Some Reflections on Agent-Based Models, Bounded Rationality and Heterogeneous Expectations

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Questions

a. Is **simulation** an effective tool to go from microfoundations with heterogeneous agents to macro conclusions?

b. How to handle the problem of **individual expectations**?

c. How to handle **price determination** and **market clearing** (or not)?

Is Simulation an Effective Tool?

Simulations alone are **not** enough, because

- "wilderness of ABMs", too many degrees of freedom;
- often simulation results are **not** (easily) reproducible;
- **limited insights**: what exactly causes the (macro) outcome?

Einstein: A scientific theory should be **as simple as possible**, but **no simpler**.

Strong need for the **simplest ABM** explaining macro phenomena through micro interactions

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How to model Heterogeneous Expectations of Boundedly Rational Individuals?

Brock and Hommes (1997): as an **evolutionary selection process** among different rules ranging from simple to sophisticated

- agents choose from a (small) list of simple **forecasting heuristics** and more complicated (costly) rules
- **adaptive learning**: some parameters of the heuristics are updated over time, e.g. anchor $\equiv$ time average
- **performance based reinforcement learning:** agents evaluate the **performances** of all heuristics, and tend to **switch** to more successful rules; **impacts are evolving** over time

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What about "Wilderness of Bounded Rationality"?

"Wilderness of Bounded Rationality" is tamed by

- **small list** of forecasting **heuristics** with fixed parameters or some adaptive learning
- **evolutionary selection** of better performing rules, with 2 or 3 parameters for speed of switching (details not important)
- same **heterogeneous expectations model** fits empirical data and laboratory experiments in **different market environments**

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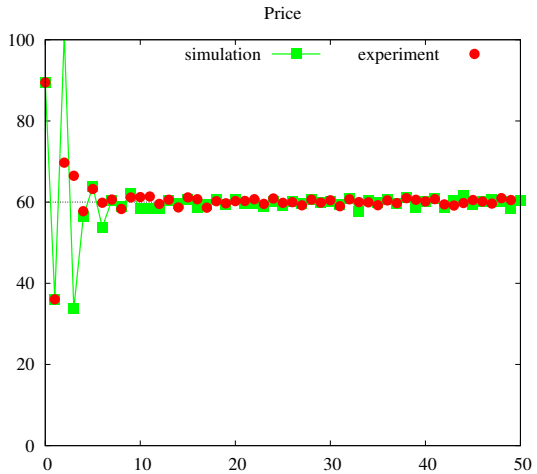
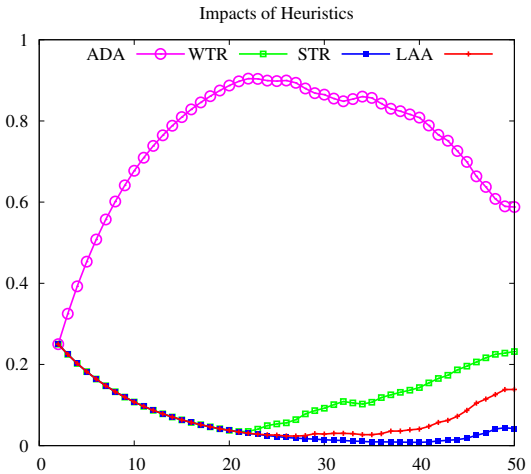
What would be the outcome of such a learning process?

Lab Experiments and Heuristics Switching Model: (Hommes, 2010)





for Muth's cobweb model with **negative expectations feedback**
quick convergence to RE

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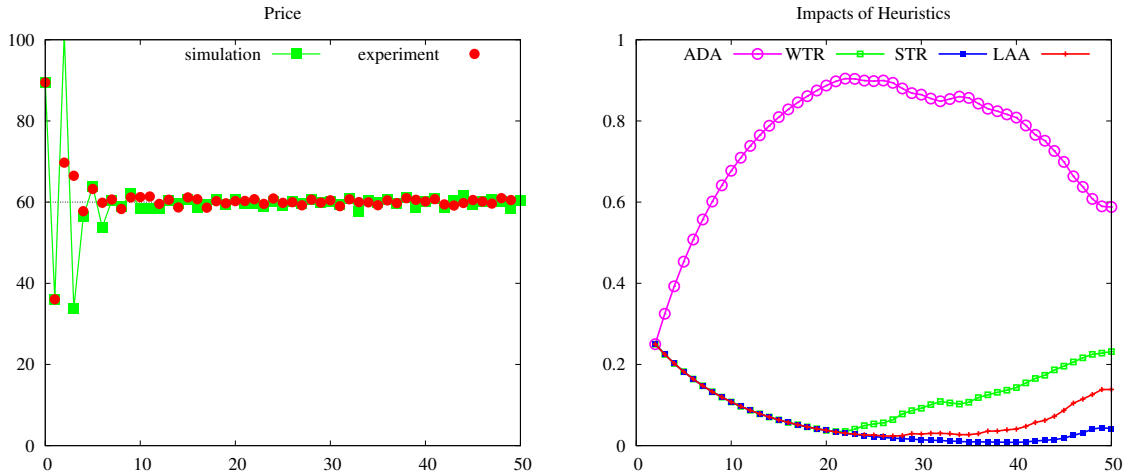

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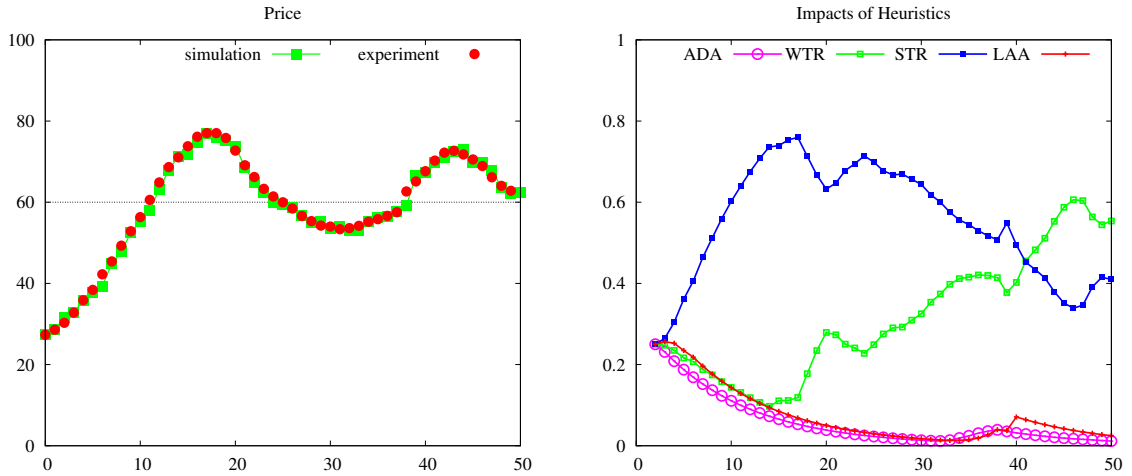

General finding: in **positive expectations feedback** systems, **trendfollowing behavior** performs relatively well and causes persistent deviations from RE benchmark

