Monetary Policy & Anchored Expectations
An Endogenous Gain Learning Model

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Inflation that runs below its desired level can lead to an unwelcome fall in ***longer-term inflation expectations****, which, in turn, can pull actual inflation even lower, resulting in an adverse cycle of ever-lower inflation and inflation expectations. [...] Well-anchored inflation expectations are critical[.]*

Jerome Powell, Chairman of the Federal Reserve [1]

(Emphases added.)

[1] "New Economic Challenges and the Fed's Monetary Policy Review," August 27, 2020.

Anchored expectations

Anchored expectations: long-run expectations at Fed's target (π^*)

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$\rightarrow$ short-run expectations "anchored" to stable mean:

$$\mathbb{E}_t \, \pi_{t+1} = \pi^* + f(shocks) \tag{1}$$

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$$\mathbb{E}_t\, \pi_{t+1} = \pi^* + f(shocks) \tag{1}$$

Unanchored expectations: long-run expectations deviate systematically from the target

$$\mathbb{E}_t\, \pi_{t+1} = \bar{\pi}_{t-1} + f(shocks) \tag{2}$$

$$\bar{\pi}_{t-1} \neq \pi^* \qquad \text{and} \qquad \bar{\pi}_{t-1} = h(shocks)$$

Unwelcome fall in longer-term inflation expectations

A standard Phillips curve with expectations anchored at the 2% target

$$\pi_t = \kappa x_t + \beta \, \mathbb{E}_t \, \pi_{t+1} + u_t \tag{3}$$

$$\pi_t = \kappa x_t + \beta (2\% + f(shocks)) + u_t \tag{4}$$

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The Fed's uneasiness: public thinks inflation averages only 1%

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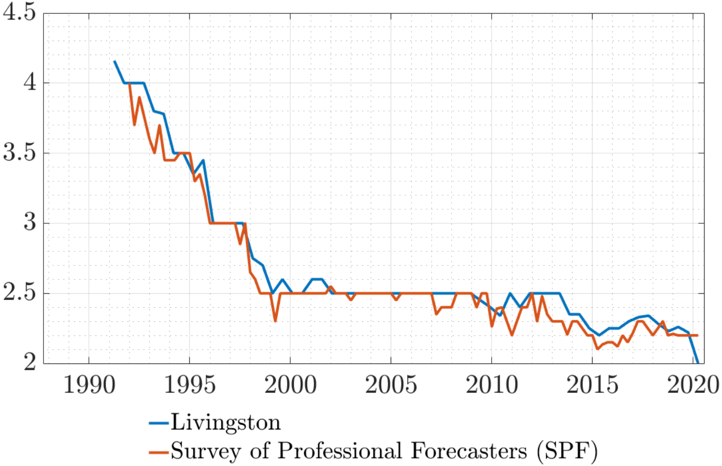
$\rightarrow$ unanchored expectations can cause a deflationary spiral

Long-run expectations drifting down?

Figure: Expectations of average inflation over 10 years ($\bar{\pi}$ in data)



▸ TIPS

Long-run expectations moving systematically?

SPF: for 1999-Q1 onward, estimate

$$\bar{\pi}_t = \beta_0 + \beta_1 fe_{t|t-1} + \epsilon_t \tag{6}$$

where $\bar{\pi}_t \equiv \mathbb{E}_t(\pi_{t+10})$ and $fe_{t|t-1} \equiv \pi_t - \mathbb{E}_{t-1}(\pi_t)$ (forecast error)

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$\Rightarrow$ 1 pp forecast error $\rightarrow$ 6 bp revision in long-run expectations

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Likely understatement: professional forecasters may run stationary models

▸ Further evidence

This project

- How to conduct monetary policy in interaction with the anchoring expectation formation?
- Model of anchoring expectation formation as an extension to adaptive learning
  $\hookrightarrow$ twist: systematic fluctuations in long-run expectations
- Estimation of the anchoring function: when do expectations become unanchored?

