Complex Systems Workshop
Lecture IV: Learning-to-Forecast Experiments

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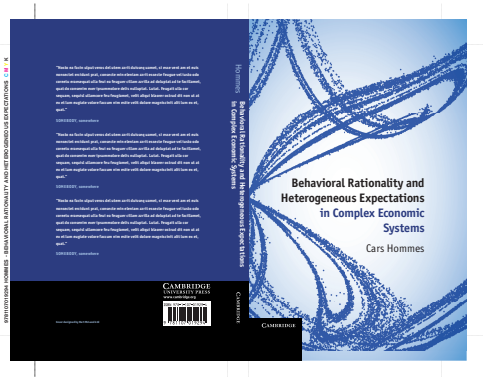
Outline

Some References

- Anufriev, M. and Hommes, C.H. (2012), Evolutionary selection of individual expectations and aggregate outcomes, American Economic Journal-Micro 4 (4), 35-64.
- Hommes, C.H., (2011), The heterogeneous expectations hypothesis: some evidence from the lab, Journal of Economic Dynamics and Control 35, 1-24.
- Hommes, C.H., (2013), Behavioral Rationality and Heterogeneous Expectations in Complex Economic Systems, Cambridge (**Chapter 8**)



Laboratory Experiments in Macro and Finance

- study behavior in **controlled** laboratory environment
- **empirical foundation** for individual decision rules for ABMs to **discipline** wilderness of bounded rationality
- **individual** (micro) as well as **aggregate** (macro) behavior
- testing **complex systems**;
  emergent macro behavior through interactions at micro level

Lucas, JPE, 1986 on Learning and Experiments

"Recent theoretical work is making it increasingly clear that the **multiplicity of equilibria** ... can arise in a wide variety of situations involving sequential trading, in competitive as well as finite agent games. All but a few of these equilibria are, I believe, behaviorally uninteresting: They do not describe **behavior that collections of adaptively behaving people** would ever hit on. I think an appropriate **stability theory** can be useful in weeding out these uninteresting equilibria ... But to be useful, stability theory must be more than simply a fancy way of saying that one does not want to think about certain equilibria. I prefer to view it as an **experimentally testable hypothesis**, as a special instance of the adaptive laws that we believe govern all human behavior."

Deviations from Rationality & Heterogeneity

Muth (1961) [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 should be tested **empirically** and in **laboratory experiments**

Learning to Forecast Experiments

Empirical test for expectations at micro and macro level

- Which **forecasting rules** do **individuals** use?
  Are expectations **heterogeneous** or do individuals **coordinate**?
- If so, do they coordinate on **RE** or **learning equilibrium**?
- Which **theory of expectations** and learning fits the **aggregate** as well as **individual** experimental data?
- How do **micro** and **macro** behaviour depend on **expectations feedback structure**?

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 (professional forecasters)

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

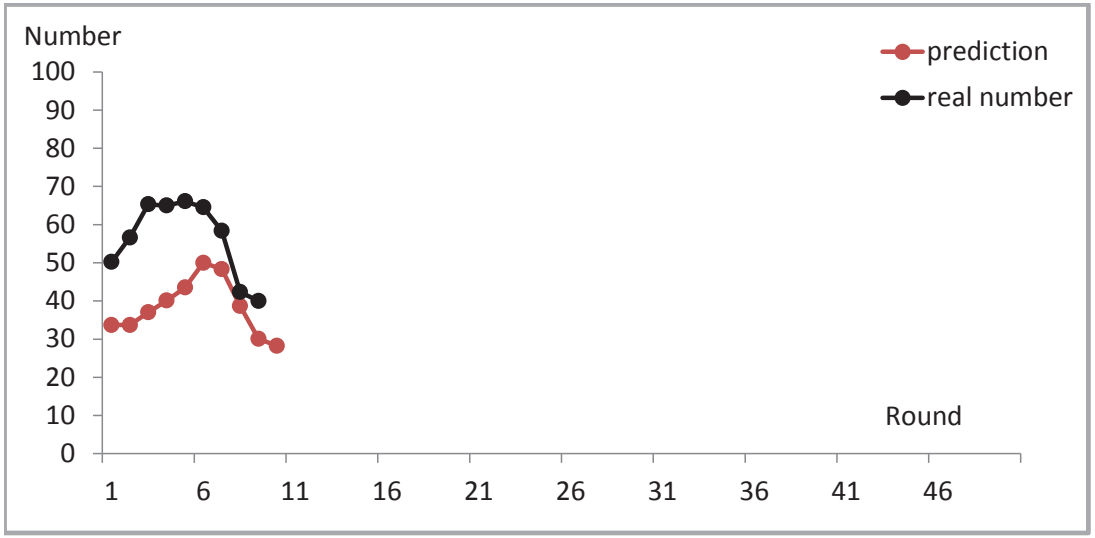
Subjects know

- 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:

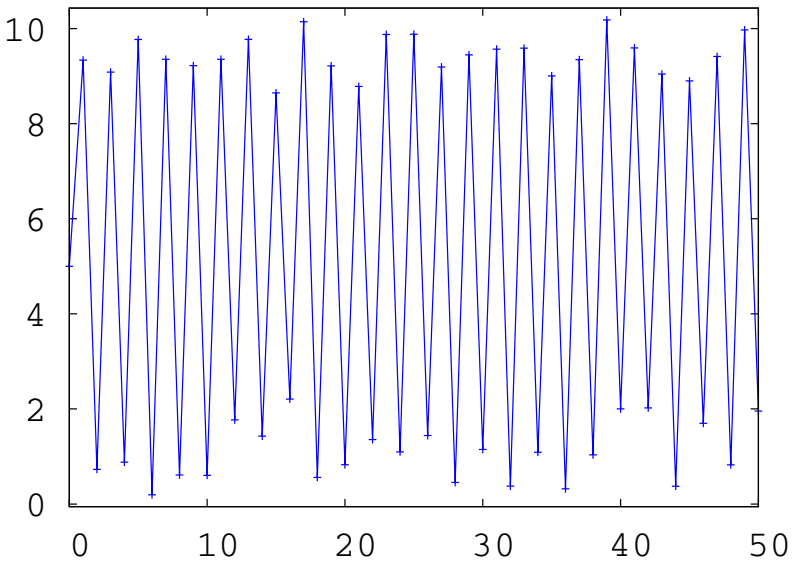
Round	Prediction	Real value
1	33,70	50,23
2	33,70	56,63
3	37,00	65,32
4	40,10	65,00
5	43,50	66,12
6	50,00	64,53
7	48,35	58,35
8	38,70	42,35
9	30,10	40,01
10	28,25	

Cobweb Experimental Setting

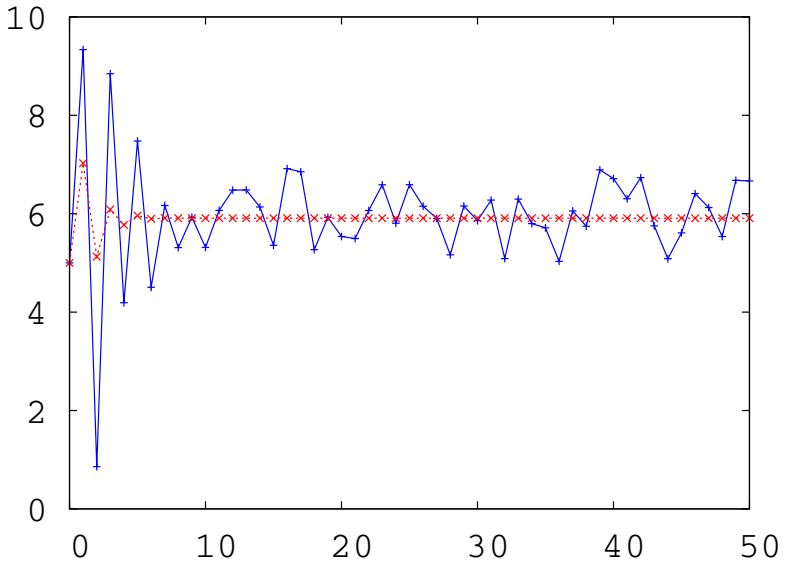
- one-period ahead
- negative feedback; supply driven
- **profit maximization**
- agents **do not know** demand and supply
- **market clearing**

$$p_t = D^{-1}(\sum_{i=1}^{K} S_\lambda(p^e_{i,t})) = \frac{a - \sum_{i=1}^{K} S_\lambda(p^e_{i,t})}{d} + \epsilon_t$$