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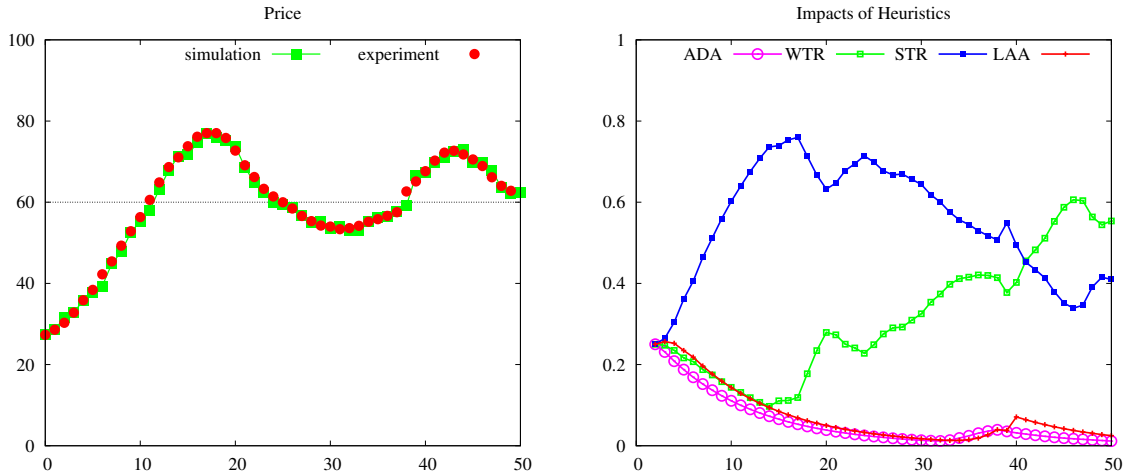

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What about **price determination** and **market clearing** (or not)?

Two observations:

- price adjustment rule through excess demand/supply has **speed of adjustment parameter** which critically affects dynamics. How large is it??
- equilibrium model with **heterogeneous expectations** can explain important macro phenomena, such as persistence in inflation and output, price stickiness, misalignments, excess volatility, etc.

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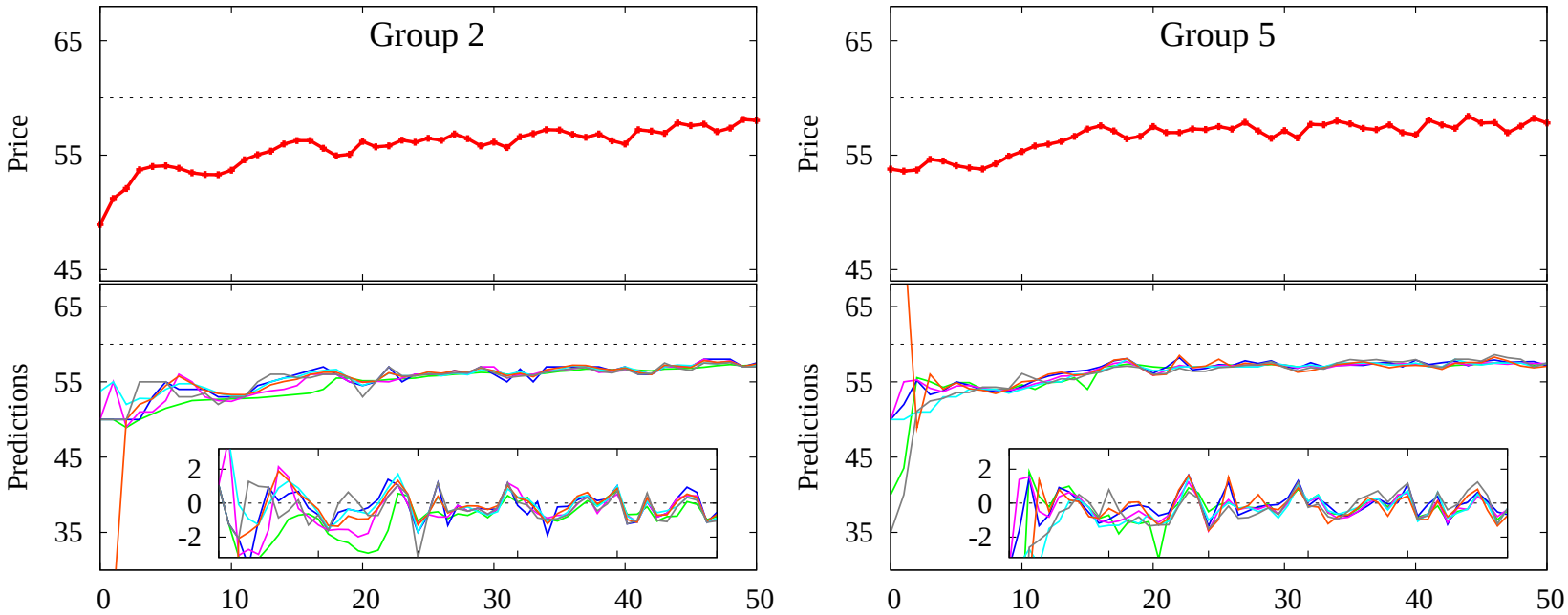
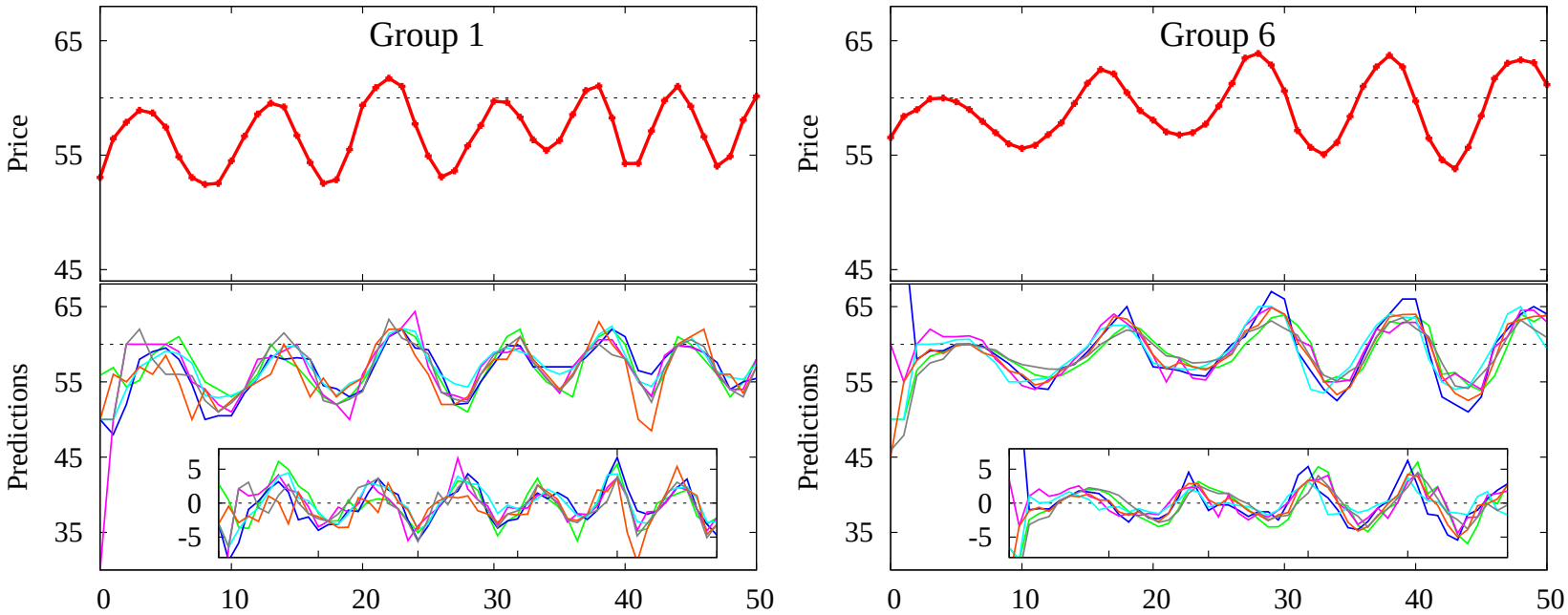
2 Groups with (Almost) Monotonic Convergence

