Complex Economic Systems in Macro & Finance
Lecture 4
Behavioural Macroeconomics with Heterogeneous Expectations

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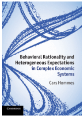
Plans of the Talk

- Behavioural Heuristics Switching Model
  - agents use simple forecasting rules and **gradually switch to better performing rules**
  - **reinforcement learning** / **survival of the fittest**
- **Empirical estimation** of heterogeneous expectations model with endogenous switching
  - macro data, US inflation
  - housing prices US, JP, NL
- **Laboratory experimental testing** of individual rules and aggregate macro behavior

Some References

- Cornea, A., Hommes, C.H. and Massaro, D. (2013), Behavioral heterogeneity in U.S. inflation dynamcis, University of Amsterdam, 2014.
- Bolt, W., Demertzis, M., Diks, C., Hommes, C.H. and van der Leij, M. (2014), Identifying booms and busts in house prices under heterogeneous expectations, Working paper De Nederlandse Bank 450 and CeNDEF, University of Amsterdam
- Assenza, T., Heemeijer, P., Hommes, C.H. and Massaro, D. (2013). Managing self-organization of expectations through monetary policy: a macro experiment, Universiteit van Amsterdam.
- Hommes, C.H., (2013), Behavioral Rationality and Heterogeneous Expectations in Complex Economic Systems, Cambridge.



Heuristics Switching Model

- Pool of heuristics whose impacts are changing over time according to **observable** past relative performance

$$U_{h,t-1} = \frac{100}{1 + |x_{t-1} - x^e_{h,t-1}|} + \eta U_{h,t-2}$$

- *Discrete choice model with asynchronous updating*

$$n_{h,t} = \delta n_{h,t-1} + (1-\delta)\frac{\exp(\beta U_{h,t-1})}{Z_{t-1}}$$

- Set of **four heuristics**

$$\begin{array}{lrcl} \text{ADA} & \pi^e_{1,t+1} & = & 0.65\pi_{t-1} + 0.35\pi_{1,t} \\ \text{WTF} & \pi^e_{2,t+1} & = & \pi_{t-1} + 0.4(\pi_{t-1} - \pi_{t-2}) \\ \text{STF} & \pi^e_{3,t+1} & = & \pi_{t-1} + 1.3(\pi_{t-1} - \pi_{t-2}) \\ \text{LAA} & \pi^e_{4,t+1} & = & 0.5(\pi^{av}_{t-1} + \pi_{t-1}) + (\pi_{t-1} - \pi_{t-2}) \end{array}$$

The "hybrid" New Keynesian Phillips curve

- Pricing behavior described in the context of models with nominal rigidities (sticky prices) and optimizing agents with **rational expectations**
- Forward-looking NKPC

$$\pi_t = \delta E_t \pi_{t+1} + \gamma mc_t$$

- Criticism: no intrinsic inertia in inflation, i.e., no structural dependence on lagged inflation (see, e.g., Rudd and Whelan (2005a,b))
- Hybrid models of the form

$$\pi_t = \theta E_t \pi_{t+1} + (1-\theta)\pi_{t-1} + \gamma mc_t$$

Empirical relevance of forward-looking behavior

- Estimation of the closed-form solution of the model under **RE**

$$\pi_t = \mu_1 \sum_{s=0}^{\infty} \delta^s E_t mc_{t+s} + \mu_2 \pi_{t-1} + \epsilon_t$$

results in mixed evidence

  - Galì and Gertler (1999), Sbordone (2005) and Kurmann (2007): predominant role of forward-looking component
  - Fuhrer (1997), Lindè (2005) and Rudd and Whelan (2006): no significant evidence for forward-looking behavior

Contributions of Cornea-H-Massaro paper

- Framework with monopolistic competition, staggered price setting and endogenous switching between different forecasting regimes
- Estimation of a NKPC with heterogeneous expectations using U.S. macroeconomic data
- Empirical relevance of forward-looking vs backward-looking behavior

Simple 2-type example (fundamentalists vs naive)

