The Heterogeneous Expectations Hypothesis: Some Evidence from the Lab

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Plan of the Talk

- Introduction & Motivation **Expectations Hypothesis**
- Learning to Forecast **Experiments** with Human Subjects
- **Heuristics Switching Model** Explaining the Experiments
- Conclusions about **Rationality** and **Heterogeneity**

Co-authors

- **Experiments**, past 10 years
  Joep Sonnemans, Jan Tuinstra, Henk vd Velden, Peter Heemeijer,
- 
- **Models explaining Experiments**
  Mikhail Anufriev, William Brock, Thomas Lux
- **New Experiments** Te Bao, Tiziana Assenza, Domenico Massaro
-  

Why are Expectations Important?

- economic decisions **today** depend upon expectations about the **future** state of the economy
- individuals **learn** from past mistakes and **adapt** their behavior accordingly
- an economy is an **expectations feedback system**
- any dynamic economic model depends crucially upon the **expectations hypothesis**

Questions about Expectations Hypothesis

- How do **individuals** form expectations and how do they **learn** and **adapt** their behaviour?
- How do individual forecasting rules **interact** at the **micro** level and which **aggregate outcome** do they co-create at the **macro** level ?
- Will **coordination** occur, even when there is limited information, or will **heterogeneity** persist?
- When does **learning** enforce convergence to REE?

Approach: Laboratory **Experiments** + Fit **Model**

Some Literature Related to this Talk

- Hommes, C.H. The Heterogeneous Expectations Hypothesis: Some Evidence from the Lab, *in preparation*.
- Hommes, C.H. and Wagener, F.O.O. (2009), Complex Evolutionary Systems in Behavioral Finance, In: T. Hens and K.R. Schenk-Hoppé (Eds.), *Handbook of Financial Markets: Dynamics and Evolution*, Elsevier, 2009, 217-276.
- Hommes, C.H., Sonnemans, J., Tuinstra, J., and van de Velden, H., (2005), Coordination of expectations in asset pricing experiments, *Review of Financial Studies* 18, 955-980.
- Heemeijer, P., Hommes, C.H., Sonnemans, J. and Tuinstra, J. (2009), Price stability and volatility in markets with positive and negative expectations feedback, *Journal of Economic Dynamics & Control*, 1052-1072.
- Anufriev, M. and Hommes, C. "Evolutionary Selection of Individual Expectations and Aggregate Outcomes", *CeNDEF Working Paper*, University of Amsterdam, September 2009.

Rational Expectations Hypothesis (Muth, 1961)

- **all** agents are the **same** and forecast **rationally**
- agents use **all** available **information**
- expectations are **model consistent** and coincide on average with realizations (no systematic forecasting errors)

Drawbacks:

- law of motion of the economy is **unknown**
- even if law of motion is known, RE requires unrealistically high **computing abilities**
- RE models **at odds with empirical observations**, especially laboratory experiments

Alternative View: Bounded Rationality

- agents use time series **observations** to form expectations
- agents **learn** and **adapt** their behavior as more observations become available
- sometimes **convergence** to REE, sometimes **learning equilibria**

Drawbacks:

- **wilderness** of bounded rationality
- (too) **many degrees of freedom**, too many parameters
- seems particularly problematic when individual have **heterogeneous expectations**

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**.

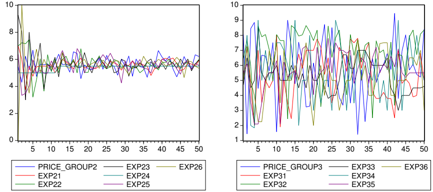
key issues:

- 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**

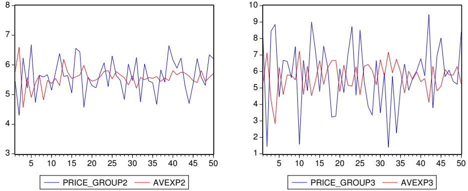
Cobweb Learning to Forecast Experiments

(Hommes et al., Macroeconomic Dynamics 2007)



stable: coordination on RE **unstable**: persistent heterogeneity

no aggregate effect excess volatility



Learning to Forecasts Laboratory Experiments

- individuals **only** have to forecast price, **ceteris paribus**, e.g. wit all other behavior assumed to be **rational**
- computerized trading yields market equilibrium price, consistent with **benchmark model**; in this talk
  - cobweb model
  - asset pricing model
  - New Keynesian macro model
- **advantage**: clean data on expectations

