Inflation Persistence, Noisy Information and the Phillips Curve

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Motivation

- Expectations play a central role in (macro)economics
- Most of work considers a limited theory of expectation formation
  - agents are perfectly and homogeneously aware of state and others' actions
- Explore the nature of expectation formation
  - consistent with data
  - how this matters for macro aggregates and monetary policy
- Significant heterogeneity and sluggishness in inflation expectations

What I do

- Surveys on inflation expectations: Bai-Perron test (structural break)
  - evidence of forecast underreaction before the mid-1980s,
  - not afterward

- Coincides with a change in Fed's communication strategy, which became more transparent

- Build a New Keynesian model extended with information frictions

- A change in US firms' belief formation in the mid-1980s can explain two empirical challenges
  - *fall in inflation persistence* and *dynamics of the Phillips Curve*

What I find

- Firms' forecasts used to underreact to information before 1985, not afterwards
  - underreaction: positive co-movement between forecast errors and revisions interpretation

$$\text{forecast error}_t = \pi_{t+4,t} - \mathbb{F}_t \pi_{t+4,t}, \qquad \text{revision}_t = \mathbb{F}_t \pi_{t+4,t} - \mathbb{F}_{t-1} \pi_{t+4,t}$$

- Explain the fall in inflation persistence in a NK context
  - inflation is more persistent in periods of forecast stickiness
  - additional persistence in expectations, increasing inflation persistence

- Explain dynamics of the Phillips curve: modest flattening
  - info frictions, Phillips curve is enlarged with anchoring and myopia; changes in backward-lookingness
  - general info structure: only modest flattening once I control for imperfect expectations

Inflation Persistence: the First Puzzle

- Monetary literature documents changes in inflation dynamics over time
- Level, persistence, volatility,...
- Persistence: Scatter Plot Structural Break Unit Root
  - fall in inflation persistence from 0.75 to 0.5 around 1980-1985 [Fuhrer & Moore (1995), Benati & Surico (2008), Cogley & Sbordone (2008), Cogley, Primiceri & Sargent (2010), Fuhrer (2010), Goldstein & Gorodnichenko (2019)] Literature Review
  - hard to square in theoretical framework
    - structural shock persistence: stable (monetary, TFP, cost-push) Monetary TFP & Cost-push
    - optimal monetary policy: insufficient or unlikely Discretion Commitment
    - change in trend inflation: insufficient Price Indexation Trend Inflation

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  - potential explanations:
    - Cogley et al. (2010): subsample, TR inflation coefficient increased, cost-push shocks less persistent, disturbances less volatile
    - Davig and Doh (2014): regime-switching, TR inflation coefficient increased, fall in volatility of cost-push shocks, explain 40% of fall
    - Bianchi & Ilut (2017): fiscal imbalances and accommodative monpol increase persistence
    - Erceg & Levin (2003): noisy information about CB inflation target explain high persistence in the 1970-80s
  - contribution: explain this fall through changes in expectations

Flattening in Phillips Curve: the Second Puzzle

- Exercise 1: study inflation persistence from structural equation, Phillips curve
  - Noisy-info Phillips curve

$$\pi_t = \omega_1 \pi_{t-1} + \kappa \tilde{y}_t + \omega_2 \beta \mathbb{E}_t \pi_{t+1}$$

  - Evidence of fall in intrinsic persistence $\omega_1 \to 0$ and myopia $\omega_2 \to 1$

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- Exercise 2: slope of Phillips curve controlling for beliefs
  - Literature arguing flattening of Phillips Curve
  - Inflation no longer affected by demand side (including interest rate)
  - In the benchmark NK inflation path given by Phillips curve

$$\pi_t = \kappa \tilde{y}_t + \beta \mathbb{E}_t \pi_{t+1}$$

  - Only possible way: $\downarrow \kappa$
  - Show that κ has fallen only modestly, and dynamics explained via changes in expectations

