Inflation Expectations and Monetary Policy Design: Evidence from the Laboratory

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General focus and motivation

- Designing a macroeconomic experiment to study expectation formation, individual uncertainty and different conducts of monetary policy
- We use a simplified version of the standard New Keynesian macro model where subjects are asked to forecast inflation
- How are subjects forming (inflation) expectations?
- Do they use one model or do they switch between different models?
- How to design monetary policy that is robust to different expectation formation mechanisms?

Motivation

- Bernanke and Friedman on the relationship between monetary policy design and inflation expectations
- Informational frictions and heterogeneity of expectations are the main features of expectation formation process $\longrightarrow$
- Necessity to use micro data (and its distribution) and not the aggregate data (mostly used so far, a few exceptions at this conference)
- Other experiments and survey data papers mostly focus on aggregate expectation formation
- Studies on micro data in the survey data literature – results might be problematic since the agents are not the same over the whole sample period

Previous literature

- Branch (EJ, 2004) and (JEDC, 2007) and Pfajfar and Santoro (JEBO 2010a, 2010b): Michigan survey of inflation expectations
- Most experiments so far reject the rational expectations assumption in favor of adaptive expectations
- They usually use OLG models: Marimon, Spear, and Sunder (JET, 1993) or Bernasconi and Kirchkamp (JME, 2000)
- Exception is Adam (EJ, 2007) who uses a simplified version of sticky price monetary model
- "Learning to forecast" experiments are also conducted in asset pricing literature: Hommes et al. (RFS, 2005) and Haruvy, Lahav, and Noussair (2007, AER)

This paper (and companion paper)

- Simplified New Keynesian framework where agents forecast inflation (and confidence intervals)
- We estimate different expectation formation mechanisms with a particular focus on adaptive learning
- We further estimate all models with recursive least squares and ask whether agents use the same expectations in the whole sample or do they switch between models
- We check expectation theories on an individual level
- We try to determine the relationship between the conduct of monetary policy and expectation formation mechanism
- Investigate measures of uncertainty and disagreement in the "economy"
- We analyze the properties of the aggregate distribution

Content

- Model
- Experimental design
- Analysis of individual expectations
- Switching between different expectation formation mechanisms
- Expectations and Monetary policy
- Conclusion and directions for future research

Model

- New Keynesian monetary model with different policy reaction functions
- IS curve:

$$y_t = -\varphi\left(i_t - E_t\pi_{t+1}\right) + y_{t-1} + g_t$$

- Phillips curve:

$$\pi_t = \lambda y_t + \beta E_t \pi_{t+1} + u_t$$

- In different treatments we try different monetary policy reaction function

Taylor rules

- Inflation forecast targeting (T1, T2, T3)

$$i_t = \gamma \left(E_t \pi_{t+1} - \overline{\pi} \right) + \overline{\pi}$$

- Inflation targeting Taylor rule (T5)

$$i_t = \gamma \left(\pi_t - \overline{\pi} \right) + \overline{\pi}$$

- McCallum-Nelson (2004) calibration:

$$\beta = 0.99, \varphi = 0.164, \lambda = 0.3, \overline{\pi} = 3$$

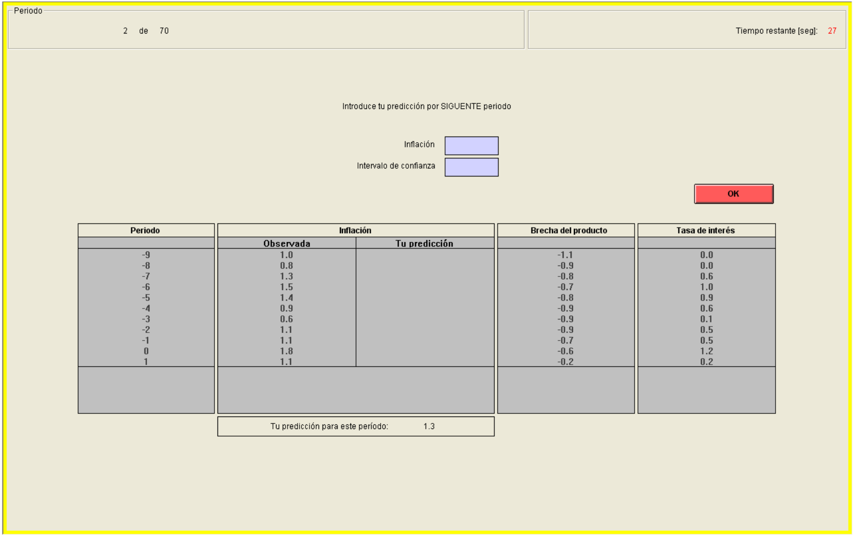
Experimental design

- 6 groups in each treatment, 1 group = simulated economy with 9 agents, 70 periods
- Subjects are presented with time series of *inflation*, *output gap* and *interest rate*.
- Their task is to make *point predictions* of next period's inflation and 95% *confidence bounds* (either symmetric or upper and lower bound)
- The payoff is a function of a subject's prediction accuracy and the size of his interval:

$$W = \max\left\{\frac{1000}{1+f} - 200,\ 0\right\} + \max\left\{\frac{1000x}{1+CI} - 200,\ 0\right\}$$

$$x = \begin{cases} 0 & \text{if} \quad CI \geq f \\ 1 & \text{if} \quad \textit{otherwise} \end{cases}, \quad f = \left|\pi_{t+1} - E_{t-1}\pi_{t+1}\right|.$$

Experimental screen



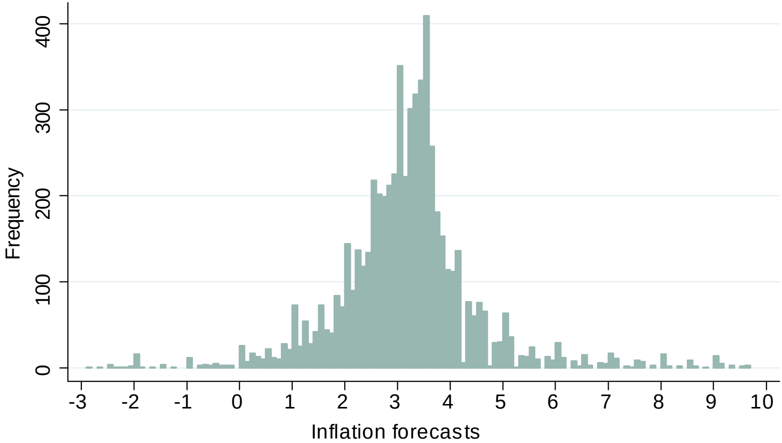
Periodo	Inflación		Brecha del producto	Tasa de interés
	Observada	Tu predicción		
-9	1.0		-1.1	0.0
-8	0.8		-0.9	0.0
-7	1.3		-0.8	0.6
-6	1.5		-0.7	1.0
-5	1.4		-0.8	0.9
-4	0.9		-0.9	0.6
-3	0.6		-0.9	0.1
-2	1.1		-0.9	0.5
-1	1.1		-0.7	0.5
0	1.8		-0.6	1.2
1	1.1		-0.2	0.2

Treatments Calibration

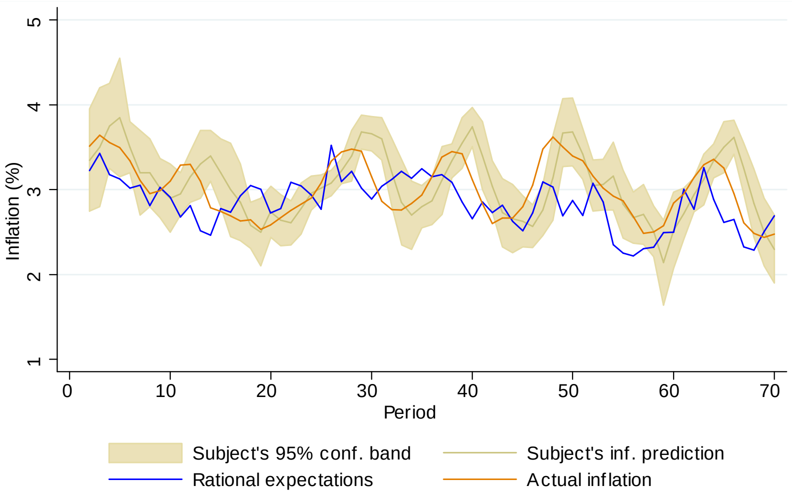
Subtreatments	Treatment A Sym. conf. int.	Treatment B Asym. conf. int.
Taylor rule (equation)	Groups	Groups
Forward looking, $\gamma = 1.5$	1-4	5-6
Forward looking, $\gamma = 1.35$	7-10	11-12
Forward looking, $\gamma = 4$	13-16	17-18
Contemporaneous, $\gamma = 1.5$	19-22	23-24

