Monetary Policy under Behavioral Expectations: Theory and Experiment

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Outline

Introduction

- Expectations play a crucial role in modern macroeconomic models
- The standard assumption is that expectations are formed rationally
- However, a lot of evidence of boundedly rational and irrational behavior in economics
- What happens to the models and their conclusions if rational expectations are replaced by a behavioral model of expectation formation?

Introduction

- Behavioral expectations benchmark: heuristic switching model (from earlier work)
- We compare results on aggregate economic behavior
  - Focus on inflation volatility (where the models yield different results)
  - Inflation volatility / price stability of crucial importance to central banks
- We derive testable hypotheses from the models with rational and behavioral expectations and test them in a learning to forecast experiment

Introduction

Looking at it from the applied side (and narrowing down the research question):

- How is inflation volatility affected if the central bank reacts to the output gap with its interest rate decisions (in addition to reacting to inflation)?
- Should a central bank that only cares about inflation (e.g. ECB) only react to inflation or also to the output gap?

Introduction

- These questions can be investigated theoretically but also empirically/experimentally
- Empirical work with observational field data has some advantages, experimental work has others
  - No issues with reverse causality or confounding factors
  - We know that the macro equations we use are actually the ones determining the outcomes in the experimental economy
- In our experiment, we solely vary the feedback mechanism from expectations to realizations (by varying one parameter of the Taylor Rule)

Macroeconomic Model

- The aggregate equations are those of a standard New Keynesian closed economy
- These equations are also fully microfounded under behavioral expectations (see Appendix A of the paper)
- I will only show aggregate equations in this talk
- Standard calibration for parameters (Clarida, Galí & Gertler, 2000)

▸ Calibration

Macroeconomic Model

Aggregate New Keynesian Equations:

IS: $$y_t = \bar{y}^e_{t+1} - \varphi(i_t - \bar{\pi}^e_{t+1}) + g_t$$

NKP: $$\pi_t = \lambda y_t + \rho\bar{\pi}^e_{t+1} + u_t$$

MP: $$i_t = max(\bar{\pi} + \phi_\pi(\pi_t - \bar{\pi}) + \phi_y(y_t - \bar{y}), 0)$$

Expectation Formation

- As (benchmark) behavioral expectation formation mechanism, we consider a heuristic switching model (HSM) that performed well in earlier work
- Important: The results are extremely robust to using different specifications of behavioral expectation formation

Expectation Formation

Beauty of the HSM:

- Agents do not need to know the exact equations governing the economy
- No high demands on agents' computational abilities
- Yet, agents are not "stupid": They update the way they form expectations over time (reinforcement learning)
- Agents do not use heuristics much that performed poorly in the past

Heuristics

- Two ingredients, heuristics and switching mechanism
- Individuals use the following four heuristic (2 period ahead forecasts; x either inflation or output gap):

$$ADA: \quad x^e_{1,t+1} = 0.65x_{t-1} + 0.35x^e_{1,t}$$

$$WTR: \quad x^e_{2,t+1} = x_{t-1} + 0.4(x_{t-1} - x_{t-2})$$

$$STR: \quad x^e_{3,t+1} = x_{t-1} + 1.3(x_{t-1} - x_{t-2})$$

$$LAA: \quad x^e_{4,t+1} = \frac{x^{av}_{t-1} + x_{t-1}}{2} + (x_{t-1} - x_{t-2})$$

Switching between Heuristics

- Agents choose between heuristics on the basis of past performance

$$U_{h,t-1} = \frac{100}{1 + |x_{t-1} - x^e_{h,t-1}|} + \eta U_{h,t-2}$$

- Updating

$$n_{h,t} = \delta n_{h,t-1} + (1-\delta)\frac{\exp(\beta U_{h,t-1})}{\sum_h \exp(\beta U_{h,t-1})}$$

Price Stability

- We care about price stability only
- This is the mandate of the ECB (and the sole objective of some other central banks)
- Which measure of price (in)stability / inflation volatility?