prices, individual predictions and individual errors



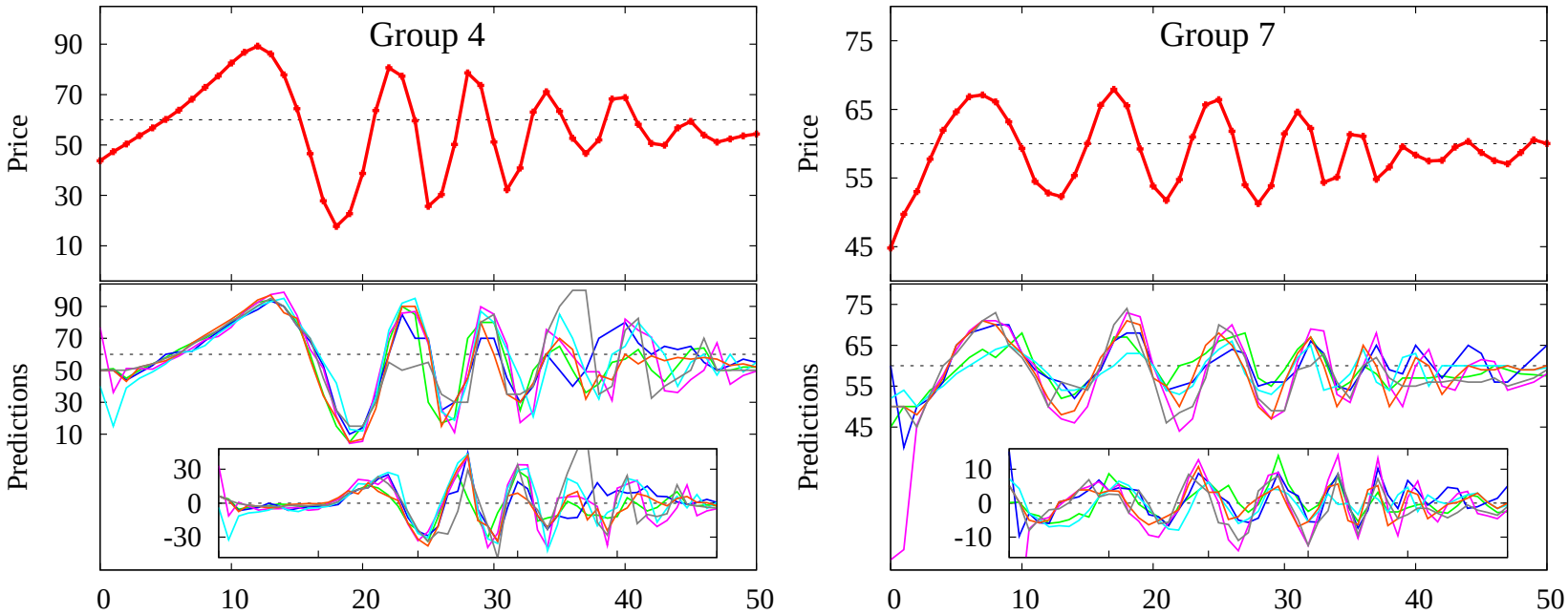
2 Groups with Perpetual Oscillations

prices, individual predictions and individual errors



2 Groups with Damping Oscillations

prices, individual predictions and individual errors



Four forecasting heuristics

- adaptive rule

$$\text{ADA} \quad p^e_{1,t+1} = 0.65\, p_{t-1} + 0.35\, p^e_{1,t}$$

- weak trend-following rule

$$\text{WTR} \quad p^e_{2,t+1} = p_{t-1} + 0.4\,(p_{t-1} - p_{t-2})$$

- strong trend-following rule

$$\text{STR} \quad p^e_{3,t+1} = p_{t-1} + 1.3\,(p_{t-1} - p_{t-2})$$

- anchoring and adjustment heuristics with learnable anchor

$$\text{LAA} \quad p^e_{4,t+1} = 0.5\, p^{av}_{t-1} + 0.5\, p_{t-1} + (p_{t-1} - p_{t-2})$$

Evolutionary Switching

Brock and Hommes (1997), Anufriev and Hommes (2009)

- performance measure of heuristic i is

$$U_{i,t-1} = -\left(p_{t-1} - p^e_{i,t-1}\right)^2 + \eta\, U_{i,t-2}$$

parameter $\eta \in [0,1]$ – the strength of the agents' memory

- discrete choice model with asynchronous updating

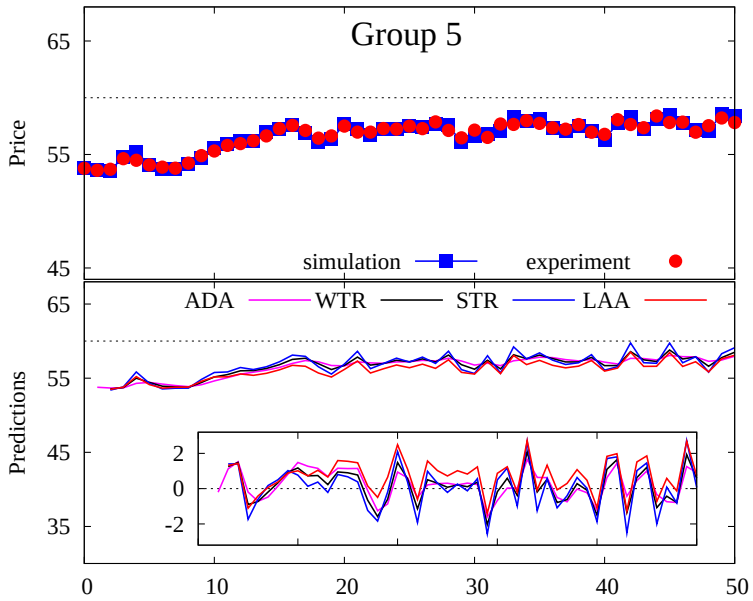
$$n_{i,t} = \delta\, n_{i,t-1} + (1-\delta)\, \frac{\exp(\beta\, U_{i,t-1})}{\sum_{i=1}^{4} \exp(\beta\, U_{i,t-1})}$$

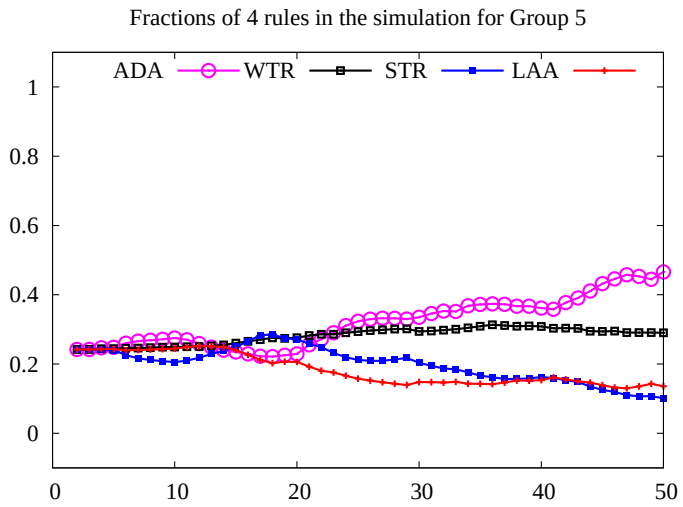
parameter $\delta \in [0,1]$ – the inertia of the traders
parameter $\beta \geq 0$ – the intensity of choice

