Long-Run Inflation Expectations

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Introduction

- We develop a model of **long-run** inflation expectations
- Inflation follows trend-cycle model and forecasters observe noisy signals about trend
- We estimate the model using U.S. SPF data
  - Leverage *time-series and cross-sectional* dimensions of data
- We aim to assess:
  - Deviations from **rationality** $\rightarrow$ Need for cognitive biases?
  - Expectations' sensitivity to public vs. private information
  - How well central bank communications support **anchoring**

Main findings

1. **Rationality is rejected**, as most forecasters are affected by
   - Persistent expectations bias
     - ⇒ This bias explains highly persistent forecast errors in SPF data
   - Overconfidence in private information
     - ⇒ This bias explains overreaction in the SPF data

2. Assessing the **anchoring** of long-run inflation expectations in the US
   - Expectations hardly respond to short-term changes in inflation
   - Expectations are fairly coordinated but less so at the ELB
   - In 2022Q4, anchoring-compatible inflation path
     - does not require target undershooting due to persistent expectations bias
     - is consistent with FOMC projections

Related literature

A model of long-run inflation expectations

Forecasting model

Forecasters form expectations believing inflation can be characterized by a **trend-cycle model**:

$$
\begin{aligned}
\pi_t \quad &= \quad \underbrace{\bar{\pi}_t} \quad + \quad \underbrace{\psi_t} \quad + \quad \underbrace{\sigma_\omega \omega_t} \\
\text{Inflation} \quad &= \quad \text{Trend} \quad + \quad \text{Cycle} \quad + \quad \text{IID}
\end{aligned}
$$

$$
\begin{aligned}
\text{Trend :} \quad \bar{\pi}_t \quad &= \quad \bar{\pi}_{t-1} + \sigma_{\lambda,t}\lambda_t \\
\text{Cycle :} \quad \psi_t \quad &= \quad \phi_t \psi_{t-1} + \sigma_{\eta,t}\eta_t
\end{aligned}
$$

Detailed model equations

Rational forecasters' signal extraction problem

- Knowledge of the time-varying parameters trend-cycle model
- Three signals for each forecaster i:

1. Inflation signal
2. Coordinating signal:

$$\tilde{\boldsymbol{s}}_{\boldsymbol{t}}(\boldsymbol{i}) = \bar{\pi}_t + \boldsymbol{\alpha}(\boldsymbol{i}) v_{c,t} \quad \text{where } v_{c,t} = \rho_c v_{c,t-1} + \boldsymbol{\sigma}_{\boldsymbol{c},\boldsymbol{t}} \nu_{c,t}, \quad \boldsymbol{\alpha}(\boldsymbol{i}) > 0$$

3. Idiosyncratic signal:

$$\boldsymbol{s}_{\boldsymbol{t}}(\boldsymbol{i}) = \bar{\pi}_t + v_t(i) \qquad \text{where } v_t(i) = \boldsymbol{\rho}(\boldsymbol{i}) v_{t-1}(i) + \boldsymbol{\sigma}_{\boldsymbol{\nu}}(\boldsymbol{i}) \nu_t(i)$$

- Rational forecasters solve a signal extraction problem ⇒ **Bayesian updating**

Details

Cognitive abilities of forecasters

Rational model:

- Forecasters are capable to correctly assess the true value of parameters of their signal extraction problems

Behavioral model:

- Forecasters may **misperceive** some parameters of their signal extraction problem

1. The persistence of the coordinating signal: $\boldsymbol{\rho_c^*(i)} \neq \rho_c$
2. The relative volatility of the coordinating signal: $\boldsymbol{\alpha^*(i)} \neq \boldsymbol{\alpha(i)}$
3. The persistence of their idiosyncratic signal: $\boldsymbol{\rho^*(i)} \neq \boldsymbol{\rho(i)}$
4. The innovation volatility of their idiosyncratic signal: $\boldsymbol{\sigma_\nu^*(i)} \neq \boldsymbol{\sigma_\nu(i)}$

No specific misperception imposed ex-ante: Likelihood estimation identifies misperception

Two-Step Estimation

Two-step estimation

STEP 1: State-of-the-art estimation of trend inflation Detailed model estimates

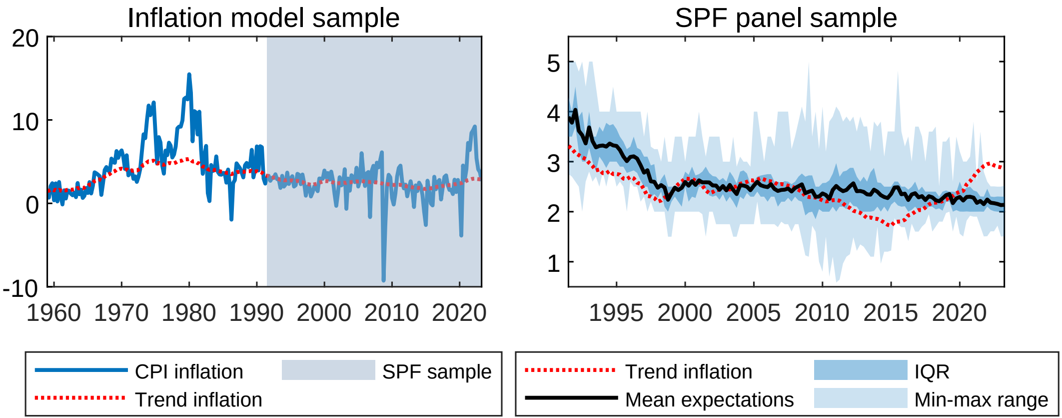
- Estimate the time-varying parameters of forecasters' trend-cycle model
- Estimate the latent states: the trend and the cycle
- Data: US quarter-on-quarter headline CPI inflation (Sample: 1959Q1-2023Q2)

STEP 2: Panel estimation of our model of expectations Details

Likelihood estimation based on the following observable variables

- US CPI inflation
- estimated cyclical and trend component from Step 1
- individual SPF long-run CPI inflation expectations (Sample: 1991Q3-2023Q2)

Estimation: trend inflation and SPF



Two challenges for the model:

1. **Persistent gaps between expectations and trend**
2. **Great deal of heterogeneity** ▸ All forecasters

Estimated models and deviations from rationality

Two deviations from rationality

Two biases correct key **misspecifications of the rational model** ▸ Details

1. **Persistent expectations bias** $(\rho_c^*(i) < \rho_c)$
   - makes effects of coordinating signal **more persistent**
   - explains excess persistence in forecast errors
2. **Overconfidence in private information** $(\sigma_\nu^*(i) < \sigma_\nu(i))$
   - **raises heterogeneity** in the responses to idiosyncratic signals
   - detects excess heterogeneity in LR inflation expectations

Almost all forecasters are affected by these two biases ▸ Robustness

Forecast errors and nonrational behaviors

- What features in the data do the two identified cognitive biases help explain?
- The regression framework of Coibion and Gorodnichenko (2015) and Bordalo et al. (2020) helps answer these questions

$$\bar{\pi}_t - E_t^i \bar{\pi}_t = \beta_0^p + \beta_1^p \left(E_t^i \bar{\pi}_t - E_{t-1}^i \bar{\pi}_t \right) + \varepsilon_t^i$$