Measuring Inflation Volatility

- Important: The results are qualitatively the same for all measures

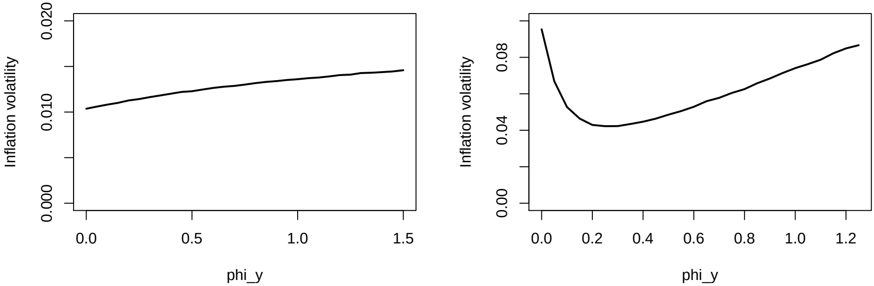
Possibilities:

- Mean squared deviation from target: $\frac{1}{T}\sum_{t=1}^{T}(\pi_t - \bar{\pi})^2$
- Standard deviation: $\sqrt{\frac{1}{T}\sum_{t=1}^{T}(\pi_t - \pi^{av})^2}$
- Relative deviation: $\frac{1}{T-1}\sum_{t=2}^{T}(\pi_t - \pi_{t-1})^2$
- Precise welfare measure $\frac{1}{T}\sum_{t=1}^{T} f(\pi_t, Var_i(\pi_{i,t}^e))$

- We use the relative deviation

▸ Example

Main Theoretical Result



(a) Rational model

(b) Behavioral model

Figure: Inflation volatility as function of ϕ_y

Policy Implications and Intuition

- Policy implications of the behavioral model are straightforward:
  A CB that only cares about price stability should still react to the output gap!
- What's the intuition of the results?

Introduction

- Behavioral theory gives different results from rational theory
- But how do actual people behave?
- One way to find out: experimentation
  - Full control:
  - Macro equations are correct description of reality (by design)
  - Incentivized elicitation of forecasts
  - Random assignment to treatments (no reverse causality, no confounding factors, etc.)

Introduction

- The experiment is a learning-to-forecast experiment
- We do not try to mimic all elements of the macroeconomy in the laboratory with all possible choices!
- We only elicit forecasts from subjects – everything else is done by the computer
- Reflects the focus on expectation formation
  - The monetary policy rule changes the feedback from expectations to realizations

Design and Implementation

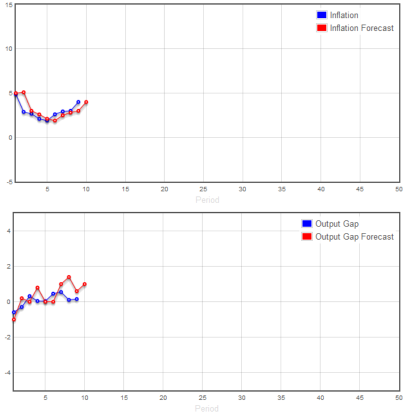
- Subjects forecast output gap and inflation
- Average forecast of a group is used as average expectation in the macro model to generate the next realization
- Groups of 6
- Inflation target is 3.5
- Between subjects design & within session randomization

Design and Implementation

- Subjects in both treatments receive absolutely identical instructions
- Subjects receive only qualitative information about the experimental economy
- Each subject is either paid for inflation forecasts or output gap forecasts

▸ Payment

Charts



Information table

Turn	Inflation	Your Inflation Forecast	Output Gap	Your Output Gap Forecast	Interest Rate	Your Score (O)	Your Score (I)
10		4.00		1.00			
9	4.01	3.00	0.16	0.60	5.05	69.23	49.83
8	3.00	2.80	0.11	1.40	3.52	43.62	83.17
7	2.94	2.50	0.55	1.00	3.65	69.00	69.58
6	2.61	1.90	0.46	0.00	3.11	68.60	58.40
5	1.89	2.10	0.04	0.00	1.83	96.13	82.86
4	2.09	2.60	0.05	0.80	2.13	57.00	66.34
3	2.67	3.00	0.32	0.00	3.13	75.67	75.21
2	2.88	5.10	-0.29	0.20	3.14	66.91	31.07
1	4.87	5.00	-0.59	-1.00	5.98	70.98	88.62

Player Actions

You are now in period 10

Enter your forecast for inflation in period 11

Submit

Enter your forecast for the output gap in period 11

Player Information

Your total score for output gap is 617.14

Your total score for inflation is 605.09

Please submit your forecast.

