Experiments and Models of Non-Rational Behaviour

Cars Hommes

CeNDEF, University of Amsterdam
and Tinbergen Institute

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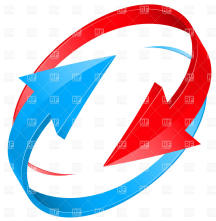
Main Ingredients of the Talk

- financial markets and the economy as **complex evolving systems** of **interacting agents**
- **behavioral** theory of **heterogeneous** expectations of **boundedly rational** individuals
- empirical validation of individual (micro) and aggregate (macro) behaviour through **laboratory experiments**

Economy as Expectations Feedback System

beliefs/expectations



realizations

mapping from all **heterogeneous beliefs** to price realizations

$$p_t = F(p^e_{1,t+1}, p^e_{2,t+1}, \cdots p^e_{H,t+1})$$

simple mapping from **average beliefs** into **price realizations**

$$p_t = f(\frac{1}{H}\sum_{h=1}^{H} p^e_{h,t+1}) = f(\overline{p^e_{t+1}})$$

rational solution: beliefs on average equal to realizations

$p^* = f(p^*)$: **perfectly self-fulfilling expectations**

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

Learning to Forecast Experiments (Ctd)

Subjects' task and incentive

- forecasting a price for 50 periods
- **better** forecasts yield **higher** earnings

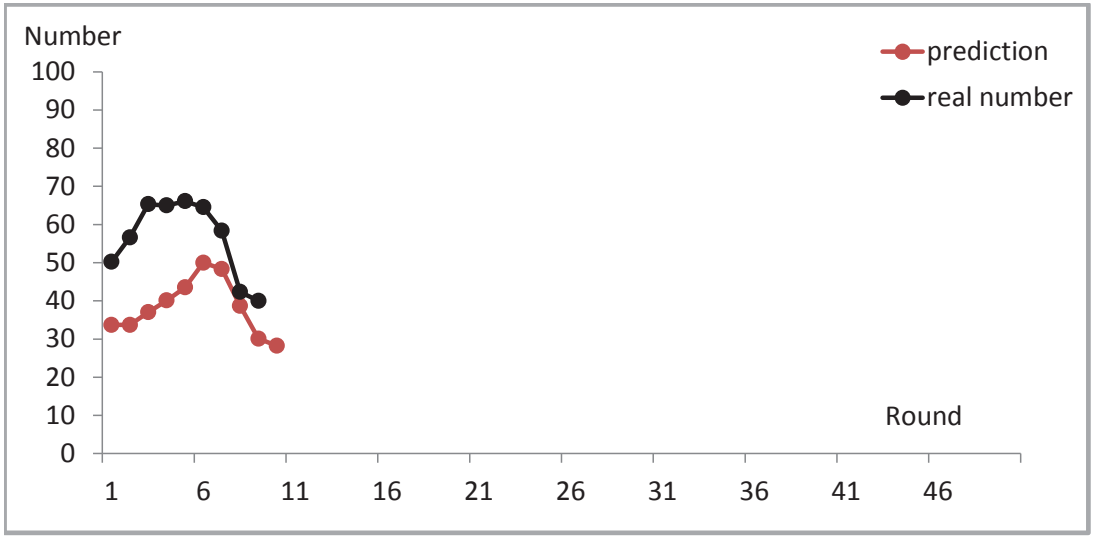
Subjects know

- only **qualitative information** about the market
- price p_t derived from equilibrium between **demand** and **supply**
- type of expectations feedback: **positive** or **negative**
- **past information**: at time t participant h can see past prices (up to p_{t-1}), own past forecasts (up to $p_{t,h}$) and own earnings (up to $e_{t-1,h}$)

Subjects do not know

- exact equilibrium **equation**, e.g. $p_t = f(\bar{p}^e_{t+1})$ or $p_t = f(\bar{p}^e_t)$
- exact **demand schedule** of themselves and others
- number and **forecasts of other** participants

Example Computer Screen Experiment



Total earnings:	Earnings this period:	Remaining time:
10357	1298	00

What is your prediction this period? Your prediction must be between 0 and 100	Prediction:

Round	Prediction	Real value
1	33,70	50,23
2	33,70	56,63
3	37,00	65,32
4	40,10	65,00
5	43,50	66,12
6	50,00	64,53
7	48,35	58,35
8	38,70	42,35
9	30,10	40,01
10	28,25	

Three Different Experimental Settings

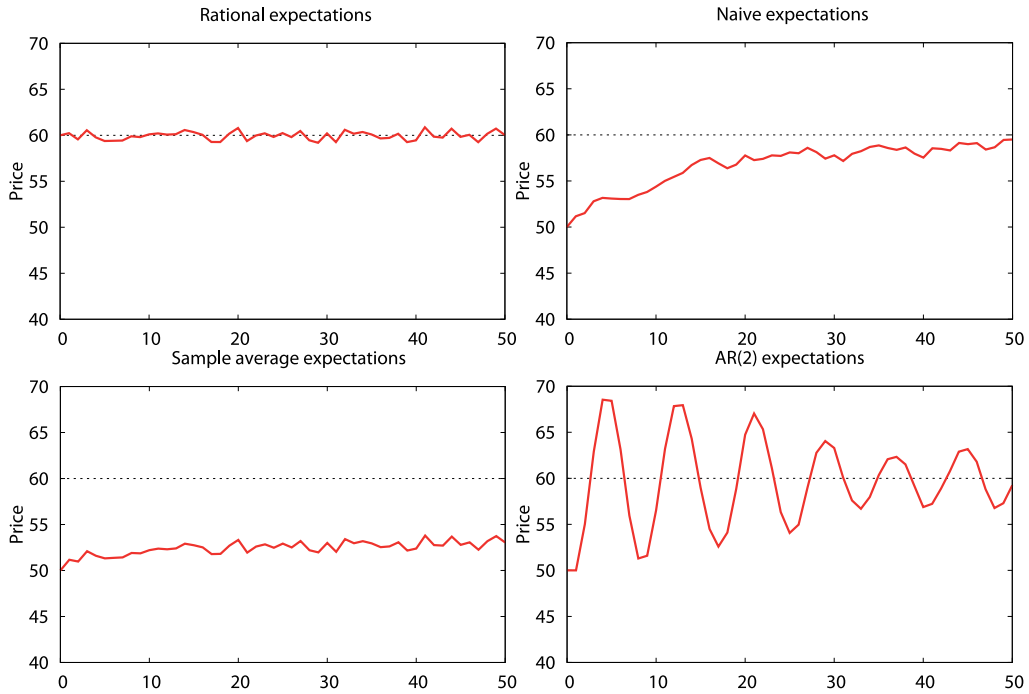
- **asset pricing experiment** (with/without robot trader)
  - two-period ahead
  - positive feedback

$$p_t = \frac{1}{1+r}\left((1-n_t)\frac{p^e_{t+1,1}+\cdots+p^e_{t+1,6}}{6}+n_t\,p^f+\bar{y}+\varepsilon_t\right)$$