Forecast Errors and Overreaction: Data vs. Models

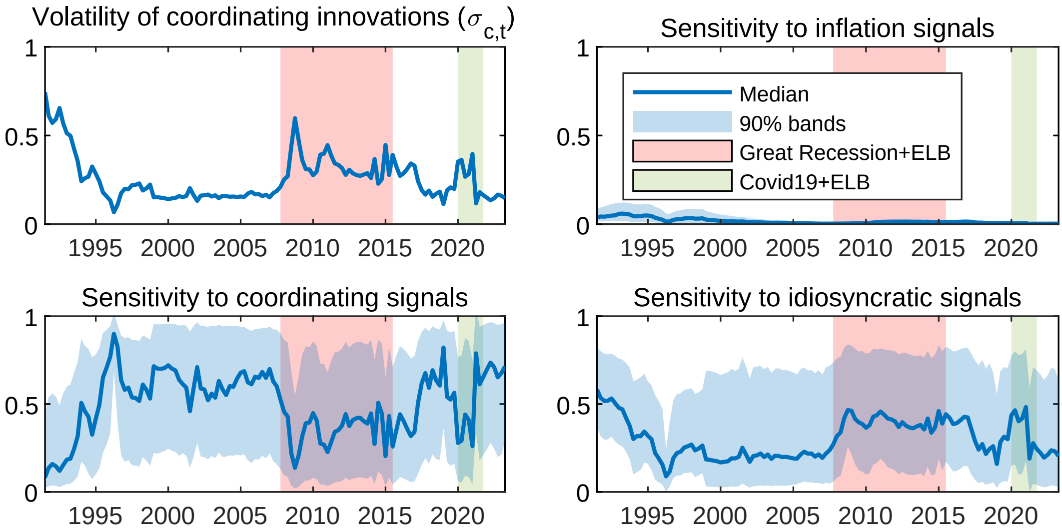
	β_0^p	SE	β_1^p	SE	R^2
I. Data					
FE based on estimated trend	-0.14**	0.05	-0.48***	0.03	0.07
FE based on realized future inflation	-0.31***	0.09	-0.48***	0.06	0.03
SPF short-run inflation expectations	0.00	0.00	0.11	0.18	0.00
II. Models					
Rational model	-0.02	0.01	-0.39***	0.03	0.07
Behavioral model	-0.12***	0.03	-0.47***	0.02	0.11
Behavioral model - Only overconf.	-0.04	0.02	-0.47***	0.02	0.08

We uncover **two key features of the data** and show that each is explained by one of the **two cognitive biases** in the behavioral model

1. Persistent negative FE ($\beta_0^p < 0$) $\Rightarrow$ Persistent expectations bias
2. Strong evidence of overreaction ($\beta_1^p < 0$) $\Rightarrow$ Overconfidence

Assessing the anchoring of long-run inflation expectations in the US

Expectations' sensitivity and anchoring



Anchoring-compatible path of inflation

Policy maker in Dec 2022: Which inflation path is consistent with anchored expectations going forward?

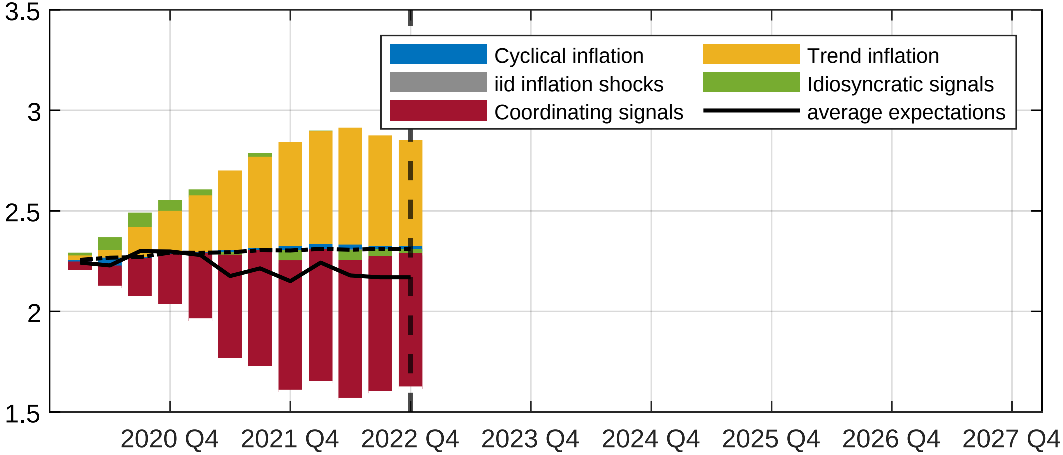
Assumptions

1. Level of average CPI expectations in 2022Q4 is consistent with anchoring (median PCE expectations are at 2)
2. Innovations to the idiosyncratic signal are set to zero

Procedure

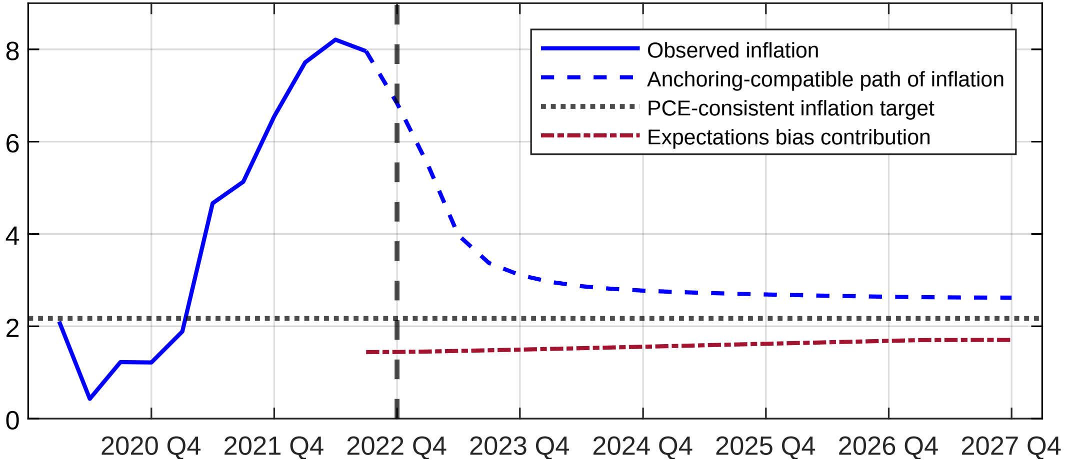
1. Target a path of anchored average expectations
2. Guess a path for trend inflation $\bar{\pi}_t$
3. Given trend inflation, we ask the model what path of inflation and coordinating signals are consistent with anchored expectations
4. Estimate trend of the inflation path from 3. to verify the guess

