The Optimal Inflation Target and the Natural Rate of Interest

P. Andrade  J. Galí  H. Le Bihan  J. Matheron

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The views expressed here do not necessarily represent those of the Banque de France or the Eurosystem
Motivation

- Evidence of a decline in the natural rate of interest
- Implications for monetary policy $\Rightarrow \uparrow$ incidence of the ZLB
- Calls for a higher inflation target (Ball, Blanchard et al., Williams, ...)

$\Rightarrow$ Is a higher inflation target warranted? How much higher?
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$\Rightarrow$ Is a higher inflation target warranted? How much higher?

This paper:
- quantitative analysis of the optimal inflation target ($\pi^*$) as a function of the steady state real rate ($r^*$)
- based on an estimated medium-scale NK model (US and euro area)
- focus on the role of parameter uncertainty
Main Findings

- The relation between $r^*$ and $\pi^*$ is downward sloping, but not necessarily one-for-one.
- For a plausible range of $r^*$ the slope of the $(r^*, \pi^*)$ locus is about $-0.9$.
- That finding is robust to:
  - parameter uncertainty
  - source of variation in $r^*$
  - alternative assumptions
Related literature


- Quantitative analysis of the optimal inflation target in the presence of the ZLB: Coibion et al. (2012), Dordal-i-Carreras et al. (2016), Kiley and Roberts (2017), Blanco (2016),...

Our contribution:

- explicit analysis of the relation between $r^*$ and $\pi^*$
- joint modelling of (i) price and wage stickiness (with partial indexation) and (ii) a ZLB constraint
- optimization under parameter uncertainty
The Model

- Representative household with preferences:

\[ E_t \sum_{s=0}^{\infty} \beta^s \left\{ e^{\zeta_{g,t+s}} \log(C_{t+s} - \eta C_{t+s-1}) - \frac{\chi}{1 + \nu} \int_{0}^{1} N_{t+s}(h)^{1+v} dh \right\} \]

and budget constraint

\[ P_t C_t + e^{\zeta_{q,t}} Q_t B_t \leq \int_{0}^{1} W_t(h) N_t(h) dh + B_{t-1} - T_t + D_t \]

- Final goods: perfect competition with technology

\[ Y_t = \left( \int_{0}^{1} Y_t(f)^{(\theta_p - 1)/\theta_p} df \right)^{\theta_p/(\theta_p - 1)} \]

- Intermediate goods: monopolistic competition with technology

\[ Y_t(f) = Z_t L_t(f)^{1/\phi} \]

where \( Z_t = Z_{t-1} e^{\mu_z + \zeta_{z,t}} \)
The Model

- Price setting à la Calvo, with stochastic subsidies $\zeta_{u,t}$, and partial indexation

  $P_t(f) = \Pi_{t-1}^{\gamma_p} P_{t-1}(f)$

- Wage setting à la Calvo, with partial indexation

  $W_t(h) = e^{\gamma_z \mu_z \Pi_{t-1}^{\gamma_w} W_{t-1}(h)}$

- Interest rate rule:

  $i_t = \max\{i_t^n, 0\}$

  where

  $i_t^n - i = \rho_i (i_{t-1}^n - i) + (1 - \rho_i) [a_{\pi}(\pi_t - \pi^*) + a_y(y_t - y_t^n)] + \zeta_{r,t}$

  with $i = \rho + \mu_z + \pi^*$ and where $\pi^*$ defines the inflation target.
Solution Method

1. Detrending by $Z_t$
2. Log-linearization around deterministic steady state
3. Solution under the ZLB as in Bodenstein et al. (2009) and Guerrieri and Iacoviello (2015)
Calibration and Estimation

- Calibrated parameters: \( 1/\phi = 0.7 \); \( \theta_p = 6 \); \( \theta_w = 3 \)
- Remaining parameters estimated using Bayesian approach (without ZLB)
- Gaussian priors for \((\rho, \mu_z, \pi^*)\) with means consistent with average inflation, GDP growth and real rate in each economy
- Sample period: 1985Q2-2008Q3
- Vector of observables:
  \[
  x_t = [\Delta \log GDP_t, \Delta \log GDP\; Deflator_t, \Delta \log Wage_t, \; Short\; term\; rate_t]
  \]
- Parameter estimates
  \((a)\) \( r^{ea} > r^{us} \) \(\Rightarrow\) larger \( \pi \) cushion needed in the US
  \((b)\) greater indexation in the US \(\Rightarrow\) more tolerance of higher inflation
Optimal Inflation Target