- **positive** versus **negative** feedback; one-period ahead $p_t = f(p^e_t)$:
  - **positive** feedback: linear, slope $+0.95$;
  - **negative** feedback: linear, slope -0.95.
- **New Keynesian Macromodel**: aggregate inflation and output depend on individual forecasts of **both** inflation and output (and monetary policy rule):

$$(\pi_t, y_t) = F(\pi^e_{t+1}, y^e_{t+1})$$

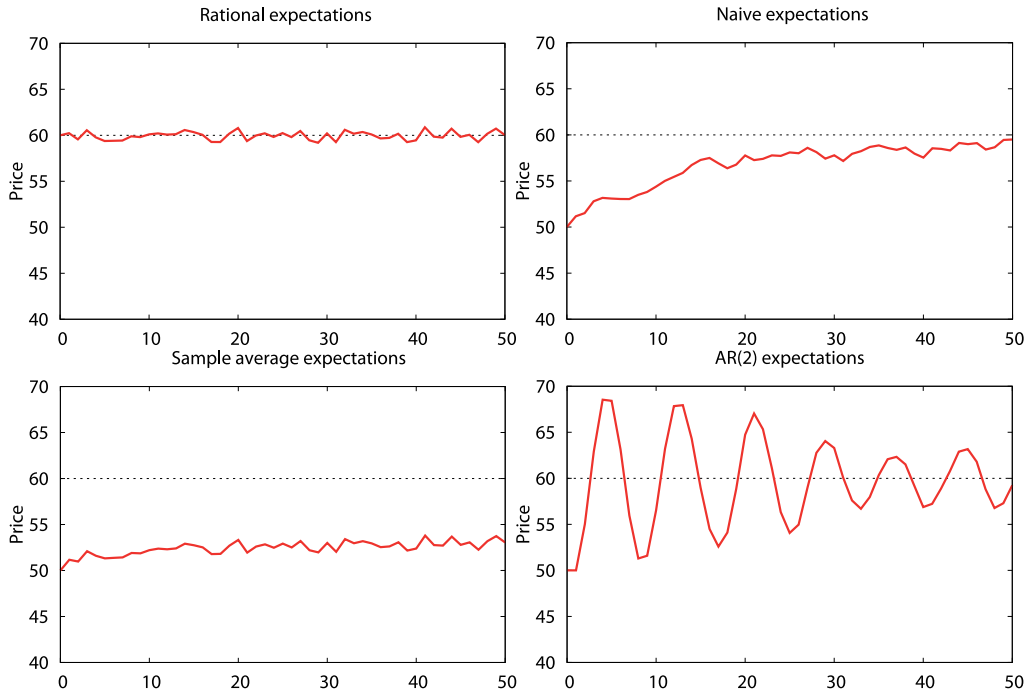
Asset Pricing Experiment Simulation Benchmarks



AR2 // anchor and adjustment rule

$$p^e_{t+1} = 30 + \tfrac{3}{2}p_{t-1} - p_{t-2} = (60 + p_{t-1})/2 + (p_{t-1} - p_{t-2})$$

Asset Pricing Experiment Simulation Benchmarks



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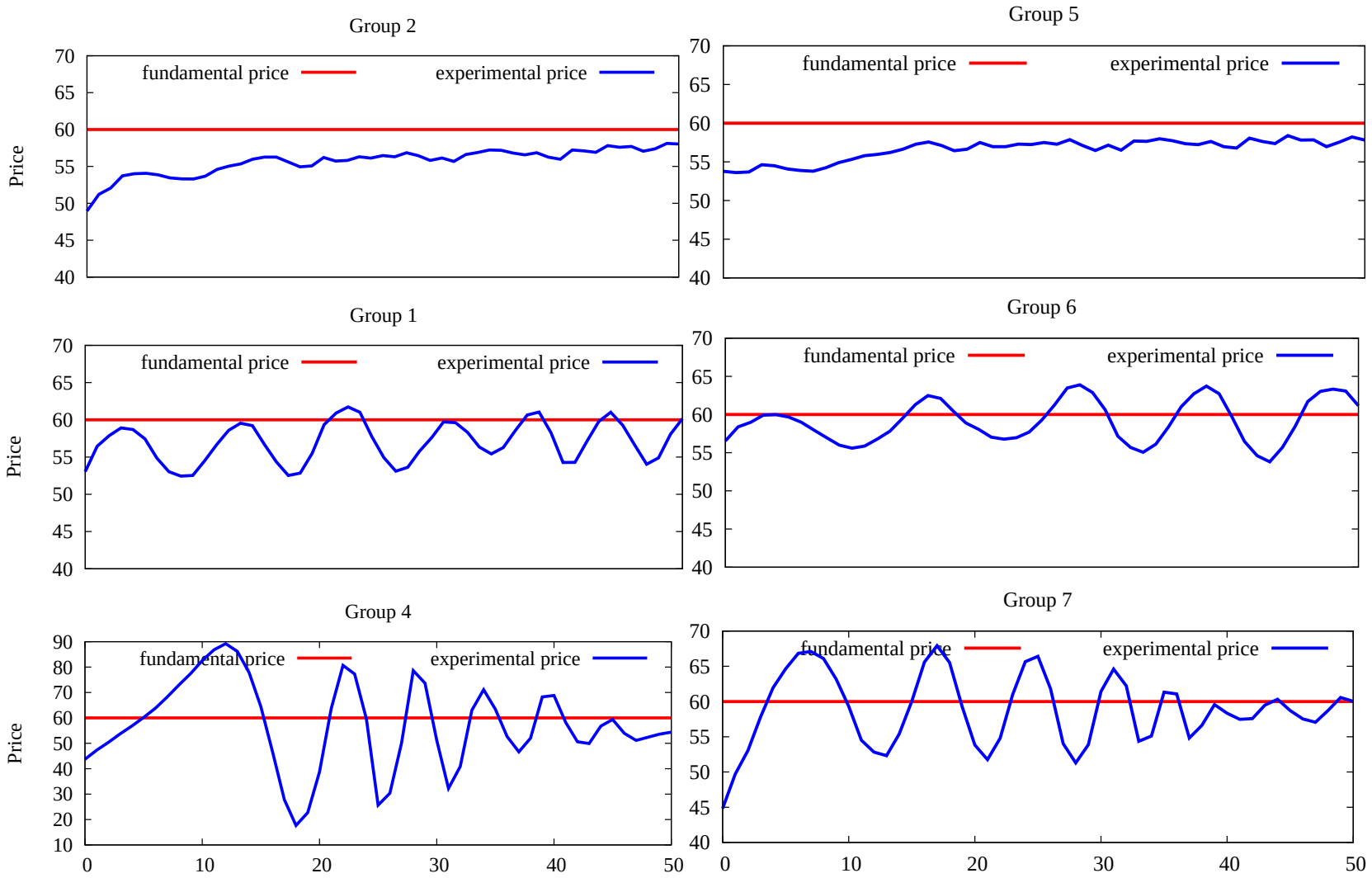
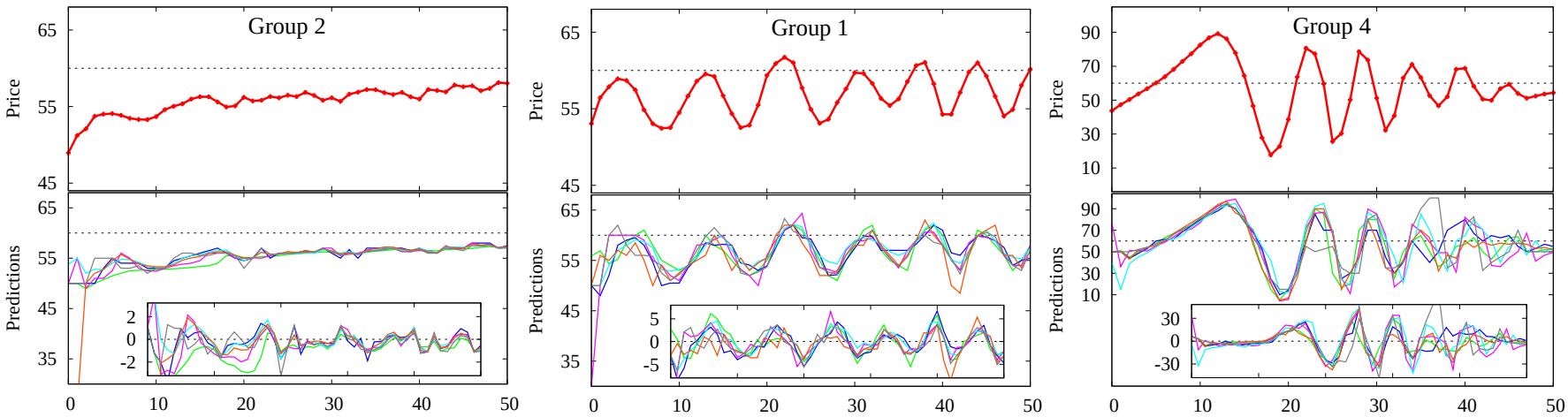
Asset Pricing Experiment (with Robot Trader)