Preview of results

- Optimal policy aggressive when expectations unanchor, accommodates when anchored

- Taylor rule policy less aggressive on inflation than under rational expectations

$\hookrightarrow$ Anchoring-optimal Taylor rule eliminates 75% of loss from volatility

Related literature

- **Optimal monetary policy in New Keynesian models**
  Clarida, Gali & Gertler (1999), Woodford (2003)

- **Adaptive learning**
  Evans & Honkapohja (2001, 2006), Eusepi & Preston (2011), Milani (2007, 2014), Lubik & Matthes (2018), Bullard & Mitra (2002), Preston (2005, 2008), Ferrero (2007), Molnár & Santoro (2014), Mele et al. (2019)

- **Anchoring and the Phillips curve**
  Sargent (1999), Williams (2006), Svensson (2015), Afrouzi et al. (2015), Hooper et al. (2019), Hebden et al. (2020), Afrouzi & Yang (2020), Reis (2020), Gobbi et al (2019), Carvalho et al (2019)

Today’s talk

1. Model of anchoring expectations: key elements

2. Features of optimal policy under anchoring expectation formation

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The New Keynesian backbone

- IS- and Phillips curve under rational expectations:

$$x_t = \mathbb{E}_t \, x_{t+1} - \sigma i_t + \mathbb{E}_t \, \pi_{t+1} + \sigma r_t^n \tag{7}$$

$$\pi_t = \kappa x_t + \beta \, \mathbb{E}_t \, \pi_{t+1} + u_t \tag{8}$$

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- Here instead: adaptive learning

$$\hat{\mathbb{E}}_t \pi_{t+1} = \bar{\pi}_{t-1} + b^{RE} s_t \tag{9}$$

(s_t = exogenous states)

Recursive least squares

$$\bar{\pi}_t = \bar{\pi}_{t-1} + \underbrace{k_t}_{\in(0,1),\text{ gain}} \underbrace{\Big(\pi_t - (\bar{\pi}_{t-1} + b^{RE} s_{t-1})\Big)}_{fe_{t|t-1}\text{, forecast error}} \tag{10}$$

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$$\bar{\pi}_t = \bar{\pi}_{t-1} + \underbrace{k_t}_{\in(0,1),\text{ gain}} \underbrace{\left(\pi_t - (\bar{\pi}_{t-1} + b^{RE} s_{t-1})\right)}_{fe_{t|t-1},\text{ forecast error}} \tag{10}$$

Decreasing gain learning:

$$\bar{\pi}_t = \bar{\pi}_{t-1} + \frac{1}{t} fe_{t|t-1} \tag{11}$$

$\rightarrow$ sample mean of full sample of forecast errors

Recursive least squares

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Decreasing gain learning:

$$\bar{\pi}_t = \bar{\pi}_{t-1} + \frac{1}{t}\, fe_{t|t-1} \tag{11}$$

→ sample mean of full sample of forecast errors

Constant gain learning:

$$\bar{\pi}_t = \bar{\pi}_{t-1} + k\, fe_{t|t-1} \tag{12}$$

→ sample mean of most recent observations only

Anchoring mechanism: endogenous gain

$$\bar{\pi}_t = \bar{\pi}_{t-1} + k_t\big(\pi_t - (\bar{\pi}_{t-1} + b_1 s_{t-1})\big) \tag{13}$$

$k_t = \mathbf{g}(fe_{t|t-1})$: anchoring function

Anchoring mechanism: endogenous gain

$$\bar{\pi}_t = \bar{\pi}_{t-1} + k_t\big(\pi_t - (\bar{\pi}_{t-1} + b_1 s_{t-1})\big) \tag{13}$$

$k_t = \mathbf{g}(fe_{t|t-1})$: anchoring function

$$\mathbf{g}(fe_{t|t-1}) = \sum_i \alpha_i b_i(fe_{t|t-1}) \tag{14}$$

$b_i(fe_{t|t-1})$ = basis, here: second order spline (piecewise linear)

α_i = approximating coefficients, here: use $\hat{\alpha}$ from estimation

Estimate Functional forms in literature

Today's talk

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2. Features of optimal policy under anchoring expectation formation