Treatments

- Two treatments, only difference is in the Taylor rule
- T1: $\phi_\pi = 1.5,\ \phi_y = 0$
- T2: $\phi_\pi = 1.5,\ \phi_y = 0.5$

Hypotheses

- Outcome of interest is inflation volatility
- Null-hypothesis derived from RE, alternative from BE:

	T1 ($\phi_y = 0$)	T2 ($\phi_y = 0.5$)
RE		
BE		

Inflation Data

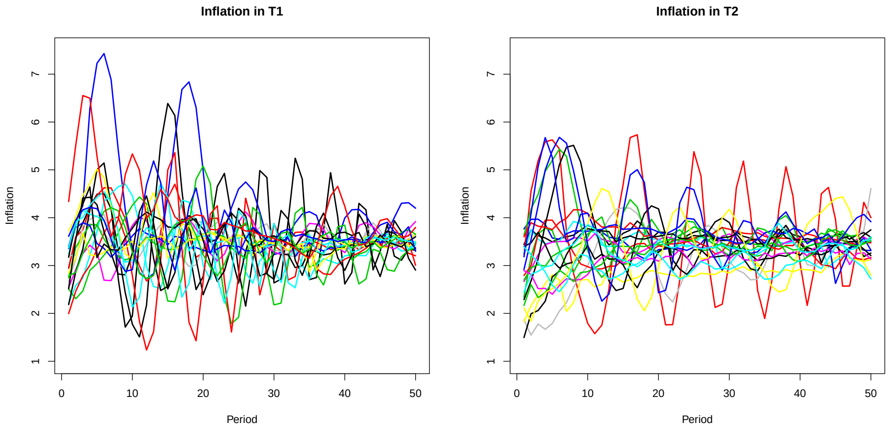


Figure: Realized inflation for all groups in both treatments

Inflation Volatility

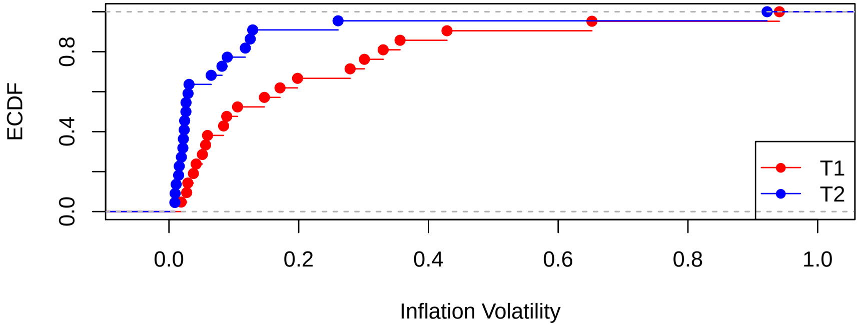


Figure: Empirical distribution functions of inflation volatility

- Difference statistically significant (Wilcoxon rank-sum, $p<0.01$)

Further Data: Output Gap

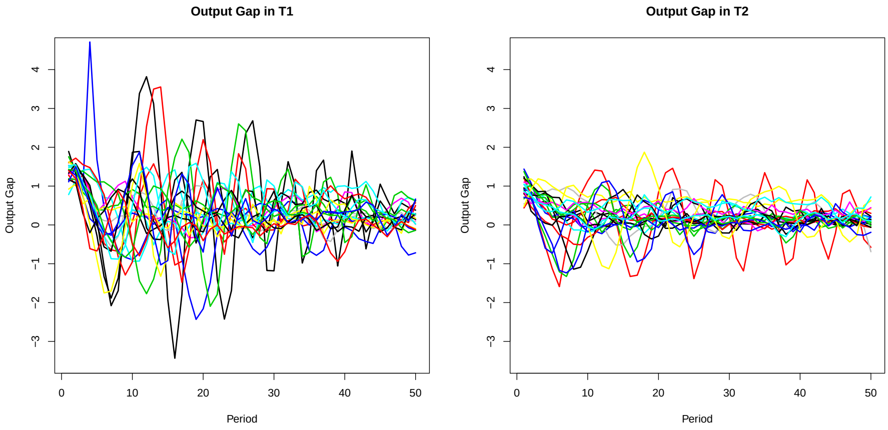


Figure: Realized output gap in both treatments

Further Data: Interest Rates

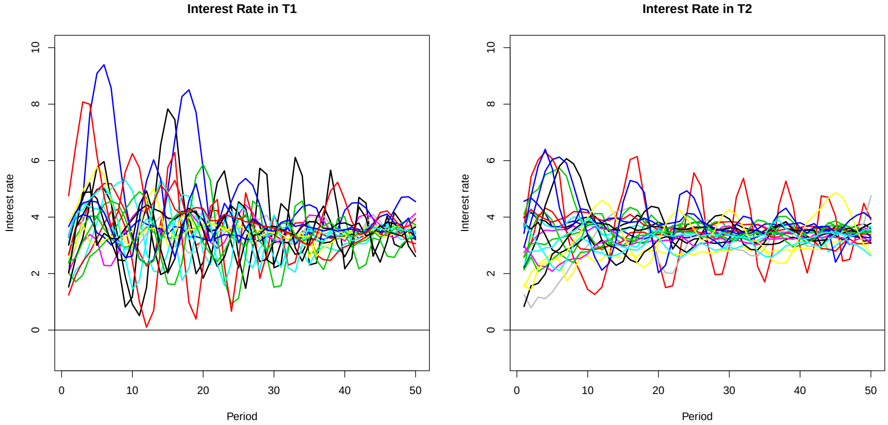


Figure: Interest rate in both treatments

Performance of HSM and other Models

Mean squared errors of two-period-ahead predictions from different models of expectation formation