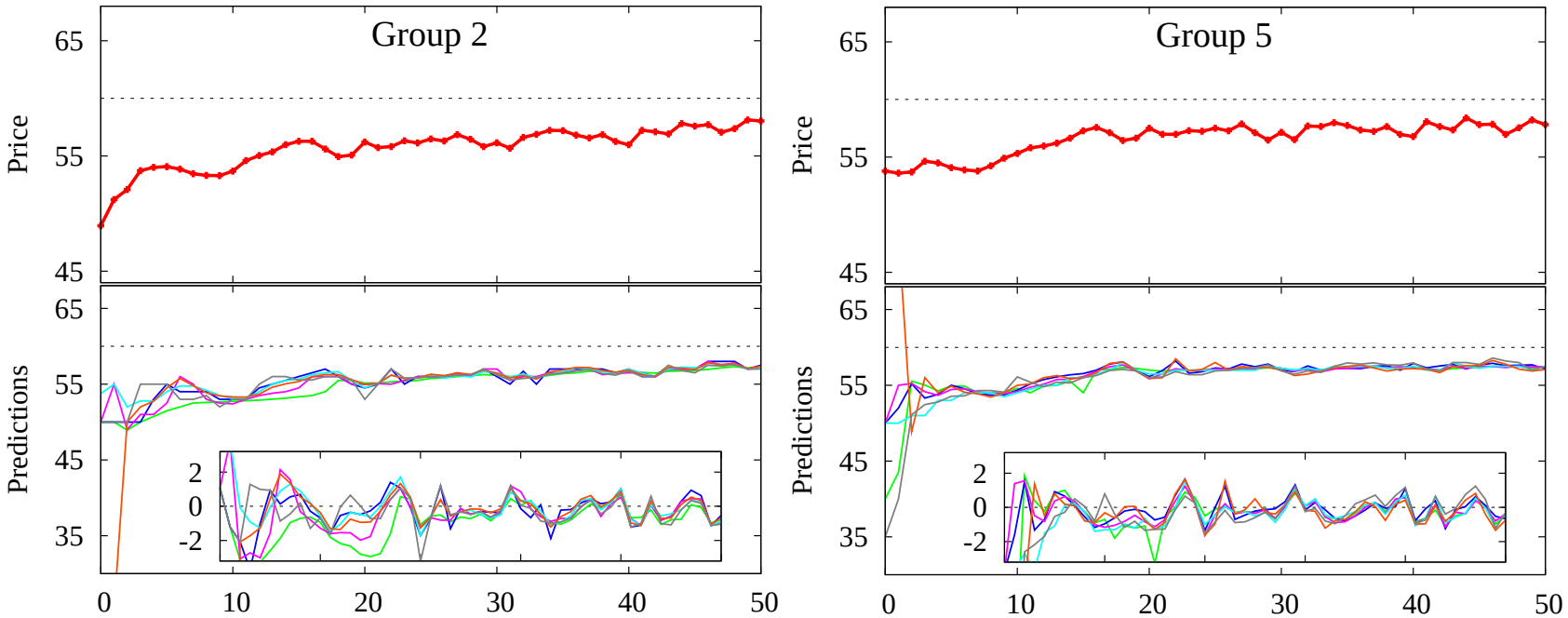


Asset Pricing Experiment

Strong coordination of individual forecasts and errors

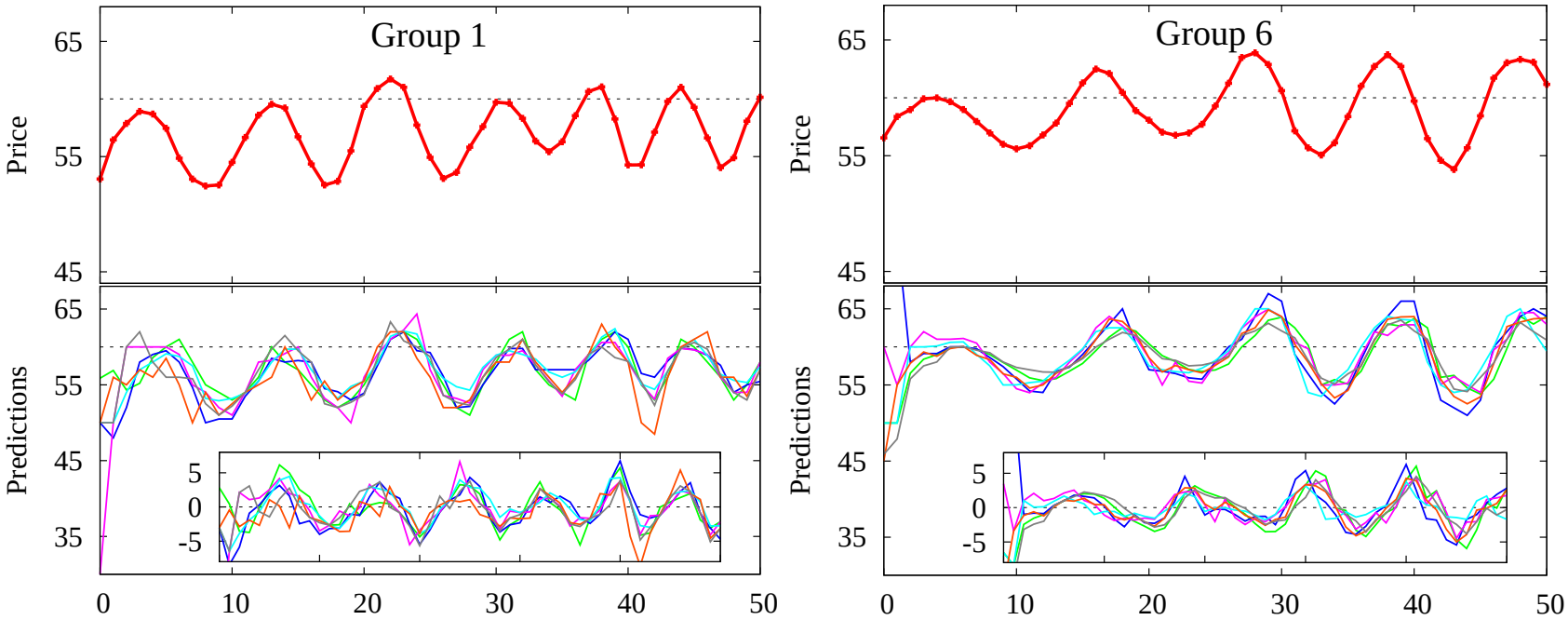


Groups with (Almost) Monotonic Convergence prices, individual predictions and individual errors



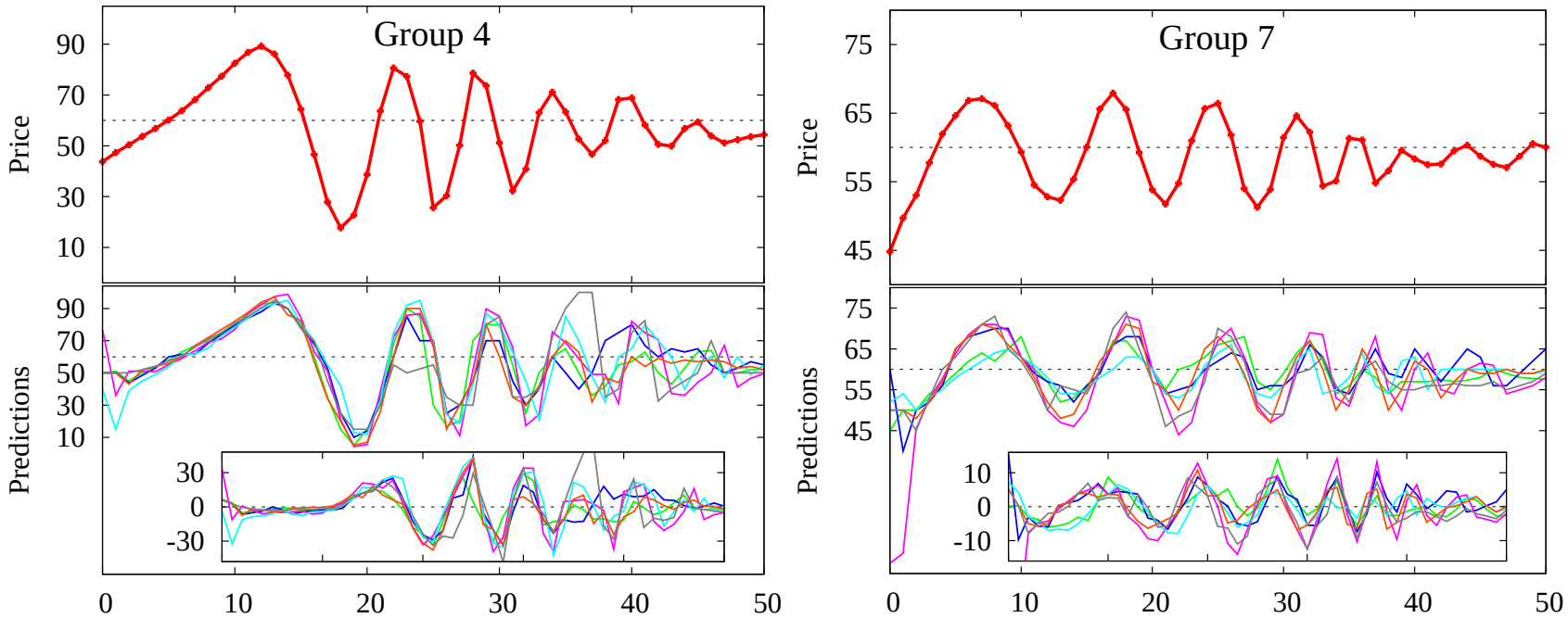
2 Groups with Perpetual Oscillations

prices, individual predictions and individual errors



2 Groups with Damping Oscillations

prices, individual predictions and individual errors



Summary Results Asset Pricing Experiment

Results are inconsistent with rational, fundamental forecasting

