

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



The Economy as a Complex Adaptive System

- ▶ **interactions** of many consumers, firms, traders, banks at the **micro-level**
- ▶ **structure** at the aggregate **macro-level**
(e.g. fat tails in distribution of firm size, financial returns, clustered volatility, bubbles and crashes, etc.)
- ▶ key **difference**: in economics the “**atoms can think**”!
economic actors **learn** from past and **adapt** their behavior
- ▶ extreme cases: **rational** versus **random** behaviour
Need a **theory of bounded rationality**

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**.*

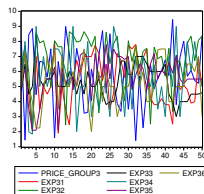
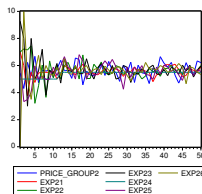
key issues:

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

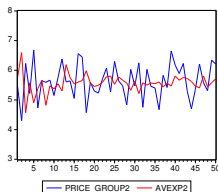
This can be tested in **Learning to Forecast Experiments**

Cobweb Learning to Forecast Experiments

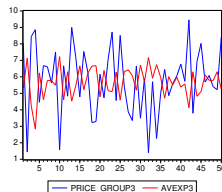
(Hommes et al., Macroeconomic Dynamics 2007)



stable: coordination on RE
no aggregate effect



unstable: persistent heterogeneity
excess volatility



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**; 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

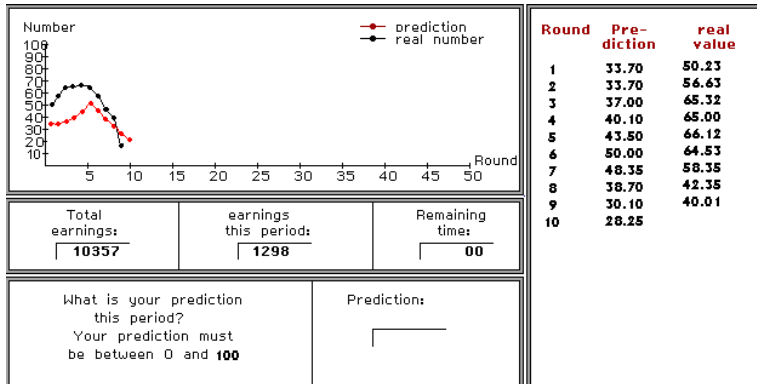
Subjects **know**

- ▶ 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. $p_t = f(\bar{p}_{t+1}^e)$ or $p_t = f(\bar{p}_t^e)$
- ▶ exact **demand schedule** of themselves and others
- ▶ number and **forecasts of other** participants

Example Computer Screen Experiment



Three Different Experimental Settings

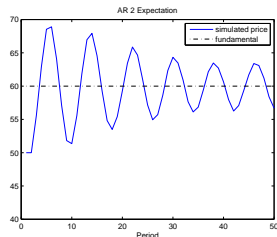
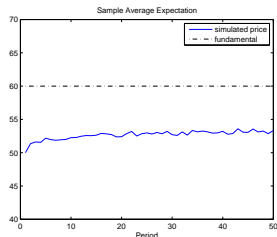
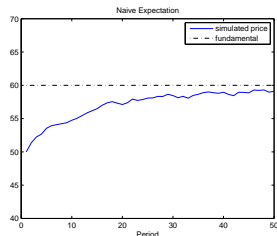
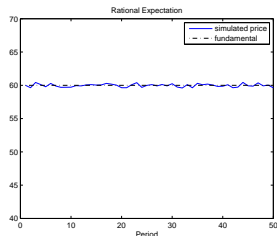
- ▶ **asset pricing experiment** (with/without robot trader)
 - ▶ two-period ahead
 - ▶ positive feedback