Challenges to anchoring expectations in late 2022



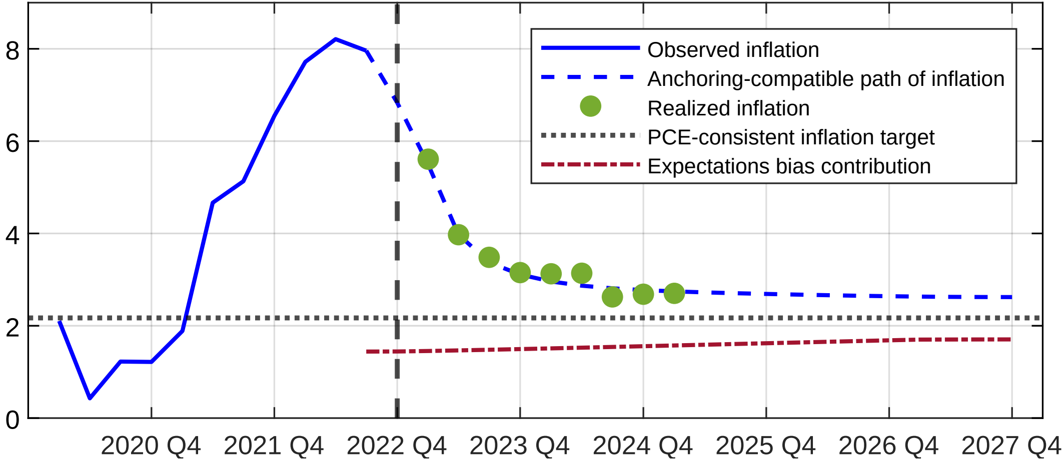
Challenge: Preventing trend inflation from getting ingrained in expectations ▸ Full sample

Application: Anchoring compatible-path of inflation as of end 2022



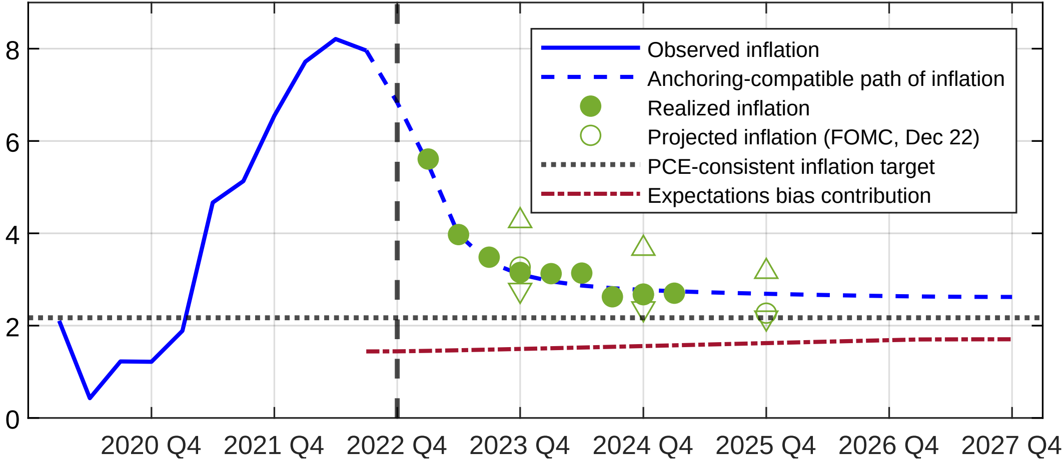
Why convergence from above? Persistent expectations bias counters the deanchoring forces due to trend inflation ▸ interpretations

Application: Anchoring compatible-path of inflation as of end 2022



Anchoring-compatible path in 2022Q4 is broadly consistent with **2023-24 inflation**

Application: Anchoring compatible-path of inflation as of end 2022



Anchoring-compatible path in 2022Q4 is broadly consistent with **FOMC projections**

Conclusion

This paper: A model of long-run inflation expectations applied to US SPF data

1. **Rationality is rejected**, as most forecasters are affected by
   - Persistent expectations bias due to public information
     $\Rightarrow$ This bias explains highly persistent forecast errors in SPF data
   - Overconfidence in private information
     $\Rightarrow$ This bias explains overreaction in the SPF data
2. **Strong evidence for anchoring** of US long-run inflation exp. over last 25 years
   - Expectations hardly respond to short-term changes in inflation
   - Expectations are fairly coordinated but less so at the ELB
   - In 2022Q4, anchoring-compatible inflation path is consistent with FOMC projections
   - Persistent expectations bias has rendered target undershooting unnecessary
     but this outcome is conditional on the prevailing economic condition

Appendix

Related Literature ◂ back

- **Testing the FIRE assumption on survey and experimental data**
  Coibion and Gorodnichenko (2012, 2015), Bordalo et al. (2020), Kohlhas and Walther (2021), Angeletos et al. (2021), Bianchi et al. (2022, 2023), Broer and Kohlhas (2022), Afrouzi et al. (2023), Farmer et al. (2023).
- **Variation in disagreement over time or across horizons**
  Mankiw et al. (2004), Patton and Timmermann (2010), Dovern et al. (2012), Andrade and Bihan (2013), Andrade et al. (2016), Giacomini et al. (2020), Goldstein and Gorodnichenko (2022), Crump et al. (2023), Goldstein (2023).
- **Estimation of trend-cycle models and link with expectations**
  Stock and Watson (2007); Cogley et al. (2010); Henzel (2013); Mertens (2016); Chan et al. (2018); Mertens and Nason (2020).
- **Anchoring of inflation expectations** (Kurmar et al., 2015)
  1. **Average long-run inflation forecasts stable and close to target**
     Orphanides and Williams (2005), Beechey et al. (2011), Carvalho et al. (2020).
  2. **Long-run expectations do not respond much to incoming data**
     Bernanke (2007), Gürkaynak et al. (2007), Dräger and Lamla (2014), Barlevy et al. (2021), Corsello et al. (2021), Armantier et al. (2022).
  3. **Defined based on higher order moments of expectations**
     Grishchenko et al. (2019), Reis (2021), Binder et al. (2023).

Inflation model

The model of inflation, π_t is:

$$\begin{aligned} \pi_t &= \bar{\pi}_t + \psi_t + \sigma_\omega \omega_t \\ \bar{\pi}_t &= \bar{\pi}_{t-1} + \sigma_{\lambda,t}\lambda_t \\ \psi_t &= \phi_t \psi_{t-1} + \sigma_{\eta,t}\eta_t \end{aligned}$$

where ω_t, λ_t, and η_t are i.i.d. $\mathcal{N}(0,1)$.

$$\begin{aligned} \ln(\sigma^2_{\eta,t}) &= \ln(\sigma^2_{\eta,t-1}) + \gamma_\eta \omega_{\eta,t} \\ \ln(\sigma^2_{\lambda,t}) &= \ln(\sigma^2_{\lambda,t-1}) + \gamma_\lambda \omega_{\lambda,t}, \end{aligned}$$

where $\omega_{\eta,t}$ and $\omega_{\lambda,t}$ are i.i.d. $\mathcal{N}(0,1)$.

$$\phi_t = \phi_{t-1} + \gamma_\phi \omega_{\phi,t},$$

where $\omega_{\phi,t}$ is distributed $\mathcal{N}(0,1)$ and $\phi_t \in (0,1)$. back

