Asymmetry in Inflation Persistence under Inflation Targeting

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Inflation-targeting and inflation asymmetries

- The behavior of inflation in many advanced economies is increasingly difficult to understand.
- Low inflation ("lowflation") experienced in many economies following the Global Financial Crisis (GFC)
- The argument is: inflation-targeting (IT) central banks are responding asymmetrically to deviations of inflation from target (Thoma, 2012; Beckworth, 2016). The mechanism is:
  - Central Banks more aggressive responding to shocks when inflation is above target
  - Central Banks less aggressive responding to shocks when inflation is below target.
- The explanation albeit appealing may not be appropriate:
  - The fact that Central Banks have been unable to increase inflation is not necessarily an indication that they did not put in enough effort.
  - Maybe it is inflation that has been unresponsive (Gilchrist et al. (2017), Coibion and Gorodnichenko (2015) and Del Negro et al. (2015).)

This Paper

Empirical and Theoretical Findings

- Is inflation persistence asymmetric around Central Bank's target?
- Test empirically using a low-order threshold autoregressive (TAR) model. IT countries: Australia, Canada, New Zealand, Sweden (long-standing IT), the Euro-Area and the United States.
- Find evidence that inflation is more persistent below target than above target.
- Provide theoretical explanation based on a new Keynesian framework where agents are learning (Learning Models).
  - In expansions, (inflation usually above target) agents experience larger forecasting errors and thus put more weight on recent events.
  - In downturns, agents observe less sizeable forecasting errors and thus place less weight on recent events.

Main Empirical Results

- We use a threshold autoregressive (TAR) model (Tong (2012); Hansen (1996); Hansen (1997)) to test for asymmetry in inflation persistence
- Estimates of threshold are either close to or slightly above the upper bound of a country's announced inflation target.
- *Low persistence regime:* Autoregressive coefficient during high regime is small in absolute magnitude, and often not significantly different to zero.
- *High persistence regime:* During low regime we find a positive (and significant) *AR* coefficient.
- Canadian inflation shows no evidence of asymmetry.
- The intercept does not vary according to a threshold (expectations are well anchored)

Background Literature

- Persistent increase in inflation rates across many economies in 1970s/1980s, and unit root hypothesis (Rose, 1988; Henry and Shields, 2004).
- With the decline in inflation in 1990s has the degree of persistence declined? (Cogley and Sargent, 2002, 2005; Stock, 2002; Levin and Piger, 2002; O'Reilly and Whelan, 2005; Pivetta and Reis, 2007; Benati, 2008; Noriega and Ramos-Francia, 2009; Beechey and Österholm, 2012). Examine the behaviour of inflation persistence across different regimes for monetary policy.
- Instead, we are interested in inflation persistence under a single monetary policy regime (IT). Is inflation persistence asymmetric around a central bank's target for inflation?

Threshold Model for Inflation

- A threshold model for inflation-targeting countries

$$\pi_t = \mu + \theta_1 \pi_{t-1} I[\pi_{4,t-d} \leq \gamma] + \theta_2 \pi_{t-1}(1 - I[\pi_{4,t-d} \leq \gamma]) + u_t$$

  where $I[.]$ is an indicator function, $\pi_{4,t-d}$ is transition variable and γ is threshold.

- For transition variable, $\pi_{4,t-d}$ $(d = 1, ..., 4)$, we consider four-quarter-ended inflation

$$\pi_{4,t} = \pi_t + \pi_{t-1} + \pi_{t-2} + \pi_{t-3}$$

- Inflation expectations are well anchored (intercept term constant across regimes).

AR Models

- *Main results*

  - Low-order autoregressive process with low values for $AR(1)$ coefficient.

  - We test lags 2-4 are not significant.

  - Canada inflation can be approximated by white noise.

  - During IT regime, inflation shocks are not very persistent.