Optimal policy - responding to unanchoring

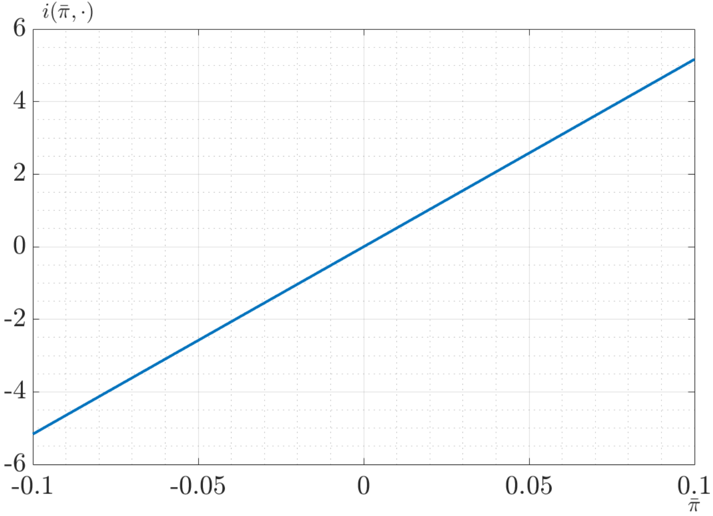
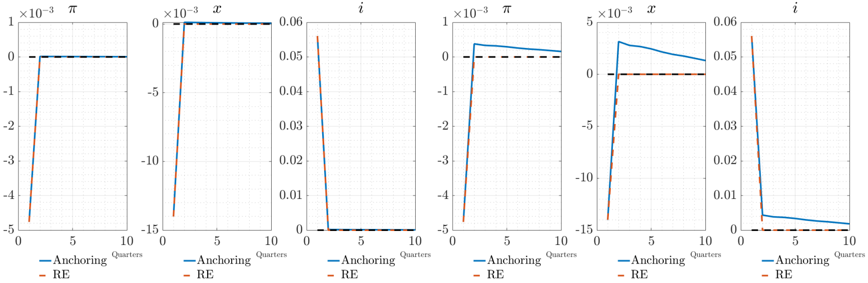


Figure: Policy function: $i(\bar{\pi}$, all other states at their means)

The intertemporal volatility tradeoff

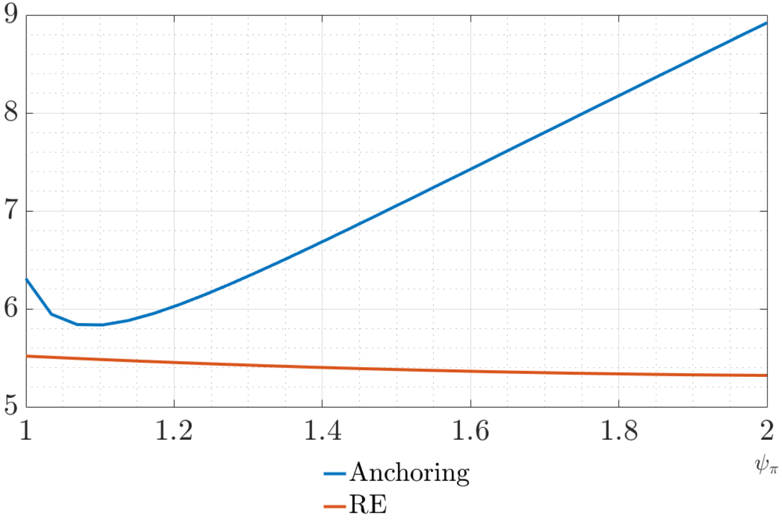


(a) Expectations anchored (b) Expectations unanchored

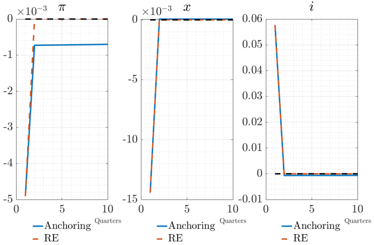
Figure: Impulse responses after a contractionary monetary policy shock

Optimal Taylor-coefficient on inflation

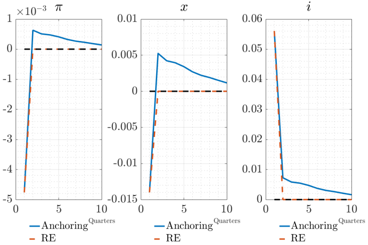
Figure: Central bank loss as a function of ψ_π



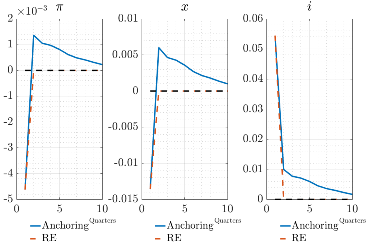
The intertemporal volatility tradeoff - again