Cobweb Experiment Simulation Benchmarks



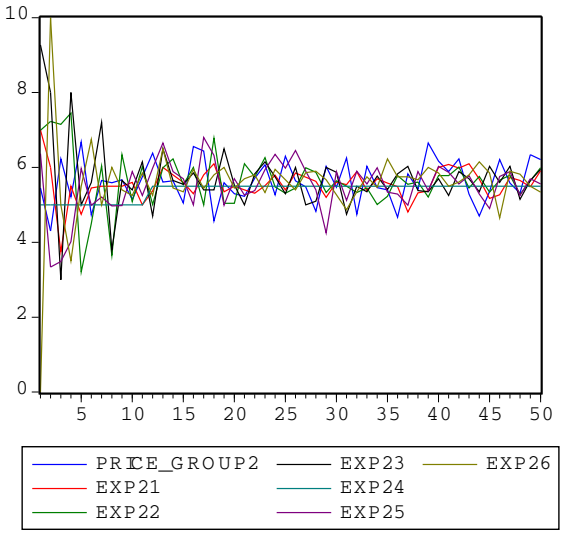
naive expectations



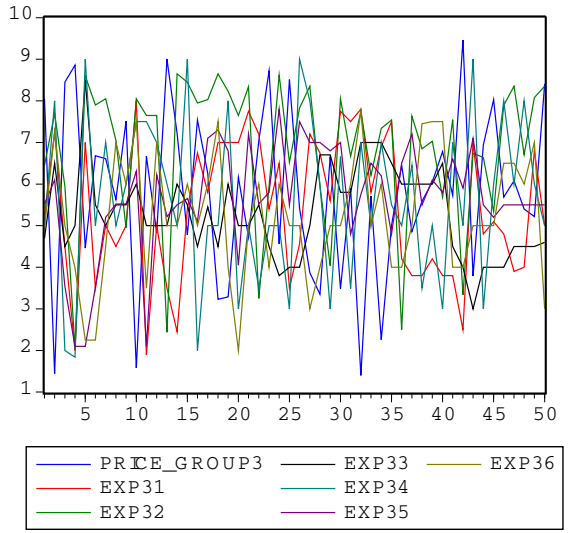
sample average learning

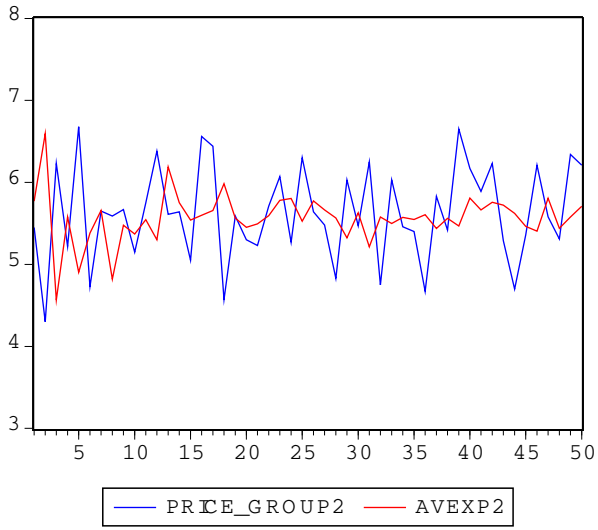
Cobweb Experiment

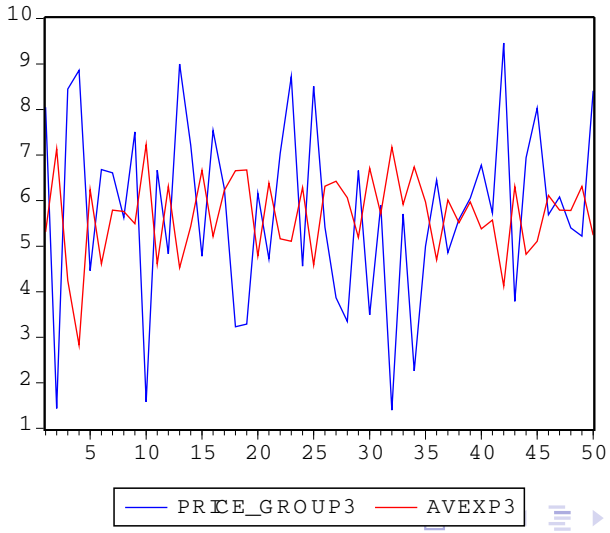
stable treatment



unstable treatment



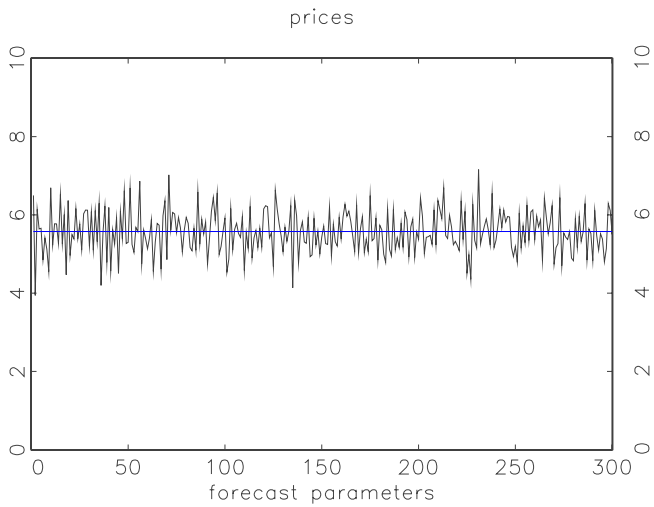




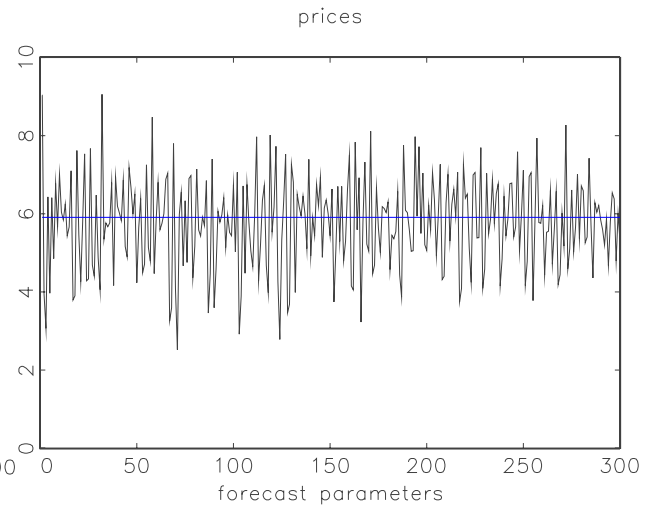
Cobweb GA Simulations ($p_{i,t+1} = \alpha_i + \beta_i(p_t - \alpha_i)$)

Hommes and Lux, *Macroeconomic Dynamics* 2012

stable treatment



unstable treatment



Asset Pricing Experimental Setting

- **asset pricing experiment** (with/without robot trader)
  - two-period ahead
  - positive feedback
  - mean-variance **utility maximization** and **market clearing**
  - mean dividend $\bar{y} = 3$ and interest rate $r = 0.05$ are **known**
    fundamental price $p^f = \bar{y}/r = 60$ is **not known**
    (but can be computed)

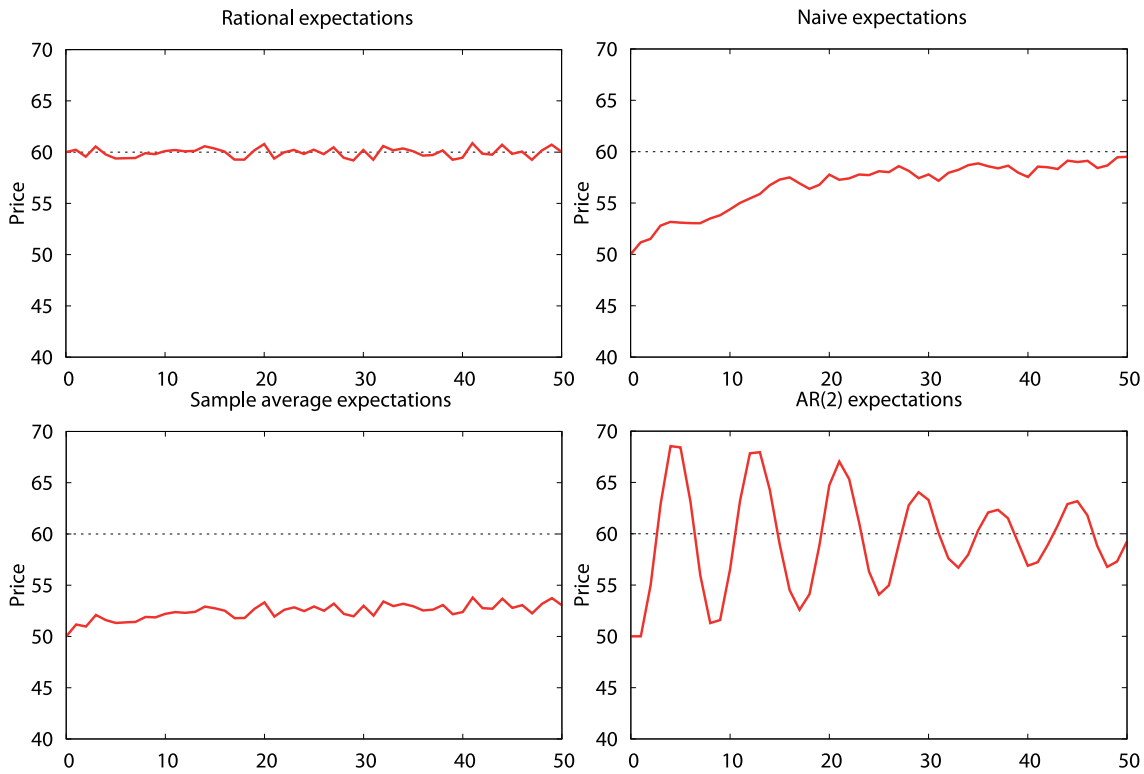
$$p_t = \frac{1}{1+r}\left((1-n_t)\frac{p^e_{t+1,1} + \cdots + p^e_{t+1,6}}{6} + n_t\, p^f + \bar{y} + \varepsilon_t\right)$$