Testing for Asymmetry

- Non-linearity tests: Luukkonen, Saikkonen, and Terasvirta (1988, LST)

$$\begin{aligned}\pi_t &= \mu + \theta\pi_{t-1} + c_1(\pi_{t-1}\pi_{4,t-d}) + c_2(\pi_{t-1}\pi_{4,t-d}^2) \\ &\quad + c_3(\pi_{t-1}\pi_{4,t-d}^3) + u_t^*\end{aligned}$$

for $d = 1, ..., 4$. Test the null of linearity

$$H_0 : c_1 = c_2 = c_3 = 0$$

Testing for Asymmetry

Indicator	*Australia*	*Canada*	*New Zealand*	*Sweden*	*United States*	*Euro-Area*
$\pi_{4,t-1}$	0.803	0.182	0.065	0.009	0.199	0.396
$\pi_{4,t-2}$	0.204	0.474	0.039	0.593	0.942	0.076
$\pi_{4,t-3}$	0.053	0.874	0.471	0.723	0.014	0.131
$\pi_{4,t-4}$	0.107	0.720	0.482	0.882	0.006	0.305

Table: Test for Linearity against Two Regime TAR Model for Quarterly Inflation Rate. The p-values for the F-test for non-linearity by Luukkonen, Saikkonen, and Terasvirta (1988). For Australia, Canada and Sweden the data sample is 1993:1 - 2015:4, for New Zealand and the United States it is 1991:1 - 2015:4, while for the Euro-Area the data sample is 2001:1 - 2016:3.

TAR Estimates

	Australia	*New Zealand*	*Sweden*	*United States*	*Euro-Area*
Indicator	$\pi_{4,t-3}$	$\pi_{4,t-2}$	$\pi_{4,t-1}$	$\pi_{4,t-4}$	$\pi_{4,t-2}$
Constant	1.455(0.30)***	1.364(0.21)***	0.708(0.16)***	1.157(0.20)***	0.839(0.25)***
θ_1: *High Pers.*	0.475(0.10)***	0.372(0.08)***	0.741(0.16)***	0.425(0.09)***	0.701(0.17)***
θ_2: *Low Pers.*	0.017(0.14)	-0.269(0.16)	0.078(0.08)	-0.322(0.58)	0.425(0.10)***
γ *Threshold*	3.17	3.47	2.67	3.24	1.96

Table: TAR Model Estimates

Generalization to Phillips Curve TAR

- Extension to backward looking Phillips Curve TAR

$$\pi_t = \mu + [\theta_1 \pi_{t-1} + \delta_1 x_{t-1}] I[\pi_{4,t-d} \leq \gamma]$$

$$+[\theta_2 \pi_{t-1} + \delta_2 x_{t-1}](1 - I[\pi_{4,t-d} \leq \gamma]) + u_t$$

where x_{t-1} is a measure of economic slack (e.g., output gap, unemployment).

Generalization to Phillips Curve TAR

Extension to backward looking Phillips Curve TAR (Output Gap)

	Australia	*New Zealand*	*Sweden*	*United States*	*Euro-Area*
Indicator	$\pi_{4,t-3}$	$\pi_{4,t-2}$	$\pi_{4,t-1}$	$\pi_{4,t-4}$	$\pi_{4,t-2}$
Constant	1.490(0.32)***	1.363(0.21)***	0.676(0.17)***	1.110(0.22)***	0.917(0.28)***
θ_1: *High Pers.*	0.465(0.11)***	0.340(0.07)***	0.824(026)***	0.436(0.10)***	0.681(0.16)***
θ_2: *Low Pers.*	0.013(0.12)	-0.270(0.14)*	0.090(0.10)	-0.367(0.55)	0.387(0.10)***
δ_1: *High Pers.*	0.004(0.40)	0.459(0.22)**	-0.266(0.38)	0.085(0.13)	0.090(0.08)
δ_2: *Low Pers.*	1.170(0.81)	0.003(0.45)	0.068(0.31)	-0.241(0.18)	0.202(0.16)
γ *Threshold*	3.17	3.47	2.67	3.24	1.96

Table: Phillips Curve TAR Estimates with Output Gap

Extension to backward looking Phillips Curve TAR (Unemployment)

	Australia	*New Zealand*	*Sweden*	*United States*	*Euro-Area*
Indicator	$\pi_{4,t-3}$	$\pi_{4,t-2}$	$\pi_{4,t-1}$	$\pi_{4,t-4}$	$\pi_{4,t-2}$
Constant	1.807(0.95)**	2.457(0.56)***	2.984(1.13)**	1.089(0.49)**	2.505(1.73)
θ_1: *High Pers.*	0.494(0.12)***	0.342(0.09)***	0.762(0.17)***	0.473(0.09)***	0.743(0.18)***
θ_2: *Low Pers.*	-0.094(0.13)	-0.381(0.16) **	-0.164(0.05)***	-0.602(0.149)	0.217(0.18)
δ_1: *High Pers.*	-0.068(0.13)	-0.172(0.07)**	-0.312(0.14)**	-0.011(0.06)	-0.196(0.16)
δ_2: *Low Pers.*	0.008(0.14)	-0.098(0.08)	-0.097(0.14)	0.173(0.11)	-0.112(0.15)
γ *Threshold*	3.17	3.47	2.67	3.24	1.96