Literature Learning to Forecasts Experiments

- **OG-experiments**: Marimon, Spear and Sunder (1993), Marimon and Sunder (1993, 1994, 1995)
- **asset pricing** experiments: Hommes et al. (2005, 2008)
- **positive** versus **negative feedback** experiments: Heemeijer et al. (2009)
- **macro experiments** inflation/output: Adam (2007), Pfajfar and Santoro (2009), Assenza et al. (2009)
- **survey** Duffy (2008), *Experimental Macroeconomics*

Challenge: universal theory of heterogeneous expectations

Experimental Data: http://www1.fee.uva.nl/cendef

Learning to Forecast Experiments (Ctd)

Subjects' task and incentive

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

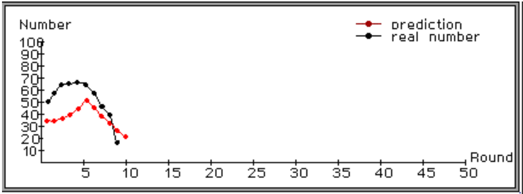
Subjects know

- 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: 10357

earnings this period: 1298

Remaining time: 00

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

Prediction:

Round	Pre-diction	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

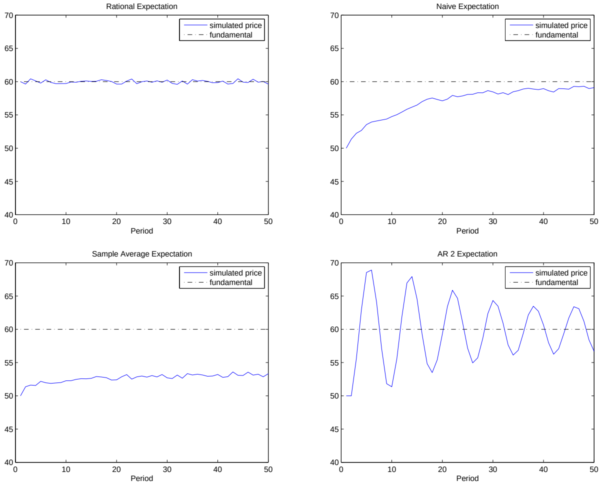
$$p_t = \frac{1}{1+r}\left((1-n_t)\frac{p^e_{t+1,1}+\cdots+p^e_{t+1,6}}{6} + n_t p^f + \bar{y} + \varepsilon_t\right)$$

- **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.

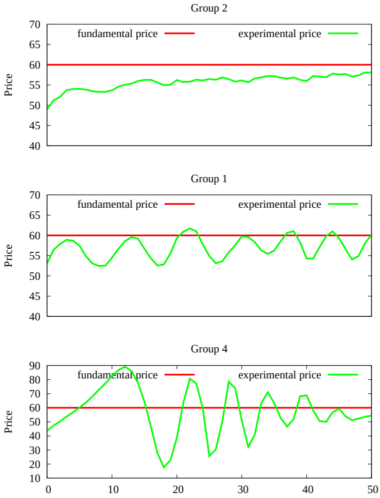
- **New Keynesian Macromodel**: aggregate inflation and output depend on individual forecasts of **both** inflation and output (and monetary policy rule):

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

Asset Pricing Experiment Simulation Benchmarks

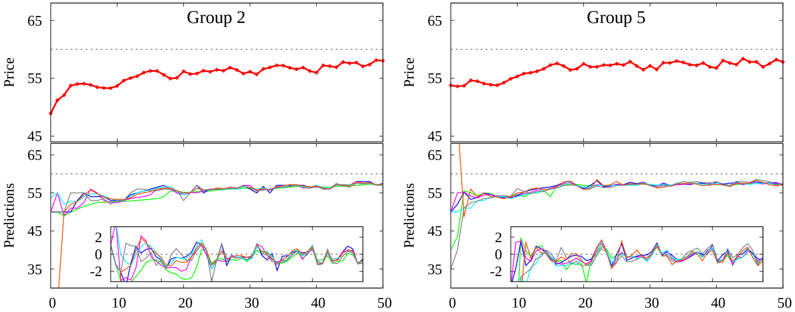


Asset Pricing Experiment (with Robot Trader)