Forecasters' long-run inflation expectations

Forecasters state-space model can be written as

$$\xi_t(i) = \boldsymbol{\Phi_t(i)}\xi_{t-1}(i) + \mathbf{R_t(i)}e_t(i) \quad (1)$$

$$s_t(i) = \mathbf{D(i)}\xi_t(i) + \boldsymbol{Q}u_t \quad (2)$$

where

$$\xi_t(i) = [\psi_t, \bar{\pi}_t, v_{c,t}, v_t(i)]'$$

$$e_t(i) = [\eta_t, \lambda_t, \nu_{c,t}, \nu_t(i)]'$$

$$y_t(i) = [\pi_t, \tilde{s}_t(i), s_t(i)]'$$

$$u_t = [\omega_t, \omega_{2,t}, \omega_{3,t}]'$$

$\Rightarrow$ Forecasters update expectations about states using Bayes rule

$$\xi_{t|t}(i) \equiv \mathbb{E}\left(\xi_t(i)|y_t(i), \pi^{t-1}\right) = \left(\mathbf{I}_4 - \mathbf{K}_t(i)\,\mathbf{D(i)}\right)\xi_{t|t-1}(i) + \mathbf{K}_t(i)\,y_t(i)$$

where $\mathbf{K}_t(i)$ denotes Kalman gain. back

Kalman filter derivation

The Kalman filter recursion is given by:

$$
\begin{aligned}
\xi_{t|t-1}(i) &= \boldsymbol{\Phi_t(i)}\xi_{t-1|t-1}(i) \\
P_{t|t-1}(i) &= \boldsymbol{\Phi_t(i)}P_{t-1|t-1}(i)\,\boldsymbol{\Phi_t(i)}' + \mathbf{R}_t(i)\mathbf{R}_t(i)' \\
s_{t|t-1}(i) &= \mathbf{D(i)}\xi_{t|t-1}(i) \\
F_{t|t-1}(i) &= \mathbf{D(i)}P_{t|t-1}(i)\,\mathbf{D(i)}' + \mathbf{QQ}' \\
\xi_{t|t}(i) &= \xi_{t|t-1}(i) + \underbrace{P_{t|t-1}(i)\mathbf{D(i)}'\left[F_{t|t-1}(i)\right]^{-1}}_{K_t(i)}\left[y_t(i) - \mathbf{D(i)}\xi_{t|t-1}(i)\right] \\
P_{t|t}(i) &= P_{t|t-1}(i) - P_{t|t-1}(i)\,\mathbf{D(i)}'\left[F_{t|t-1}(i)\right]^{-1}\mathbf{D(i)}P_{t|t-1}(i)
\end{aligned}
$$

Then, re-arrange the Kalman equation as follows:

$$
\begin{aligned}
\xi_{t|t}(i) &= \xi_{t|t-1}(i) + K_t(i)\left[y_t(i) - D(i)\xi_{t|t-1}(i)\right] \\
&= \left[\mathbf{I}_4 - K_t(i)\,D(i)\right]\Phi_t(i)\xi_{t-1|t-1}(i) + K_t(i)\,y_t(i) \\
&= \left[\mathbf{I}_4 - K_t(i)\,D(i)\right]\Phi_t(i)\xi_{t-1|t-1}(i) + K_t(i)\left[D(i)\xi_t(i) + Qu_t\right] \\
&= \left[\mathbf{I}_4 - K_t(i)\,D(i)\right]\Phi_t(i)\xi_{t-1|t-1}(i) \\
&\quad + K_t(i)\left[D(i)(\Phi_t(i)\xi_{t-1}(i) + R_t(i)e_t(i)) + Qu_t\right]
\end{aligned}
$$

Kalman filter derivation (cont.)

In the **behavioral model** each forecaster is allowed to have forecaster-specific views on the model parameters of the coordinating and idiosyncratic signal processes which can be different from the "true" estimates. Denoting perceived parameters with * we get

$$\begin{aligned} \xi_{t|t}(i) &= \xi_{t|t-1}(i) + K_t^*(i)\left[y_t(i) - \mathbf{D}^*(\mathbf{i})\xi_{t|t-1}(i)\right] \\ &= \left[\mathbf{I}_4 - K_t^*(i)\,\mathbf{D}^*(\mathbf{i})\right]\boldsymbol{\Phi}_t^*(\boldsymbol{i})\xi_{t-1|t-1}(i) + K_t^*(i)\left[\mathbf{D}(\mathbf{i})(\boldsymbol{\Phi}_t^*(\boldsymbol{i})\xi_{t-1}(i) + \mathbf{R_t}(\mathbf{i})e_t(i)) + \mathbf{Q}u_t\right] \end{aligned}$$

back

Estimation of inflation model

Data: US CPI inflation, quarter-on-quarter annualized growth rates

Sample: 1959Q1-2023Q2

Parameters:

	Prior				Posterior
	Shape	Scale	Mean	[5%, 95%]	Mean
γ_η^2	5	0.04	0.01	[0.004,0.02]	0.0538
γ_λ^2	5	0.04	0.01	[0.004,0.02]	0.0113
γ_ϕ^2	5	0.004	0.001	[0.0004,0.002]	0.0015
σ_ω^2	3	0.2	0.1	[0.032,0.245]	0.1425

Table: Prior and posterior for parameters distributed as Inverse Gamma (Shape,Scale)

back

Estimation of inflation model (cont)

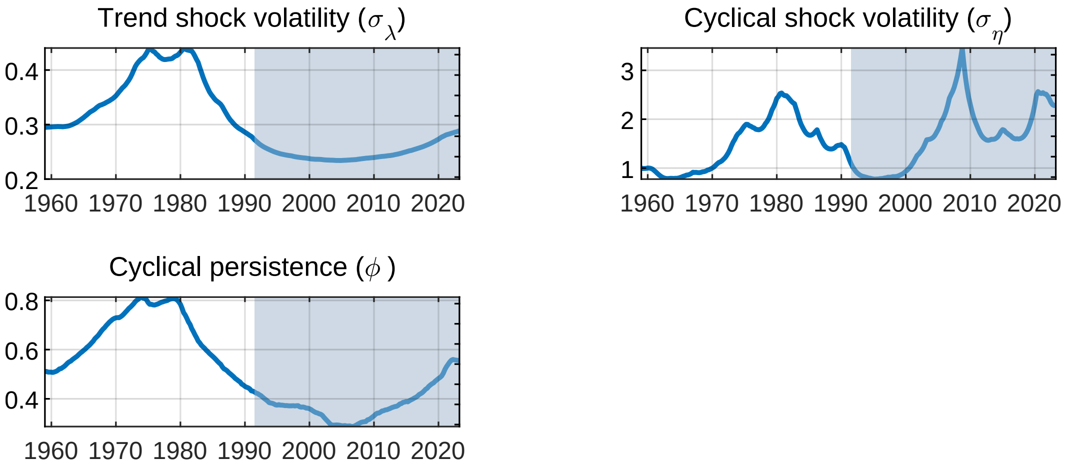


Figure: Time-varying parameter estimates (posterior means) back

Estimation of forecaster panel model

Transition equation:

$$\begin{bmatrix} \xi_t \\ \overrightarrow{\xi}_{t|t} \\ \omega_t \end{bmatrix} = \widetilde{\boldsymbol{\Phi}}_t \begin{bmatrix} \xi_{t-1} \\ \overrightarrow{\xi}_{t-1|t-1} \\ 0 \end{bmatrix} + \widetilde{\mathbf{R}}_t \begin{bmatrix} \eta_t \\ \lambda_t \\ \nu_{c,t} \\ \overrightarrow{\nu_{v,t}} \\ \omega_t \end{bmatrix}$$