Two Other Experimental Settings

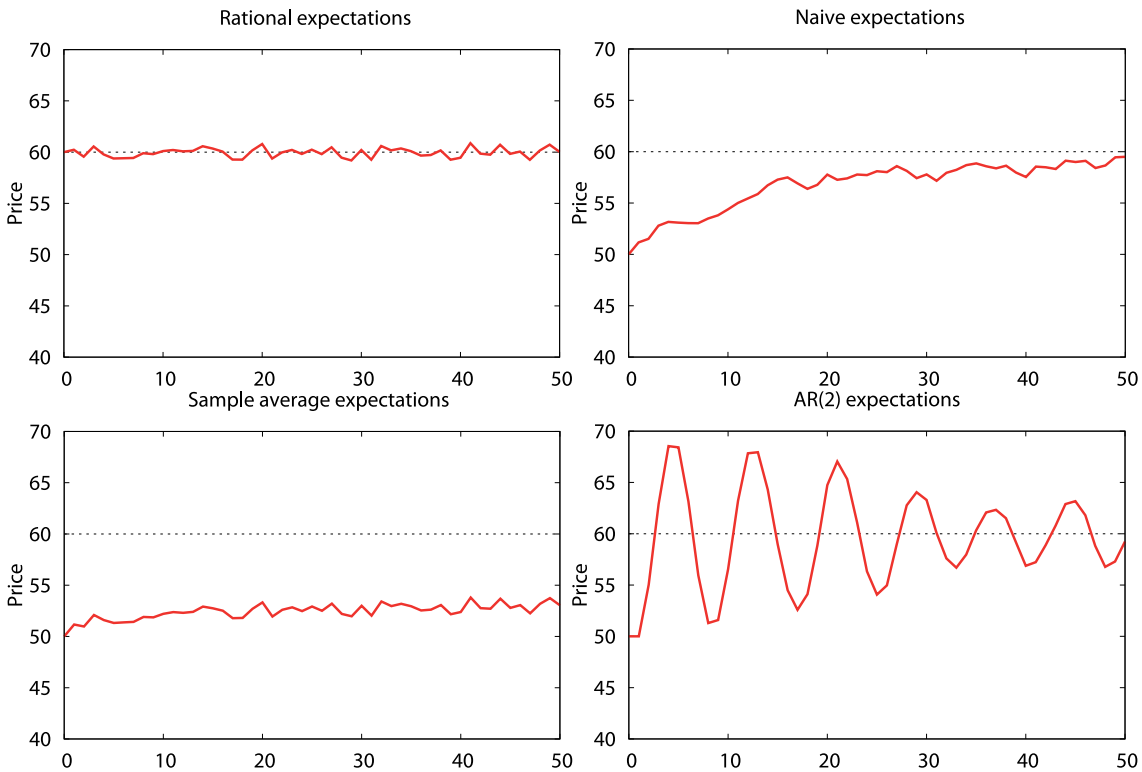
- **positive** versus **negative** feedback; one-period ahead $p_t = f(p_t^e)$:
  - **positive** feedback: linear, slope $+0.95$;
  - **negative** feedback: linear, slope -0.95.
- **New Keynesian Macromodel**: aggregate inflation and output depend on individual forecasts of **both** inflation and output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

$$(\pi_t, y_t) = F(\pi_{t+1}^e, y_{t+1}^e)$$

Asset Pricing Experiment Simulation Benchmarks



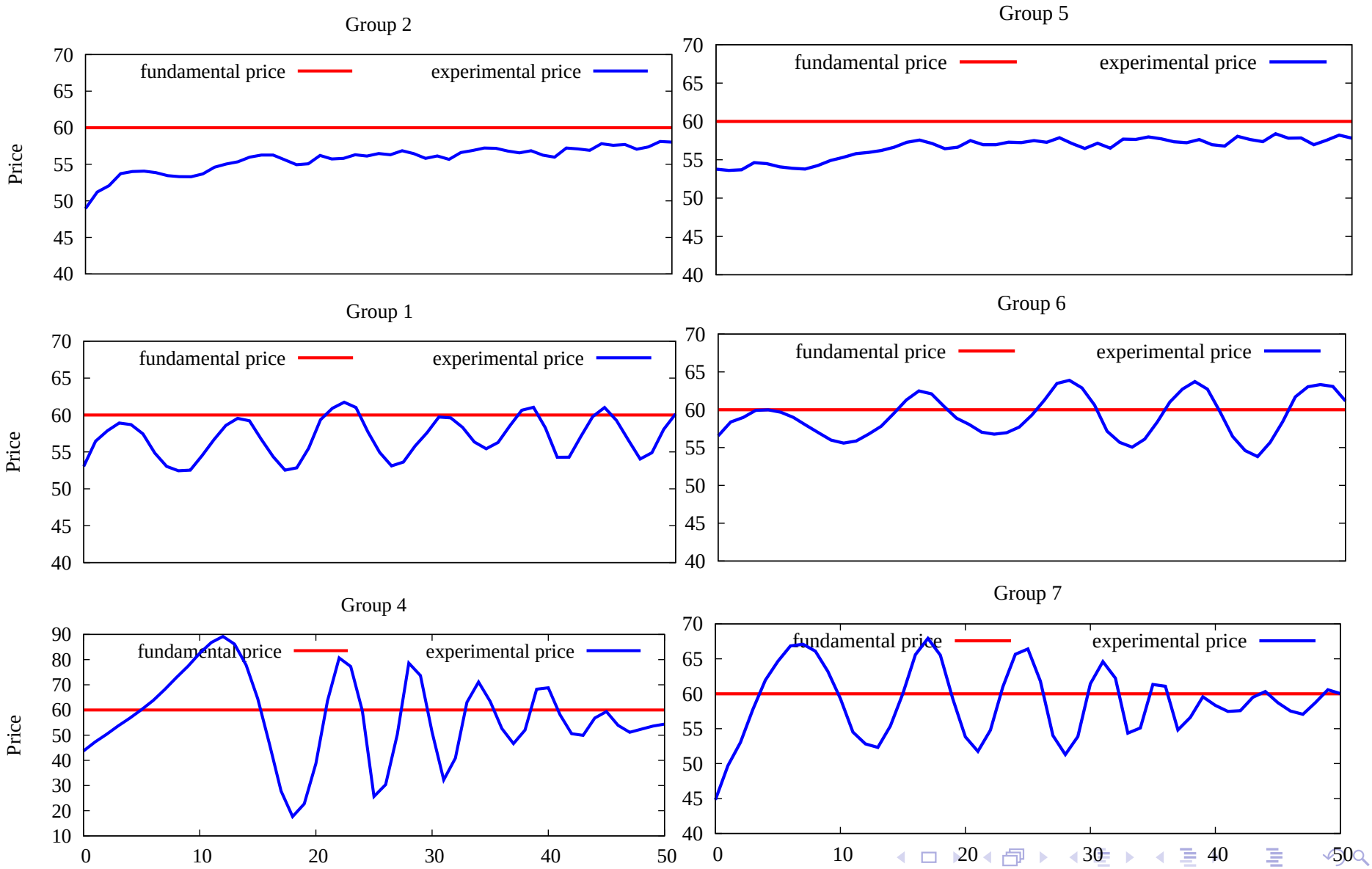
Asset Pricing Experiment Simulation Benchmarks



AR2 // anchor and adjustment rule

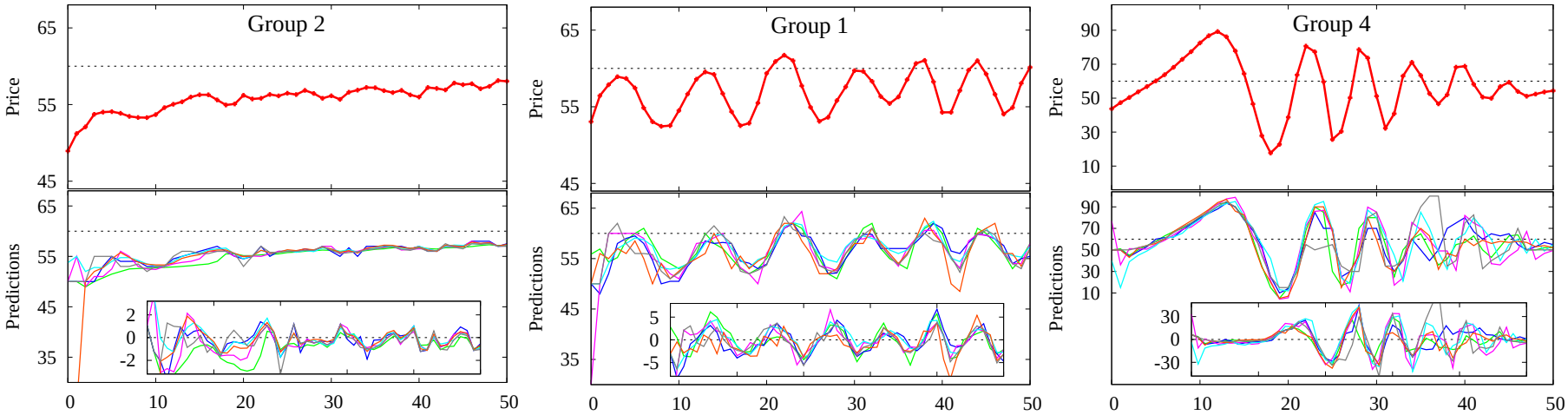
$$p^e_{t+1} = 30 + \tfrac{3}{2}p_{t-1} - p_{t-2} = (60 + p_{t-1})/2 + (p_{t-1} - p_{t-2})$$