Table: Treatments

- We gathered 40,320 data points from 216 subjects.
- Mean 3.06% where the inflation target is set to 3%
- The standard deviation varies substantially across groups, the largest being 6.31 and the lowest 0.26



Results – Individual expectations



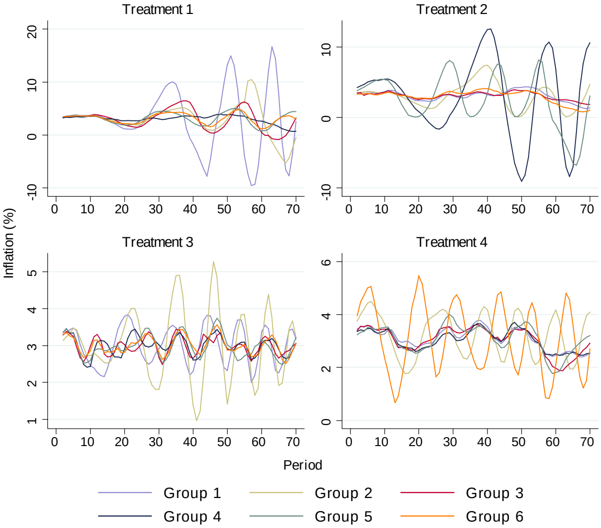


Figure 2: Group comparison of average expected inflation and realized inflation by treatment.

Models of expectation formation

- Rational expectations (efficient use of information):

$$\pi_t - \pi^k_{t|t-1} = a + (b-1)\,\pi^k_{t|t-1}, \tag{1}$$

- Information stickiness type regression:

$$\pi^k_{t+1|t} = \lambda_1\eta_0 + \lambda_1\eta_1 y_{t-1} + (1-\lambda_1)\,\pi^k_{t|t-1}, \tag{2}$$

- Trend extrapolation:

$$\pi^k_{t+1|t} - \pi_{t-1} = \tau_0 + \tau_1\,(\pi_{t-1} - \pi_{t-2}), \tag{3}$$

- Adaptive expectations:

$$\pi^k_{t+1|t} = \pi^k_{t-1|t-2} + \vartheta\left(\pi_{t-1} - \pi^k_{t-1|t-2}\right), \tag{4}$$

- General model:

$$\pi^k_{t+1|t} = \alpha + \gamma\pi_{t-1} + \beta y_{t-1} + \mu i_{t-1} + \zeta\pi^k_{t-1|t-2} + \varepsilon_t. \tag{5}$$

Adaptive learning

- PLMs:

$$\pi^k_{t+1|t} = \phi_{0,t-1} + \phi_{1,t-1}\pi_{t-1}$$

$$\pi^k_{t+1|t} = \phi_{0,t-1} + \phi_{1,t-1}y_{t-1} + \varepsilon_t .$$

$$\pi^k_{t+1|t} = \phi_{0,t-1} + \phi_{1,t-1}\pi^k_{t-1|t-2} + \varepsilon_t .$$

$$\pi^k_{t+1|t} - \pi_{t-1} = \phi_{0,t-1} + \phi_{1,t-1}\left(\pi_{t-1} - \pi_{t-2}\right).$$

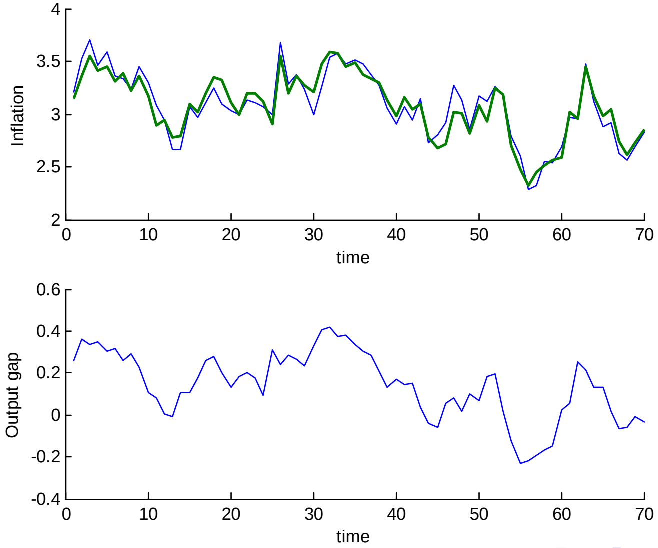
- where agents update coefficients according to:

$$\widehat{\phi}_t = \widehat{\phi}_{t-2} + \vartheta X'_{t-2}\left(\pi_t - X_{t-2}\widehat{\phi}_{t-2}\right)$$