Table: Phillips Curve TAR Estimates with Unemployment

Inflation Expectations

A threshold model using Survey of Professional Forecasters (SPF)

$$\pi_t = \mu + \theta_1 \pi_{t-1} I[\pi^{SPF}_{t-d} \leq \gamma] + \theta_2 \pi_{t-1}(1 - I[\pi^{SPF}_{t-d} \leq \gamma]) + u_t$$

	United States	*United States*
Indicator	$\pi^{SPF4}_{4,t-3}$	$\pi^{SPF5}_{4,t-2}$
Constant	1.943(0.31)**	1.941(0.30)***
θ_1*: High Pers.*	0.290(0.08)**	0.329(0.07)**
θ_2*: Low Pers.*	-0.015(0.28)	-0.041(0.25)
γ *Threshold*	2.33	2.34
Linearity (p-values)	9.7e-07	0.062

Table: TAR Estimates using Inflation Expectations (SPF)

Robustness Checks

Two episodes

- The **missing disinflation** in the wake of the Great Recession
  - We estimate TAR model until 2006:Q4. Results for Australia, New Zealand and Sweden are robust. For US, θ_1 estimate is 0.146 (much lower and insignificant).
- Other robustness checks
  - Run US model with PCE. TAR estimates are similar.
  - Inflation Rates in the Pre-IT Regime. Evidence of asymmetry is weak as shown by linearity tests (test rejects linearity only for Sweden).

New Keynesian Model

The basic model is a standard new Keynesian model with backwards inflation indexation:

- Phillips Curve:

$$\pi_t = (1-\gamma)\,\beta E_t \pi_{t+1} + \kappa x_t + \gamma \pi_{t-1} + e_t$$

- Euler Equation (linearized)

$$x_t = E_t x_{t+1} - \frac{1}{\sigma}\left(i_t - E_t \pi_{t+1}\right)$$

- Taylor rule (Strictly targeting inflation)

$$i_t = \rho_\pi E_t \pi_{t+1} + \varepsilon_t$$

Adaptive Learning Model

- Agents understand that inflation and output gap must be functions of the state variables
- The solution to the model for output gap is

$$x_t = \phi_0^x + \phi_1^x \pi_{t-1} + \psi_e^x e_t + \psi_\varepsilon^x \varepsilon_t$$

  and for inflation is

$$\pi_t = \phi_0^\pi + \phi_1^\pi \pi_{t-1} + \psi_e^\pi e_t + \psi_\varepsilon^\pi \varepsilon_t$$

- However, they do not know the true parameters (rational expectation parameters) $\phi_0^x, \phi_0^\pi, \phi_1^x, \phi_1^x$
- $\psi_e^x, \psi_\varepsilon^x, \psi_e^\pi, \psi_\varepsilon^\pi$ are functions of the above parameters
- They form beliefs $\phi_{0,t-1}^x, \phi_{0,t-1}^\pi, \phi_{1,t-1}^x, \phi_{1,t-1}^x$ for the above parameters and update them using information from period $t-1$

Adaptive Learning Model

- The learning algorithm is

$$\phi_t = \phi_{t-1} + g_t R_t^{-1} q_{t-1} \left(z_t - \phi'_{t-1} q_{t-1} \right)'$$

$$R_t = R_{t-1} + g_t \left(q_{t-1} q'_{t-1} - R_{t-1} \right)$$

where

$$\phi_t \equiv \begin{bmatrix} \phi^{\pi}_{0,t} & \phi^{x}_{0,t} \\ \phi^{\pi}_{1,t} & \phi^{x}_{1,t} \end{bmatrix}, \quad q_{t-1} = \begin{bmatrix} 1 \\ \pi_{t-1} \end{bmatrix}, \quad z_t = \begin{bmatrix} \pi_t \\ x_t \end{bmatrix}$$

- The gain parameter g_t plays an important role
  - If $g_t = 1/t$ then the above algorithm behaves as a recursive least squares (RLS) one
  - If g is constant, then new information receives constant weight and older information is weighted less