Evidence on Imperfect Expectations

Fed Communication History

Since the late 1960s, Fed's public disclosure and transparency improved

- 1966: FOMC announced decisions once a year (Annual Report)
- 1967: released Policy Report (PR) 90 days after decision
- 1976: PR enlarged and delay reduced to 45 days
- 1976-1993: information contained in PR increased
  - Fed objectives: max employment, stable prices and moderate interest rates
  - macroeconomic forecasts on real GNP and inflation from FOMC members
  - "tilt" (predisposition regarding possible future action)
  - "ranking of policy factors"
  - minutes
- 1994: immediate release of PR after meeting if change
- 1999: immediate release of "tilt"
- 2000: immediate announcement and press conference after meeting

Data

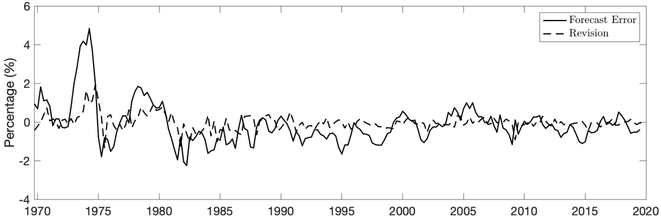
- Survey of Professional Forecasters, 1968:Q4-2020:Q1
  - conducted by ASA, NBER and Philly Fed
  - every quarter forecasters asked on forecasts of macro variables
  - asked to give nowcast, quarter-ahead forecast, etc. up to five quarters
  - forecasters work at Wall Street financial firms, commercial banks, consulting firms, research centers and other private sector companies
  - used extensively in the literature [Coibion & Gorodnichenko (2012, 2015), Bordalo et al. (2020), Broer & Kohlhas (2021)]

- Results robust to Livingston Survey

Evidence on expectations

- Focus on annual inflation forecasts forecasting frictions
- Coibion & Gorodnichenko (2012, 2015): positive co-movement between ex-ante forecast error and forecast revision interpretation

$$\text{forecast error}_t = \pi_{t+4} - \mathbb{F}_t \pi_{t+4}, \qquad \text{revision}_t = \mathbb{F}_t \pi_{t+4} - \mathbb{F}_{t-1} \pi_{t+4}$$



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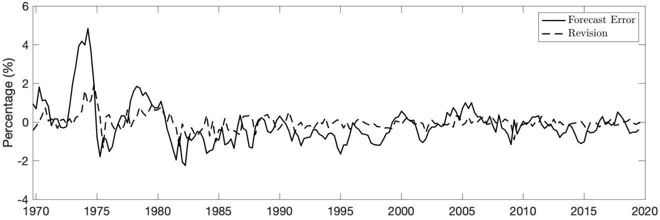
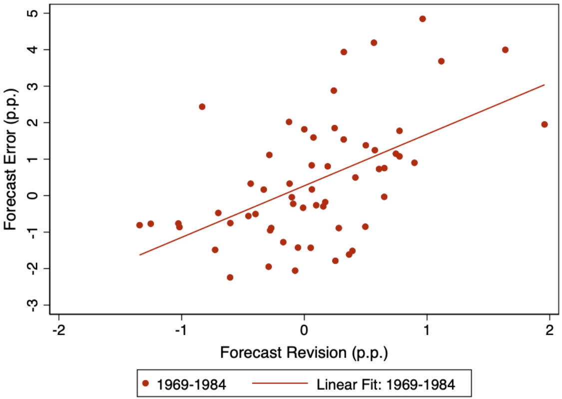


Underrevision behavior pre-1985...

Figure First-Vintage inflation and forecasts



Underrevision behavior vanished!

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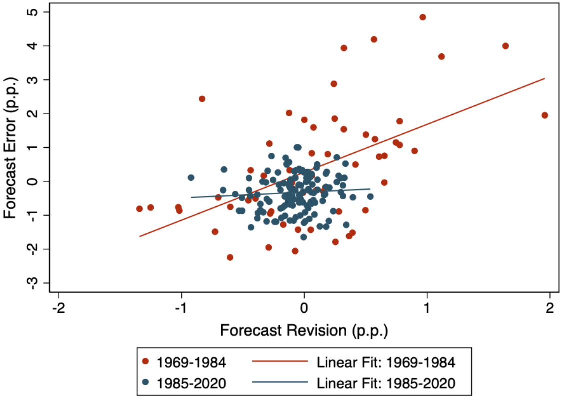