Asset Pricing Experiment (with Robot Trader)



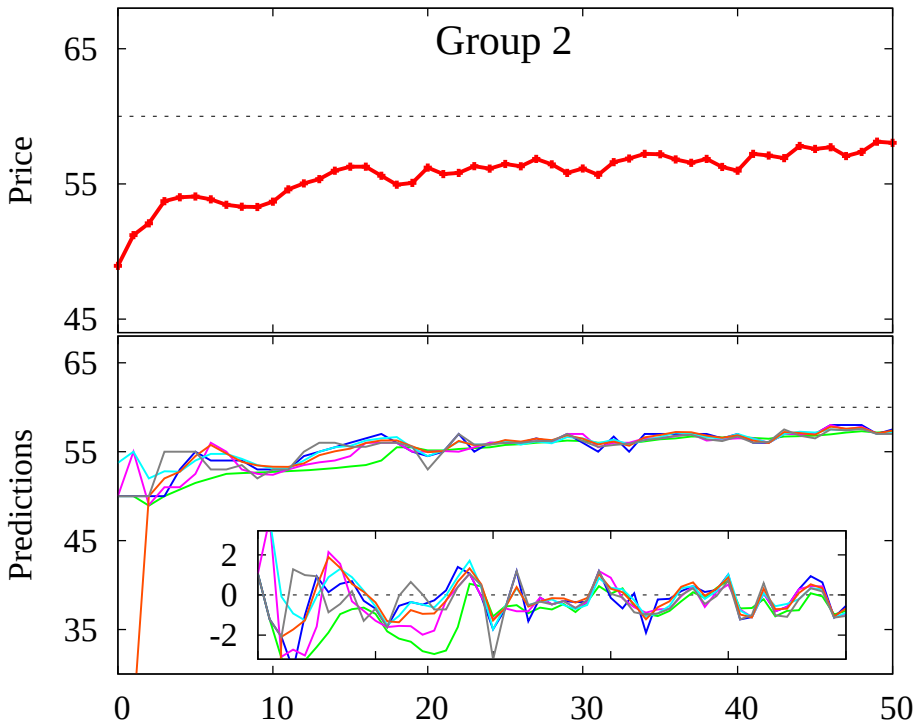
Asset Pricing Experiment

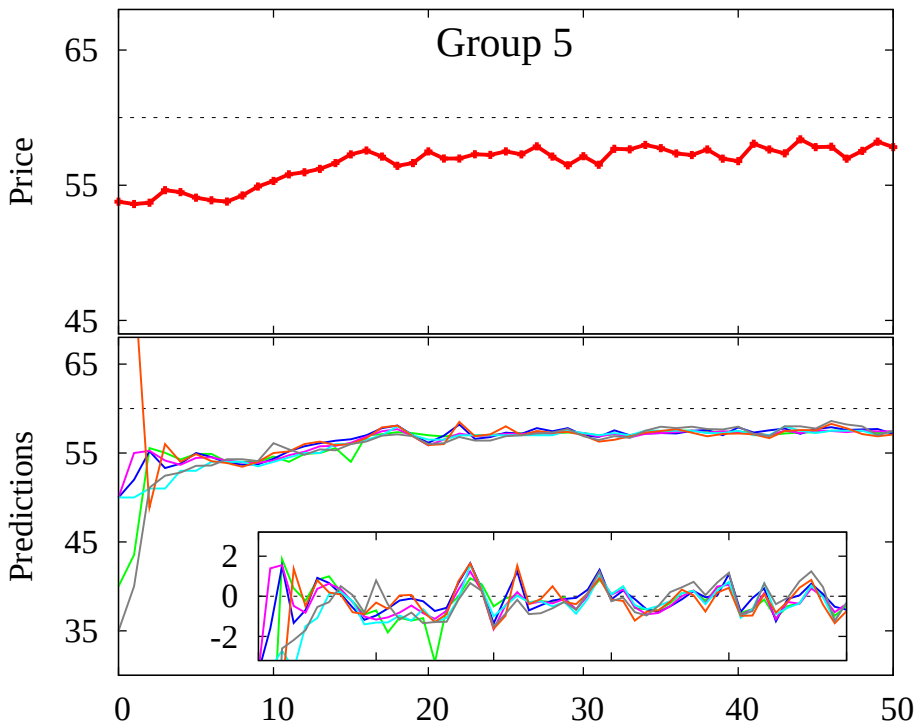
Strong coordination of individual forecasts and errors



Groups with (Almost) Monotonic Convergence

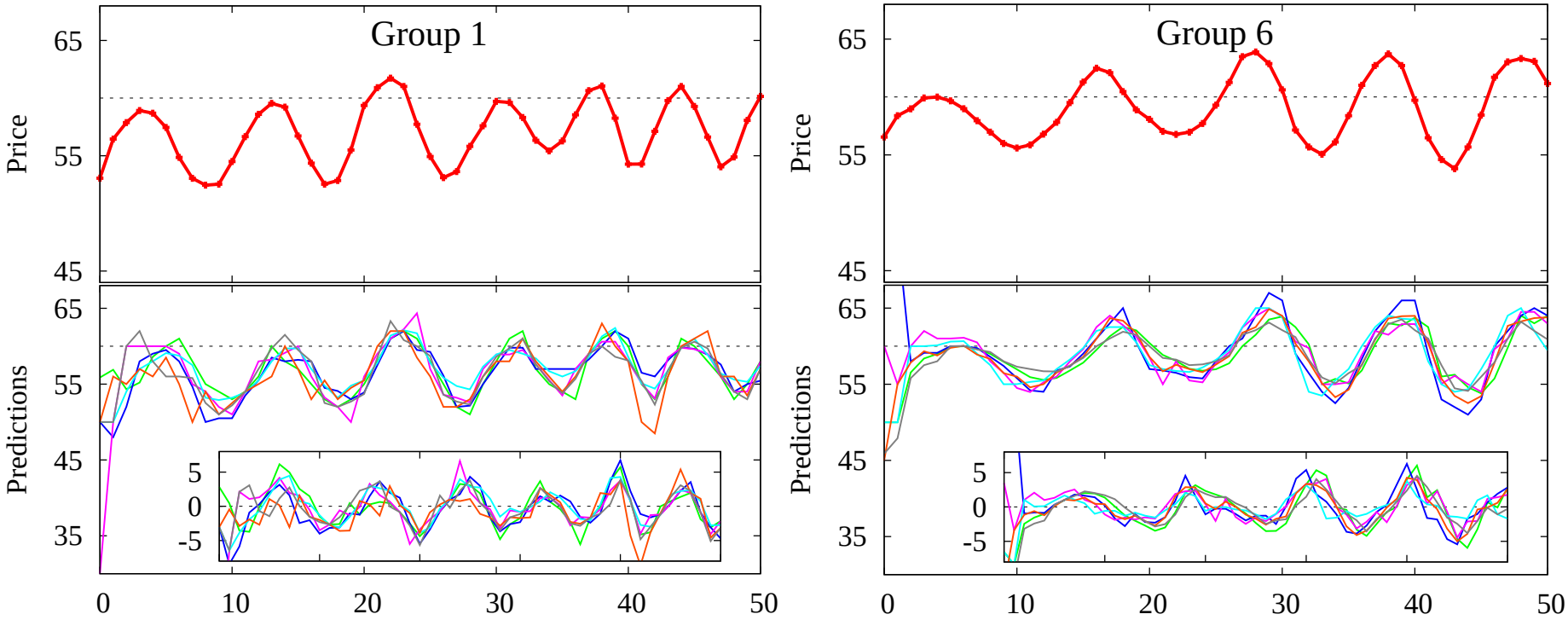
prices, individual predictions and individual errors