Adaptive Gain

Gradient Descent Algorithm

- The target is to choose g_t^s where $s \in \{\pi, x\}$, to minimize the mean square error

$$M_t^s = M\frac{1}{2}\left(\bar{z}^s\right)^2 E\left(z_t^s - q_{t-1}'\phi_{t-1}^s\right)^2 \tag{1}$$

- Differentiating (1) with respect to the gain g^s produces the following stochastic gradient:

$$\frac{\partial M_t^s}{\partial g^s} = -E\left(\bar{z}^s\right)^2\left(z_t^s - q_{t-1}'\phi_{t-1}^s\right)q_{t-1}'\frac{\partial \phi_{t-1}^s}{\partial g^s} \tag{2}$$

- Differentiating ϕ_t^s and R_t with respect to g^s implies

$$\frac{\partial \phi_t^s}{\partial g^s} = \left(I - g_t^s R_t^{-1} q_{t-1} q_{t-1}'\right)\frac{\partial \phi_{t-1}^s}{\partial g^s} + \left(I - g^s R_t^{-1}\frac{\partial R_t}{\partial g^s}\right)R_t^{-1} q_{t-1}\left(z_t^s - \phi_{t-1}' q_{t-1}\right)' \tag{3}$$

$$\frac{\partial R_t}{\partial g^s} = \left(1 - g_t^s\right)\frac{\partial R_{t-1}}{\partial g^s} + q_{t-1}q_{t-1}' - R_{t-1} \tag{4}$$

Adaptive Gain

Gradient Descent Algorithm

- Minimizing the mean squared error (1) implies adjusting the gain such that the stochastic gradient $\frac{\partial M_t^s}{\partial g^s} dg^s < 0$ is negative, where dg^s is the change in the gain.
- An adaptive algorithm that satisfies this condition is the following

$$g_t^s = g_{t-1}^s + \gamma \left(\bar{z}^s \right)^2 E \left(z_t^s - q_{t-1}' \phi_{t-1}^s \right) q_{t-1}' \frac{\partial \phi_{t-1}^s}{\partial g^s} \tag{5}$$

- Where

$$\frac{\partial \phi_{t-1}^s}{\partial g^s} = \left(I - g_{t-1}^s R_{t-1}^{-1} q_{t-2} q_{t-2}' \right) \frac{\partial \phi_{t-2}^s}{\partial g^s} + \left(I - g^s R_{t-1}^{-1} \frac{\partial R_{t-1}}{\partial g^s} \right) R_{t-1}^{-1} q_{t-2} \left(z_{t-1}^s - \phi_{t-2}' q_{t-2} \right)' \tag{6}$$

- If $\left(z_t^s - q_{t-1}' \phi_{t-1}^s \right)$ and $\left(z_{t-1}^s - q_{t-2}' \phi_{t-2}^s \right)$ have the same sign, then the gain increases while if their sign is opposite the gain is updated downwards.

Simulations

Adaptive Learning with an Adaptive Gain

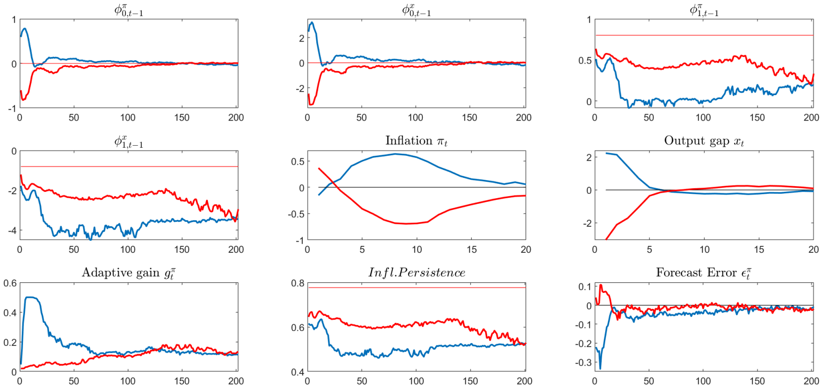


Figure: The dashed red (solid blue) lines are the Impulse responses after a 1 sd shock that increases (decreases) the federal funds rate for the adaptive gain algorithm.