- Second order approximation to household expected utility: $\mathcal{W}(\pi; \theta)$
- The case of no parameter uncertainty:

$$\pi^*(\theta) = \arg \max_\pi \mathcal{W}(\pi; \theta)$$

with solution obtained via numerical simulations allowing for occasionally binding ZLB, and with $\theta$ taken to be the mean, the median or the mode of the posterior distribution of parameter estimates:

$$\Rightarrow \pi^*_{US} \in [2.21\%, 2.12\%, 1.85\%]$$

$$\Rightarrow \pi^*_{EA} \in [1.58\%, 1.49\%, 1.31\%]$$
Welfare Losses and the Inflation Target

No Parameter Uncertainty

(a) US

(b) EA
ZLB Incidence and the Inflation Target

No Parameter Uncertainty
Optimal Inflation Target

- Second order approximation to household expected utility: \( \mathcal{W}(\pi; \theta) \)
- The case of no parameter uncertainty:
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  \pi^*(\theta) = \arg \max_{\pi} \mathcal{W}(\pi; \theta)
  \]
  with solution obtained via numerical simulations allowing for occasionally binding ZLB, and with \( \theta \) taken to be the mean, the median or the mode of the posterior distribution of parameter estimates:
  \[
  \Rightarrow \pi^*_{US} \in [2.21\%, 2.12\%, 1.85\%]
  \]
  \[
  \Rightarrow \pi^*_{EA} \in [1.58\%, 1.49\%, 1.31\%]
  \]
- Allowing for parameter uncertainty:
  \[
  \pi^{**} = \arg \max_{\pi} \int_\theta \mathcal{W}(\pi; \theta)p(\theta | X_T) d\theta
  \]
  \[
  \Rightarrow \pi^{**}_{US} = 2.4\%
  \]
  \[
  \Rightarrow \pi^{**}_{EA} = 2.2\%
  \]
The Optimal Inflation Target and the Natural Rate of Interest

- The baseline \((r^*, \pi^*)\) relation

  (a) varying \(\mu_z\)
  (b) varying \(\rho\)
The \((r^*, \pi^*)\) Locus
(at the posterior mean)
ZLB Incidence and the Steady State Real Rate

At the optimal inflation target

(a) US

(b) EA
The Optimal Inflation Target and the Natural Rate of Interest

- The baseline \((r^*, \pi^*)\) relation
  (a) varying \(\mu_z\)
  (b) varying \(\rho\)

- The \((r^*, \pi^*)\) relation under uncertainty: shift of \(-1\%\) in the distribution of \(r^*(\theta)\) due to a \(-1\%\) shift in the mean of \(\mu_z\)

\[
\pi_{**}^* = \arg \max_{\pi} \int_{\theta_\Delta} \mathcal{W}(\pi; \theta_\Delta) p(\theta_\Delta | X_T) d\theta_\Delta
\]
Impact on Welfare of a Downward Shift in $r^*(\theta)$
under Parameter Uncertainty
Impact on Welfare of a Downward Shift in $r^*(\theta)$ under Parameter Uncertainty
Further Experiments

- Average vs target inflation
Average vs Target Inflation

(a) US

(b) EA
Further Experiments

- Average vs target inflation
- A negative effective lower bound (ELB)

\[ i_t \geq -0.40\% \]
A Negative Effective Lower Bound in the Euro Area
Further Experiments

- Average vs target inflation
- A negative effective lower bound (ELB)

\[ i_t \geq -0.40\% \]

- Known reaction function: \((\rho_i, a_\pi, a_y)\) fixed at posterior means
A Known Reaction Function