(a) $\psi_\pi = 1.01$



(b) $\psi_\pi = 1.5$



(c) $\psi_\pi = 2$

Losses for optimal Taylor-rule coefficient on inflation

RE-optimal coefficient: $\psi_\pi^{RE} = 2.21$

Anchoring-optimal coefficient: $\psi_\pi^{A} = 1.09$

Table: Loss for RE and anchoring models for choice of RE- or anchoring-optimal ψ_π

Anchoring, ψ_π^{RE}	Anchoring, ψ_π^{A}	RE, ψ_π^{RE}
9.6901	5.8296	5.3148

$\rightarrow$ If model is anchoring, anchoring-optimal ψ_π^{A} gets 75% of the distance to RE-optimal ψ_π^{RE} under RE

Conclusion

- First theory of monetary policy for potentially unanchored expectations
- Optimal policy frontloads aggressive interest rate response to suppress potential unanchoring
- Matters: already anchoring-optimal Taylor rule reduces losses by 75%
- Future work: how to anchor at zero-lower bound?

Appendix

Calibration - parameters from the literature

β	0.98	stochastic discount factor
σ	1	intertemporal elasticity of substitution
α	0.5	Calvo probability of not adjusting prices
κ	0.0842	slope of the Phillips curve
ψ_π	1.5	coefficient of inflation in Taylor rule*
ψ_x	0.3	coefficient of the output gap in Taylor rule*
$\bar{g}$	0.145	initial value of the gain
λ_x	0.05	weight on the output gap in central bank loss
ρ_r	0	persistence of natural rate shock
ρ_i	0	persistence of monetary policy shock*
ρ_u	0	persistence of cost-push shock

* pertains to sections where Taylor rule is in effect

Calibration - matching moments

σ_r	0.01	standard deviation, natural rate shock
σ_i	0.01	standard deviation, monetary policy shock*
σ_u	0.5	standard deviation, cost-push shock
$\hat{\alpha}_i$	(0.33; 0.25; 0.001; 0.24; 0.33)	coefficients in anchoring function

Calibrated ($\sigma_j,\ j = r, i, u$) or estimated ($\hat{\alpha}_i$) to match the autocovariances of inflation, output gap, interest rate and one-period ahead inflation expectations for lags $0, \ldots, 4$.

* pertains to sections where Taylor rule is in effect

Breakeven inflation

Figure: Market-based inflation expectations, various horizons, %

Return

Correcting the TIPS from liquidity risk

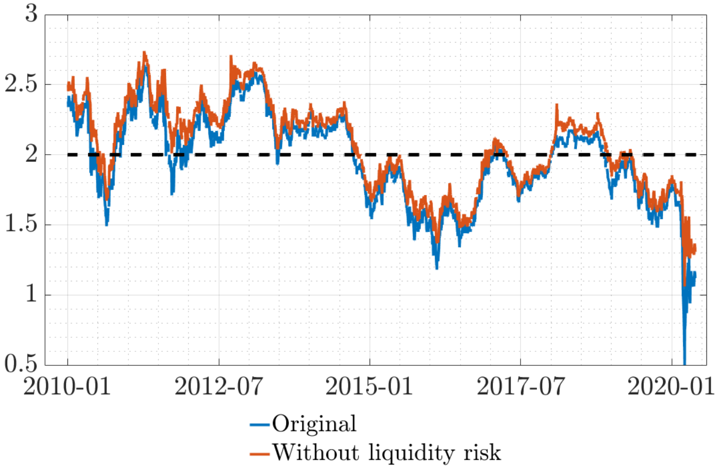


Figure: Market-based inflation expectations, 10 year, %

Return

Further evidence

Figure: Livingston Survey of Firms:
Interquartile range of 10-year ahead inflation expectations