- ξ_t: Inflation model and belief processes, i.e. $\xi_t = \begin{bmatrix} \psi_t & \bar{\pi}_t & v_{c,t} & \overrightarrow{v_t} \end{bmatrix}'$
- $\overrightarrow{\xi}_{t|t}$: vector of individual forecasters' expectations $\xi_{t|t}(i)$ Link

back

Estimation of forecaster panel model

Measurement equation:

$$
\begin{bmatrix} \pi_t^{cpi} \\ \psi_t^{est} \\ \bar{\pi}_t^{est} \\ \mathbb{E}_t \pi_t^{long}(1) \\ \mathbb{E}_t \pi_t^{long}(2) \\ \vdots \\ \mathbb{E}_t \pi_t^{long}(N) \end{bmatrix} = \begin{bmatrix} \mathbf{D_{CPI}} & \mathbf{0}_{1\times k} & \mathbf{0}_{1\times k} & \dots & \mathbf{0}_{1\times k} & \sigma_\omega \\ \mathbf{1}_1 & \mathbf{0}_{1\times k} & \mathbf{0}_{1\times k} & \dots & \mathbf{0}_{1\times k} & 0 \\ \mathbf{1}_2 & \mathbf{0}_{1\times k} & \mathbf{0}_{1\times k} & \dots & \mathbf{0}_{1\times k} & 0 \\ \mathbf{0}_{1\times k} & \mathbf{1}_2 & \mathbf{0}_{1\times k} & \dots & \mathbf{0}_{1\times k} & 0 \\ \mathbf{0}_{1\times k} & \mathbf{0}_{1\times k} & \mathbf{1}_2 & \dots & \mathbf{0}_{1\times k} & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ \mathbf{0}_{1\times k} & \mathbf{0}_{1\times k} & \mathbf{0}_{1\times k} & \dots & \mathbf{1}_2 & 0 \end{bmatrix} \begin{bmatrix} \xi_t \\ \xi_{t|t}(1) \\ \xi_{t|t}(2) \\ \vdots \\ \xi_{t|t}(N) \\ \omega_t \end{bmatrix},
$$

where $\mathbf{D_{CPI}}$ is a zero row vector of length N+k-1 with elements 1 and 2 equal to 1 and k=4. $\mathbf{1}_n$ denotes the $1 \times n$ row vector with elements all equal to zero except the n-th one which is equal to one. ◂ back

Selection of forecasters

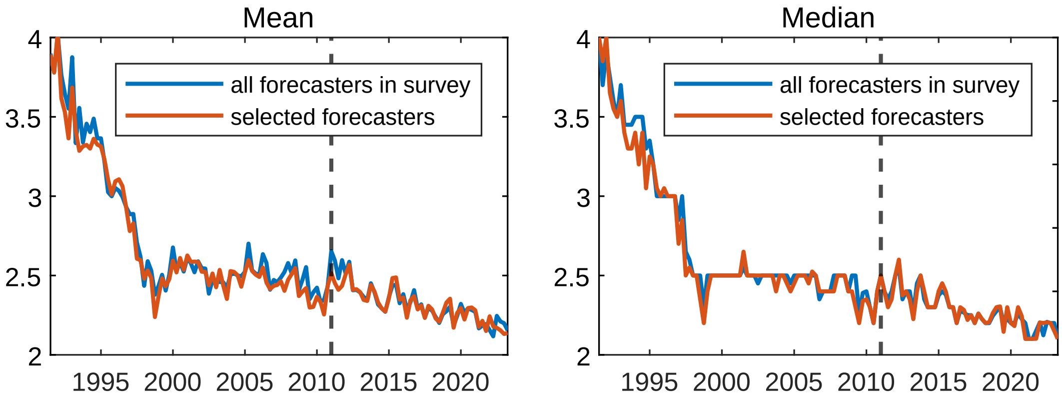


Figure: Time series of inflation expectations: mean(lhs) and median (rhs)

Note: Dashed vertical line indicates 2011Q1 before which we use 10Y and afterwards 5Y5Y expectations.

back to estimation

Selection of forecasters (cont)

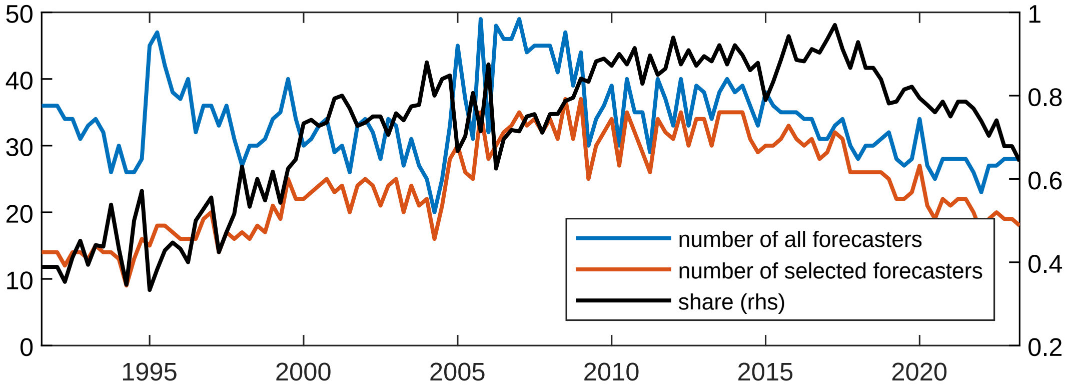
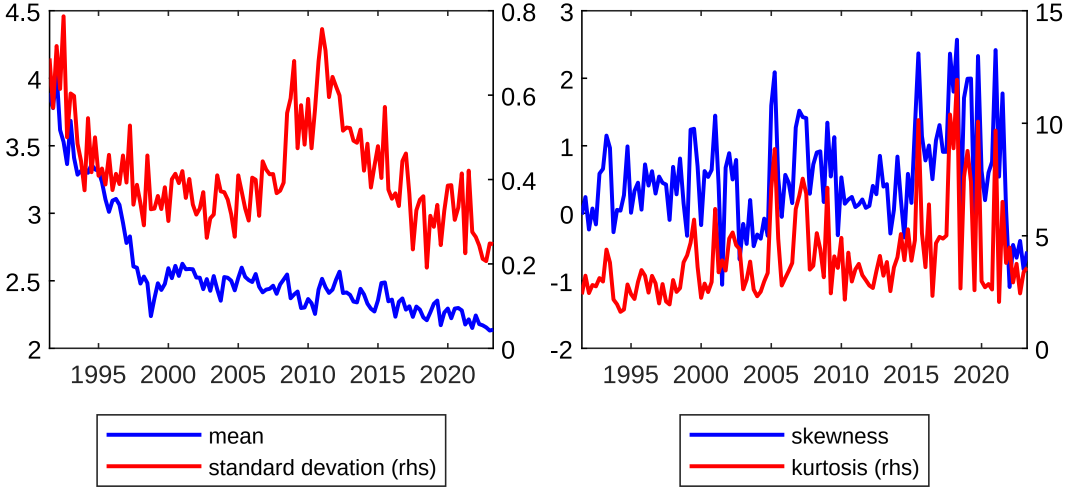