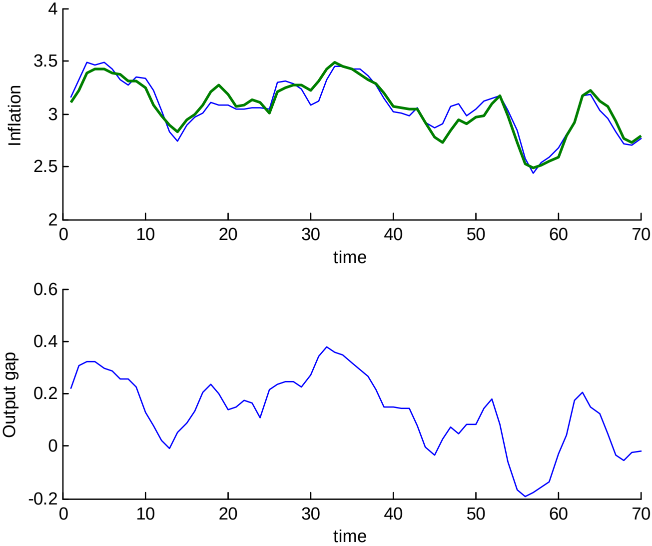
and $X_t = \begin{pmatrix} 1 & \pi_t \end{pmatrix}$ and $\widehat{\phi}_t = \begin{pmatrix} \phi_{0,t} & \phi_{1,t} \end{pmatrix}$.

- Gain parameter: the mean value is 0.0447 with a standard deviation of 0.0537 (median 0.0260) and most fall within $0.01 - 0.07$.

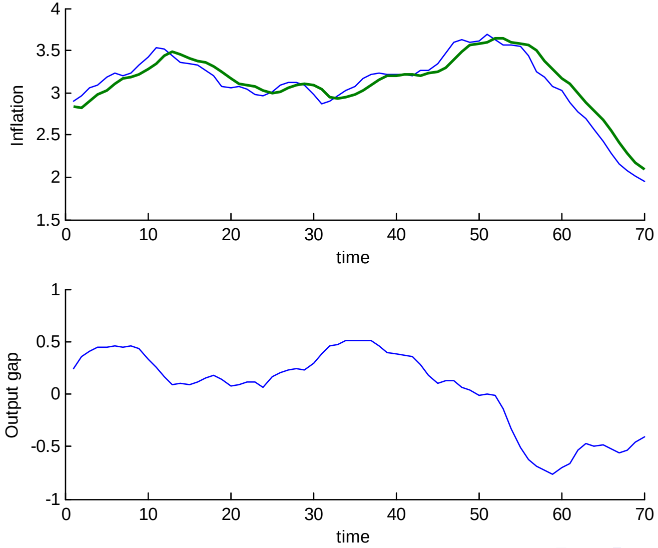
T1 case: Rational expectations



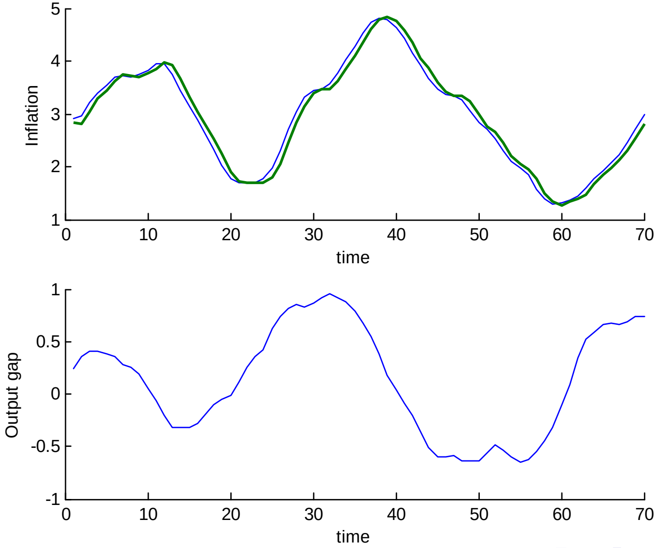
T1 case: AL: PLM of REE form without errors (gain=0.05)