One would like to explain:

- three qualitatively different patters
  - (almost) monotonic convergence
  - constant oscillations
  - damping oscillations
- coordination of agents in their predictions
- no homogeneous expectations model fits these experiments need **heterogeneous expectations model**

Estimation of Individual Predictions

...for the last 40 periods

- in converging groups agents use **adaptive expectations**

$$p^e_{t+1} = w\, p_{t-1} + (1-w)\, p^e_t$$

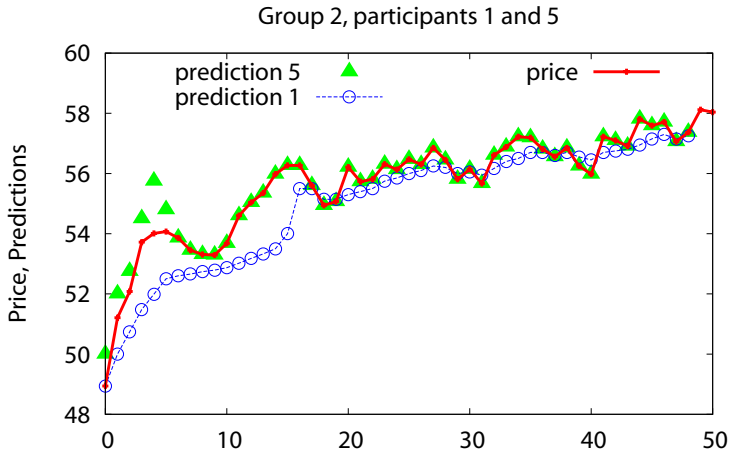
- often agents used **simple linear rules**
  anchor and adjustment rule