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

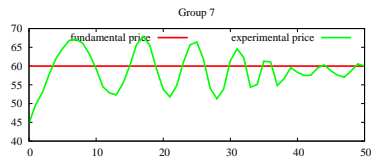
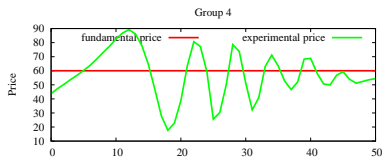
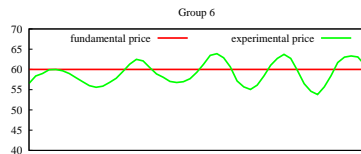
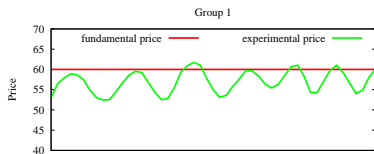
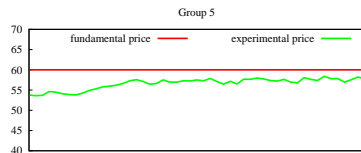
- ▶ **positive** versus **negative** feedback; one-period ahead $p_t = f(p_t^e)$:
 - ▶ **positive** feedback: linear, slope +0.95;
 - ▶ **negative** feedback: linear, slope -0.95.
- ▶ **New Keynesian Macromodel**: aggregate inflation and output depend on individual forecasts of **both** inflation and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

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

Asset Pricing Experiment Simulation Benchmarks

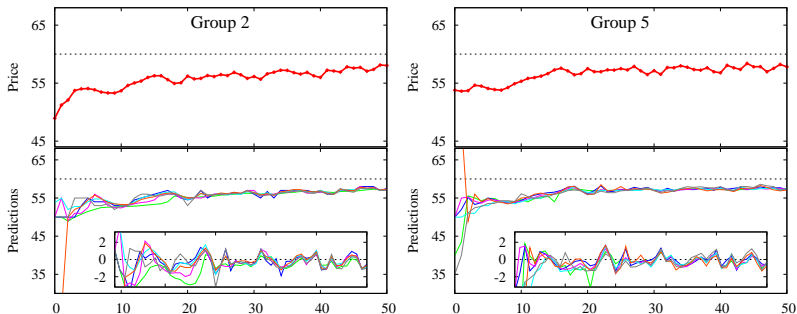


Asset Pricing Experiment (with Robot Trader)



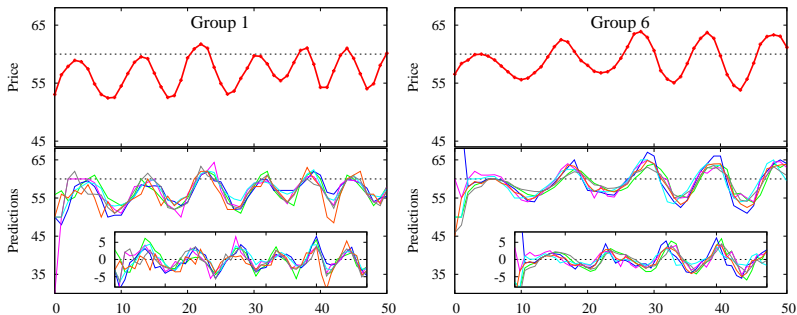
2 Groups with (Almost) Monotonic Convergence

prices, individual predictions and individual errors



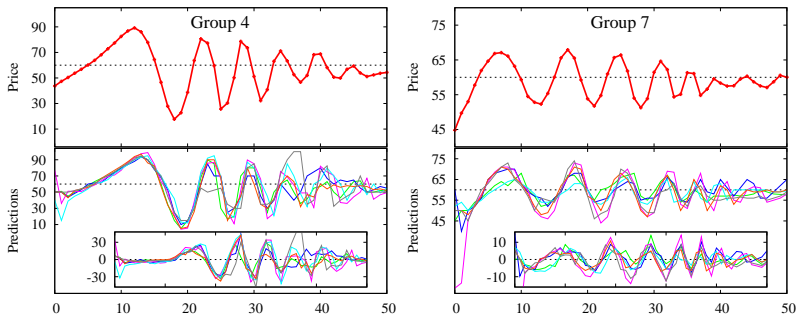
2 Groups with Perpetual Oscillations

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 patterns**
 - ▶ (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**