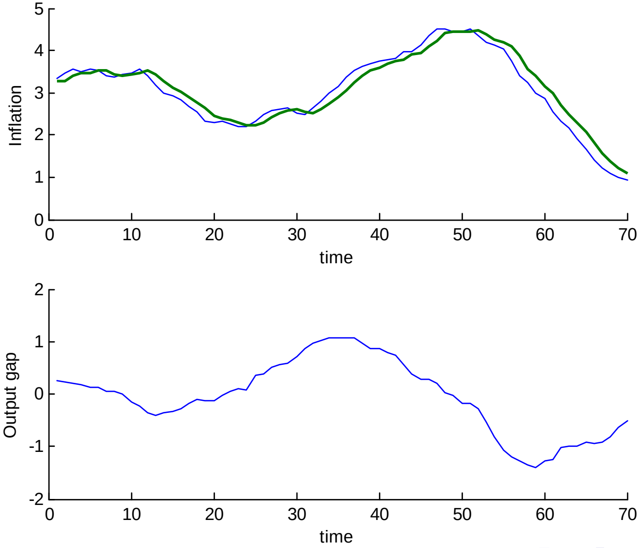
T1 case: AL: steady state learning (gain=0.5)



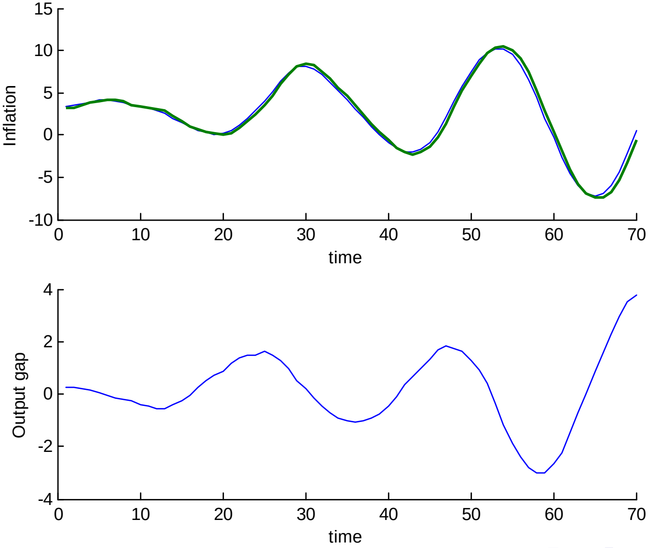
T1 case: AL: steady state learning (gain=1.5)



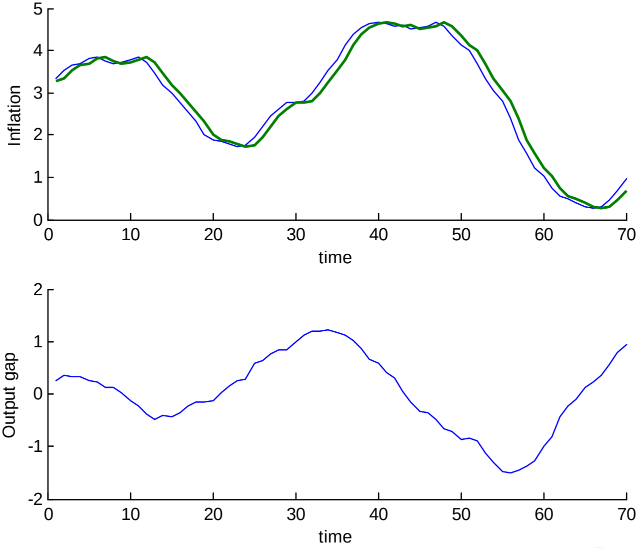
T1 case: Adaptive expectations (gain=0.75)



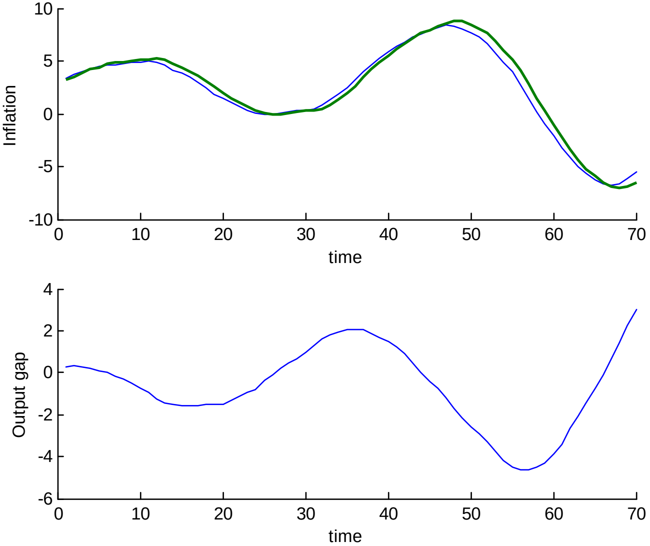
T1 case: Adaptive expectations (gain=1.5)