Group 5 (Convergence)

experimental prices
simulated prices, predictions and errors

Parameters: $\beta = 0.4, \eta = 0.7, \delta = 0.9$



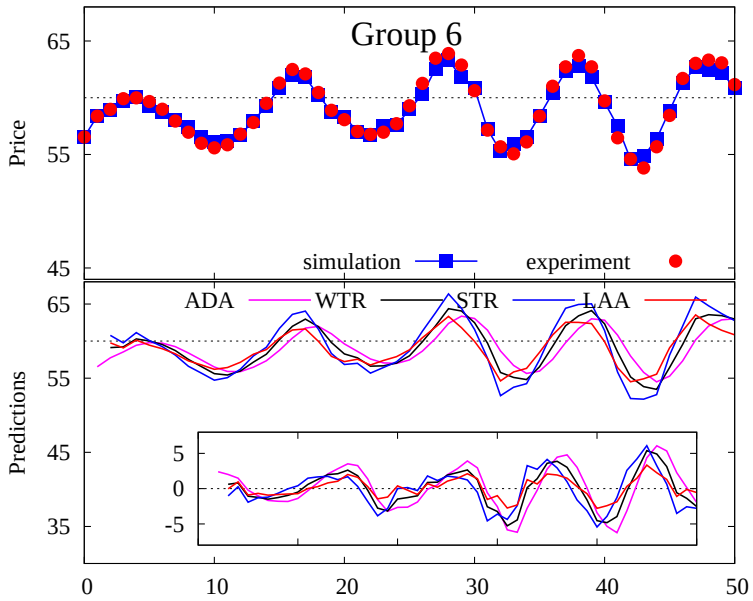


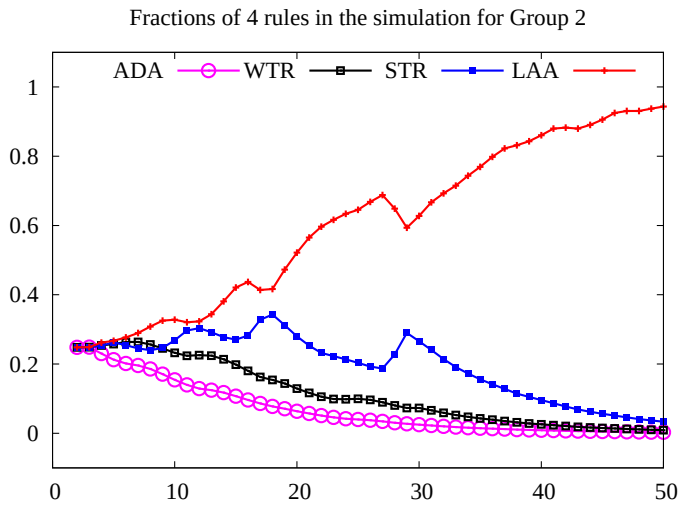
Group 6 (Constant Oscillations)

experimental prices

simulated prices, predictions and errors

Parameters: $\beta = 0.4, \eta = 0.7, \delta = 0.9$



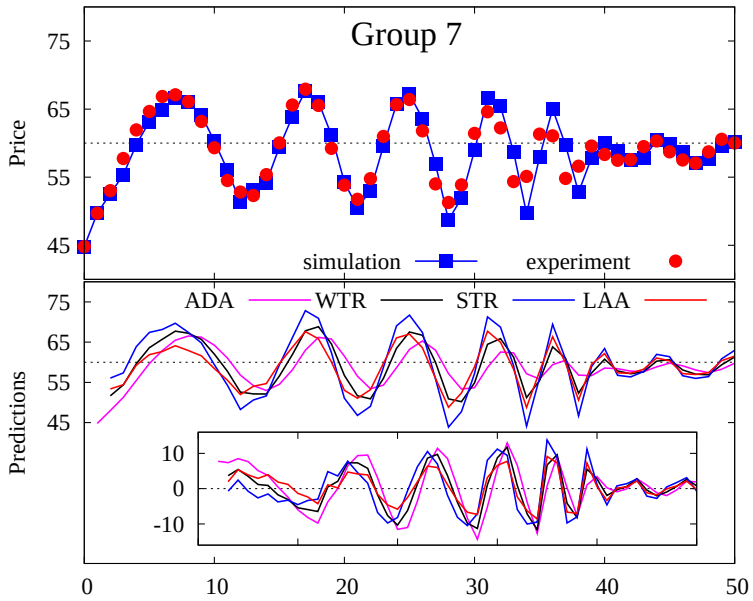


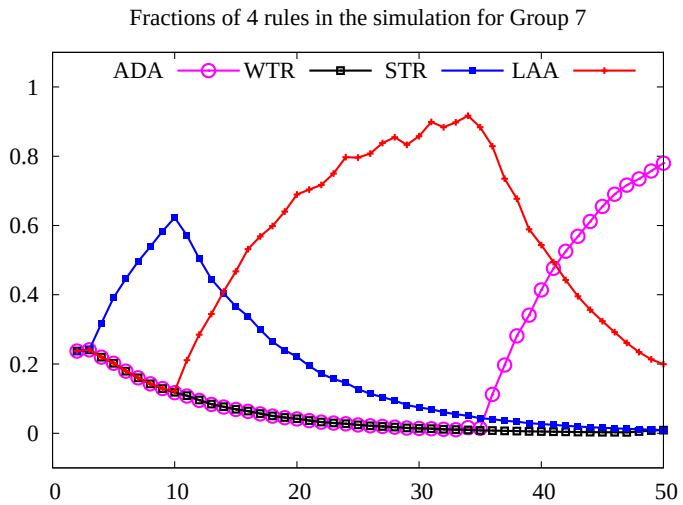
Group 7 (Damping Oscillations)