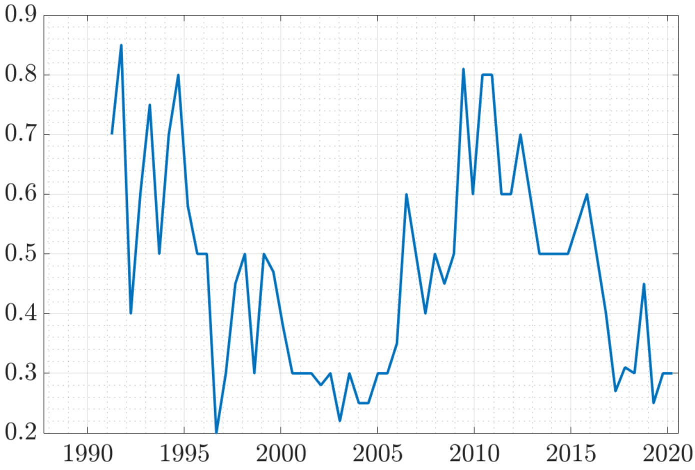


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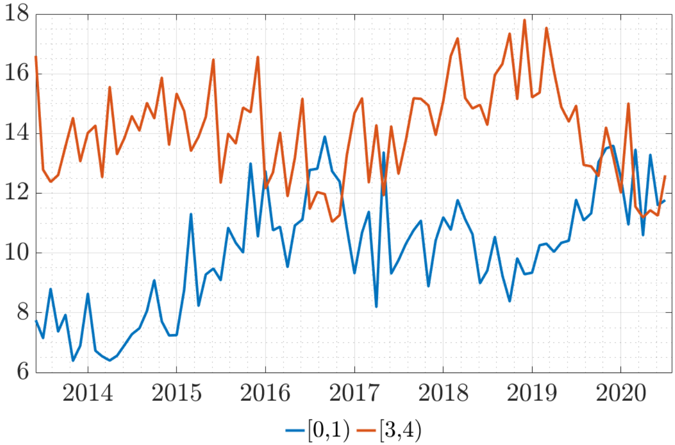
Figure: New York Fed Survey of Consumers:
Percent of respondents indicating 3-year ahead inflation will be in a particular range



Return

Oscillatory dynamics in adaptive learning

Consider a stylized adaptive learning model in two equations:

$$\pi_t = \beta f_t + u_t \tag{15}$$
$$f_t = f_{t-1} + k(\pi_t - f_{t-1}) \tag{16}$$

Solve for the time series of expectations f_t

$$f_t = \underbrace{\frac{1-k^{-1}}{1-k^{-1}\beta}}_{\approx 1} f_{t-1} + \frac{k^{-1}}{1-k^{-1}\beta} u_t \tag{17}$$

Solve for forecast error $fe_t \equiv \pi_t - f_{t-1}$:

$$fe_t = \underbrace{-\frac{1-\beta}{1-k\beta}}_{\lim_{k\to 1} = -1} f_{t-1} + \frac{1}{1-k\beta} u_t \tag{18}$$

Functional forms for **g** in the literature

- Smooth anchoring function (Gobbi et al, 2019)

$$p = h(y_{t-1}) = A + \frac{BCe^{-Dy_{t-1}}}{(Ce^{-Dy_{t-1}} + 1)^2} \tag{19}$$

$p \equiv Prob$(liquidity trap regime)
y_{t-1} output gap

- Kinked anchoring function (Carvalho et al, 2019)

$$k_t = \begin{cases} \frac{1}{t} & \text{when} \quad \theta_t < \bar{\theta} \\ k & \text{otherwise.} \end{cases} \tag{20}$$

θ_t criterion, $\bar{\theta}$ threshold value

Return

Choices for criterion θ_t

- Carvalho et al. (2019)'s criterion

$$\theta_t^{CEMP} = \max |\Sigma^{-1}(\phi_{t-1} - T(\phi_{t-1}))| \tag{21}$$

Σ variance-covariance matrix of shocks
$T(\phi)$ mapping from PLM to ALM

- CUSUM-criterion

$$\omega_t = \omega_{t-1} + \kappa k_{t-1}(fe_{t|t-1}fe'_{t|t-1} - \omega_{t-1}) \tag{22}$$

$$\theta_t^{CUSUM} = \theta_{t-1} + \kappa k_{t-1}(fe'_{t|t-1}\omega_t^{-1}fe_{t|t-1} - \theta_{t-1}) \tag{23}$$

ω_t estimated forecast-error variance

Return

Recursive least squares algorithm

$$\phi_t = \left(\phi'_{t-1} + k_t R_t^{-1} \begin{bmatrix} 1 \\ s_{t-1} \end{bmatrix} \left(y_t - \phi_{t-1} \begin{bmatrix} 1 \\ s_{t-1} \end{bmatrix} \right)' \right)' \tag{24}$$

$$R_t = R_{t-1} + k_t \left(\begin{bmatrix} 1 \\ s_{t-1} \end{bmatrix} \begin{bmatrix} 1 & s_{t-1} \end{bmatrix} - R_{t-1} \right) \tag{25}$$