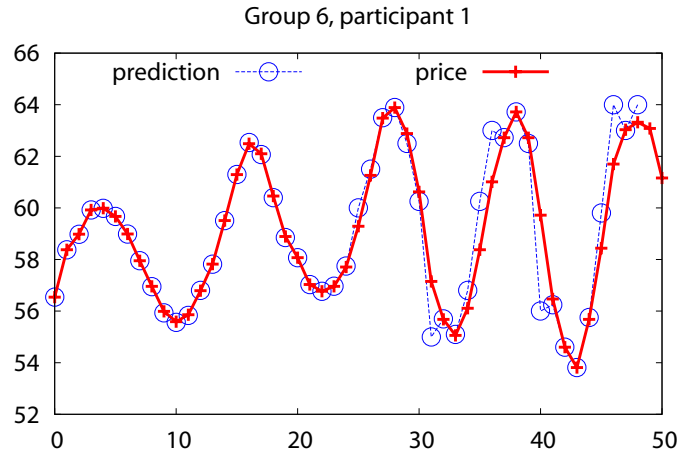
$$\begin{array}{ll} p^e_{t+1} = & \alpha + \beta_1\, p_{t-1} + \beta_2\, p_{t-2} \\ \text{e.g.} & (60 + p_{t-1})/2 + (p_{t-1} - p_{t-2}) \\ \text{or LAA} & (p^{av}_{t-1} + p_{t-1})/2 + (p_{t-1} - p_{t-2}) \end{array}$$

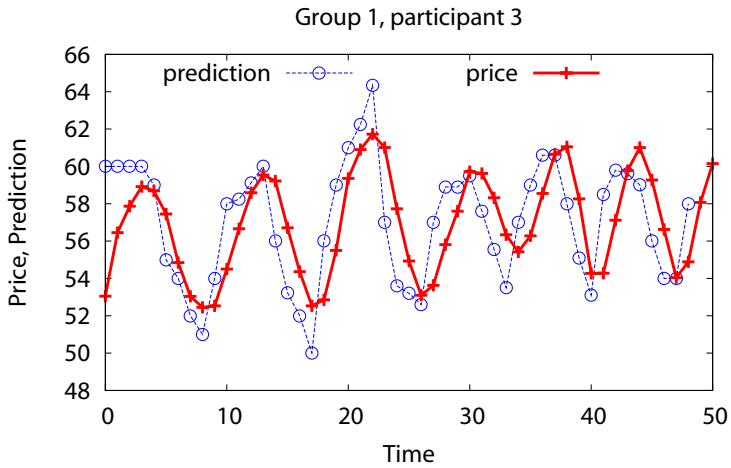
in particular **trend-extrapolating rules**

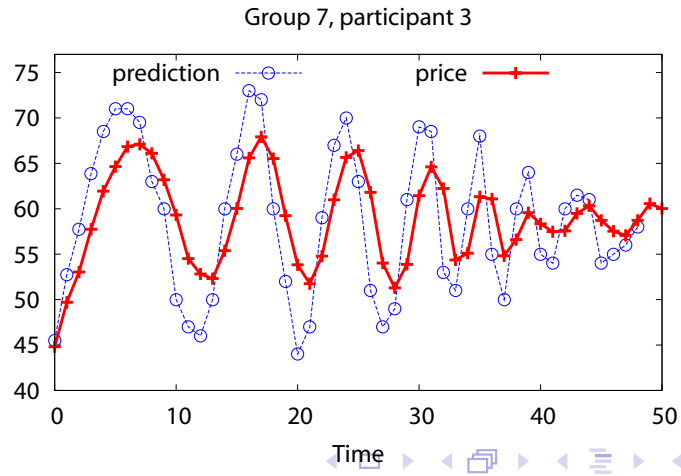
$$p^e_{t+1} = p_{t-1} + \gamma\,(p_{t-1} - p_{t-2}) \qquad 0.4 \leq \gamma \leq 1.3$$

Examples of Individual Predictions and Switching









Heterogeneous Expectations Heuristics Switching Model

Anufriev and Hommes, AEJ:Micro 2012

- agents choose from a number of simple **forecasting heuristics**
- **adaptive learning**: some parameters of the heuristics are updated over time, e.g. anchor $\equiv$ average
- **performance based reinforcement learning:**
  (extension of Brock and Hommes, *Econometrica* 1997)
  agents evaluate the **performances** of all heuristics, and tend to **switch** to more successful rules; **impacts are evolving** over time

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 with Asynchronous Updating

- 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

Stochastic Simulations (one step ahead forecast)

Anufriev and Hommes (2012)

- uses **past experimental data**
- **same information** as participants in experiments

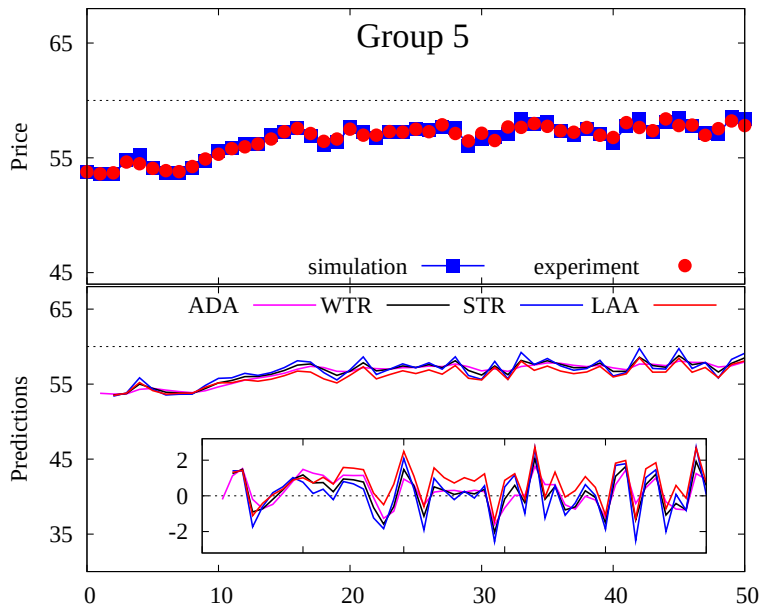
Parameters fixed at: $\beta = 0.4, \eta = 0.7, \delta = 0.9$

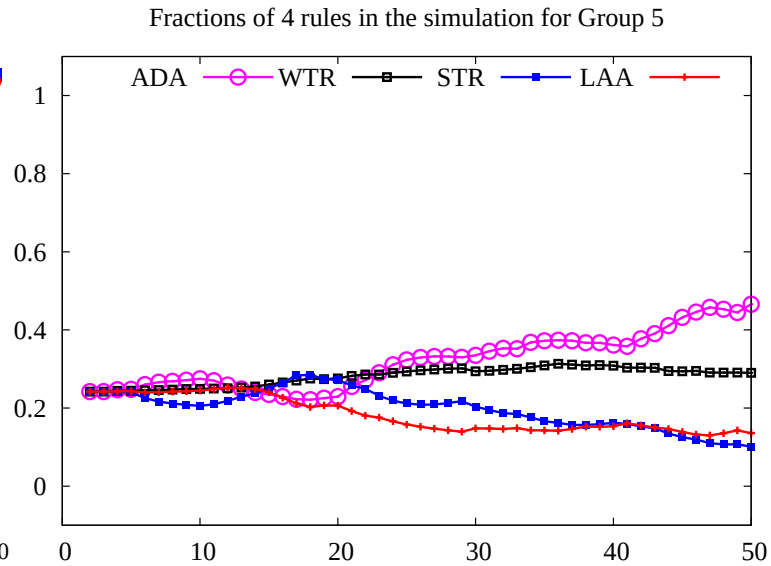
- initial fractions **equal**, i.e. $n_{ht} = 0.25$
- initial prices **as in experiments**