experimental prices

simulated prices, predictions and errors

Parameters: $\beta = 0.4, \eta = 0.7, \delta = 0.9$



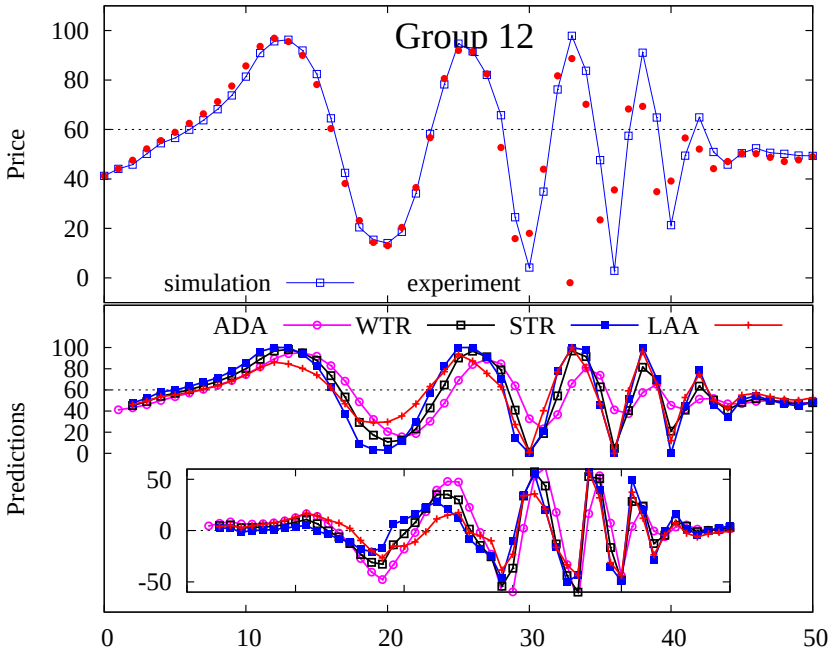


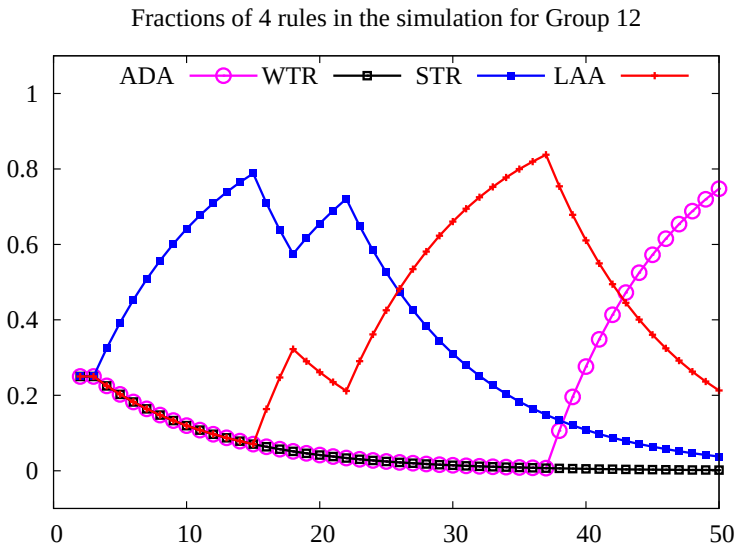
Asset Pricing Experiments without Fundamental Trader

experimental prices

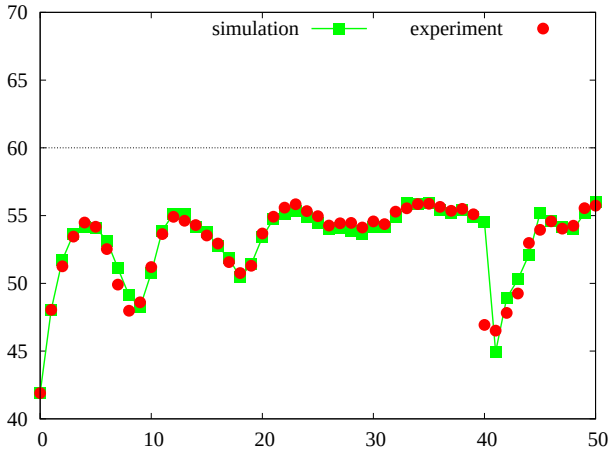
simulated prices, predictions and errors

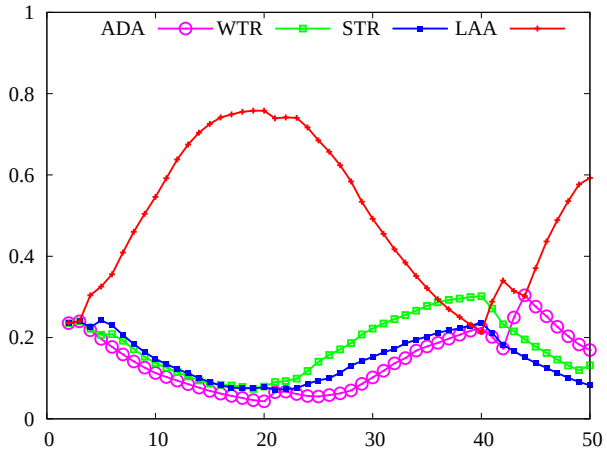
Parameters: $\beta = 0.4, \eta = 0.7, \delta = 0.9$

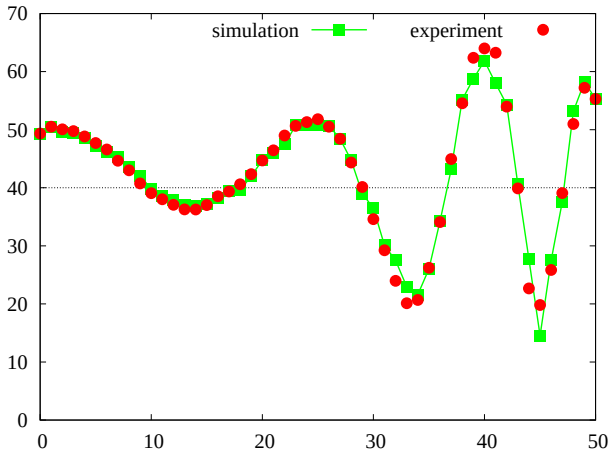


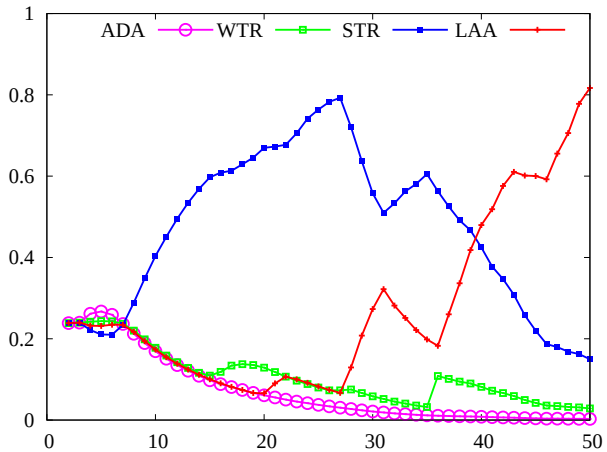


More Asset Pricing Experiments
Group 3 (Typing Error) and Fundamental $p^* = 40$









Positive versus Negative Feedback Experiments

Heemeijer et al. (JEDC 2009); Te Bao, MPhil thesis, 2009

- **negative feedback** (strategic substitute environment)

$$p_t = 60 - \frac{20}{21}[\sum_{h=1}^{6} \frac{1}{6} p_{ht}^e] - 60] + \epsilon_t$$