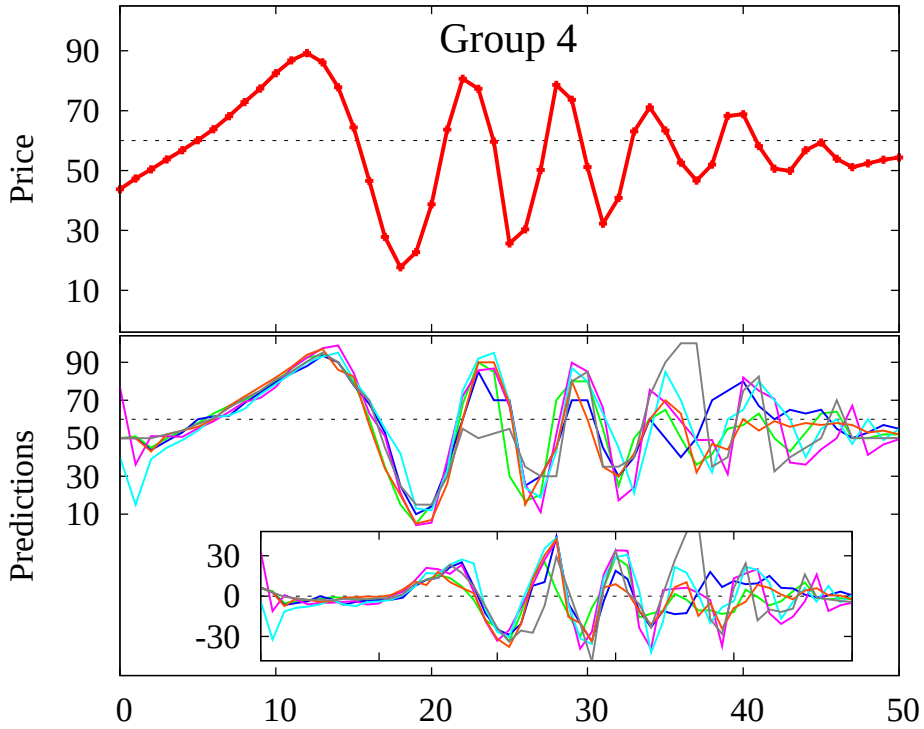
2 Groups with Perpetual Oscillations

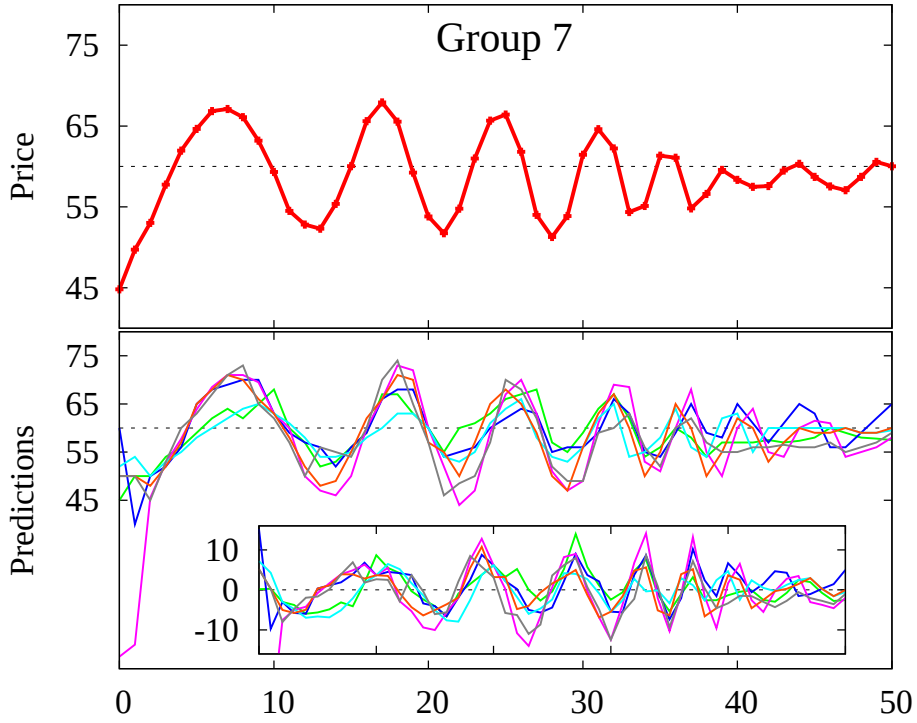
prices, individual predictions and individual errors



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**

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

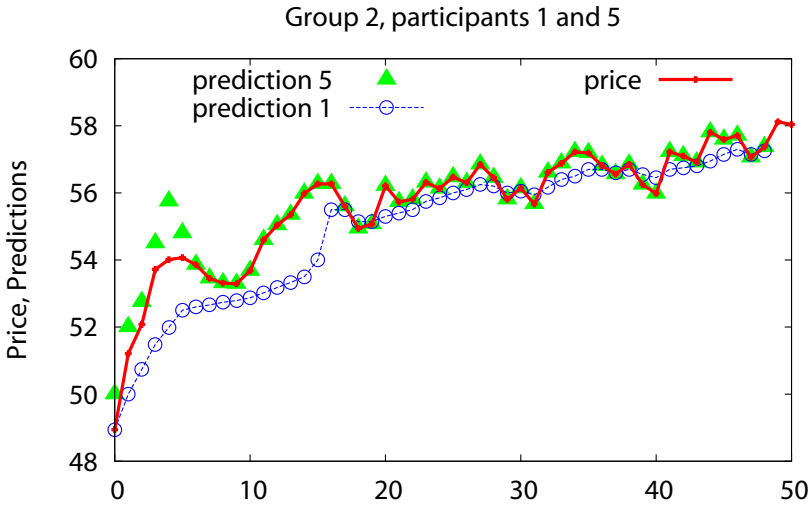
- often agents used **simple linear rules**
  anchor and adjustment rule

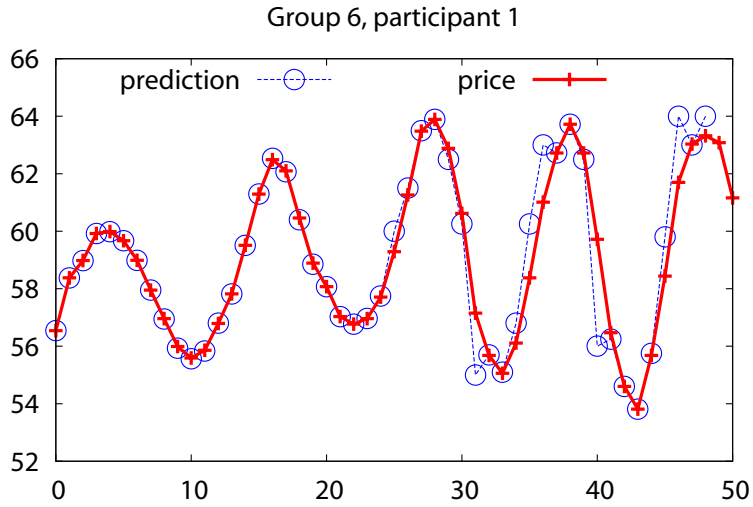
$$\begin{array}{lll} p^e_{t+1} = & & \alpha + \beta_1\, p_{t-1} + \beta_2\, p_{t-2} \\ \text{e.g.} & & (60 + p_{t-1})/2 + (p_{t-1} - p_{t-2}) \\ \text{or} & \text{LAA} & (p^{av}_{t-1} + p_{t-1})/2 + (p_{t-1} - p_{t-2}) \end{array}$$

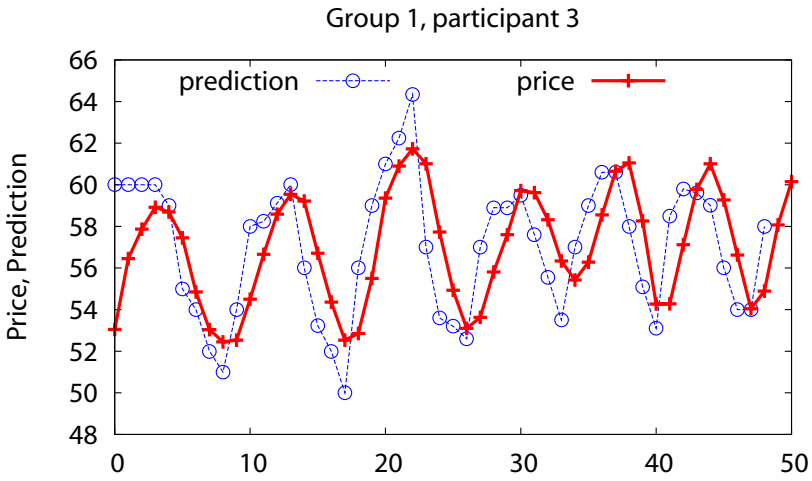
  in particular **trend-extrapolating rules**

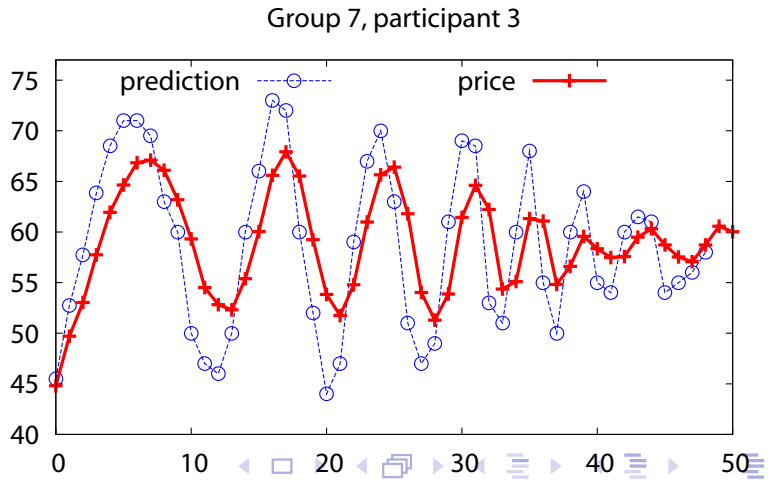
$$p^e_{t+1} = p_{t-1} + \gamma\,(p_{t-1} - p_{t-2}) \qquad 0.4 \leq \gamma \leq 1.3$$