Impulse Responses - 1% Fedfunds Rate Shock

g=0.08

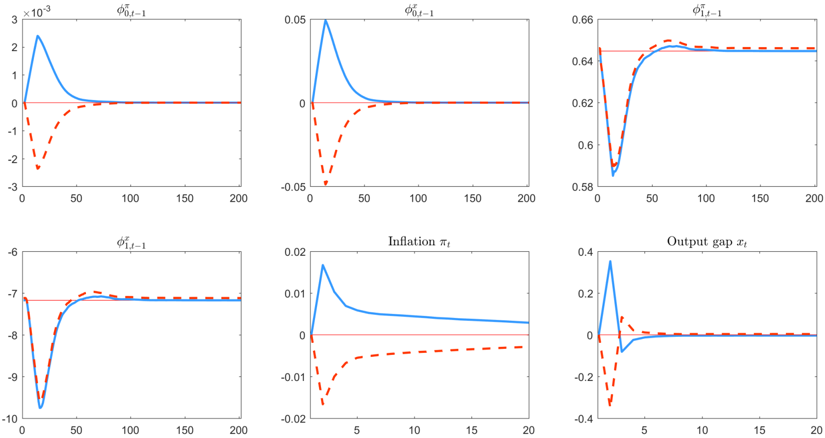


Figure: The dashed red (solid blue) lines are the Impulse responses after a 1 sd shock that increases (decreases) the federal funds rate for gain parameter $g = 0.08$.

Impulse Responses - 1% Cost-Push Shock

g=0.08

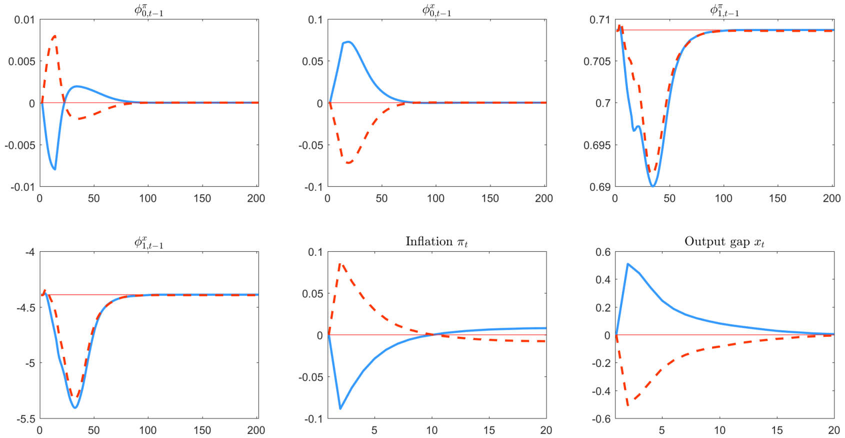


Figure: The dashed red (solid blue) lines are the Impulse responses after a 1 sd cost-push shock that increases (decreases) inflation for gain parameter $g = 0.08$.

Histograms - Inflation Persistence Parameter

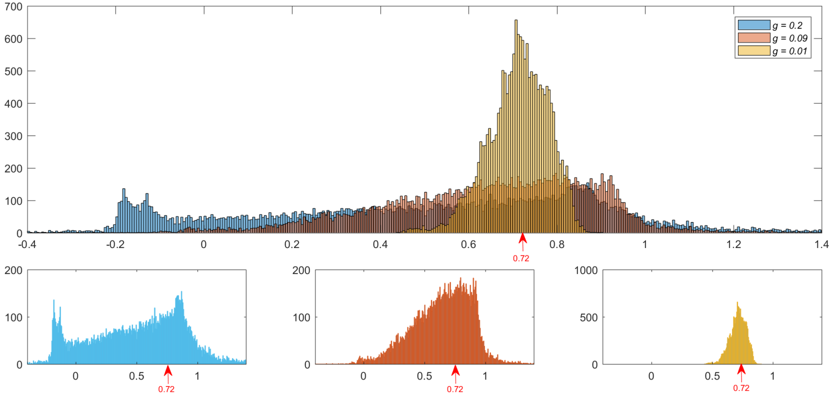


Figure: Histograms of the distribution of the inflation persistence parameter, for various constant gain parameter values. The top plot contains all the bottom 3 distributions together. The distributions are becoming skewed to the left as the gain increases.

Testing the Model Assumptions

Exercises

1. First we generate artificial data from the theoretical model to run the same empirical exercise in an effort to match EU data
2. The assumption that the gain parameter increases in expansions which is equivalent to agents focusing more on recent events in expansions is tested.
3. As relying on more recent events leads to higher forecasting errors, we investigate if forecasting errors increase in expansions and whether they are associated with lower persistence.