	Inflation $T1$	Output gap $T1$	Inflation $T2$	Output gap $T2$
HSM	**0.072**	**0.141**	**0.040**	**0.022**
RE	0.541	0.753	0.422	0.222
ADA	0.254	0.399	0.168	0.095
WTR	0.106	0.193	0.063	0.037
STR	0.246	0.415	0.088	0.068
LAA	0.107	0.180	0.063	0.037

Fractions

Discussion

- We consider a macro model with behavioral expectations: results are partly very different from the fully rational model
- The behavioral model gives a policy recommendation that is different from the same model with RE: Even a CB only interested in price stability should react to changes in the output gap!
- Laboratory evidence supports this policy recommendation
- The evidence from the laboratory furthermore gives support to using the behavioral model

▸ Additional intuition

Thank you for your attention!

Related Literature

- Theory:

  Orphanides and Williams (2006), Branch and McGough (2009, 2010), Woodford (2010), De Grauwe (2011, 2012a), Anufriev et al. (2013), Kurz et al. (2013), etc.; see Woodford (2013) for an overview.

- Experiments:

  Kryvtsov and Petersen (2013), Pfajfar and Zakelj (2014), Assenza et al. (2014b), Cornand and M'Baye (2016), etc.; see Assenza et al. (2014a), and Cornand and Heinemann (2014) for an overview.

Feedback

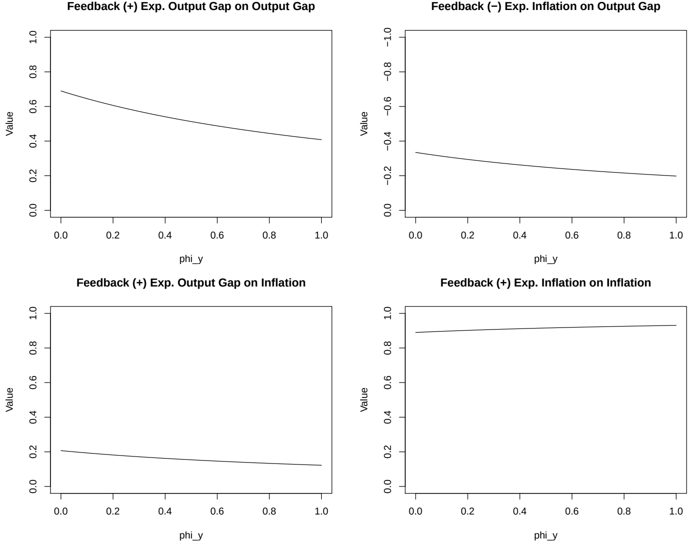
- Is there additional intuition for our results?
- From behavioral micro/finance: price expectations tend to deviate particularly from fundamentals with sizable positive feedback (from expectations to realizations)

Matrix form of the macro equations (ZLB not binding)

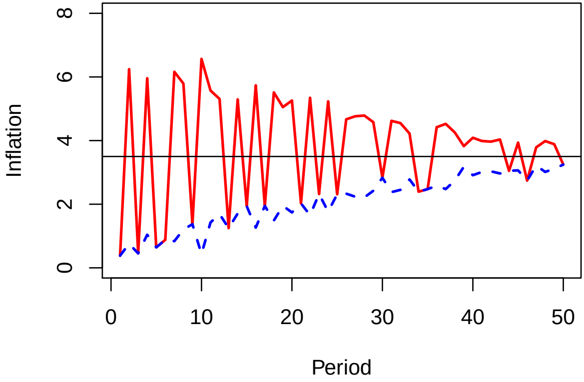
$$\begin{bmatrix} y_t \\ \pi_t \end{bmatrix} = \Omega \begin{bmatrix} \varphi\bar{\pi}(\phi_\pi - 1) + \varphi\phi_y\bar{y} \\ \lambda\varphi\bar{\pi}(\phi_\pi - 1) + \lambda\varphi\phi_y\bar{y} \end{bmatrix} + \Omega \begin{bmatrix} 1 & \varphi(1 - \phi_\pi\rho) \\ \lambda & \lambda\varphi + \rho + \rho\varphi\phi_y \end{bmatrix} \begin{bmatrix} \bar{y}^e_{t+1} \\ \bar{\pi}^e_{t+1} \end{bmatrix} + \Omega \begin{bmatrix} 1 & -\varphi\phi_\pi \\ \lambda & 1 + \varphi\phi_y \end{bmatrix} \begin{bmatrix} g_t \\ u_t \end{bmatrix}$$