Figure: Number of total and selected forecasters in the US SPF survey

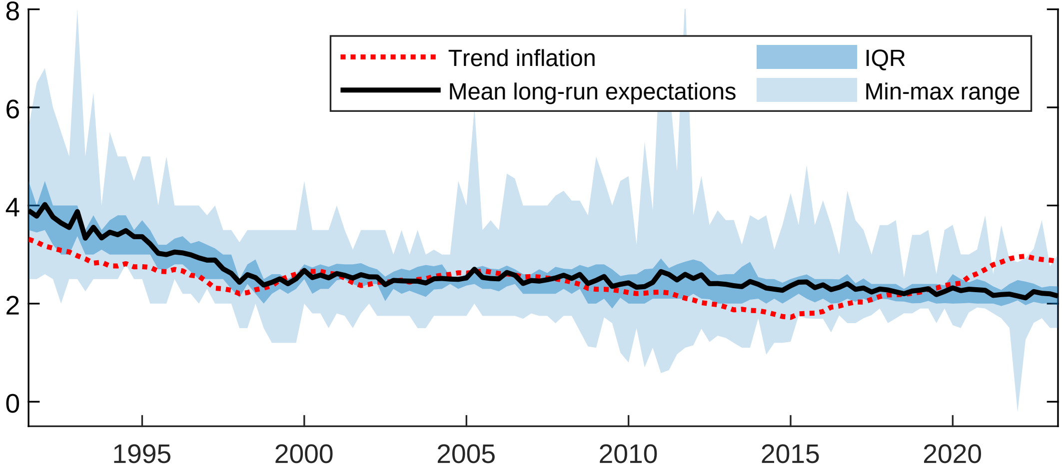
back to estimation

Moments of expectations distribution



back to estimation

Panel estimation: the data (all forecasters)



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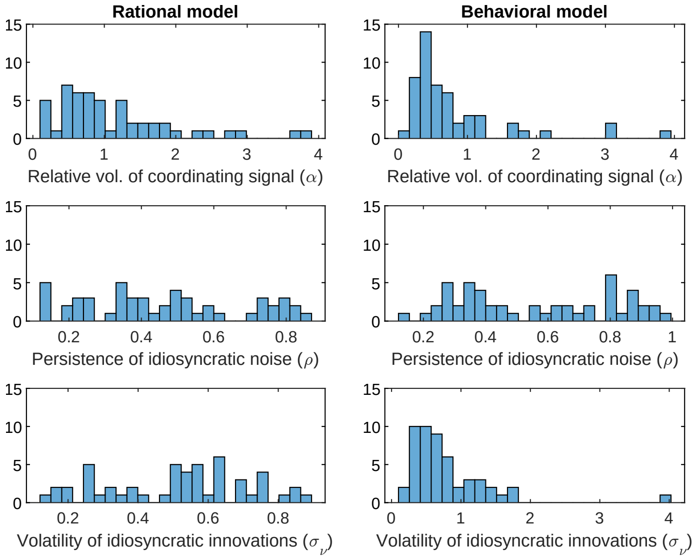
Panel estimation: forecaster-specific parameter estimates

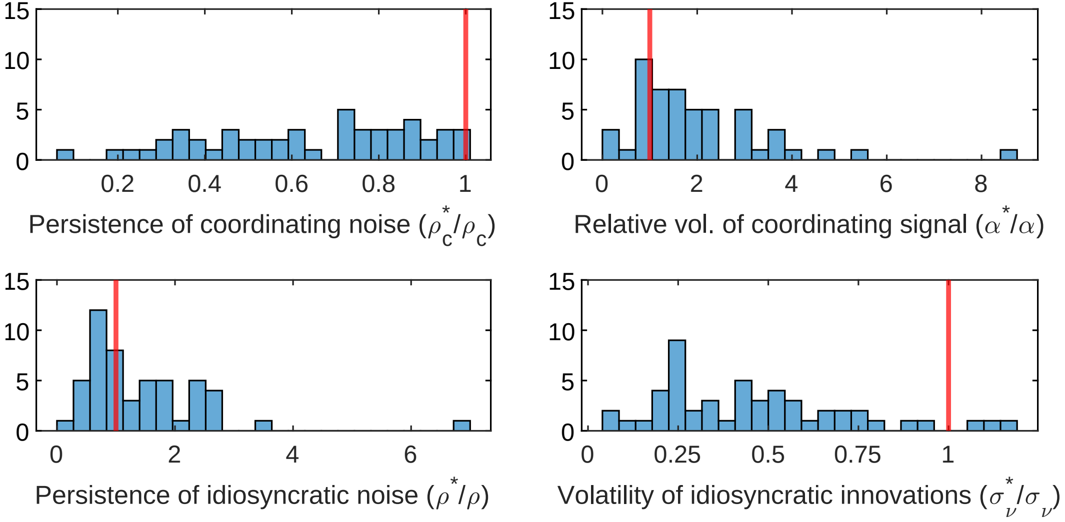


Panel estimation: parameter estimates

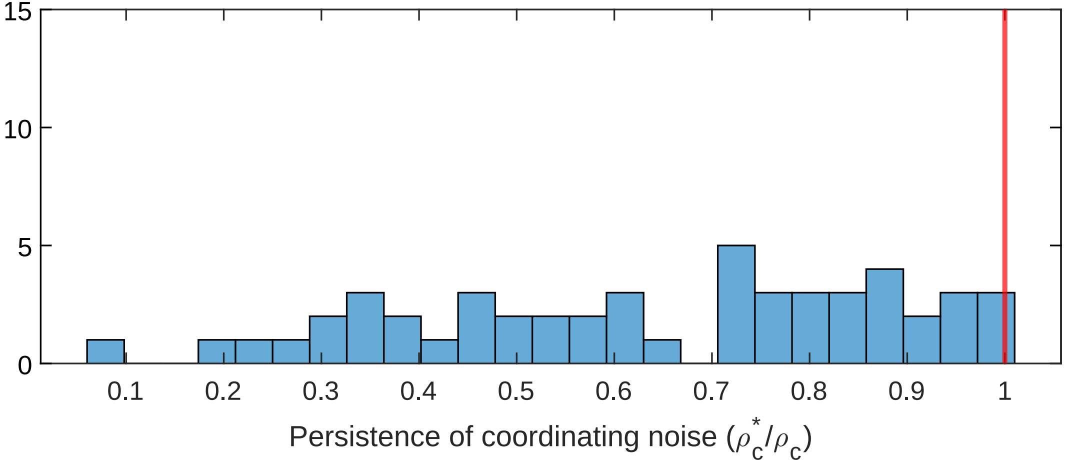
	Prior moments					Posterior mode	
Parameters	Distr.	Par(1)	Par(2)	Mean	5%-95%	Rational	Behavioral
ρ_c	B	2.63	2.63	0.50	[0.17,0.83]	0.99	0.96
$\alpha(i)$	G	2.00	1.00	2.00	[0.36,4.74]	see fig.	see fig.
$\rho(i)$	B	2.63	2.63	0.50	[0.17,0.83]	see fig.	see fig.
$\sigma_\nu(i)$	logN	0.00	1.00	1.65	[0.19,5.18]	see fig.	see fig.
$\rho_c^*(i)$	B	2.63	2.63	0.50	[0.17,0.83]	NA	see fig.
$\alpha^*(i)$	G	2.00	1.00	2.00	[0.36,4.74]	NA	see fig.
$\rho^*(i)$	B	2.63	2.63	0.50	[0.17,0.83]	NA	see fig.
$\sigma_\nu^*(i)$	logN	0.00	1.00	1.65	[0.19,5.18]	NA	see fig.

