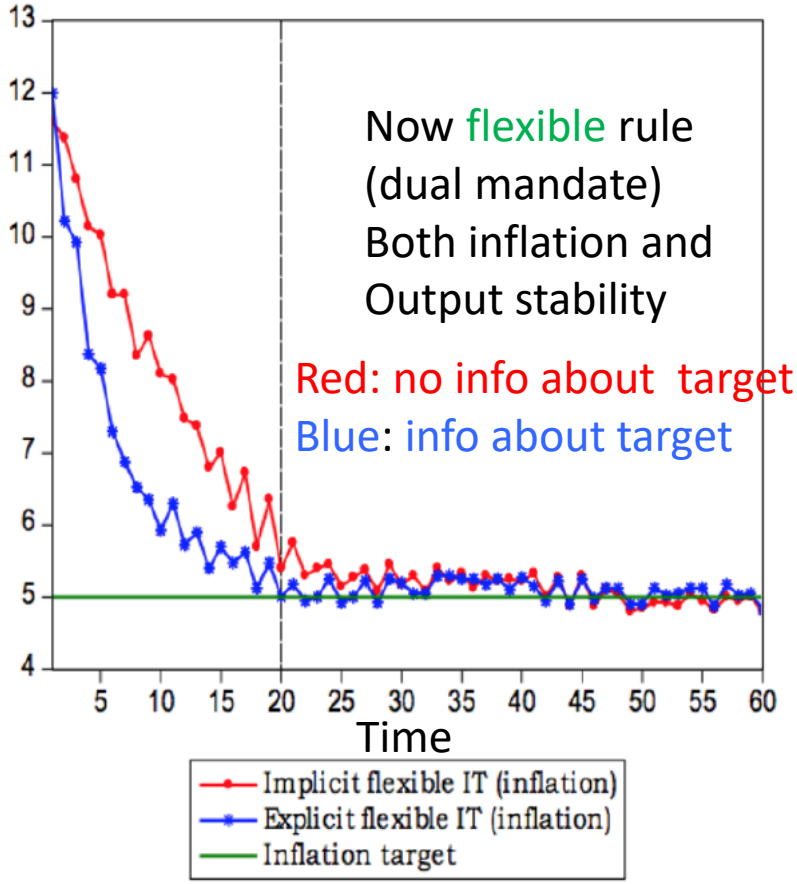
within a New-Keynesian framework (reduced form)

Cornand and M'Baye (2015): Communication under strict vs. flexible IT





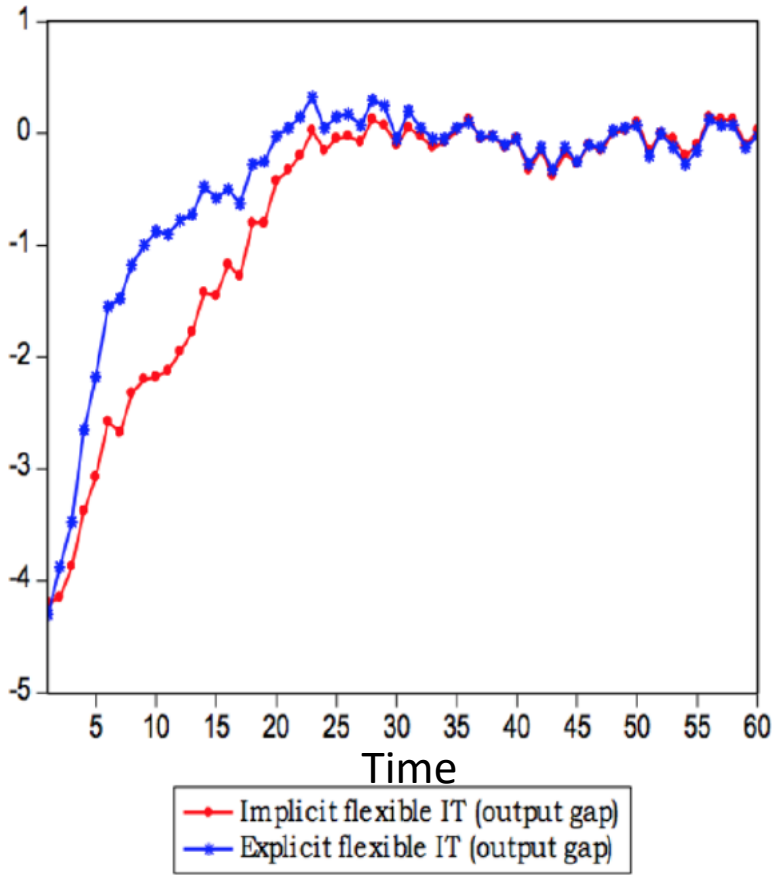
Cornand-M'Baye (2015): Communication under strict vs. flexible IT