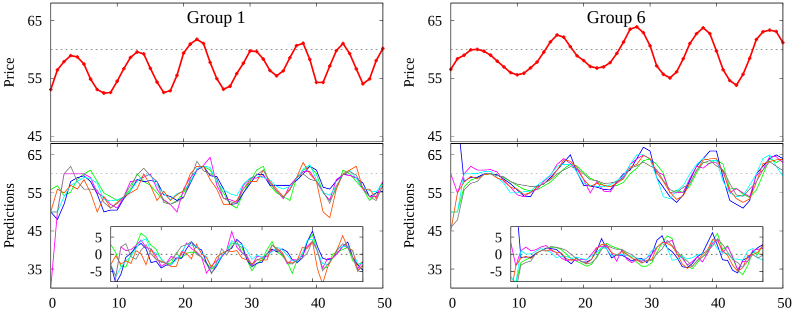
2 Groups with (Almost) Monotonic Convergence

prices, individual predictions and individual errors



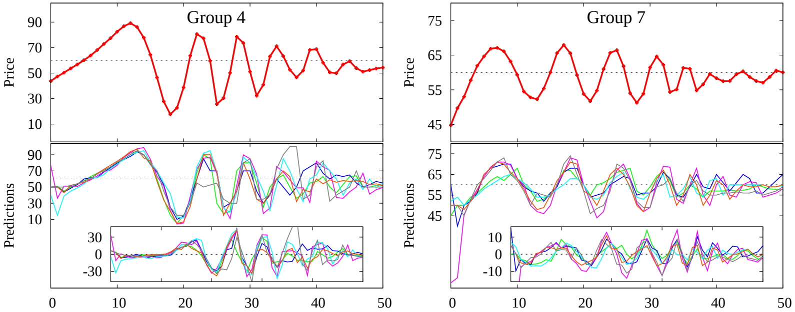
2 Groups with Perpetual Oscillations

prices, individual predictions and individual errors



2 Groups with Damping Oscillations

prices, individual predictions and individual errors



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

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

in particular **trend-extrapolating rules**

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

Heterogeneous Expectations Model
Heuristics Switching Model

- 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:**
  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

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

- weak trend-following rule

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

- strong trend-following rule

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

- anchoring and adjustment heuristics with learnable anchor

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

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

Stochastic Simulations (one step ahead forecast)

Anufriev and Hommes (2009)

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

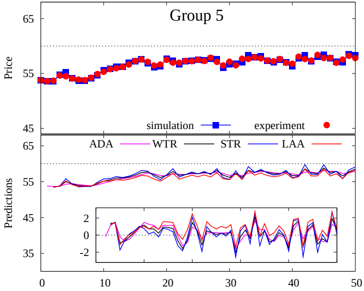
Parameters fixed at: $\beta = 0.4, \eta = 0.7, \delta = 0.9$

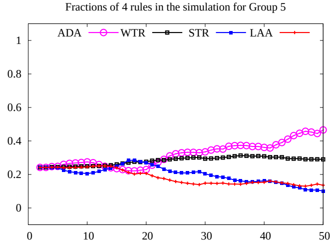
- initial fractions **equal**, i.e. $n_{ht} = 0.25$
- initial prices **as in experiments**

Group 5 (Convergence)

experimental prices
simulated prices, predictions and errors

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

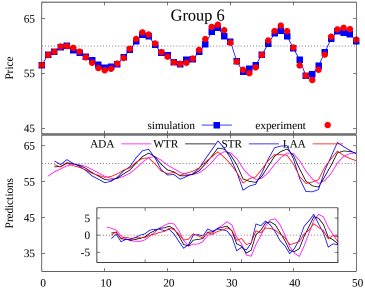




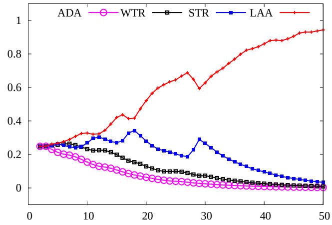
Group 6 (Constant Oscillations)

experimental prices
simulated prices, predictions and errors

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



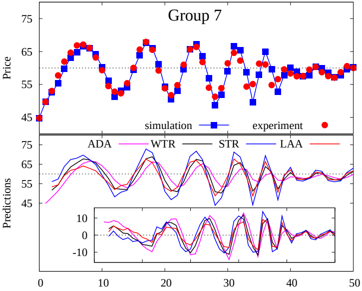
Fractions of 4 rules in the simulation for Group 2