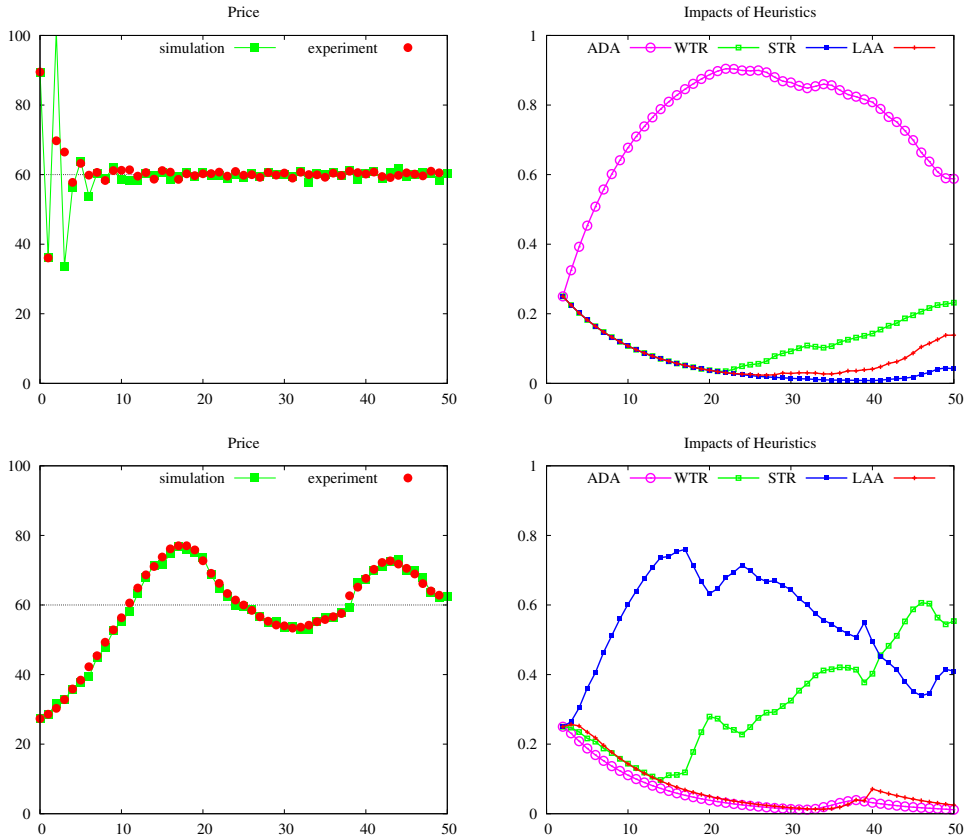
- **positive feedback** (strategic complementarity environment)

$$p_t = 60 + \frac{20}{21}[\sum_{h=1}^{6} \frac{1}{6} p_{ht}^e - 60] + \epsilon_t$$

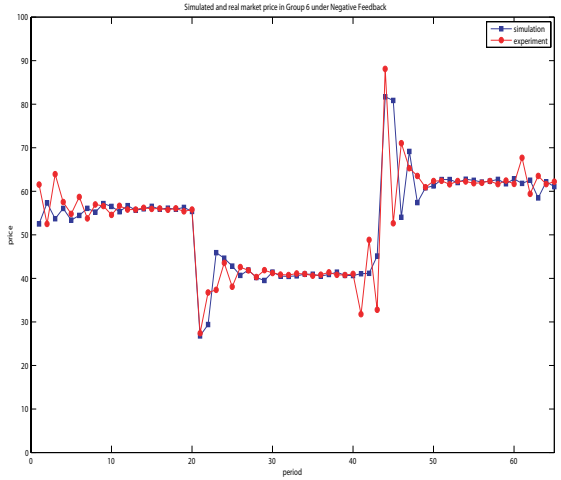
- **different types of shocks** ϵ_t: small resp. large permanent shocks
- **common feature**: same RE equilibrium
- **only difference**: sign in the slope of linear map $+0.95$ vs -0.95

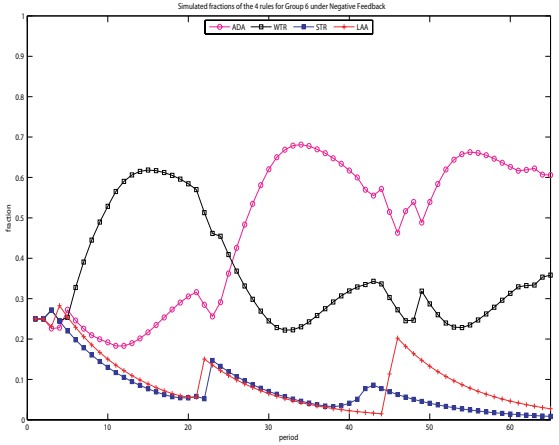
Positive vs Negative Feedback; Small Shocks Heuristics Switching Model Simulations

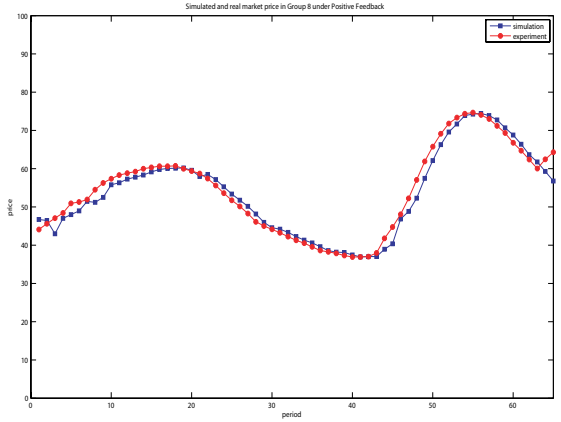
Parameters: $\beta = 0.4, \eta = 0.7, \delta = 0.9$