- Fundamental inflation (solution under homogeneous RE)

$$\pi_t = \gamma \sum_{s=0}^{\infty} \delta^s E_t mc_{t+s}$$

- Fundamentalists expectations

$$E_t^f \pi_{t+1} = \gamma \sum_{s=1}^{\infty} \delta^{s-1} E_t^f mc_{t+s}$$

- VAR methodology (Campbell and Shiller (1987))

$$Z_t = AZ_{t-1} + u_t \;\Rightarrow\; E_t^f \pi_{t+1} = \gamma e_1{}'(I - \delta A)^{-1} AZ_t$$

- Naive expectations

$$E_t^n \pi_{t+1} = \pi_{t-1}$$

Evolutionary selection of expectations

- Discrete choice model (Brock and Hommes, *Econometrica* 1997)

$$n_{i,t} = \frac{\exp(\beta U_{i,t-1})}{\sum_{i=1}^{I} \exp(\beta U_{i,t-1})}$$

$n_{i,t}$ fraction of agents using predictor i at time t

- Fitness measure

$$U_{i,t} = -\frac{FE_t^i}{\sum_{i=1}^{I} FE_t^i} \quad \text{where} \quad FE_{t-1}^i = \sum_{k=1}^{K} |E_{t-k-1}^i \pi_{t-k} - \pi_{t-k}|,$$

The full model (fundamentalists vs naive)

- NKPC with heterogeneous beliefs and endogenous switching

$$\pi_t = \delta(n_{f,t}E_t^f\pi_{t+1} + (1-n_{f,t})E_t^n\pi_{t+1}) + \gamma mc_t + \xi_t \ ,$$

where

$$\begin{aligned}
E_t^f\pi_{t+1} &= \gamma e_1'(I-\delta A)^{-1}AZ_t \\
E_t^n\pi_{t+1} &= \pi_{t-1} \\
n_{f,t} &= \frac{1}{1+\exp\left(\beta\left(\frac{FE_{t-1}^f - FE_{t-1}^n}{FE_{t-1}^f + FE_{t-1}^n}\right)\right)} \\
FE_{t-1}^i &= \sum_{k=1}^{K} |E_{t-k-1}^i\pi_{t-k} - \pi_{t-k}|, \qquad \text{with } \ i = f, n
\end{aligned}$$

Baseline VAR specification

- Quarterly U.S. data from 1960:Q1 to 2010:Q4
- Fundamentalists forecast

$$E_t^f \pi_{t+1} = \gamma e_1'(I - \delta A)^{-1} A Z_t$$

- Start with broad VAR in output gap (y_t), unit labor costs (ulc_t), labor share of income (lsi_t), inflation rate (π_t) which reduces to a four-lag bivariate VAR

$$\begin{aligned} Y_t &= [y_t, \Delta lsi_t]' \\ Z_t &= [Y_t, Y_{t-1}, Y_{t-2}, Y_{t-3}]' \\ A &= (Z_{-1}' Z_{-1})^{-1} Z_{-1}' Z \end{aligned}$$

- Portmanteau test: p-value $Q(20) = 0.796$, $R^2 = 0.943$

Estimation results

Table : NLS estimates of switching model

Parameter	β	γ
Estimate	4.783***	0.005**
Std. error	1.327	0.002
R^2 from Inflation Equation	0.780	
R^2 from Output Gap VAR Equation	0.943	

Notes: Standard errors are computed using White's HCCME.
*, **, *** denote significance at the 10%, 5%, and 1% level.

- **robust** w.r.t. **VAR specification** (including π_{t-1})
- **robust** w.r.t. **marginal cost specification**

The fit of the model

one-period ahead forecasts

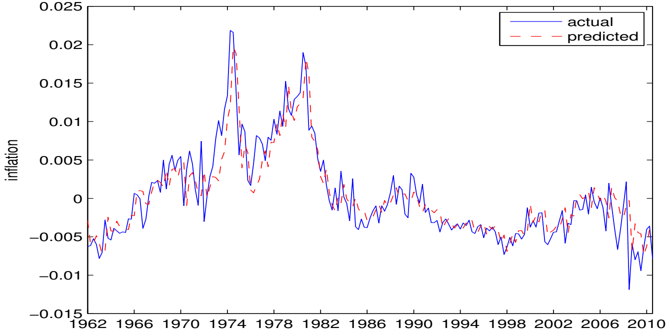
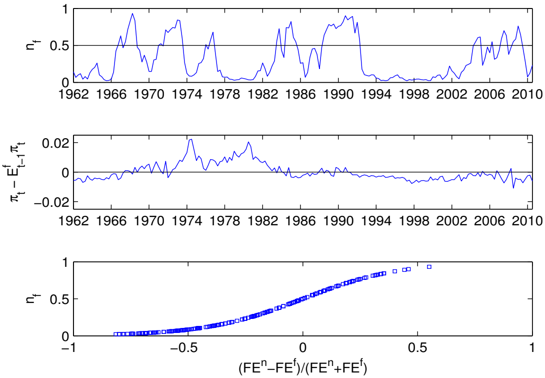