Return

Actual laws of motion

$$y_t = A_1 f_{a,t} + A_2 f_{b,t} + A_3 s_t \tag{26}$$

$$s_t = h s_{t-1} + \epsilon_t \tag{27}$$

where

$$y_t \equiv \begin{pmatrix} \pi_t \\ x_t \\ i_t \end{pmatrix} \qquad s_t \equiv \begin{pmatrix} r_t^n \\ u_t \end{pmatrix} \tag{28}$$

and

$$f_{a,t} \equiv \hat{\mathbb{E}}_t \sum_{T=t}^{\infty} (\alpha\beta)^{T-t} y_{T+1} \qquad f_{b,t} \equiv \hat{\mathbb{E}}_t \sum_{T=t}^{\infty} (\beta)^{T-t} y_{T+1} \tag{29}$$

Return

Anchoring function in the data

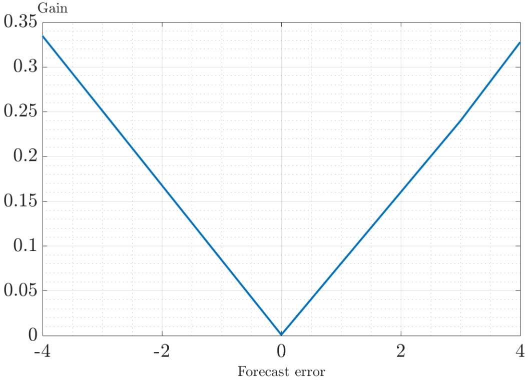


Figure: Learning gain as a function of forecast errors in inflation (pp)

Return

No commitment - no lagged multipliers

Simplified version of the model: planner chooses $\{\pi_t, x_t, f_t, k_t\}_{t=t_0}^{\infty}$ to minimize

$$\mathcal{L} = \mathbb{E}_{t_0} \sum_{t=t_0}^{\infty} \beta^{t-t_0} \Big\{ \pi_t^2 + \lambda x_t^2 + \varphi_{1,t}(\pi_t - \kappa x_t - \beta f_t + u_t) + \varphi_{2,t}(f_t - f_{t-1} - k_t(\pi_t - f_{t-1})) + \varphi_{3,t}(k_t - \mathbf{g}(\pi_t - f_{t-1})) \Big\}$$

$$2\pi_t + 2\frac{\lambda}{\kappa} x_t - \varphi_{2,t}(k_t + \mathbf{g}_\pi(\pi_t - f_{t-1})) = 0 \tag{30}$$

$$-2\beta\frac{\lambda}{\kappa} x_t + \varphi_{2,t} - \varphi_{2,t+1}(1 - k_{t+1} - \mathbf{g}_\mathbf{f}(\pi_{t+1} - f_t)) = 0 \tag{31}$$

Return

Target criterion system for anchoring function as changes of the gain

$$
\begin{aligned}
\varphi_{6,t} &= -cfe_{t|t-1}x_{t+1} + \left(1 + \frac{fe_{t|t-1}}{fe_{t+1|t}}(1-k_{t+1}) - fe_{t|t-1}\mathbf{g}_{\bar{\pi},t}\right)\varphi_{6,t+1} \\
&\quad - \frac{fe_{t|t-1}}{fe_{t+1|t}}(1-k_{t+1})\varphi_{6,t+2} \qquad (32)\\
0 &= 2\pi_t + 2\frac{\lambda_x}{\kappa}x_t - \left(\frac{k_t}{fe_{t|t-1}} + \mathbf{g}_{\pi,t}\right)\varphi_{6,t} + \frac{k_t}{fe_{t|t-1}}\varphi_{6,t+1} \qquad (33)
\end{aligned}
$$

$\varphi_{6,t}$ Lagrange multiplier on anchoring function

The solution to (33) is given by:

$$
\varphi_{6,t} = -2\,\mathbb{E}_t \sum_{i=0}^{\infty}\left(\pi_{t+i} + \frac{\lambda_x}{\kappa}x_{t+i}\right)\prod_{j=0}^{i-1}\frac{\frac{k_{t+j}}{fe_{t+j|t+j-1}}}{\frac{k_{t+j}}{fe_{t+j|t+j-1}} + \mathbf{g}_{\pi,t+j}} \qquad (34)
$$