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**

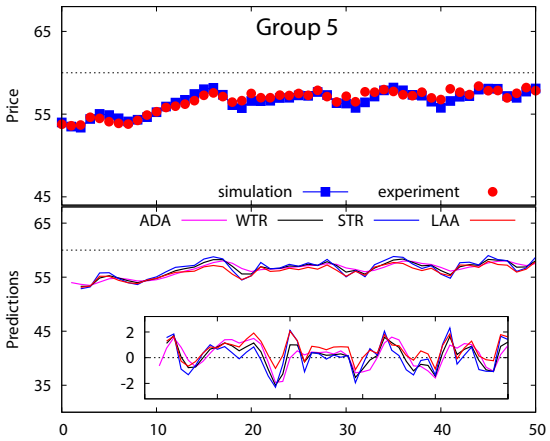
- **discrete choice model with asynchronous updating**

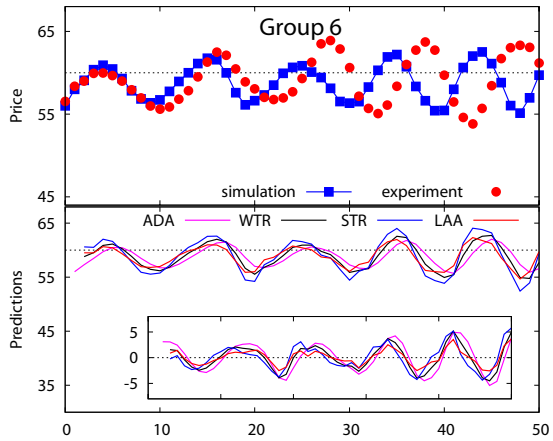
$$n_{i,t} = \delta\, n_{i,t-1} + (1-\delta)\, \frac{\exp(\beta\, U_{i,t-1})}{\sum_{i=1}^{4} \exp(\beta\, U_{i,t-1})}$$

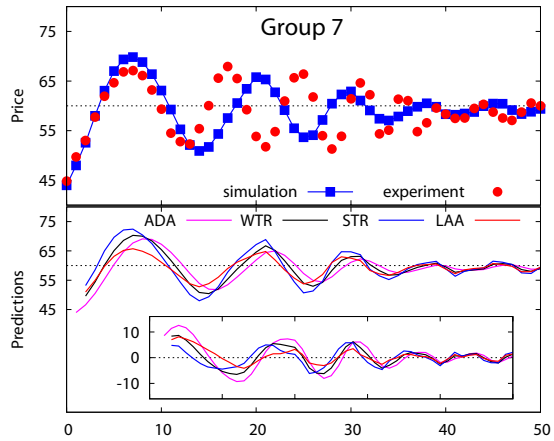
parameter $\delta \in [0,1]$ – the inertia of the traders
parameter $\beta \geq 0$ – the intensity of choice

Simulated Paths (50 periods ahead)

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







Stochastic Simulations (one step ahead forecast)

Anufriev and Hommes (2012)

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

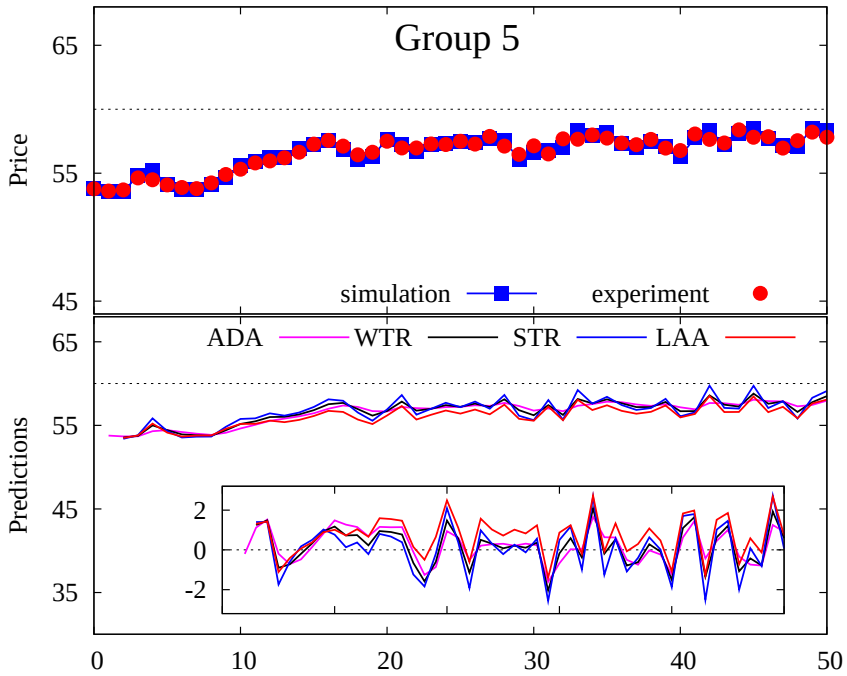
Parameters fixed at: $\beta = 0.4, \eta = 0.7, \delta = 0.9$

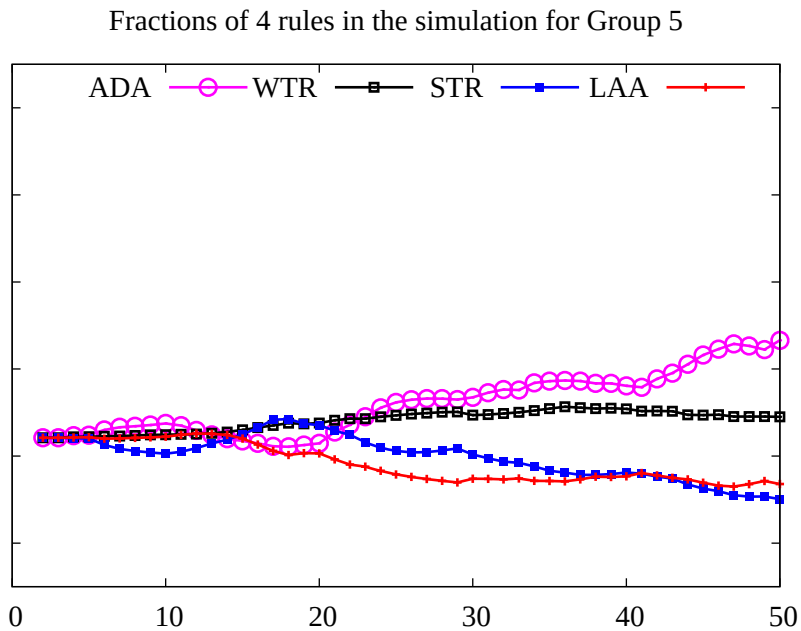
- initial fractions **equal**, i.e. $n_{ht} = 0.25$
- initial prices **as in experiments**

Group 5 (Convergence)