Figure : Actual vs. predicted inflation

Evolution of weight of fundamentalists $n_{f,t}$



on average more **backward looking** agents

Mean	**0.316**
Median	0.231
Maximum	0.933
Minimum	0.020
Std. Dev.	0.271
Skewness	0.634
Kurtosis	2.025
Auto-corr. Q(-1)	0.902

Top panel: Time series of the fraction of fundamentalists $n_{f,t}$

Middle panel: Distance between actual and fundamental inflation

Bottom panel: Scatter plot of $n_{f,t}$ vs relative forecast error of naive rule

Estimation 2-type model Housing Market

Two trader types, with forecasting rules

$$\begin{array}{rclll} f_{1t} & = & \phi_1 x_{t-1}, & 0 \leq \phi_1 < 1 & \textbf{fundamentalists} \\ f_{2t} & = & \phi_2 x_{t-1}, & \phi_2 > 1, & \text{trend extrapolators} \end{array}$$

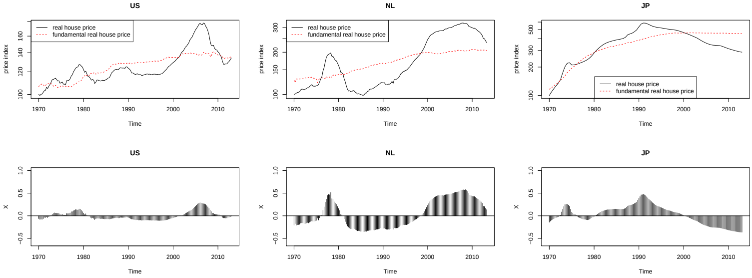
$$x_t = \frac{1}{R}[n_{1t}\phi_1 x_{t-1} + (1 - n_{1t})\phi_2 x_{t-1}] + \epsilon_t$$

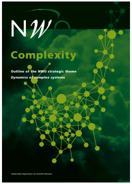
$$\phi_t = \frac{n_t\phi_1 + (1 - n_t)\phi_2}{R} \qquad \textbf{market sentiment}$$

- $\phi_t < 1$: mean reversion;
- $\phi_t > 1$: explosive, trend following

Bubbles and Crashes in Housing Markets

joint with DNB in NWO Comlexity program

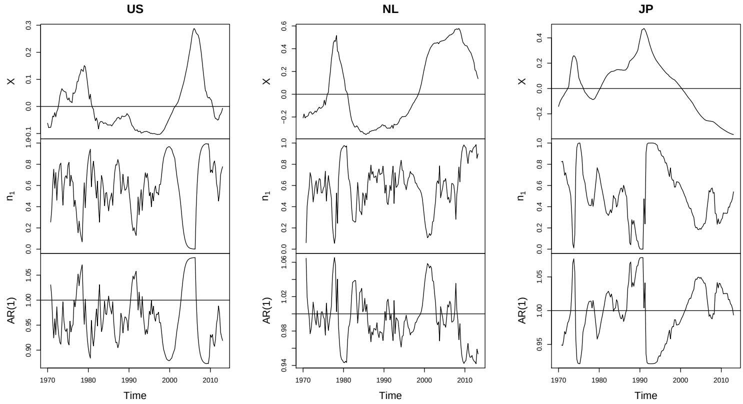


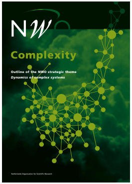


De Nederlandsche Bank Eurosysteem

Persistent Bubbles and Crashes in Housing Markets

joint with DNB in NWO Comlexity program





Learning to Forecasts Laboratory Experiments

- individuals **only** have to forecast price, **ceteris paribus**, e.g. with all other behavior assumed to be **rational**, demand/supply derived from profit/utility **maximization**
- computerized trading yields market equilibrium price, consistent with **benchmark model**, e.g.
  - cobweb model
  - asset pricing model
  - New Keynesian macro model
- **advantage**: clean data on expectations
- **Challenge**: universal theory of heterogeneous expectations