$$p_{t+1}^e = w p_{t-1} + (1 - w) p_t^e$$

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

$$p_{t+1}^e = \alpha + \beta_1 p_{t-1} + \beta_2 p_{t-2}$$

e.g. $(60 + p_{t-1})/2 + (p_{t-1} - p_{t-2})$
or LAA $(p_{t-1}^{av} + p_{t-1})/2 + (p_{t-1} - p_{t-2})$

in particular **trend-extrapolating rules**

$$p_{t+1}^e = p_{t-1} + \gamma (p_{t-1} - p_{t-2}) \quad 0.4 \leq \gamma \leq 1.3$$

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

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

- ▶ weak trend-following rule

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

- ▶ strong trend-following rule

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

- ▶ anchoring and adjustment heuristics with learnable anchor

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

Evolutionary Switching

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

- ▶ **performance measure** of heuristic i is

$$U_{i,t-1} = -(p_{t-1} - p_{i,t-1}^e)^2 + \eta U_{i,t-2}$$

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

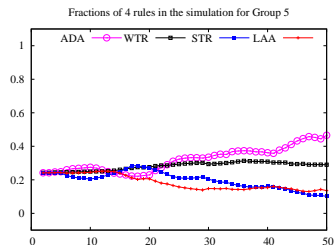
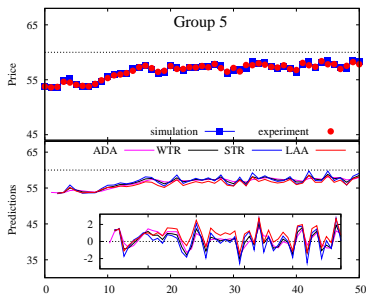
- ▶ initial fractions **equal**, i.e. $n_{ht} = 0.25$
- ▶ initial prices **as in experiments**

Group 5 (Convergence)

experimental prices

simulated prices, predictions and errors

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

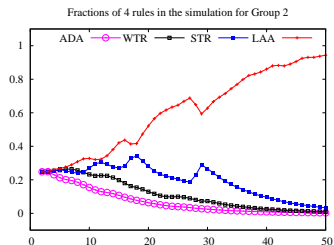
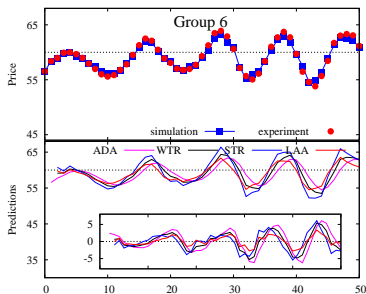


Group 6 (Constant Oscillations)

experimental prices

simulated prices, predictions and errors

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

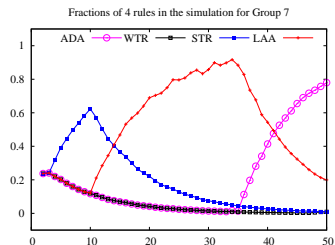
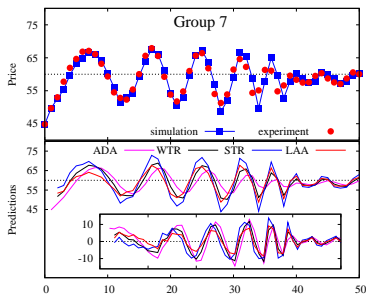