experimental prices
simulated prices, predictions and errors

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

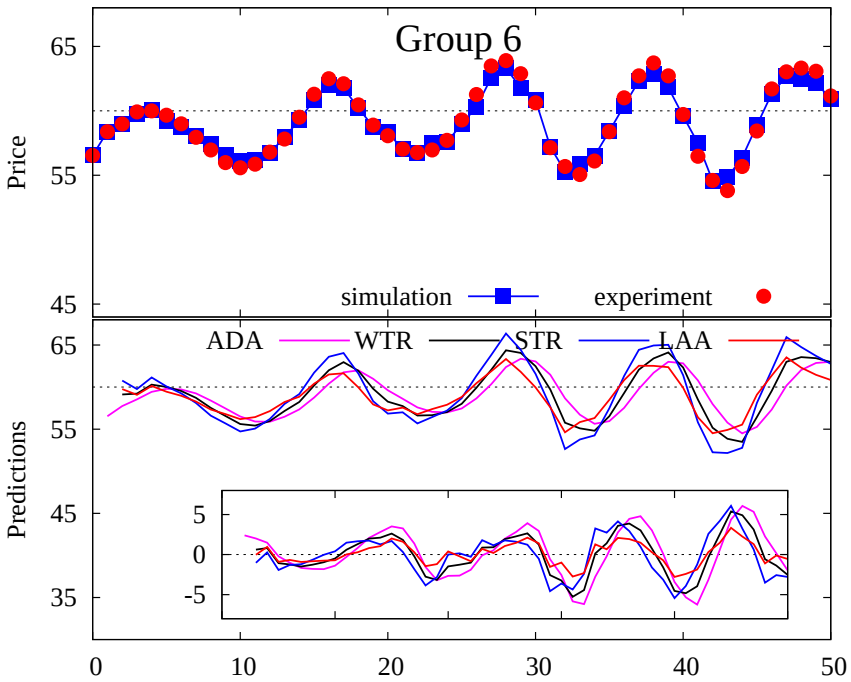


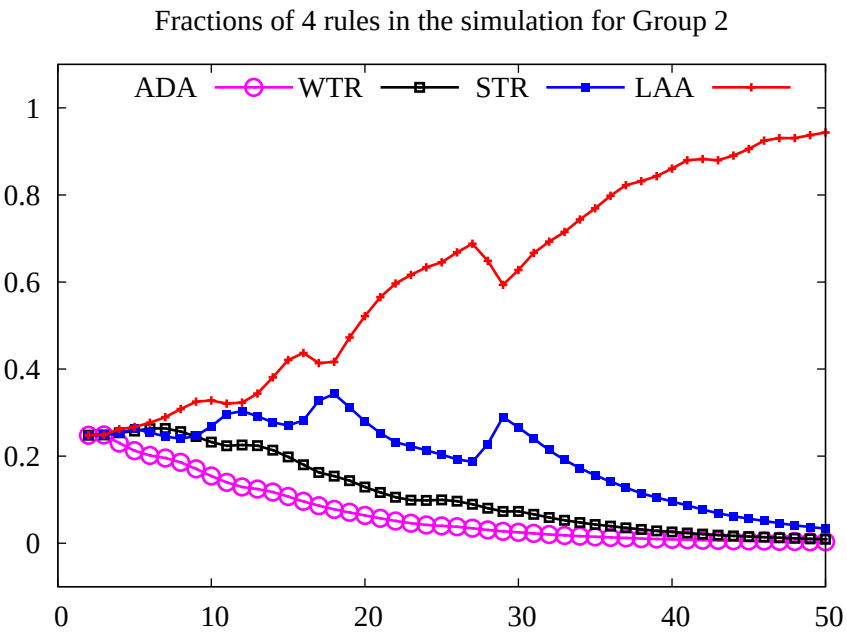


Group 6 (Constant Oscillations)

experimental prices
simulated prices, predictions and errors

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

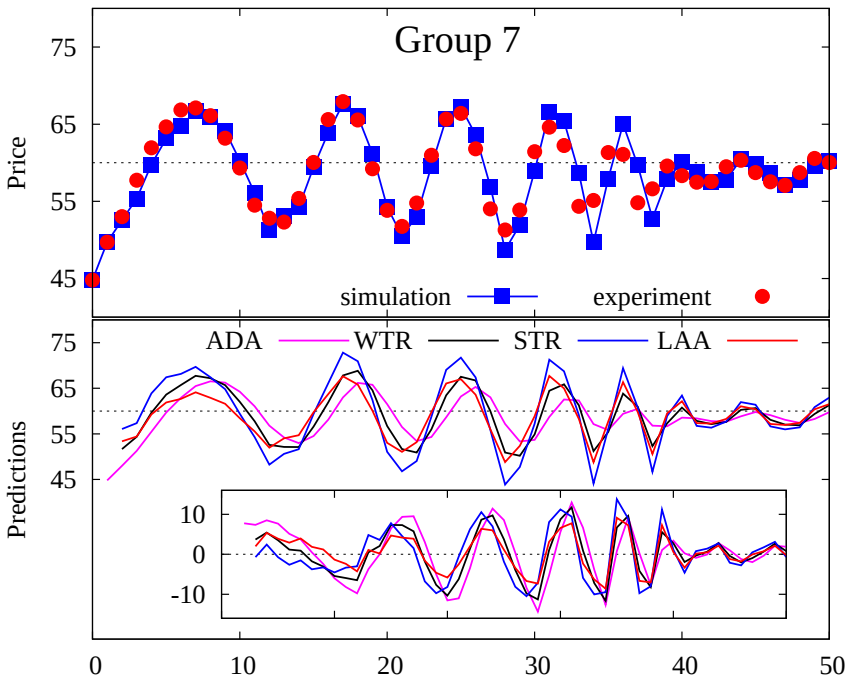


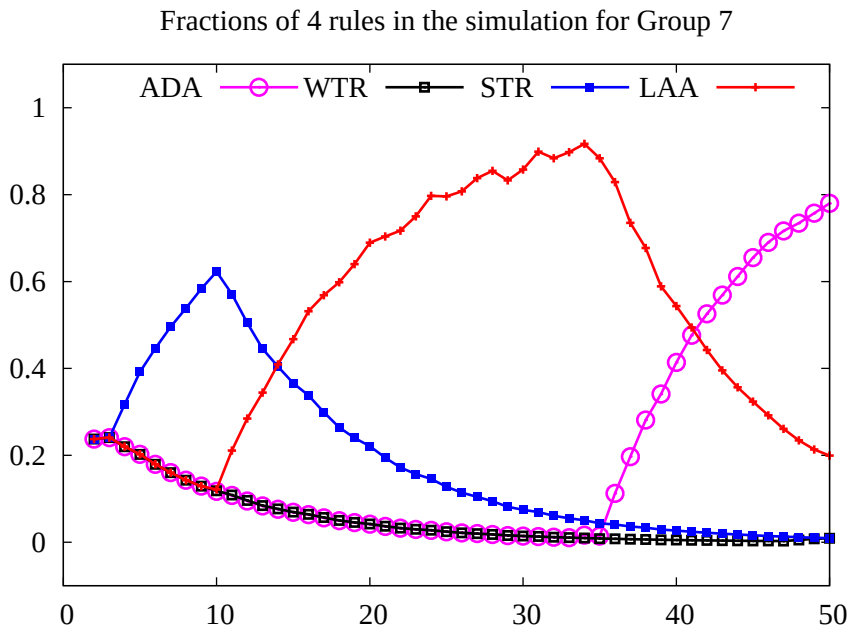


Group 7 (Damping Oscillations)

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)

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

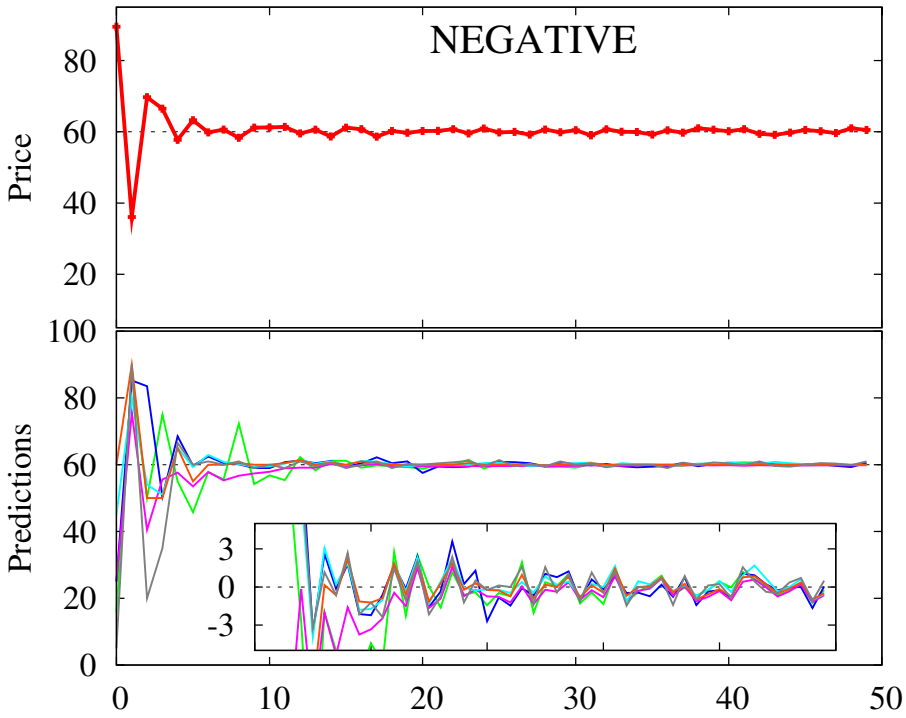
- **positive feedback** (strategic complementarity environment)

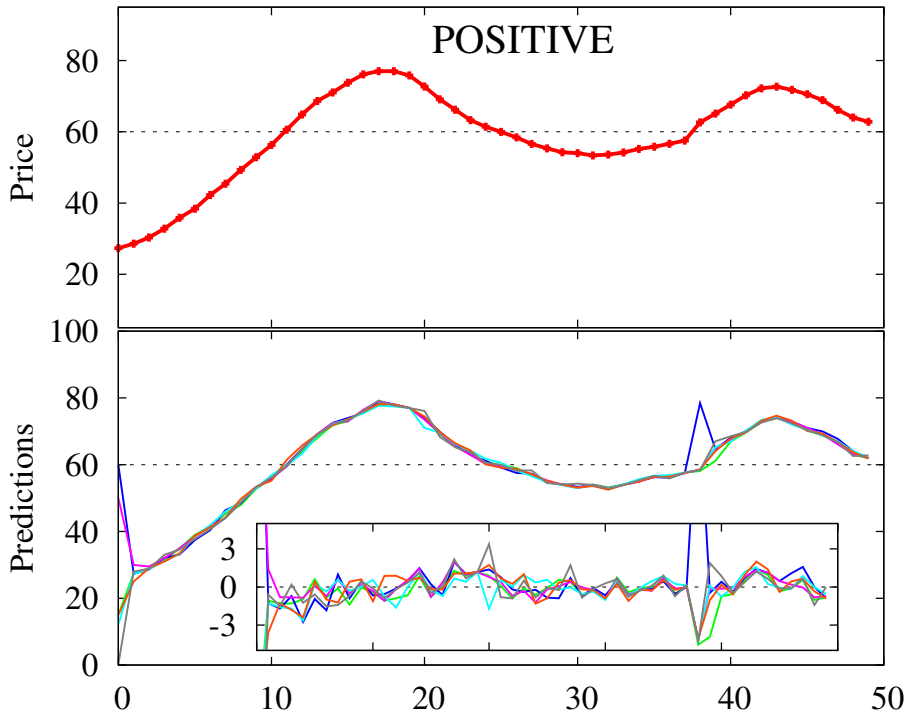
$$p_t = 60 + \frac{20}{21}[\sum_{h=1}^{6} \frac{1}{6} p_{ht}^e - 60] + \epsilon_t$$