with $\Omega \equiv 1/(1 + \lambda\varphi\phi_\pi + \varphi\phi_y)$

Feedback


Feedback (+) Exp. Output Gap on Output Gap
Value
0.0
0.2
0.4
0.6
0.8
1.0
phi_y
Feedback (−) Exp. Inflation on Output Gap
Value
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
phi_y
Feedback (+) Exp. Output Gap on Inflation
Value
phi_y
Feedback (+) Exp. Inflation on Inflation
Value
phi_y

Measuring Volatility: Example



Return

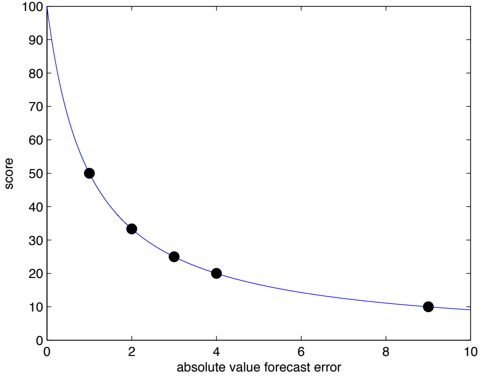
Parameters

- Parameters for the NK equations (in quarterly terms; Clarida, Galí, Gertler 2000)
  - $\varphi = 1$
  - $\lambda = 0.3$
  - $\rho = 0.99$

Return

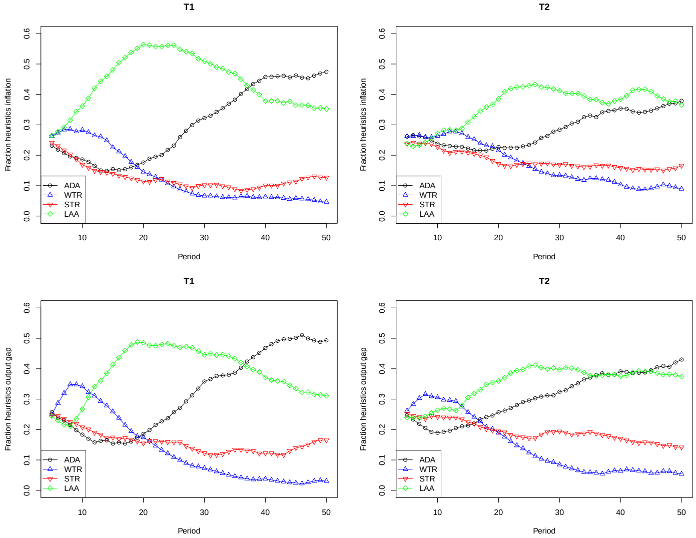
- Parameters for the heuristic switching model:
  - $\delta = 0.9$
  - $\eta = 0.7$
  - $\beta = 0.4$

Incentives Subject Payments



Return

Fractions Heuristics



◂ Back

NK Model with Heterogeneous Expectations

NK model consistent with heterogeneous expectations in more general form:

$$y_t = \bar{y}^e_{t+1} - \varphi(i_t - \bar{\pi}^e_{t+1}) + \Phi_t(c) + g_t$$

$$\pi_t = \lambda y_t + \rho\bar{\pi}^e_{t+1} + \Psi_t(p) + u_t$$

with

$$\Phi_t(c) = \int_i (E_{i,t}c_{i,t+1} - E_{i,t}c_{t+1})$$

$$\Psi_t(p) = (1-\omega)\beta \int_i (E_{i,t}p_{i,t+1} - E_{i,t}p_{t+1})$$

Random Utility Model

- Agents i observe performance of each rule h with some noise

$$\tilde{U}_h = U_h + \epsilon_{hi}$$

- $P_h = Pr[\tilde{U}_h > \{\tilde{U}_{h'}\}_{\forall h' \neq h}] = Pr[U_h + \epsilon_{hi} > \{U_{h'} + \epsilon_{h'i}\}_{\forall h' \neq h}]$
- When error terms are IID following double exponential

$$P_h = \exp(\beta U_h) / \sum_h \exp(\beta U_h)$$

- β inversely proportional to noise variance
  - $\beta \to \infty$: no errors
  - $\beta \to 0$: uniform probabilities

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