Table: **Prior distribution and posterior mode for the parameters.** B, G and logN stand for beta, gamma, and log-normal distributions. Par(1) and Par(2) are the shape and scale for the gamma distribution, respectively, the shape parameters α and β for the beta distribution and the logarithm of location μ and logarithm of scale σ for the log-normal distribution.

Panel estimation: behavioral model's parameter estimates

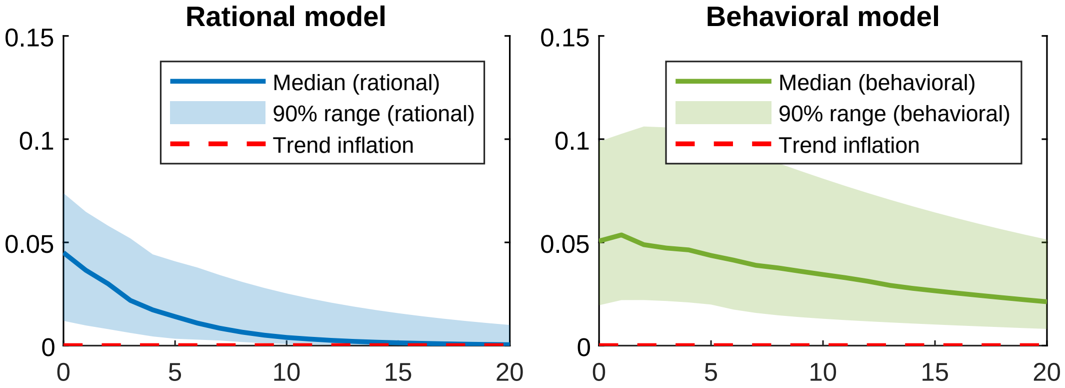


Deviation from rationality #1



Almost all forecasters underestimate the persistence of shocks to coordinating signal

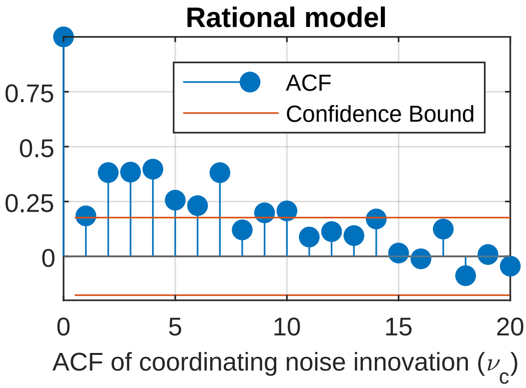
Propagation of the shocks to the coordinating signal

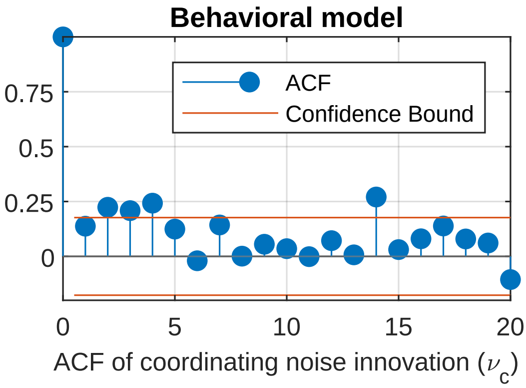


Persistent expectations bias: In the behavioral model, the coordinating signal moves all expectations persistently away from the trend ⇒ Large and persistent forecast errors

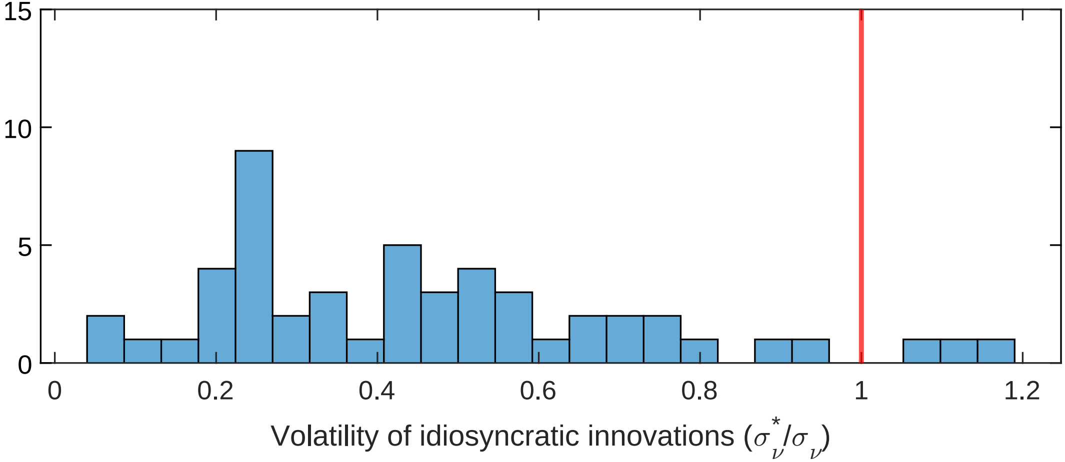
because, by underestimating the persistence of noise in the coordinating signal, agents are induced by this noise to mistakenly believe that the trend has changed