A Monetary Economy with Nominal Rigidities

- Standard model for monetary policy analysis

$$
\begin{aligned}
y_t &= y^e_{t+1} - \varphi(i_t - \pi^e_{t+1}) + \epsilon_t && \textbf{output} \\
\pi_t &= \lambda y_t + \beta \pi^e_{t+1} + \upsilon_t && \textbf{inflation} \\
i_t &= \text{Max}\{\overline{\pi} + \phi_\pi(\pi_t - \overline{\pi}), 0\} && \textbf{monetary policy rule}
\end{aligned}
$$

Complication: the standard forward looking New Keynesian model requires agents to forecast **two** variables!

Experimental desigh: **two different groups** of forecasters inflation and output gap to limit cognitive efforts

Experimental Results

Three Treatments:

(a) inflation target $\bar{\pi} = 2$ and weak Taylor rule ($\phi_\pi = 1$);

(b) inflation target $\bar{\pi} = 2$ and aggressive Taylor rule ($\phi_\pi = 1.5$);

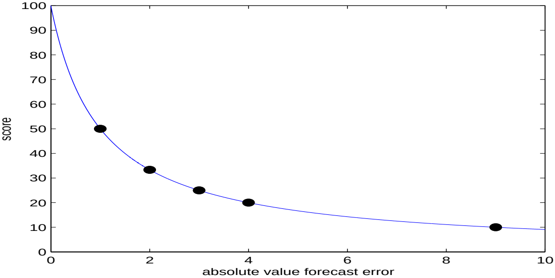
(c) inflation target $\bar{\pi} = 3.5$ and aggressive Taylor rule ($\phi_\pi = 1.5$)

Instructions for Participants

- **General information**
  - Participants are assigned the fictitious role of professional forecasters
- **Information about the economy**
  - Subjects do **not** know the data generating process, but receive qualitative information about the economy and the type of expectations feedback
    - inflation depends **positively** on inflation forecasts and output gap forecasts;
    - output gap depends **positively** on inflation forecasts and output gap forecasts, but **negatively** on the interest rate.

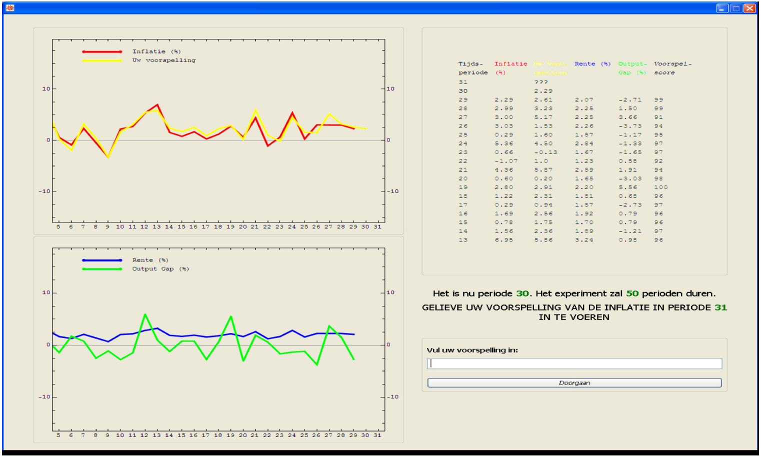
Earnings

Payoff function: $\text{score} = \frac{100}{1+f}$ where f is the absolute value of the forecast error expressed in percentage points



Absolute forecast error	0	1	2	3	4	9
Score	100	50	$33\frac{1}{3}$	25	20	10

Screenshot Experiment



Tijds-periode	Inflatie (%)	Uw Voor-spelling	Rente (%)	Output-Gap (%)	Voorspel-score
31		???			
30		2.29			
29	2.29	2.61	2.07	-2.71	99
28	2.99	3.23	2.25	1.50	99
27	3.00	5.17	2.25	3.66	91
26	3.03	1.53	2.26	-3.73	94
25	0.29	1.60	1.57	-1.17	95
24	5.36	4.50	2.84	-1.33	97
23	0.66	-0.13	1.67	-1.65	97
22	-1.07	1.0	1.23	0.58	92
21	4.36	5.87	2.59	1.91	94
20	0.60	0.20	1.65	-3.03	98
19	2.80	2.91	2.20	5.56	100
18	1.22	2.31	1.81	0.68	96
17	0.29	0.94	1.57	-2.73	97
16	1.69	2.56	1.92	0.79	96
15	0.78	1.75	1.70	0.79	96
14	1.56	2.36	1.89	-1.21	97
13	6.95	5.86	3.24	0.98	96