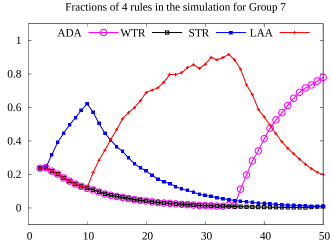


Group 7 (Damping Oscillations)

experimental prices
simulated prices, predictions and errors

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

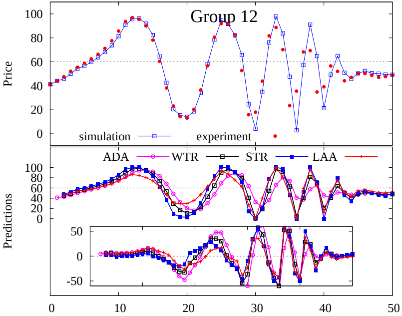


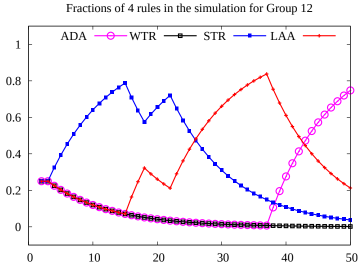


Asset Pricing Experiments without Fundamental Trader

experimental prices
simulated prices, predictions and errors

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





Positive versus Negative Feedback Experiments

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

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

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

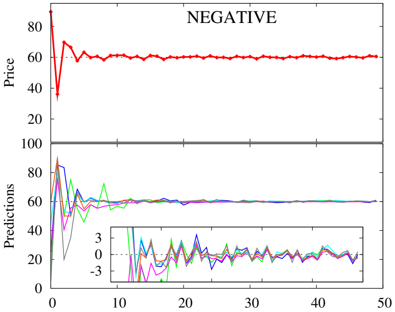
- **positive feedback** (strategic complementarity environment)

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

- **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

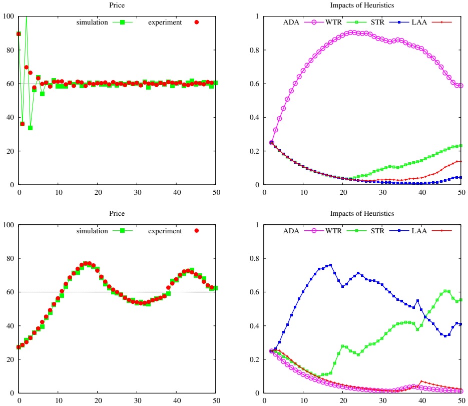
Negative vs. Positive Feedback Experiments

Prices, Individual Predictions and Errors

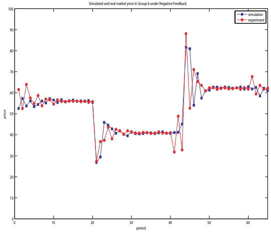


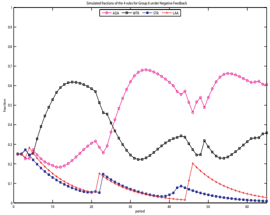
Positive vs Negative Feedback; Small Shocks
Heuristics Switching Model Simulations

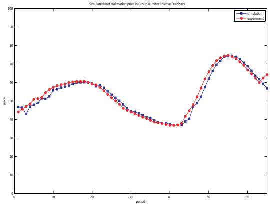
Parameters: $\beta = 0.4, \eta = 0.7, \delta = 0.9$

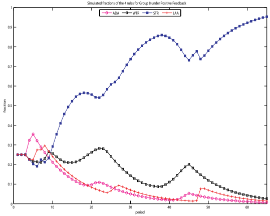


Positive/Negative Feedback; Large Shocks



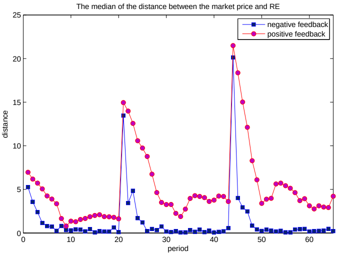


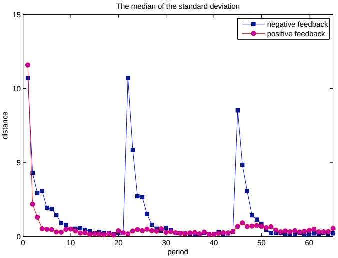




Positive/Negative Feedback; Large Shocks Coordination & Price Discovery

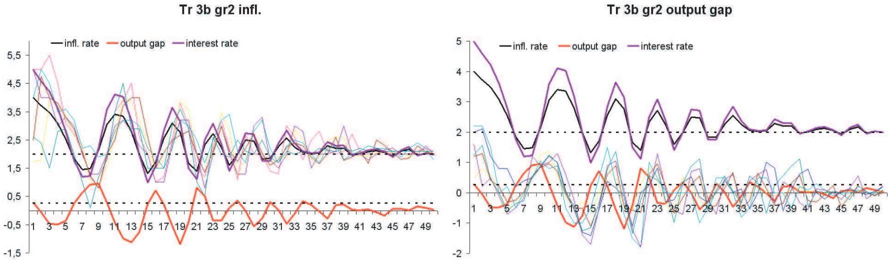
median absolute distance to RE fundamental price;
median standard deviation of individual predictions