Now flexible rule (dual mandate) Both inflation and Output stability

Red: no info about target

Blue: info about target



Applications of the level-k model

- Experimental economics, for many different lab and field experiments (see surveys Crawford et al, 2013, Camerer 2003, Mauersberger and Nagel, 2018)
- Behavioral microeconomics, e.g. Crawford bargaining (2015)
- Epistemic game theory, e.g. Kets (2012), Brandenburger (2017)
- Business field experiments: (e.g. classifying managers Goldfarb and Xiao, 2011)
- Macroeconomics, e.g. Garcia Schmidt, Woodford (2016)
- Survey data on inflation expectations with managers (Coibion et al. (2018)
- Building heuristics for strategic management (Marchiori, Nagel, Schmidt (2019)

New-Keynesian models and level k

- Garcia-Schmidt and Woodford:
  - use level k to explain why one only observes a sluggish response of inflation after the financial crisis 2007-2011: monetary policy commitments to keep the nominal interest rate very low need not be deflationary.
- Farhi and Werning:
  - Sluggish response is there but quantitatively not large under standard calibrations
  - Need to combine level k with incomplete markets
- Angeletos and Lian: level k helps solving
  - Forward guidance puzzle: announced rise in interest rate 1,000,000 years from now has same effect as announced rise tomorrow?
  - NOT under level k where future expected effects are dampened.
  - Why fiscal interventions can be effective

Codependency of the System, Mind, and Nature

guided by economic theory, experiments, and technology

To bring all together

Technology:

Computer, I-phone, fMRI, eyetracking etc

(Economic) System - apriori

The world
as a Beauty contest
(micro, macro)
Equilibrium, rationality etc.
(apriori, objective)

Mind

(rational or bounded)

Equilibrium

Reference points
Level-K vs randomness
Sentiments and signals
Adaptive reasoning, etc.
(subjective)

A reduced form of
the complex world

Nature

HERE: The brain
Neuroscience
(objective)

BC rules – experimental data – models of behavior

- Rule change => Theoretical changes or not
- Regularities and heterogeneity in behavior
- Behavioral model: level k
- Why discuss behavior?
  - The BC game is used in many different ways and complexities in micro and macro economics for making predictions etc. , assuming often rational expectations, equilibrium behavior also in empirical observations. What can we learn from controlled experiments?

Conclusion

General aim of economics

- Understanding the complex system
  - (Game/economic) theory decomposes the parts
  - Experimental economics makes us understand behavior in those parts, reintroducing psychology and biological data, formulates descriptive theories and heuristics
  - Empirical research tries to understand the complex world, reconstructing parts, sums, and more by using data, theory and noise.

What are we missing?

- More interaction between the parts
- How far are we from the system we actually want to analyze

Discussion

- Micro-foundation of macro through game theory and experimental and behavioral economics, psychology, neuroscience, humanities
- Bounded rationality in stylized situations
- Uncertainty through parameters of the situations and other players
- Experts (conference participants) and non experts (undergraduates)
- Brain data supports different levels of reasoning

=> Construction of “Hegel” system: Economic system-Mind-Brain

Critical questions:

- Does this translate to the micro/macro theory or field data?
  - Behavioral macro: add level k to traditional models
  - Survey data include our Beauty contest games: guess others guesses and try to discover level-k reasoning and the consequences of this for other choices.

Conclusion

- Structuring economic situations (players, actions, payoff consequences, information etc.)
  - Base: Beauty Contest; ADD constant and idiosyncratic term
- Equilibrium as benchmark, structuring the strategy space (dominated strat. Equilibrium etc.)
- Parsimonious behavioral model: Level k
  - Not mentioned: learning models (Reinforcement, Bayesian), rational inattention, social preferences (level 1?) etc.
- Actual behavior serves to develop behavioral model
- Neuroeconomic tools to improve our understanding of behavior
- Implementation of level-k model into theoretical models (should encourage new experiments)