Group 5 (Convergence)

experimental prices
simulated prices, predictions and errors

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

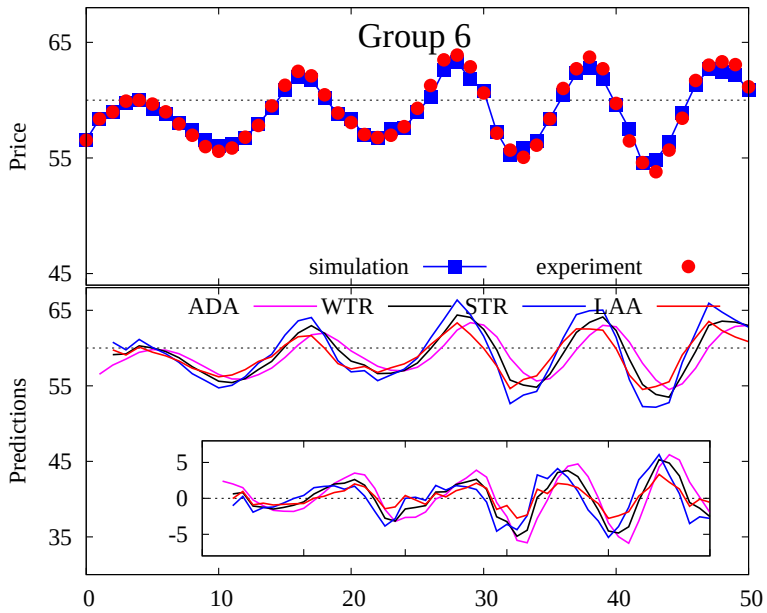


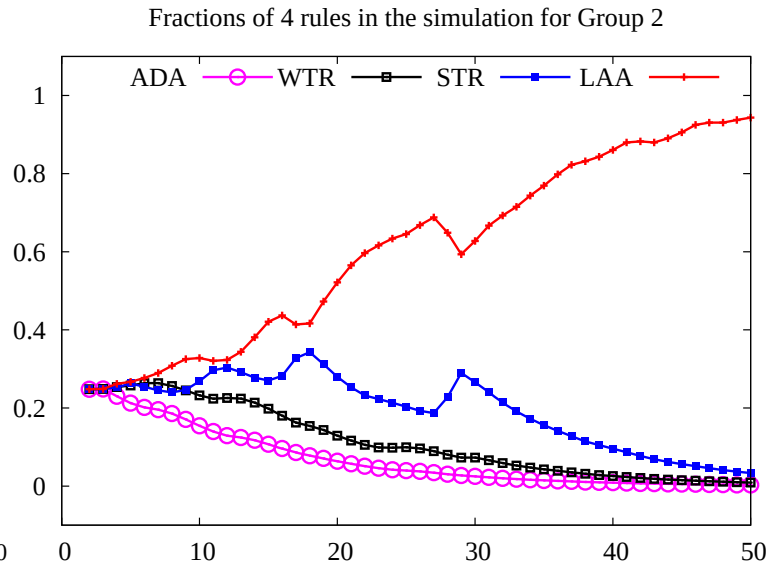


Group 6 (Constant Oscillations)

experimental prices
simulated prices, predictions and errors

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

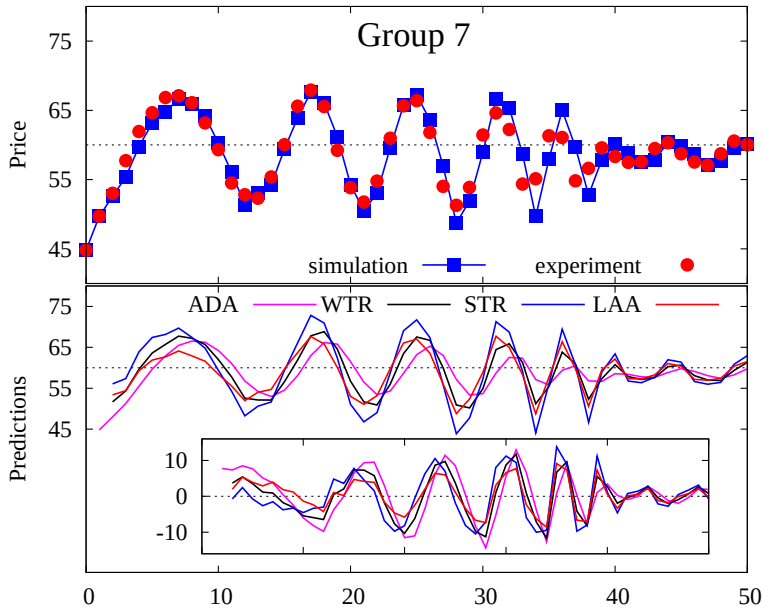


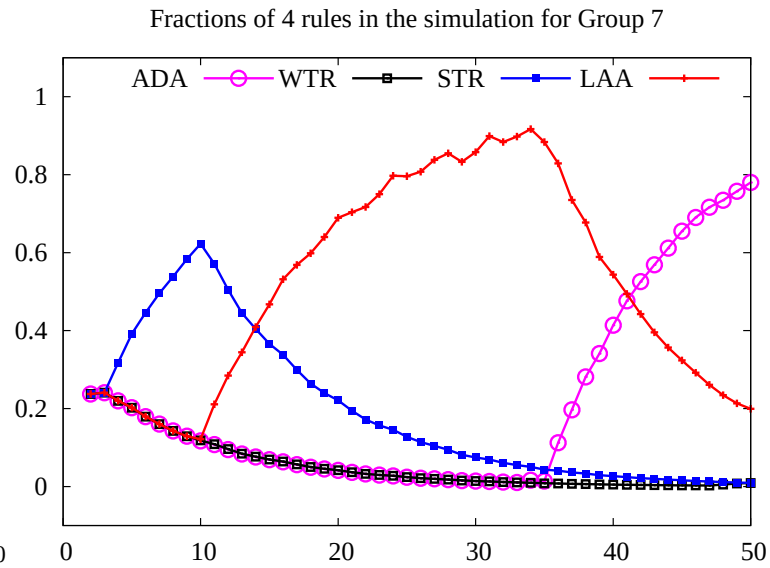


Group 7 (Damping Oscillations)

experimental prices
simulated prices, predictions and errors

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





Muth (1961) on Deviations from Rationality

[emphasis added]

Allowing for **cross-sectional differences** *in expectations is a simple matter, because their* **aggregate affect is negligible** *as long as the deviation from the rational forecast for an individual firm is* **not strongly correlated with those of the others**. *Modifications are necessary only if the* **correlation of the errors is large** *and depends systematically on other explanatory variables.*

key issues:

- are individual expectations **coordinated**?
- if so, do individuals coordinate on a **rational** or a **boundedly rational** aggregate outcome?