(a) US

(b) EA

4\pi^{**} = 2.24

4\pi^{**} = 2.36

4\pi^{**} = 3.16

4\pi^{**} = 3.28
Further Experiments

- Average vs target inflation
- A negative effective lower bound (ELB)
  \[ i_t \geq -0.40\% \]
- Known reaction function: \((\rho_i, a_\pi, a_y)\) fixed at posterior means
- Larger shocks: +30% increase in \(\sigma_q\) and \(\sigma_g\)
Larger Shocks

(a) US

(b) EA
Further Experiments

- Average vs target inflation
- A negative effective lower bound (ELB)

\[ i_t \geq -0.40\% \]

- Known reaction function: \((\rho_i, a_{\pi}, a_y)\) fixed at posterior means
- Larger shocks: +30\% increase in \(\sigma_q\) and \(\sigma_g\)
- Alternative steady state markups
Alternative Steady State Price Markups

Note: the blue dots correspond to the baseline scenario wherein all the structural parameters are set at their posterior mean $\hat{\theta}$. The red dots correspond to the counterfactual simulation with $\theta_p$ set to 10. The green dots correspond to the counterfactual simulation with $\theta_p$ set to 3.
Alternative Steady State Wage Markups

Note: the blues dots correspond to the baseline scenario wherein all the structural parameters are set at their posterior mean $\bar{\theta}$. The red dots correspond to the counterfactual simulation with $\theta_w$ set to 8. The green dots correspond to the counterfactual simulation with $\theta_w$ set to 1.5.
Further Experiments

- Average vs target inflation
- A negative effective lower bound (ELB)
  \[ i_t \geq -0.40\% \]
- Known reaction function: \((\rho_i, a_{\pi}, a_y)\) fixed at posterior means
- Larger shocks: +30% increase in \(\sigma_q\) and \(\sigma_g\)
- Alternative steady state markups
- Alternative interest rate smoothness parameter
Alternative Interest Rate Smoothing Parameters

**Figure: \((r^*, \pi^*) - US\)**

- **slope = -0.7**

**Figure: \((r^*, \pi^*) - EA\)**

- **slope = -0.6**
Conclusions

- Analysis of the \((r^*, \pi^*)\) relation
- Robust finding: a 1\% decline in \(r^*\) call for an increase of about 0.9\% in \(\pi^*\)
Conclusions

- Analysis of the \((r^*, \pi^*)\) relation
- Robust finding: a 1% decline in \(r^*\) call for an increase of about 0.9% in \(\pi^*\)
- Alternatives to an increase in \(\pi^*\):
  - unconventional monetary policies when ZLB becomes binding
  - adoption of price level targeting
  - countercyclical fiscal policies
- Transition and credibility
Table 1: Estimation Results - US