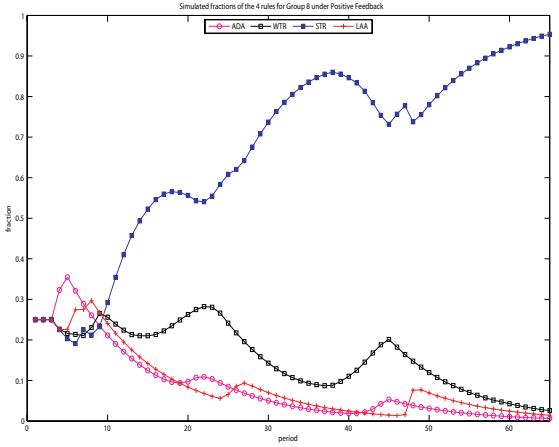


Positive/Negative Feedback; Large Shocks



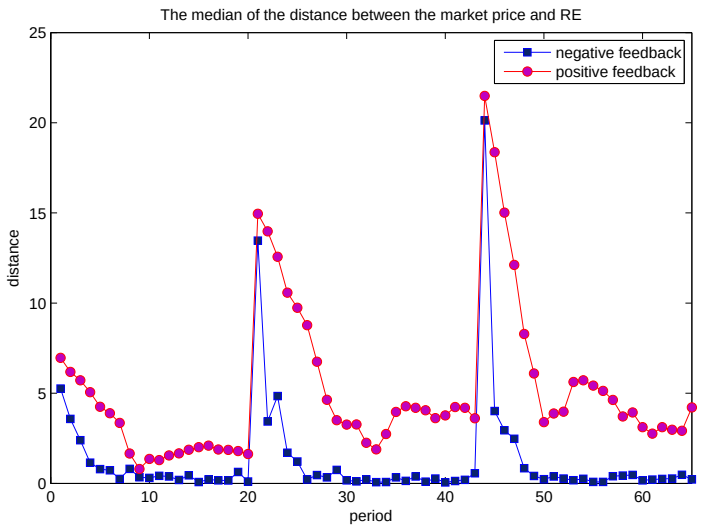


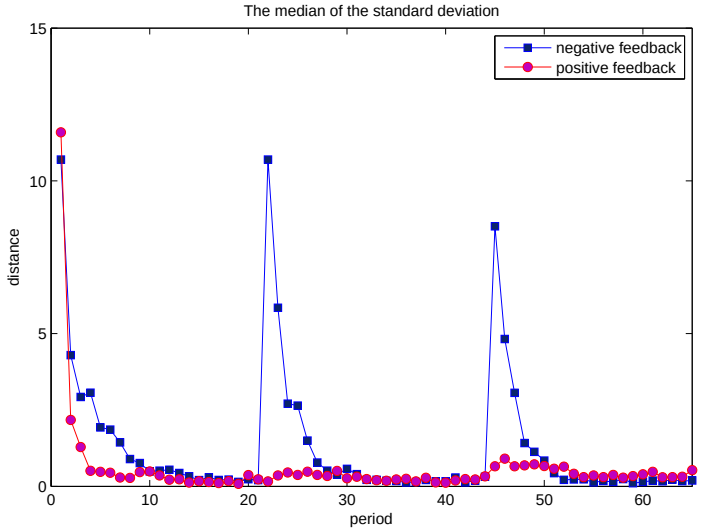




Positive/Negative Feedback; Large Shocks
Coordination & Price Discovery

median absolute distance to RE fundamental price;
median standard deviation of individual predictions





New Keynesian Macro Model; Expectations on Inflation & Output Gap

Assenza et al. (2010)

$$
\begin{aligned}
y_t &= y^e_{t+1} - \varphi(i_t - \pi^e_{t+1}) + g_t \,, && \text{output} && (1)\\
\pi_t &= \lambda y_t + \beta \pi^e_{t+1} + u_t \,, && \text{inflation} && (2)\\
i_t &= \phi_\pi(\pi_t - \overline{\pi}) + \overline{\pi} \,, && \text{interest rate rule} && (3)
\end{aligned}
$$

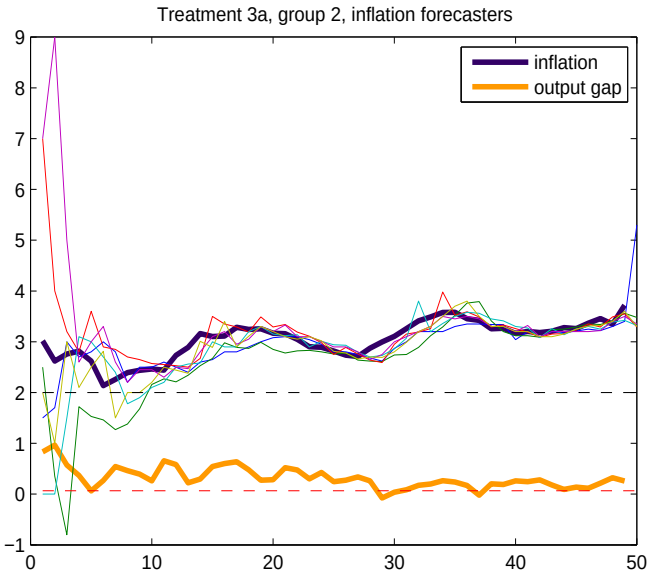
Two treatments:

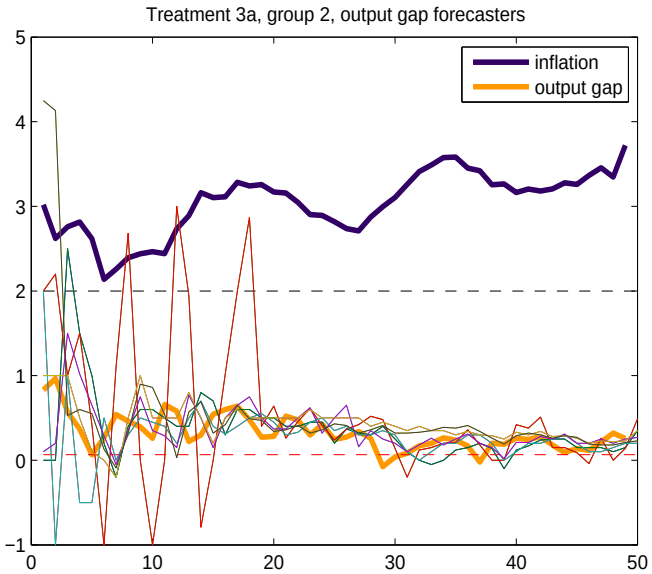
- **passive** monetary policy ($\phi_\pi = 1$)
- **aggressive** monetary policy ($\phi_\pi = 1.5$)

New Keynesian Macro Model; Expectations on Inflation & Output Gap

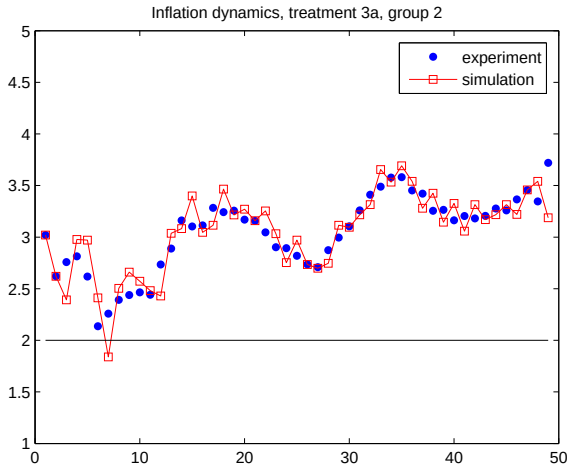
Assenza et al. (2010)

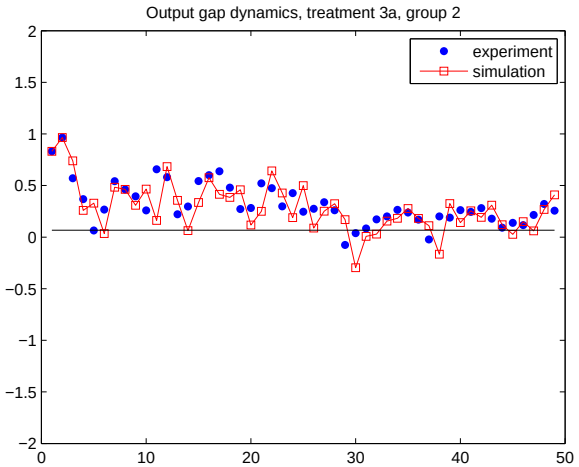
passive monetary policy (i.e. $\phi_\pi = 1$)

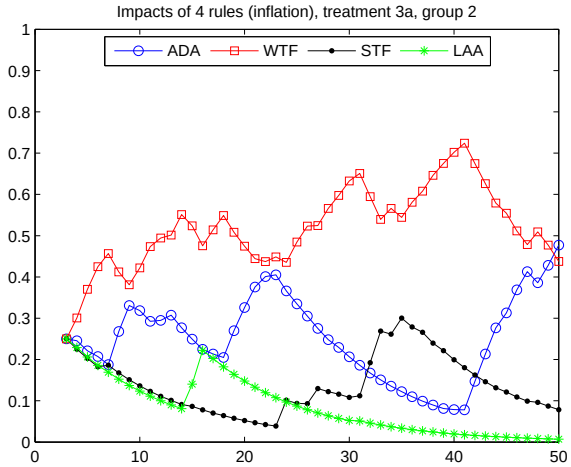


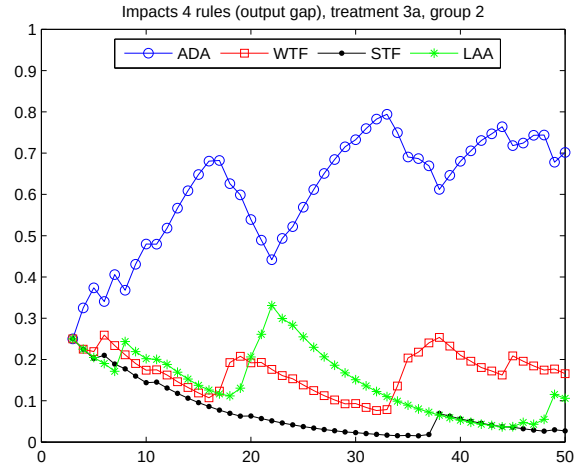


New Keynesian Macro Model: Simulations (Domenico Massaro)