This can be tested in **Learning to Forecast Experiments**

Positive versus Negative Feedback Experiments

Heemeijer et al. (JEDC 2009); Bao et al. (JEDC 2012

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

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

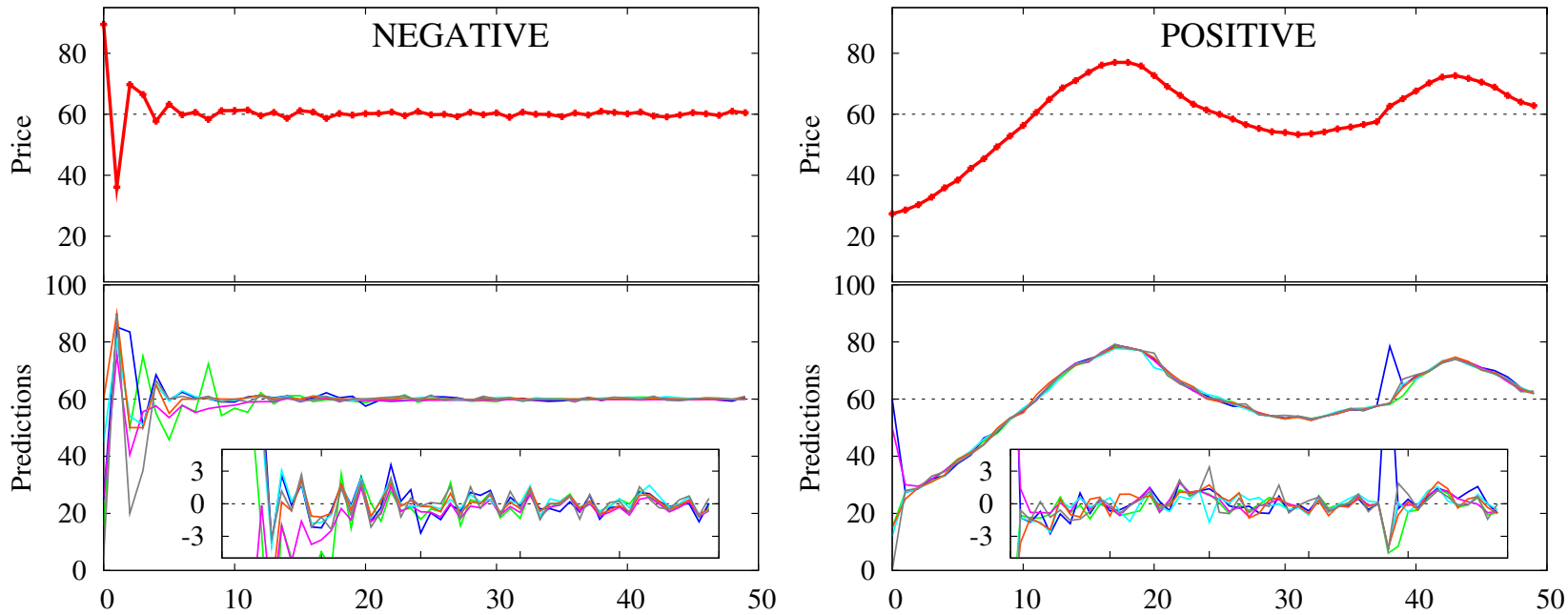
- **positive feedback** (strategic complementarity environment)

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

- **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

Negative vs. Positive Feedback Experiments

Prices, Individual Predictions and Errors

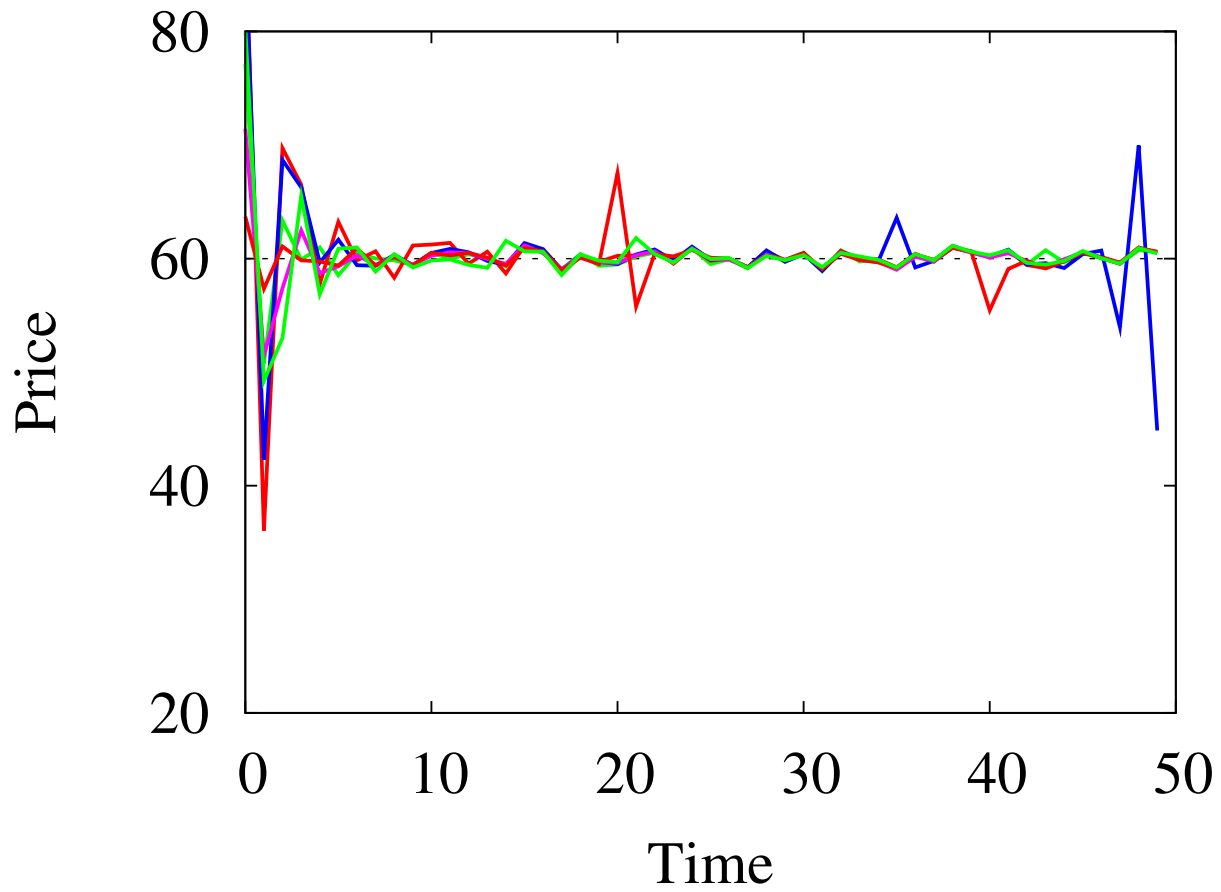


Positive Feedback: coordination on "wrong" non-RE price; coordination on **almost self-fulfilling equilibria**