Group 7 (Damping Oscillations)

experimental prices

simulated prices, predictions and errors

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

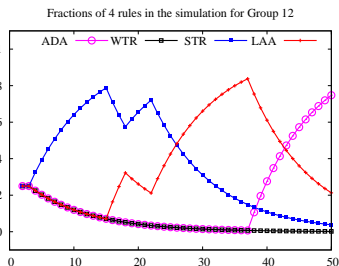
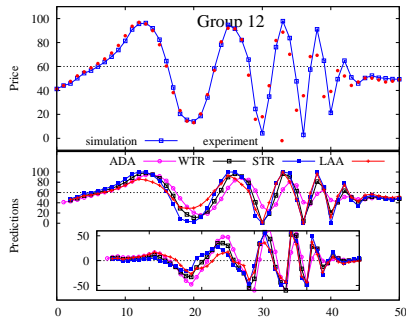


Asset Pricing Experiments without Fundamental Trader

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)

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

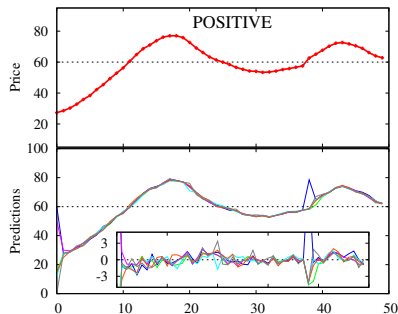
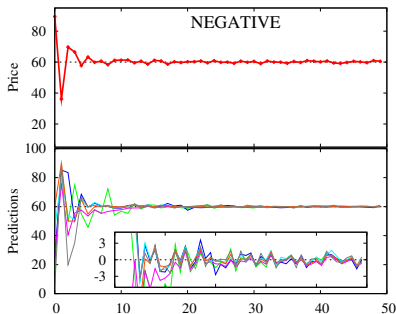
- ▶ **positive feedback** (strategic complementarity environment)

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

- ▶ **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

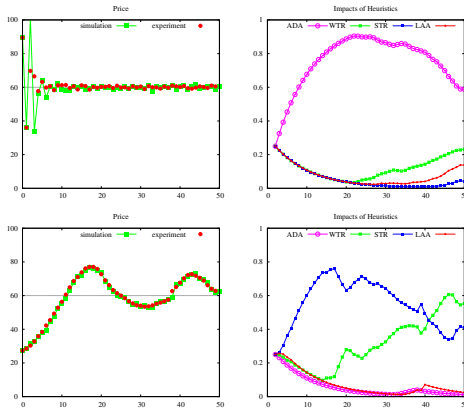
Prices, Individual Predictions and Errors



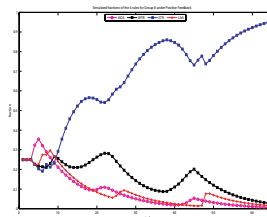
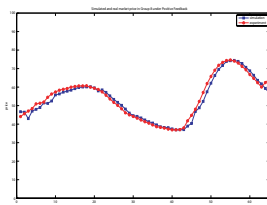
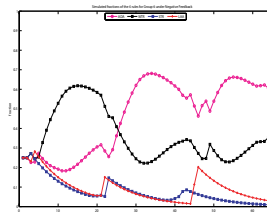
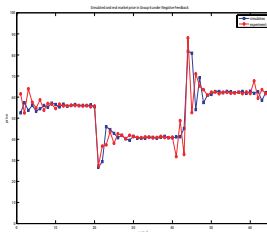
Positive vs Negative Feedback; Small Shocks

Heuristics Switching Model Simulations

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



Positive/Negative Feedback; Large Shocks

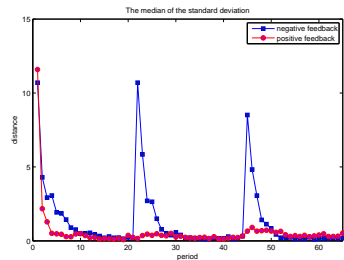
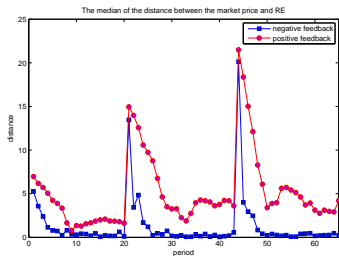