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Prior Shape</th>
<th>Prior Mean</th>
<th>Prior std</th>
<th>Post. Mean</th>
<th>Post. std</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho )</td>
<td>Normal</td>
<td>0.20</td>
<td>0.05</td>
<td>0.19</td>
<td>0.05</td>
<td>0.11</td>
<td>0.27</td>
</tr>
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<td>0.44</td>
<td>0.05</td>
<td>0.43</td>
<td>0.04</td>
<td>0.36</td>
<td>0.50</td>
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<tr>
<td>( \pi^* )</td>
<td>Normal</td>
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<td>0.05</td>
<td>0.62</td>
<td>0.05</td>
<td>0.54</td>
<td>0.69</td>
</tr>
<tr>
<td>( \alpha_p )</td>
<td>Beta</td>
<td>0.66</td>
<td>0.05</td>
<td>0.67</td>
<td>0.03</td>
<td>0.61</td>
<td>0.73</td>
</tr>
<tr>
<td>( \alpha_w )</td>
<td>Beta</td>
<td>0.66</td>
<td>0.05</td>
<td>0.50</td>
<td>0.05</td>
<td>0.43</td>
<td>0.58</td>
</tr>
<tr>
<td>( \gamma_p )</td>
<td>Beta</td>
<td>0.50</td>
<td>0.15</td>
<td>0.20</td>
<td>0.07</td>
<td>0.08</td>
<td>0.32</td>
</tr>
<tr>
<td>( \gamma_w )</td>
<td>Beta</td>
<td>0.50</td>
<td>0.15</td>
<td>0.44</td>
<td>0.16</td>
<td>0.21</td>
<td>0.68</td>
</tr>
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<td>Beta</td>
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<td>0.18</td>
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<td>0.80</td>
<td>0.03</td>
<td>0.75</td>
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<td>( \nu )</td>
<td>Gamma</td>
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<td>0.73</td>
<td>0.15</td>
<td>0.47</td>
<td>0.97</td>
</tr>
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<td>( a_{\pi} )</td>
<td>Gamma</td>
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<td>0.15</td>
<td>2.13</td>
<td>0.15</td>
<td>1.89</td>
<td>2.38</td>
</tr>
<tr>
<td>( a_{\gamma} )</td>
<td>Gamma</td>
<td>0.50</td>
<td>0.05</td>
<td>0.50</td>
<td>0.05</td>
<td>0.42</td>
<td>0.58</td>
</tr>
<tr>
<td>( \rho_{T,R} )</td>
<td>Beta</td>
<td>0.85</td>
<td>0.10</td>
<td>0.85</td>
<td>0.02</td>
<td>0.82</td>
<td>0.89</td>
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<td>( \sigma_z )</td>
<td>Inverse Gamma</td>
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<td>1.06</td>
<td>0.22</td>
<td>0.74</td>
<td>1.38</td>
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<td>( \sigma_R )</td>
<td>Inverse Gamma</td>
<td>0.25</td>
<td>1.00</td>
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<td>0.01</td>
<td>0.09</td>
<td>0.11</td>
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<td>( \sigma_q )</td>
<td>Inverse Gamma</td>
<td>0.25</td>
<td>1.00</td>
<td>0.39</td>
<td>0.11</td>
<td>0.16</td>
<td>0.61</td>
</tr>
<tr>
<td>( \sigma_g )</td>
<td>Inverse Gamma</td>
<td>0.25</td>
<td>1.00</td>
<td>0.23</td>
<td>0.04</td>
<td>0.16</td>
<td>0.29</td>
</tr>
<tr>
<td>( \sigma_u )</td>
<td>Inverse Gamma</td>
<td>0.25</td>
<td>1.00</td>
<td>0.24</td>
<td>0.05</td>
<td>0.06</td>
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<td>( \rho_R )</td>
<td>Beta</td>
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<td>0.10</td>
<td>0.51</td>
<td>0.06</td>
<td>0.41</td>
<td>0.61</td>
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<tr>
<td>( \rho_z )</td>
<td>Beta</td>
<td>0.25</td>
<td>0.10</td>
<td>0.27</td>
<td>0.13</td>
<td>0.09</td>
<td>0.45</td>
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<td>( \rho_g )</td>
<td>Beta</td>
<td>0.85</td>
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<td>0.98</td>
<td>0.01</td>
<td>0.97</td>
<td>1.00</td>
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<td>( \rho_q )</td>
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<td>0.04</td>
<td>0.80</td>
<td>0.95</td>
</tr>
<tr>
<td>( \rho_u )</td>
<td>Beta</td>
<td>0.80</td>
<td>0.10</td>
<td>0.80</td>
<td>0.10</td>
<td>0.65</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Note: ‘std’ stands for Standard Deviation, ‘Post.’ stands for Posterior, and ‘Low’ and ‘High’ denote the bounds of the 90% probability interval for the posterior distribution.
Table 2: Estimation Results - EA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Prior Shape</th>
<th>Prior Mean</th>
<th>Prior std</th>
<th>Post. Mean</th>
<th>Post. std</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
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<td>$\rho$</td>
<td>Normal</td>
<td>0.20</td>
<td>0.05</td>
<td>0.21</td>
<td>0.05</td>
<td>0.13</td>
<td>0.29</td>
</tr>
<tr>
<td>$\mu_z$</td>
<td>Normal</td>
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<td>0.05</td>
<td>0.47</td>
<td>0.05</td>
<td>0.40</td>
<td>0.55</td>
</tr>
<tr>
<td>$\pi^*$</td>
<td>Normal</td>
<td>0.80</td>
<td>0.05</td>
<td>0.79</td>
<td>0.05</td>
<td>0.71</td>
<td>0.86</td>
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<td>Beta</td>
<td>0.66</td>
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<td>0.62</td>
<td>0.05</td>
<td>0.55</td>
<td>0.68</td>
</tr>
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<td>$\alpha_w$</td>
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<td>0.05</td>
<td>0.59</td>
<td>0.04</td>
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<td>$\gamma_p$</td>
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<td>$\eta$</td>
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<td>0.15</td>
<td>0.74</td>
<td>0.04</td>
<td>0.69</td>
<td>0.80</td>
</tr>
<tr>
<td>$\nu$</td>
<td>Gamma</td>
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<td>0.20</td>
<td>0.96</td>
<td>0.18</td>
<td>0.65</td>
<td>1.25</td>
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<tr>
<td>$\sigma_\pi$</td>
<td>Gamma</td>
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<td>0.14</td>
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<td>$\sigma_y$</td>
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<td>$\rho^\pi_R$</td>
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<td>0.23</td>
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<td>$\sigma_g$</td>
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<td>$\rho_R$</td>
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<td>$\rho_z$</td>
<td>Beta</td>
<td>0.25</td>
<td>0.10</td>
<td>0.24</td>
<td>0.10</td>
<td>0.09</td>
<td>0.39</td>
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<tr>
<td>$\rho_g$</td>
<td>Beta</td>
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<td>0.01</td>
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<td>$\rho_q$</td>
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<td>$\rho_u$</td>
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<td>0.80</td>
<td>0.10</td>
<td>0.79</td>
<td>0.10</td>
<td>0.64</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Note: ‘std’ stands for Standard Deviation, ‘Post.’ stands for Posterior, and ‘Low’ and ‘High’ denote the bounds of the 90% probability interval for the posterior distribution.
ZLB Incidence and the Steady State Real Rate