T1 case: Naive expectations



T1 case: AR(1) form with lagged inflation (coef. 1.05)



Comparison with "Classical Econometrician" and Rational Expectations

	Group							
SSE	1-1	1-2	2-1	2-2	3-1	3-2	4-1	4-2
Subjects min	524	112	4.9	22.8	7.5	40.9	21.9	3.4
Subjects max	2355	1812	37.5	76.4	30.8	80.6	123	6.5
Subjects mean	1050	352	10	40.8	15.4	61	50.3	5
Sticky info.	2110	1317	38.1	268	11.5	32.3	141	7.4
Gen. mod., $\zeta = 0$	881	355	6.7	59.3	8.4	16.5	88.3	4.5
Trend ext.	558	184	7.8	23.9	7.8	18.6	23	3.7
General model	755	310	6.9	49.1	6.8	17.2	79.1	4.4
Adaptive exp.	973	210	8.6	65.2	12.8	53.6	48.5	5.2

Table: Comparison between subjects and Classical Econometrician

Comparison procedure

- For each individual we estimate models of expectation formation
- Compute SSE and “best models” are collected for all individuals
- Definition of RE?
  - some intuition Nunes (MD, 2008)
- Survey data used bias tests and tests for efficient use of information to determine RE
- We focus on another definition...

Rational expectations

- We assume that the ALM is of the following form:

$$\pi_{t+1} = \gamma_0 + \gamma_1 \pi_{t-1} + \gamma_2 \pi_{t-2} + \gamma_3 y_{t-1} + \gamma_4 i_{t-1} + \varepsilon_t, \qquad (6)$$

  and the corresponding correctly parameterized PLM is:

$$\pi^k_{t+1|t} = \beta_0 + \beta_1 \pi_{t-1} + \beta_2 \pi_{t-2} + \beta_3 y_{t-1} + \beta_4 i_{t-1} + \varepsilon_t. \qquad (7)$$

- In order that we can claim that one subject has model consistent or RE the estimated coefficients in both regressions should not be statistically different. To test for that we estimate the following equation:

$$\pi_{t+1} - \pi^k_{t+1|t} = \mu_0 + \mu_1 \pi_{t-1} + \mu_2 \pi_{t-2} + \mu_3 y_{t-1} + \mu_4 i_{t-1} + \varepsilon_t, \qquad (8)$$

  where $\mu_i = \gamma_i - \beta_i$. For subject to forecast rationally all estimated coefficients (jointly) in equation (8) should not be statistically significant.
- Assumption about correlation of errors.

Inflation expectation formation (percent of subjects)

	Comparison		
model (eq.)	2	4	5
Rational expectations: Stat	42.1	-	-
Rational expectations: Theory	-	44.9	-
AR(1) process	0.5	0.5	0.5
Sticky information type	5.6	3.2	10.2
Adaptive expectations	5.1	4.2	11.6
Trend extrapolation	25.5	26.9	36.6
Recursive - lagged inflation	7.9	8.3	21.8
Recursive - REE	2.3	1.9	4.2
Recursive - AR(1) process	0.5	0.5	0.5
Recursive - trend extrapolation	10.6	9.7	14.8
General model, $\zeta = 0$	-	-	-

Table: Inflation expectation formation (percent of subjects)

Switching between different models

- Estimation with Recursive least squares (RLS) for each subject (for every period)
- Model with given minimal SSE is chosen as best predictor of person's behavior in period t
- "Smoothing": sometimes models perform quite similarly
- We allow for different initial values in case of adaptive learning

Switching between different models

- On average subjects:
- Switch every 4 periods
- In each period use 4.5 different models in one group $\longrightarrow$ heterogeneity is pervasive
- Use between 3 and 7 different models in the whole sample
- 35.5% of all forecasts in our experiment are made with adaptive learning