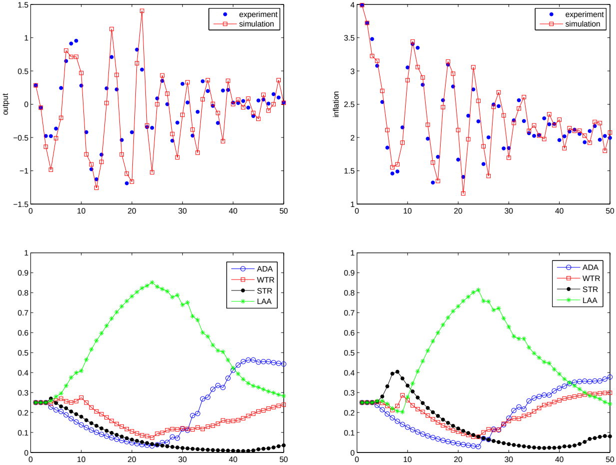


New Keynesian Macro Model; Expectations on Inflation & Output Gap

Assenza et al. (2009), Session 11:B4 Explorations in Bounded Rationality



New Keynesian Macro Model: Simulations (Domenico Massaro)



Concluding Remarks

- **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

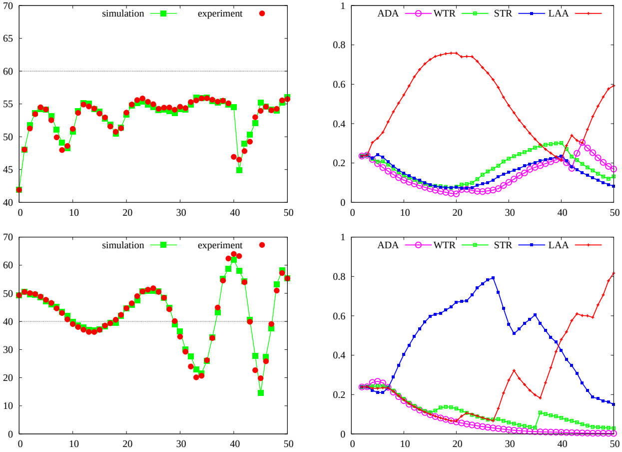
Papers and Experimental Data

- **suggestions** most welcome!
- **papers** and **experimental data** can be obtained at

  CeNDEF website **http://www1.fee.uva.nl/cendef**

Thank you very much!!

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



MSE one-step ahead forecast asset pricing experiments

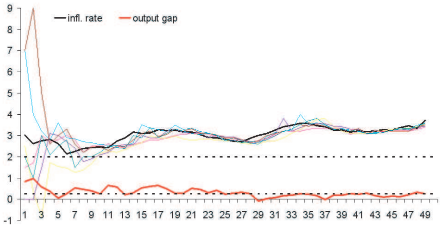
Specification	Group 2	Group 5	Group 1	Group 6	Group 4	Group 7
Fundamental Prediction	18.037	11.797	15.226	8.959	291.376	22.047
naive	0.060	0.062	3.397	2.292	126.162	12.652
AAA	5.537	3.447	2.930	0.863	60.751	5.647
ADA	0.126	**0.050**	5.440	4.303	185.591	18.825
WTR	**0.081**	0.132	1.902	1.038	86.254	8.674
STR	0.556	0.612	2.792	0.767	81.523	13.663
LAA	0.433	0.434	**0.427**	**0.603**	**60.025**	**5.564**
4 heuristics ($\delta = 1$)	0.082	0.158	1.128	0.605	62.865	6.683
4 heuristics (benchmark)	**0.066**	**0.103**	**0.426**	**0.266**	**40.766**[a]	**4.148**
4 heuristics (best fit)	0.057	0.035	0.405	0.188	33.653[a]	2.8151
$\beta \in [0, 1)$	0.99	0.99	0.1	0.99	0.13	0.23
$\eta \in [0, 1)$	0.63	0.98	0.99	0.1	0.82	0.45
$\delta \in [0, 1]$	0.80	0.00	0.45	0.78	0.60	0.44

[a] Computed for $\beta = 0.1$, $\eta = 0.7$ and $\delta = 0.9$.

New Keynesian Macro Model; Expectations on Inflation & Output Gap

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

Tr 3a gr2 infl.



Tr 3a gr2 output gap