Experimental Results

Three Treatments:

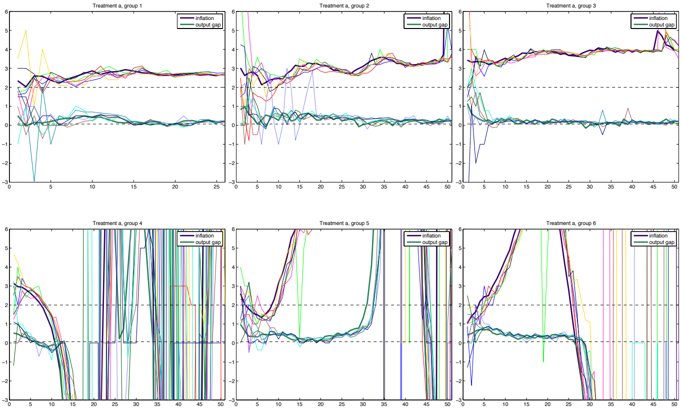
(a) inflation target $\bar{\pi} = 2$ and weak Taylor rule ($\phi_\pi = 1$);

(b) inflation target $\bar{\pi} = 2$ and aggressive Taylor rule ($\phi_\pi = 1.5$);

(c) inflation target $\bar{\pi} = 3.5$ and aggressive Taylor rule ($\phi_\pi = 1.5$)

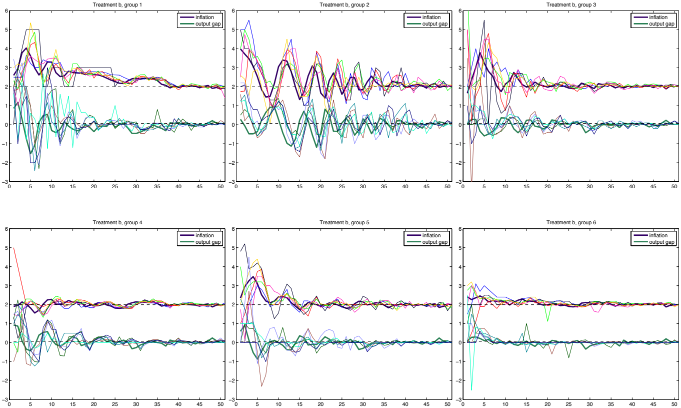
Treatment a; ($\bar{\pi} = 2$, $\phi_\pi = 1$)

coordination on some equilibrium level or
coordination on exploding inflationary/deflationary spiral



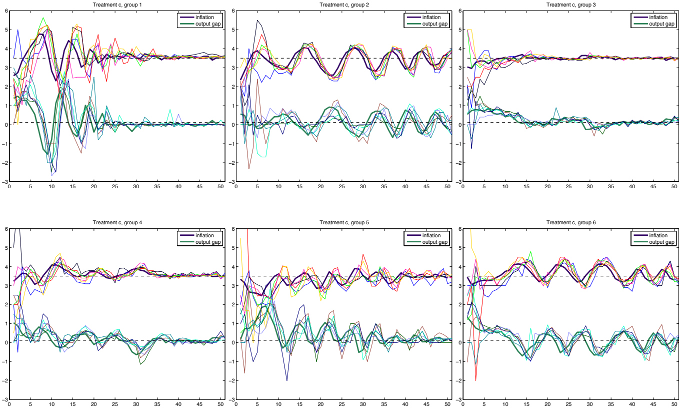
Treatment b; ($\bar{\pi} = 2$, $\phi_\pi = 1.5$)

coordination on dampened oscillations



Treatment c; ($\bar{\pi} = 3.5$, $\phi_\pi = 1.5$)

coordination on dampened or persistent oscillations



Summary of the Experimental Results

Four Different Types of Aggregate Behavior emerging through Coordination of Individual Expectations