Testing the Model Assumptions

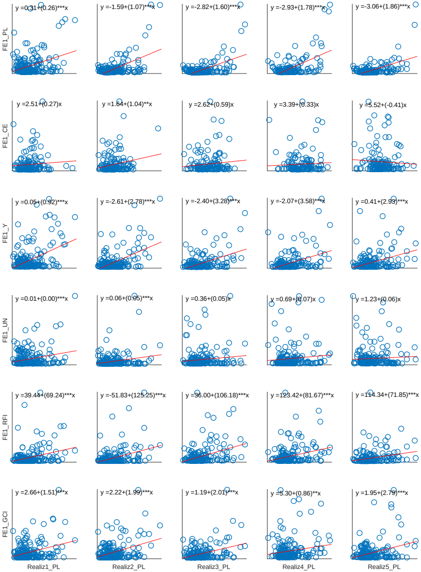
Replicating the Empirical Exercise

Linearity Test		
	Model	*EU Area*
$\pi_{4,t-1}$	0.0001	0.396
$\pi_{4,t-2}$	0.0003	0.076
$\pi_{4,t-3}$	0.0005	0.131
$\pi_{4,t-4}$	0.0003	0.305

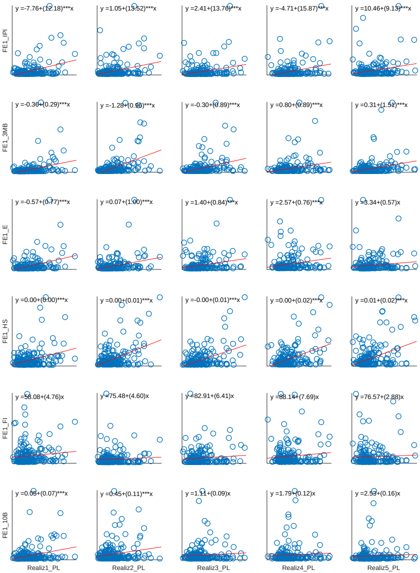
TAR Estimates		
	Model	*EU Area*
θ_1: *High Pers.*	0.798 (0.048)***	0.701(0.17)***
θ_2: *Low Pers.*	0.482 (0.060)***	0.425(0.10)***

Notes: The estimates under the "Model" label are artificial data generated by the model, to match EU data. For the purpose of this exercise 400 data points were created. HAC standard errors are in (.). See also notes Tables 4 and 5.

Scatter plots of price level over GDP and forecasting errors (FE) for various variables



Scatter plots of price level over GDP and forecasting errors (FE) for various variables



Forecasting Errors and Persistence

- Testing if asymmetry in inflation persistence is also evident in periods where forecasting errors are higher:

$$\pi_t = \mu + \theta_1 \pi_{t-1} I\left(\left(\Delta \pi^{FE}_{t-1}\right)^2 \leq \gamma \right) + \theta_2 \pi_{t-1} I\left(\left(\Delta \pi^{FE}_{t-1}\right)^2 > \gamma \right) + u_t$$

Where $\left(\Delta \pi^{FE}_{t-1}\right)^2$ is the squared of the forecast error and depends on whether the forecasting error for inflation is above a certain threshold.

- It is evident that when forecasting errors are low, there is higher persistence in inflation while when forecasting errors are low it is almost zero.
- This provides some support for the story provided in this paper

because in high inflation regimes agents tend to forget the past and thus forecasting errors tend to be higher.

Forecasting Errors and Persistence

TAR Estimates using squared forecast errors (based on SPF)

	United States
Indicator	$\left(\Delta\pi_{t-1}^{FE}\right)^2$
Constant	0.841(0.44)*
θ_1: *High Pers.*	0.550(0.19)***
θ_2: *Low Pers.*	-0.043(0.20)
γ *Threshold*	2.429
Linearity (p-values)	0.076

Table: TAR Estimates using squared forecast errors (based on SPF)

Conclusion

- Evidence of asymmetry in persistence of inflation rates in Australia, New Zealand, Sweden (long-standing IT) and Euro-Area.
- Threshold autoregressive (TAR) model and non-linearity.
- Above upper bound we find close to zero persistence, while below upper bound we find positive persistence in inflation process (stationary).
- Provide theoretical explanation based on a new Keynesian model where agents are learning and also using an adaptive gain. When inflation is higher there is a higher gain parameter (and learning) which induces a lower persistence in inflation.