	Probit RE	Probit PA	Logit RE	Logit PA	Logit FE
Cons.	-0.2502***	-0.2210***	-0.4139***	-0.3552***	
	(0.0836)	(0.0749)	(0.1449)	(0.1188)	
$\lvert\pi_{t-1} - \pi_{t-2}\rvert$	0.0422	0.0402	0.0661	0.0639*	0.0545
	(0.0293)	(0.0247)	(0.0482)	(0.0388)	(0.0354)
π_{t-1}	-0.0568***	-0.0533***	-0.0919***	-0.0857***	-0.076**
	(0.0219)	(0.0190)	(0.0345)	(0.0302)	(0.0383)
y_{t-1}	-0.1702***	-0.1596***	-0.2747***	-0.2577***	-0.2540***
	(0.0391)	(0.0381)	(0.0674)	(0.0623)	(0.0591)
i_{t-1}	0.0440**	0.0415**	0.0715**	0.0670***	0.0575**
	(0.0181)	(0.0161)	(0.0286)	(0.0254)	(0.0275)
$\left(\pi_{t-1} - \pi^k_{t-1\mid t-2}\right)^2$	0.0061	0.006	0.011	0.0099	0.0089
	(0.0171)	(0.0143)	(0.0248)	(0.0260)	(0.0359)
$\ln(\sigma^2)$ (panel)	-1.5874***		-0.5814***		
	(0.1996)		(0.2064)		
σ (panel)	0.4522***		0.7478***		
	(0.0441)		(0.0783)		
ρ (panel)	0.1670***		0.1453***		
	(0.0270)		(0.0256)		
N	14040	14040	14040	14040	13975
Groups	216	216	216	216	215
Obs per Group	65	65	65	65	65
Wald $\chi^2(9)$	34.0	31.8	31.2	32.6	36.2

Table: Determinants of swithing behavior

Monetary policy and expectations

- Monetary policy in this environment should minimize variance of inflation and output gap
- Analysis of variance of inflation: differences in medians across treatments
- Monetary policy is important! Null test that are the same in all treatments is rejected at 1% significance (Kruskal-Wallis and van der Waerden tests).
- Comparison of treatments 2, 3, 4 with treatment 1 (Kruskal-Wallis):

Treatment	Groups	Equality of the var. w T1
Inflation forc. targ. $\gamma = 1.5$	$1-6$	–
Inflation forc. targ. $\gamma = 1.35$	$7-12$	0.6310
Inflation forc. targ. $\gamma = 4$	$13-18$	0.0104
Inflation targeting $\gamma = 1.5$	$19-24$	0.0250

Table: Comparison of variance

Monetary policy and Expectations

- How can we explain the difference?
- Theory would predict differently under rational expectations...
- Average SSE of subjects and variance are highly correlated
- Look at the relationship between proportion of different rules and variance

Monetary policy and Expectations

- We estimate the following model:

$$sd_{s,t} = \eta_0 + \eta_L sd_{s,t-1} + \sum_j \eta_j p_{js,t} + \varepsilon_{st}.$$

- system GMM estimator of Blundell and Bond (1998) for dynamic panels.
- Bootstrap clustered standard errors

Monetary policy and Expectations

	reg1	reg2	reg3	reg4
$sd_{s,t}$	1.0147***	1.0121***	1.0121***	1.0099***
	(0.0085)	(0.0073)	(0.0069)	(0.0066)
Gen. mod., $\zeta = 0$	0.0018***	0.001	0.0031*	
	(0.0007)	(0.0013)	(0.0017)	
Sticky info.	-0.0029*	-0.0039	-0.0018	-0.0043**
	(0.0016)	(0.0025)	(0.0019)	(0.0020)
ADE DGL	-0.0023**	-0.0030**	-0.0008	-0.0027**
	(0.0009)	(0.0013)	(0.0015)	(0.0014)
Trend Ext.	0.0067***	0.0055***	0.0077***	0.0055***
	(0.0015)	(0.0018)	(0.0023)	(0.0014)
ADE CGL		-0.0011	0.001	
		(0.0018)	(0.0015)	
Recursive V1		-0.0021		-0.0025
		(0.0025)		(0.0018)
Recursive V4			0.0021	
			(0.0025)	
cons	-0.0759*	0.0219	-0.1895	0.0373
	(0.0417)	(0.1378)	(0.1449)	(0.0556)
N	1560	1560	1560	1560
χ^2	67328.4	54449.2	65883.1	79094.9

Table: Decision model's influence on standard deviation of inflation.