- **coordination** of individual expectations
  not perfect, **some heterogeneity** persists

- **weak** Taylor rule ($\phi_\pi = 1$): **unstable** dynamics
  - convergence to some **non-fundamental steady states**
  - **exploding** inflation-output dynamics, either increasing or decreasing

- **aggressive** Taylor rule ($\phi_\pi = 1.5$): **stable** dynamics
  - fast or slow **oscillatory convergence**
  - **permanent oscillations** if target inflation $\bar{\pi} = 3.5$

Heuristics Switching Model

- Pool of heuristics whose impacts are changing over time according to **observable** past relative performance

$$U_{h,t-1} = \frac{100}{1 + |x_{t-1} - x^e_{h,t-1}|} + \eta U_{h,t-2}$$

- *Discrete choice model with asynchronous updating*

$$n_{h,t} = \delta n_{h,t-1} + (1-\delta)\frac{\exp(\beta U_{h,t-1})}{Z_{t-1}}$$

- Set of **four heuristics**

$$\begin{array}{lrcl}
\text{ADA} & \pi^e_{1,t+1} & = & 0.65\pi_{t-1} + 0.35\pi_{1,t} \\
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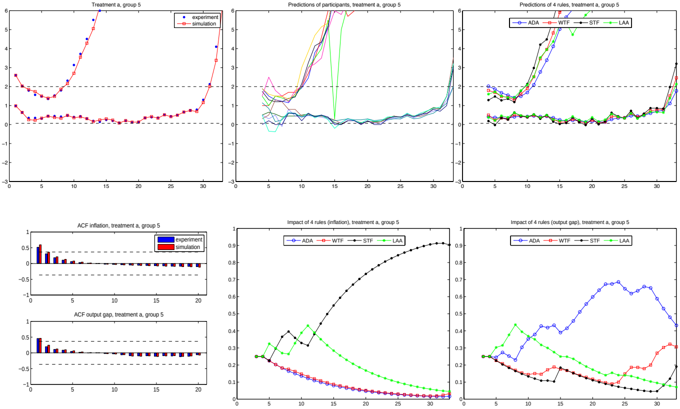
\text{STF} & \pi^e_{3,t+1} & = & \pi_{t-1} + 1.3(\pi_{t-1} - \pi_{t-2}) \\
\text{LAA} & \pi^e_{4,t+1} & = & 0.5(\pi^{av}_{t-1} + \pi_{t-1}) + (\pi_{t-1} - \pi_{t-2})
\end{array}$$

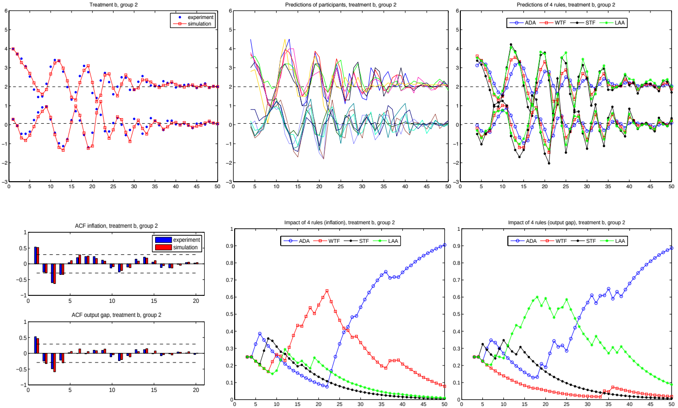
Coordination on explosive behavior($\bar{\pi} = 2$, $\phi_\pi = 1$; Tra, gr5)

through coordination on strong trend-following rule



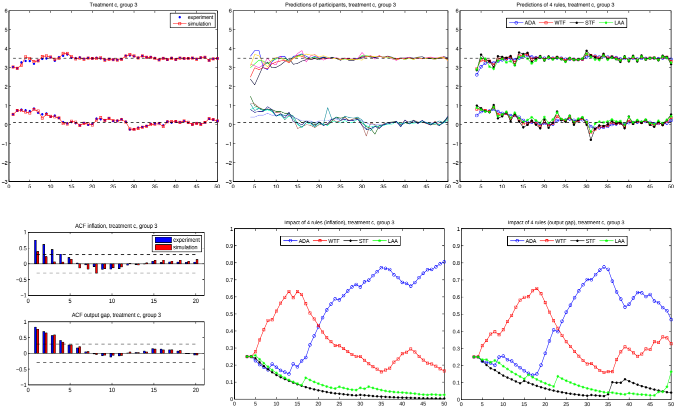
Coordination dampened oscillations ($\bar{\pi} = 2$, $\phi_\pi = 1.5$; Trb, gr2)