Understanding the Mechanism

(a) US

(b) EA

Note: The blue dots correspond to the relation linking $r^*$ and the probability of ZLB, holding the optimal inflation target $\pi^*$ at the baseline value. The red dots correspond the same relation when the optimal inflation target $\pi^*$ is set at the value consistent with a steady-state real interest rate one percentage point lower.
# The Slope of the \((r^*, \pi^*)\) Locus: Summary Table

Table 3: Effect of a decline in \(r^*\) under alternative notions of optimal inflation

<table>
<thead>
<tr>
<th></th>
<th>US</th>
<th></th>
<th></th>
<th>US</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Lower (r^*)</td>
<td></td>
<td>Baseline</td>
<td>Lower (r^*)</td>
<td></td>
</tr>
<tr>
<td>Mean of (\pi^*)</td>
<td>2.00</td>
<td>3.00</td>
<td></td>
<td>1.79</td>
<td>2.60</td>
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<tr>
<td>Median of (\pi^*)</td>
<td>1.96</td>
<td>2.90</td>
<td></td>
<td>1.47</td>
<td>2.28</td>
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<tr>
<td>(\pi^*) at post. mean</td>
<td>2.21</td>
<td>3.20</td>
<td></td>
<td>1.58</td>
<td>2.39</td>
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<tr>
<td>(\pi^*) at post. median</td>
<td>2.12</td>
<td>3.11</td>
<td></td>
<td>1.49</td>
<td>2.30</td>
<td></td>
</tr>
<tr>
<td>(\pi^{**})</td>
<td>2.40</td>
<td>3.30</td>
<td></td>
<td>2.20</td>
<td>3.10</td>
<td></td>
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<tr>
<td>(\pi^{**}), frozen MP</td>
<td>2.24</td>
<td>3.16</td>
<td></td>
<td>2.36</td>
<td>3.28</td>
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<tr>
<td>(\pi^*) at post. mean, ELB-40 bp</td>
<td>—</td>
<td>—</td>
<td></td>
<td>1.31</td>
<td>2.08</td>
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<tr>
<td>Average realized inflation at post. mean</td>
<td>2.20</td>
<td>3.19</td>
<td></td>
<td>1.56</td>
<td>2.36</td>
<td></td>
</tr>
<tr>
<td>Average realized inflation at post. mean, ELB-40 bp</td>
<td>—</td>
<td>—</td>
<td></td>
<td>1.24</td>
<td>1.97</td>
<td></td>
</tr>
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Note: all figures are in annualized percentage rate.