Return

Details on households and firms

Consumption:

$$C_t^i = \left[\int_0^1 c_t^i(j)^{\frac{\theta-1}{\theta}} dj \right]^{\frac{\theta}{\theta-1}} \tag{35}$$

$\theta > 1$: elasticity of substitution between varieties

Aggregate price level:

$$P_t = \left[\int_0^1 p_t(j)^{1-\theta} dj \right]^{\frac{1}{\theta-1}} \tag{36}$$

Profits:

$$\Pi_t^j = p_t(j)y_t(j) - w_t(j)f^{-1}(y_t(j)/A_t) \tag{37}$$

Stochastic discount factor

$$Q_{t,T} = \beta^{T-t} \frac{P_t U_c(C_T)}{P_T U_c(C_t)} \tag{38}$$

Return

Derivations

Household FOCs

$$\hat{C}_t^i = \hat{\mathbb{E}}_t^i \hat{C}_{t+1}^i - \sigma(\hat{i}_t - \hat{\mathbb{E}}_t^i \hat{\pi}_{t+1}) \tag{39}$$

$$\hat{\mathbb{E}}_t^i \sum_{s=0}^{\infty} \beta^s \hat{C}_t^i = \omega_t^i + \hat{\mathbb{E}}_t^i \sum_{s=0}^{\infty} \beta^s \hat{Y}_t^i \tag{40}$$

where 'hats' denote log-linear approximation and $\omega_t^i \equiv \frac{(1+i_{t-1})B_{t-1}^i}{P_t Y^*}$.

1. Solve (39) backward to some date t, take expectations at t
2. Sub in (40)
3. Aggregate over households i

$\rightarrow$ Obtain (7)

Return

Target criterion

Proposition

In the model with anchoring, monetary policy optimally brings about the following target relationship between inflation and the output gap

$$\pi_t = -\frac{\lambda_x}{\kappa} x_t + \frac{\lambda_x}{\kappa} \frac{(1-\alpha)\beta}{1-\alpha\beta} \left(k_t + ((\pi_t - \bar{\pi}_{t-1} - b_1 s_{t-1}))\mathbf{g}_{\pi,t} \right)$$

$$\left(\mathbb{E}_t \sum_{i=1}^{\infty} x_{t+i} \prod_{j=0}^{i-1} (1 - k_{t+1+j} - (\pi_{t+1+j} - \bar{\pi}_{t+j} - b_1 s_{t+j})\mathbf{g}_{\bar{\pi},\mathbf{t+j}}) \right)$$

where $\mathbf{g}_{z,t} \equiv \frac{\partial \mathbf{g}}{\partial z}$ *at* t, $\prod_{j=0}^{0} \equiv 1$ *and* b_1 *is the first row of* b.

General case

Two layers of intertemporal stabilization tradeoffs

$$\pi_t = -\frac{\lambda_x}{\kappa}x_t + \frac{\lambda_x}{\kappa}\frac{(1-\alpha)\beta}{1-\alpha\beta}\left(k_t + fe_{t|t-1}\mathbf{g}_{\pi,t}\right)\mathbb{E}_t\sum_{i=1}^{\infty}x_{t+i}$$
$$-\frac{\lambda_x}{\kappa}\frac{(1-\alpha)\beta}{1-\alpha\beta}\left(k_t + fe_{t|t-1}\mathbf{g}_{\pi,t}\right)\mathbb{E}_t\sum_{i=1}^{\infty}x_{t+i}\prod_{j=0}^{i-1}(k_{t+1+j} + fe_{t+1+j|t+j}\mathbf{g}_{\bar{\pi},\mathbf{t+j}})$$

Intratemporal tradeoffs in RE (discretion)

Intertemporal tradeoff: current level and change of the gain

Intertemporal tradeoff: future expected levels and changes of the gain

Lemma

The discretion and commitment solutions of the Ramsey problem coincide.

Why no commitment?

Corollary

Optimal policy under adaptive learning is time-consistent.

$\hookrightarrow$ Foreshadow: optimal policy aggressiveness time-varying