- **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

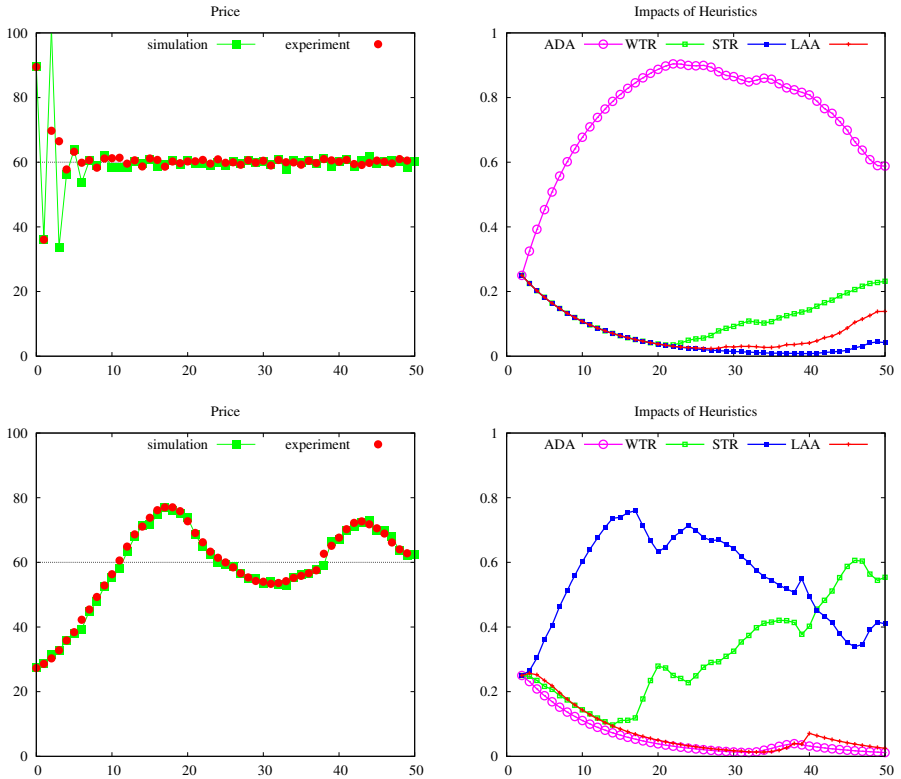




Positive Feedback: coordination on "wrong" price

Positive vs Negative Feedback; Small Shocks Heuristics Switching Model Simulations

prices strategy frequencies



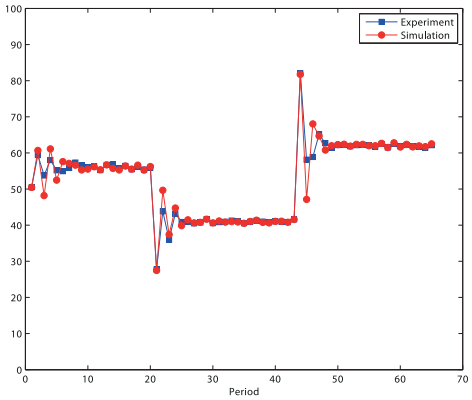
positive feedback: trend-followers amplify fluctuations

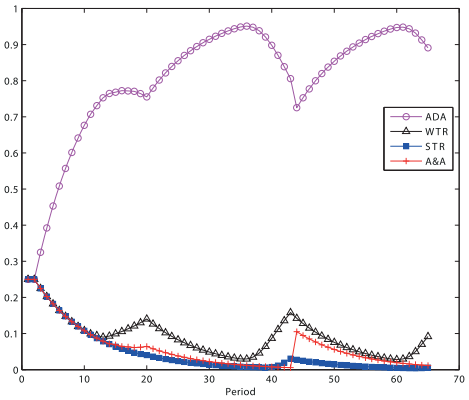
Positive/Negative Feedback; Large Shocks

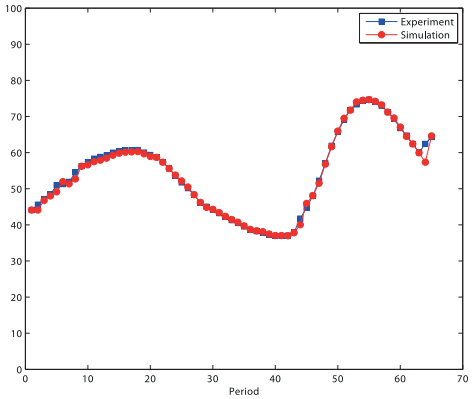
Bao et al., JEDC 2012

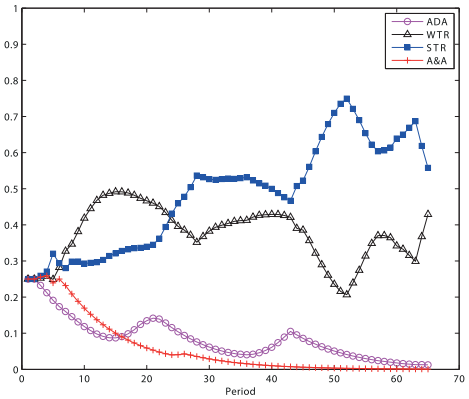
prices

strategy frequencies



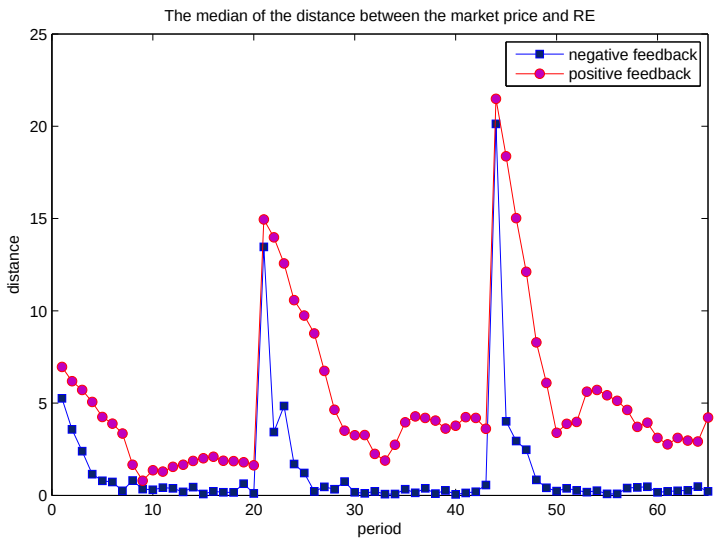




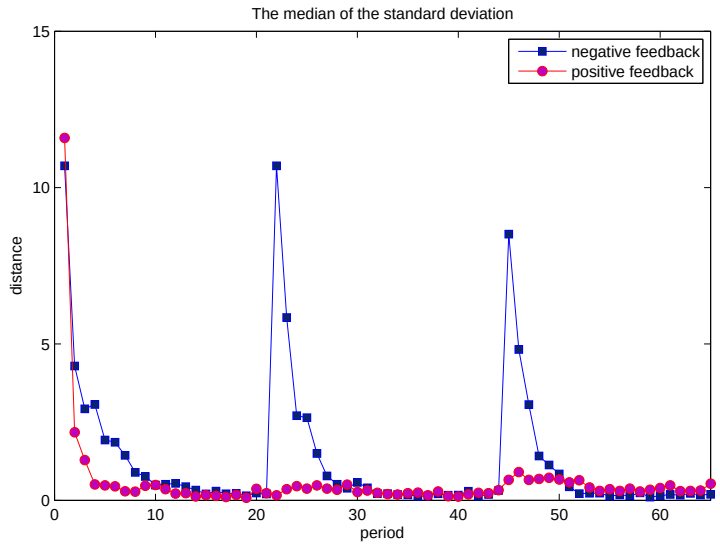


Positive/Negative Feedback; Large Shocks

distance to RE price



degree of heterogeneity



positive feedback: quick coordination on 'wrong' price

negative feedback: slower coordination on correct RE price

Conclusion: Empirical and Exper. Data consistent with Behavioral Rationality & Heterogeneous Expectations

- 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**

Future Work

- **heterogeneous expectations** modeling in **macro-economics** and **finance**
- **estimation** of HAMs
- **laboratory experiments** to test behavioral assumptions
- **policy** under **bounded rationality** and **heterogeneity**

If you have questions ...
read the book!
or ask now ...
Thank you very much!!