Positive/Negative Feedback; Large Shocks

Coordination & Price Discovery

median absolute distance to RE fundamental price;

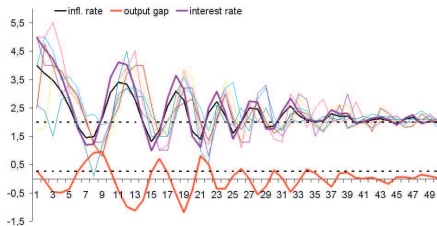
median standard deviation of individual predictions



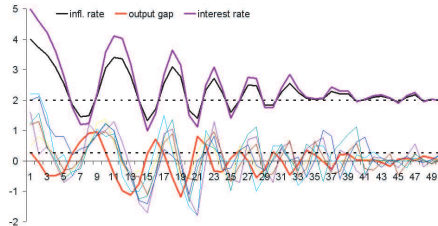
New Keynesian Macro Model; Expectations on Inflation & Output Gap

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

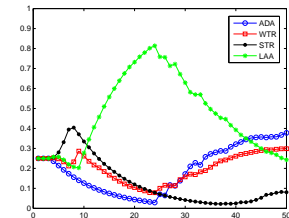
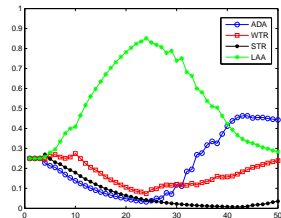
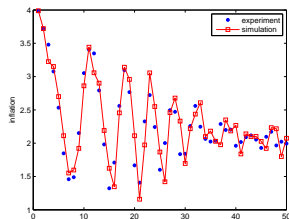
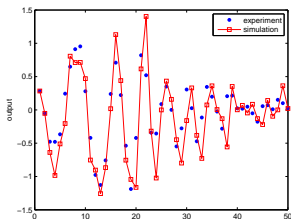
Tr 3b gr2 infl.



Tr 3b gr2 output gap



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**

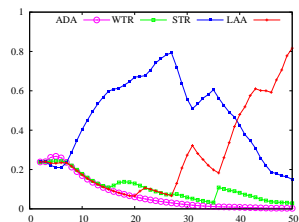
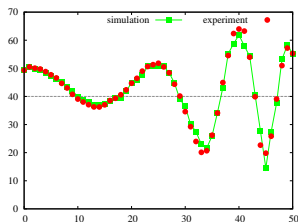
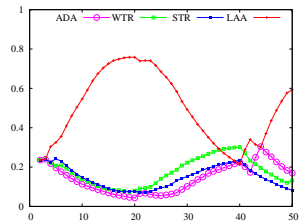
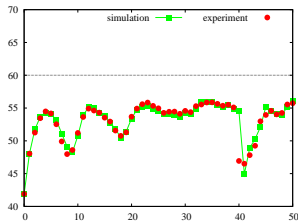
Papers and Experimental Data

- ▶ **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

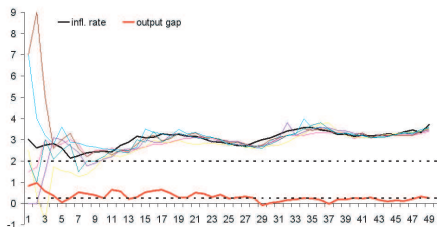
Specification	Group 2	Group 5	Group 1	Group 6	Group 4	Group 7
Fundamental Prediction	18.037	11.797	15.226	8.959	291.376	22.047
naive	0.060	0.062	3.397	2.292	126.162	12.652
AAA	5.537	3.447	2.930	0.863	60.751	5.647
ADA	0.126	0.050	5.440	4.303	185.591	18.825
WTR	0.081	0.132	1.902	1.038	86.254	8.674
STR	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