Negative Feedback Experiment: Session 1

Price in Experiments with Negative Feedback (6 groups)

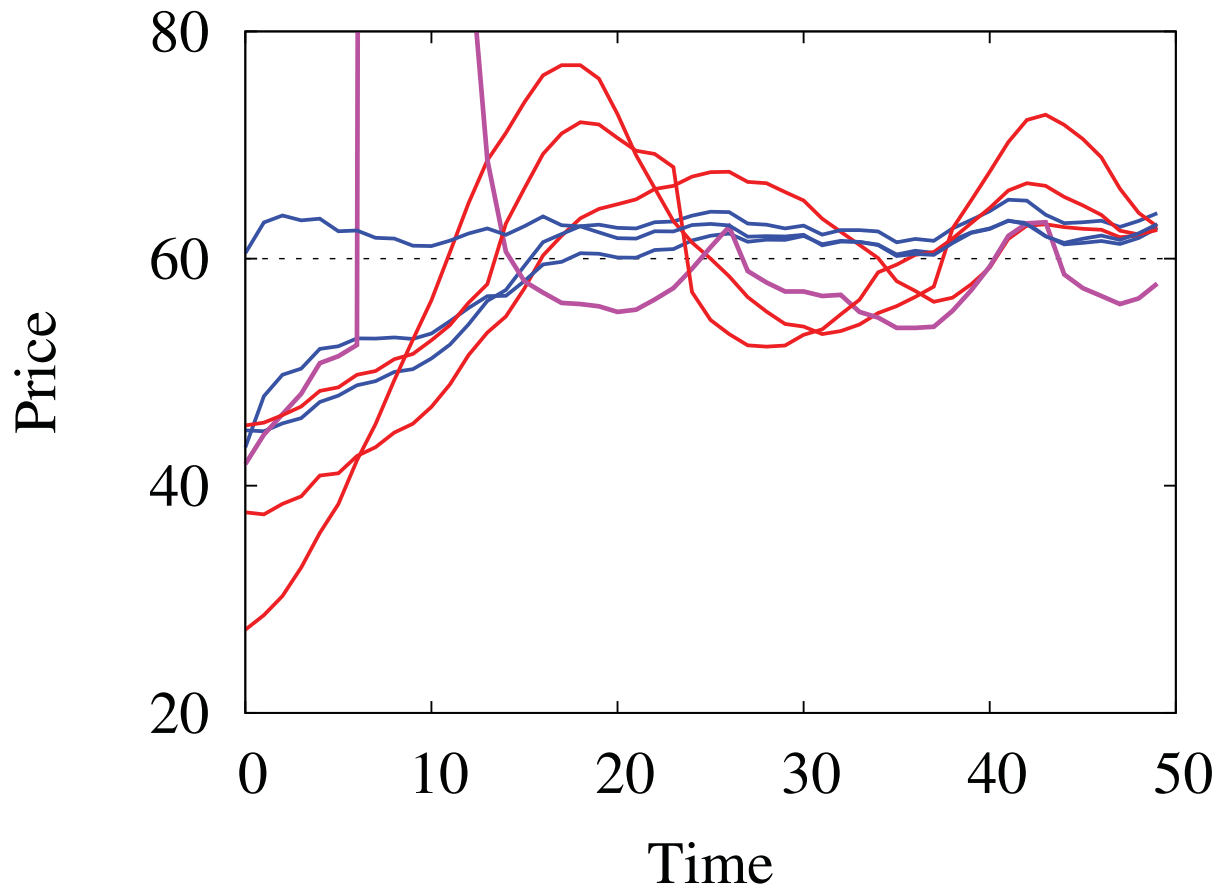
(Heemeijer et al., JEDC 2009)



Positive Feedback Experiment: Session 1

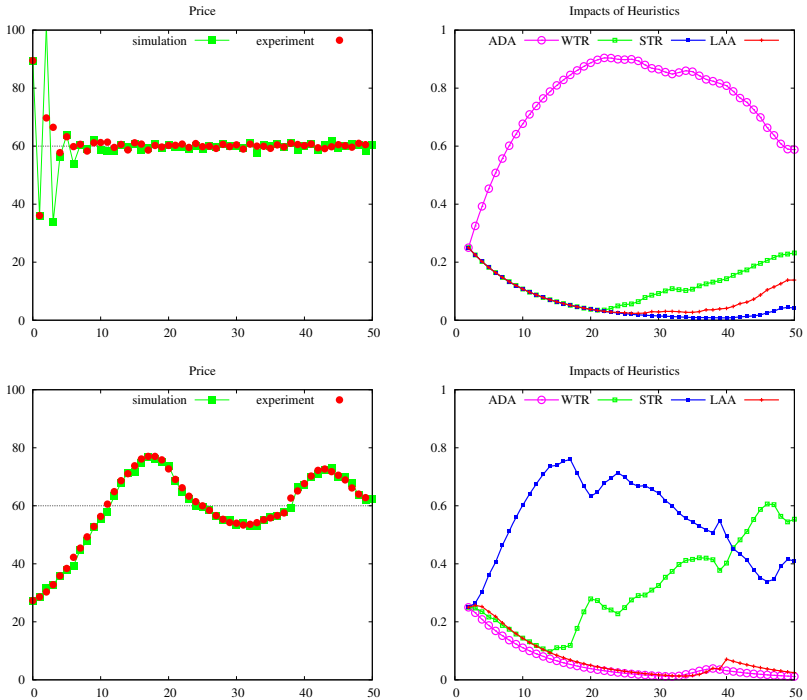
Prices in Experiments with Positive Feedback (7 groups)

(Heemeijer et al., JEDC 2009)



Positive vs Negative Feedback; Small Shocks Heuristics Switching Model Simulations

prices strategy frequencies



positive feedback: trend-followers amplify fluctuations

Conclusion: Empirical and Exper. Data consistent with Complexity View

- simple **heterogeneous expectations heuristics switching model** fits experimental **micro** and **macro** data quite nicely
- **heterogeneity** and **heuristics switching** explains
  - path dependence
  - different behaviour in different feedback systems
  - different behaviour in aggregate variables of same economy
- agents are **behaviorally rational** at the individual level: they use simple heuristics such as **adaptive expectations**, **trend following rules** and **anchor and adjustment rules**
- **positive feedback** markets are “irrational” due to coordination on "wrong" price and **survival** of (almost) **self-fulfilling trend following strategies**