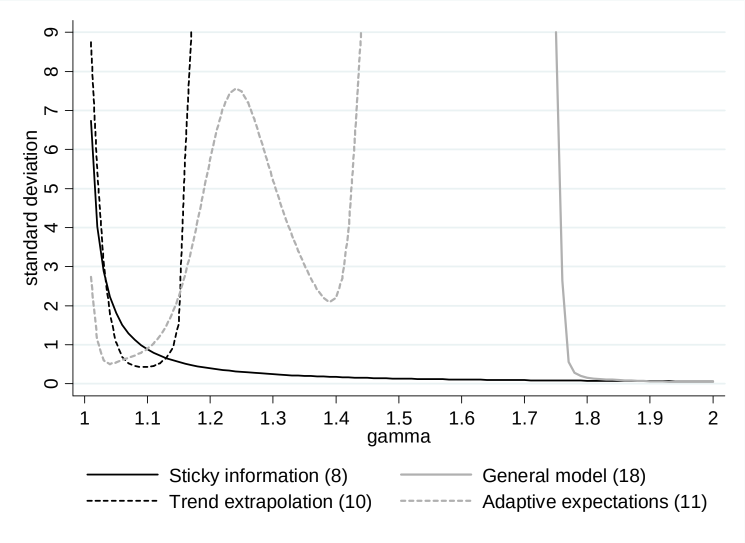


Figure A6: Variability of inflation and alternative expectation formation rules (inflation forecast targeting).

Confidence bounds (all treatments)

- How accurate are experimental subjects in determining the confidence bounds?
- Thaler (2000) finds that "when people asked about their 90% confidence limits, the answers will lie within the limits in less than 70% of the time". Giordani and Söderlind (2003, EER) get similar result.
- We find that only 60.5% of the times subjects managed to set confidence bounds that included actual inflation in the next period. (in treatment A 64.3% while in treatment B 52.8%)

Perception of Uncertainty

- We find that only 11.1% of the subjects on average overestimate risk in treatment A and 2.8% (1.4%) of the subjects in treatment B for lower (upper) bound.
- About 9.0% of the subjects in treatment A and 1.4% (8.4%) of the subjects in treatment B for lower (upper) bound on average report appropriate confidence bounds.
- All others underestimate uncertainty.

Determination of confidence bounds

$sip^k_{t+1\|t}$:	*all*	*treat.A*	*treat.B − L*	*treat.B − U*
$sip^k_{t\|t-1}$	0.4390***	0.5445***	0.4407***	0.0925
	(0.1114)	(0.0921)	(0.0485)	(0.0982)
sd^k_{t-1}	0.1167***	0.0955**	0.1357***	0.2643***
	(0.0450)	(0.0401)	(0.0220)	(0.0561)
α	0.2143***	0.2039***	0.1142***	0.1884***
	(0.0283)	(0.0285)	(0.0187)	(0.0323)
N	14904	9936	4968	4968
Wald $\chi^2_{(2)}$	140.9	259.1	346.1	34.6

Table: Confidence intervals and standard deviation of inflation

Disagreement

$sdv^j_{t+1\|t}$:	*all*	*treat.A*	*treat.B*
$sdv^j_{t\|t-1}$.	0.3127**	0.3107*	0.5462***
	(0.1466)	(0.1634)	(0.0506)
$D_1 y_{t-1}$	-0.0336	-0.032	0.0119
	(0.0323)	(0.0297)	(0.0347)
$D_2 y_{t-1}$	-0.1886***	-0.1943***	-0.2323***
	(0.0666)	(0.0709)	(0.0422)
$D_3 y_{t-1}$	-0.1799**	-0.2098**	-0.1437**
	(0.0780)	(0.0884)	(0.0593)
i_{t-1}	0.1280**	0.1331**	0.0716*
	(0.0608)	(0.0643)	(0.0370)
π_{t-1}	-0.1315**	-0.1299***	-0.0883*
	(0.0532)	(0.0491)	(0.0474)
$mr^j_{t+1\|t}$	-0.1076*	-0.1231**	-0.0629***
	(0.0560)	(0.0623)	(0.0130)
α	0.2045***	0.1956***	0.1515***
	(0.0450)	(0.0428)	(0.0449)
N	1656	1104	552
Wald χ^2 (2)	1022.2	701	726.5

Table: Analysis of Disagreement II

Conclusions

- Monetary policy influences expectation formation mechanisms and vice versa
- The presence of trend extrapolation agents will increase the variance of inflation
- There is a lot of heterogeneity in expectations as subjects use different models to forecast
- Subjects regularly switch between different expectation formation mechanisms
- Only $10 - 15\%$ of subjects on average correctly estimate the underlying risk in the economy