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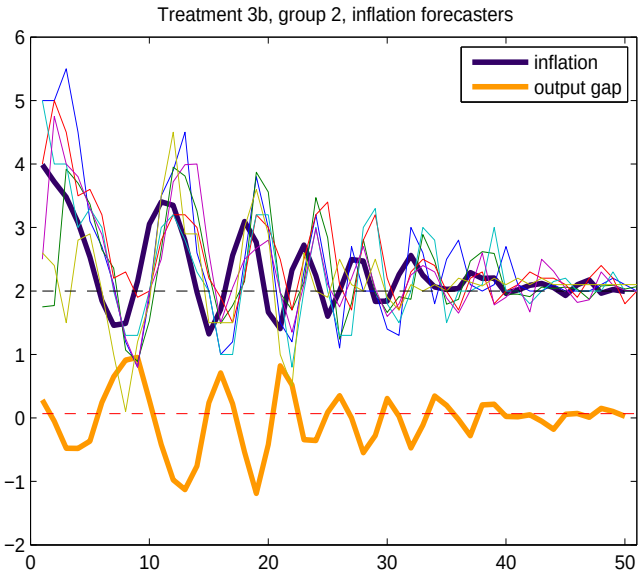
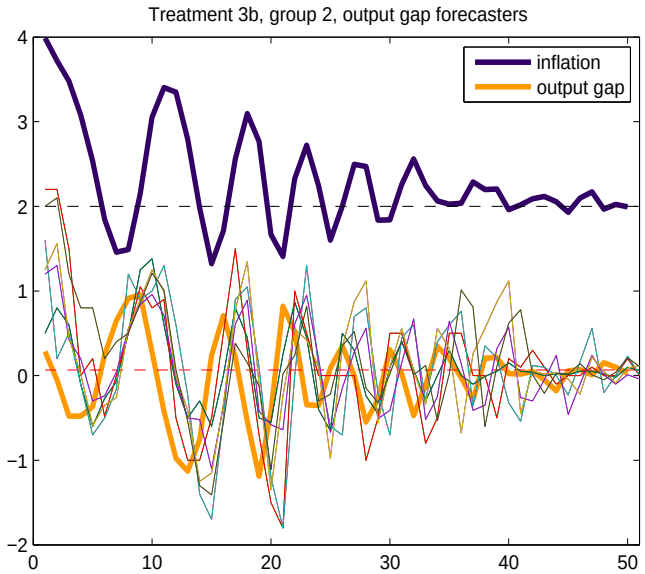
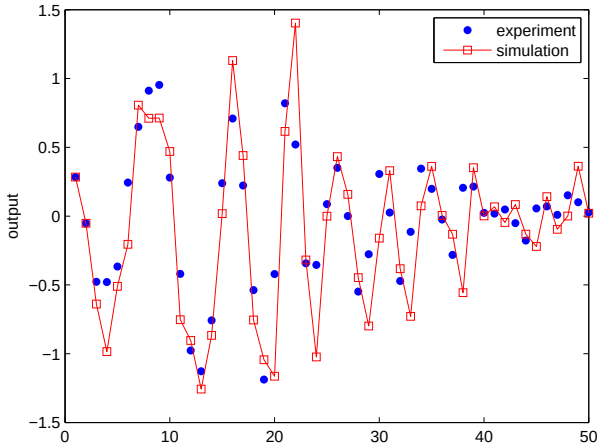
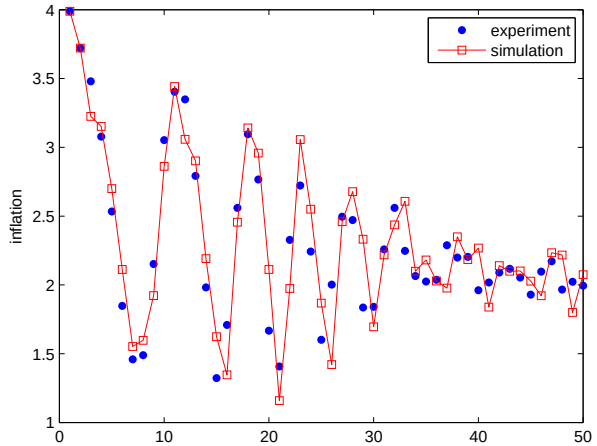
aggressive monetary policy (i.e. $\phi_\pi = 1.5$)

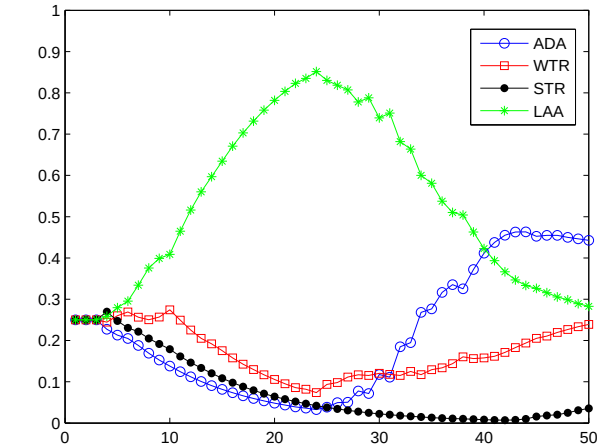


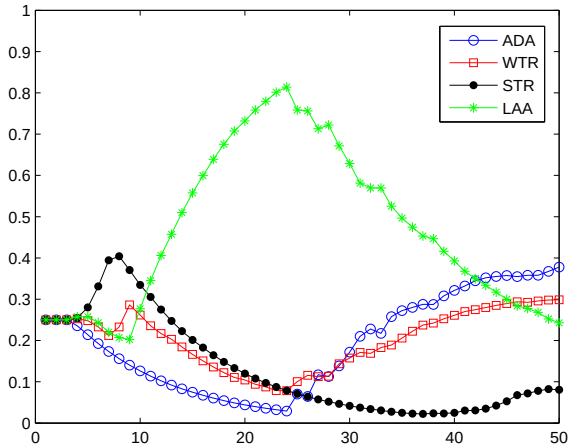


New Keynesian Macro Model: Simulations (Domenico Massaro)









Concluding Remarks on Heterogeneous Expectations

- **no homogeneous** expectations model fits **all** experiments
- **only** in stable cobweb/negative feedback quick **convergence** to REE
- **heterogeneity** in expectations is crucial, because **one model** explains observed
  - **path dependence** in **same** market environment
  - **different** aggregate outcomes in **different** markets
  - **different** forecasting behavior for different variables in one macro economy
- **challenge:** universal theory of heterogeneous expectations