through switching from trend-following to adaptive expectations



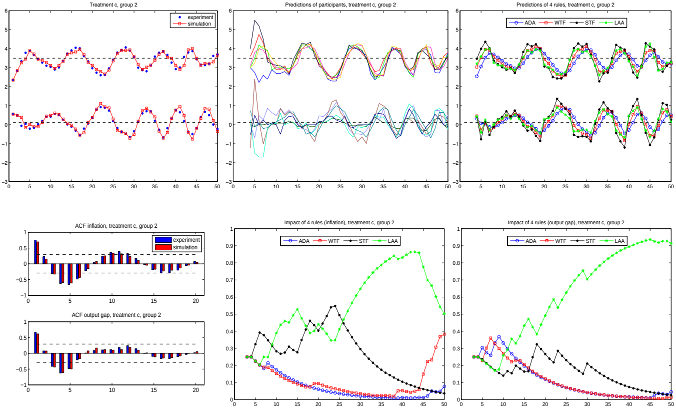
Coordination on RE steady state ($\bar{\pi} = 3.5$, $\phi_\pi = 1.5$; Trc, gr3)

through coordination on adaptive expectations



Coordination persistent oscillations ($\bar{\pi} = 3.5$, $\phi_\pi = 1.5$; Trc, gr2)

through coordination on learning-anchor-and-adjustment rule (LAA)

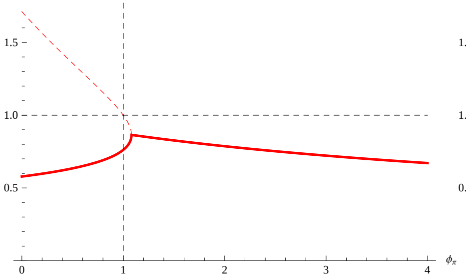


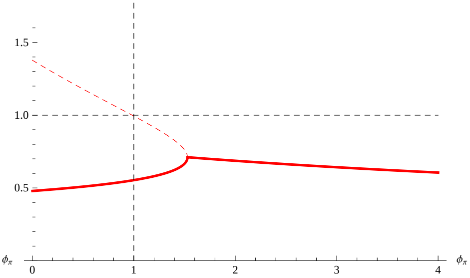
Monetary Policy and Macroeconomic Stability

Taylor rules targeting inflation: $i_t = \overline{\pi} + \phi_\pi(\pi_t - \overline{\pi})[+\phi_y(y_t - \overline{y})]$

New Keynesian DSGE Model: $(\pi_t, y_t) = F(\bar{\pi}^e_{t+1}, \bar{y}^e_{t+1})$

absolute value of eigenvalues of linear map





managing trend-following behavior: increase ϕ_π to **add negative feedback** s.t. the macroeconomy becomes sufficiently stable to **prevent survival of trend-following strategies**

Summary

- behavioral **heuristics switching model** fits **empirical** and **experimental** data at micro and macro level in NK macro framework
- **Heuristics Switching Model** explains coordination on four different **almost self-fulfilling equilibria**:
  - (non-fundamental) steady state
  - exploding inflationary/deflationary spirals
  - dampened oscillations
  - persistent oscillations around target $\bar{\pi} = 3.5$
- a more aggressive Taylor rule can **manage** the **self-organization process**, to **prevent survival of trend-following behavior** and **stabilize** the economy
- **Policy analysis** may benefit from **behavioral model of expectations**

Thanks very much!

If you have any questions ask them now! **References:**

- Assenza, T., Heemeijer, P., Hommes, C.H. and Massaro (2014), Managing self-organization of expectations through monetary policy: a macro experiment, October 2014.
- Cornea, A., Hommes, C.H. and Massaro, D. (2013), Behavioral heterogeneity in U.S. inflation dynamcis, University of Amsterdam, 2014.
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