Serial correlation of innovations to the coordinating signal



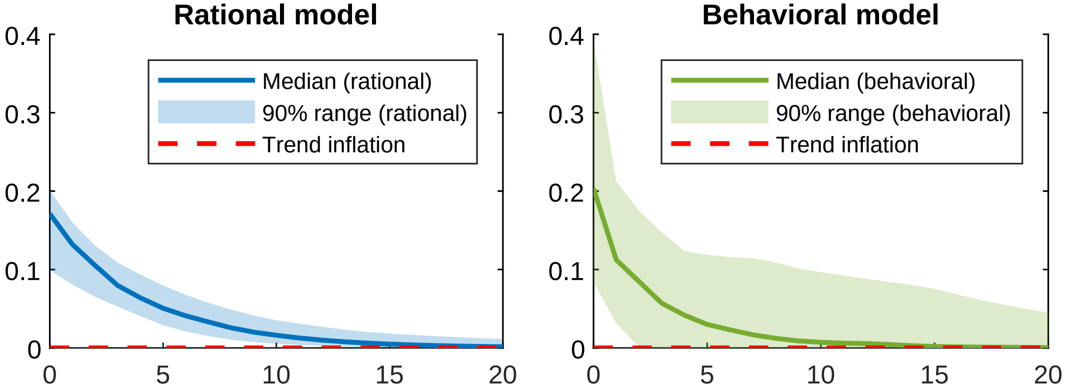


Deviation from rationality #2



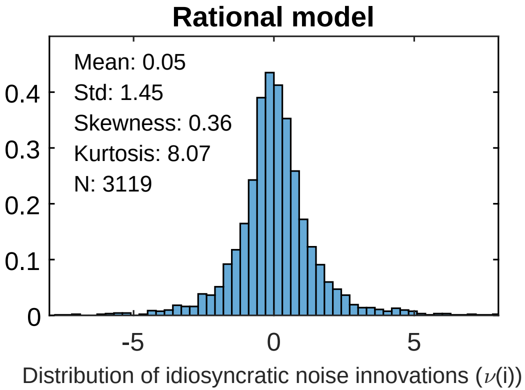
Almost all forecasters are overconfident in their private information

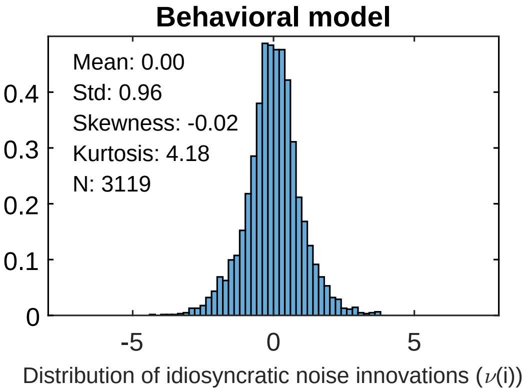
Propagation of the shocks to the idiosyncratic signals



Overconfidence in private information: The behavioral model can generate considerably more heterogeneity via idiosyncratic signals because overestimation of the precision of the idiosyncratic signal leads individual expectations to become more sensitive to this signal $\Rightarrow$ smaller innovations to idiosyncratic signals are needed to explain the heterogeneity in the SPF expectations

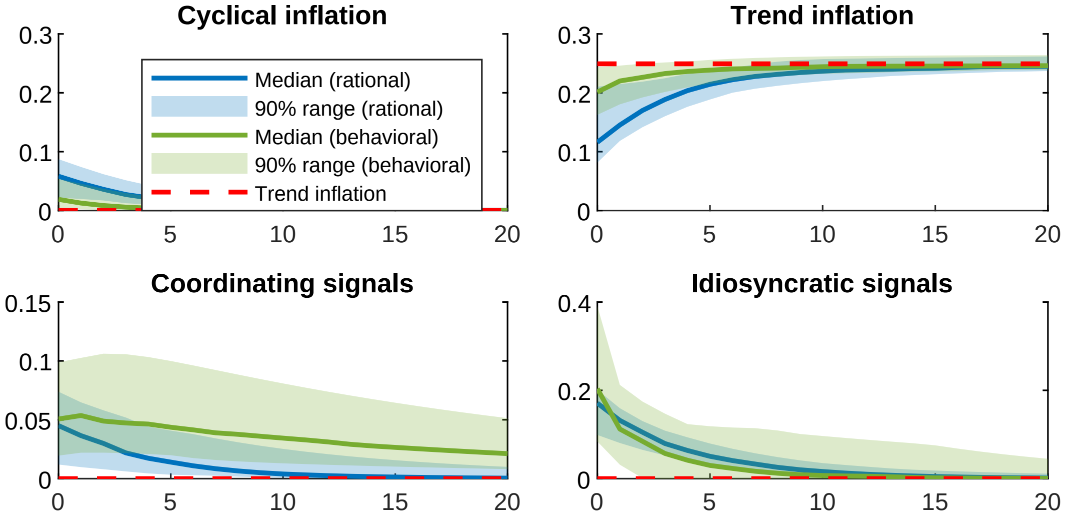
Empirical performance



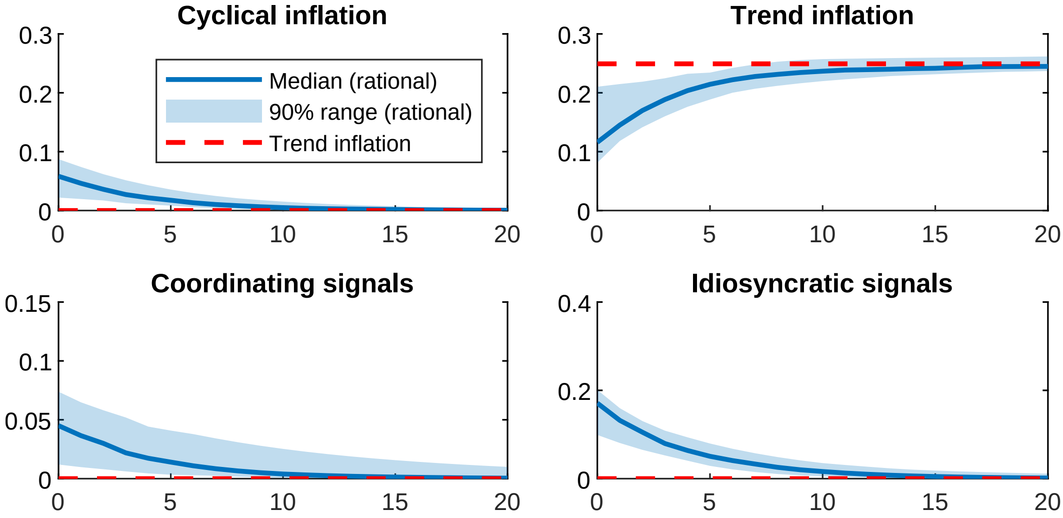


In-sample realizations of innovations to the idiosyncratic signal are smaller in size and consistent with a standardized normal

Propagation of shocks



Propagation of shocks



No shock can coordinate expectations persistently away from trend ▸ Back

Robustness and Extensions

- **Real-time estimation of trend-cycle model**
  - Forecasters only know parameters based on real-time estimation of trend-cycle model
- **Wrong model**: Forecasters believe in baseline model but "true trend" comes from different model such as
  - 5-year MA of inflation
  - 10-year MA of inflation
- **Alternative trend-cycle model specifications**
  - core instead of headline CPI inflation
  - constant vs time-varying parameter model

$\Rightarrow$ These alternatives would not resolve the misspecification plaguing the rational model

Expectation bias: a proxy for reputation

- The bias emerges b/c expectations insensitive to trend inflation
- It may be interpreted as a real-time measure of reputation
- What are the gains from reputation?
  - No need to undershoot the inflation target
  - Anchoring requires less tightening, supporting a soft landing
- The model can track changes in the bias in real time
  - The bias will get smaller if expectations move closer to trend
  - Signaling additional tightening needed to retain anchoring

back