Communication Policy | Outliers (scatter plot) | Structural Break | Individual | Rolling Sample | Livingston | fe vs. fr individual

Disagreement | Structural Break (inflation level) | IRF Forecast Error | Disagreement IRF | Bai-Perron test (structural break) | Back to "Back to Data"

Evidence on β_{rev}

$$\text{forecast error}_t = \alpha_{\text{rev}} + \beta_{\text{rev}}\text{revision}_t + \beta_{\text{rev},*}\text{revision}_t \times \mathbb{1}_{\{t \geq t^*\}} + u_t$$

	Full Sample	1968:Q4-1984:Q4	1985:Q1-2020:Q1	Structural Break
Revision	1.230***	1.414***	0.169	1.501***
	(0.250)	(0.283)	(0.193)	(0.317)
Revision × $\mathbb{1}_{\{t \geq t^*\}}$				-1.111***
				(0.379)
Observations	197	58	139	197

Robust standard errors in parenthesis

Control: constant

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Back to "Evidence on Expectations" Back to "Underrevision Behavior has Vanished"

Individual Rolling Sample Livingston Disagreement Structural Break (inflation level) IRF Forecast Error Disagreement IRF Bai-Perron test (structural break)

Scatter Plot

Additional Evidence: Forecast Errors and Monetary Shocks

- Estimate IRFs of forecast error on Romer & Romer monetary shocks

$$\text{forecast error}_{t+h} = \beta_h \varepsilon_t + \gamma \mathbf{X}_t + u_t$$

  - $\mathbf{X}_t = \{4 \text{ lags of R\&R shocks}, 4 \text{ lags of FE}\}$
- Test for a change after 1985

$$\text{forecast error}_{t+h} = (\beta_h + \beta_{h*} \times \mathbb{1}_{\{t \geq t^*\}})\varepsilon_t + \gamma \mathbf{X}_t + u_t$$

- Results consistent with a fall in information frictions

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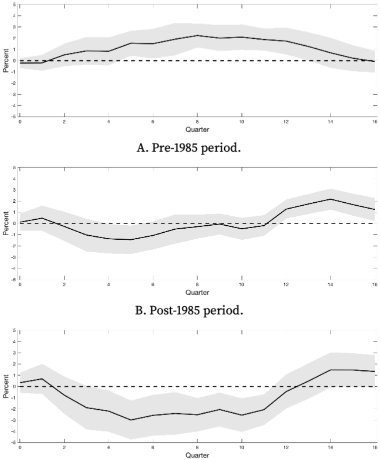
Figure IRFs of FE to Monetary Shocks



A. Pre-1985 period.

B. Post-1985 period.

C. Change.

Additional Evidence: Disagreement and Monetary Shocks

- *disagreement* at time t: cross-sectional standard deviation of forecasts at time t

$$disagreement_t = \sigma_i(\mathbb{F}_{it}\pi_{t+4,t})$$

- Estimate IRFs of forecast error on Romer & Romer monetary shocks, test for change after 1985

$$\text{disagreement}_{t+h} = (\beta_h + \beta_{h*} \times \mathbb{1}_{\{t \geq t^*\}})\varepsilon_t + \gamma \mathbf{X}_t + u_t$$

  - Sticky information: disagreement should increase after a monetary shock
  - Noisy information: disagreement should not react to monetary shocks
  - Full information: no reaction

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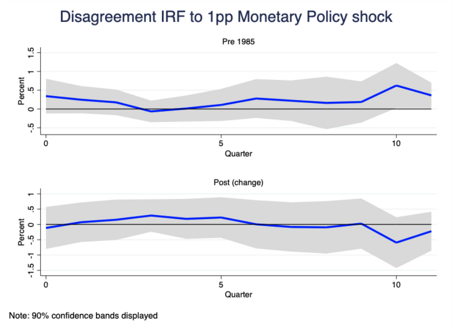

Additional Evidence: Livingston Survey

- Survey conducted semiannually, estimate the following structural-break variant

$$\pi_{t+2} - \mathbb{F}_t \pi_{t+2} = \alpha_{rev} + \beta_{rev}(\mathbb{F}_t \pi_{t+2} - \mathbb{F}_{t-2} \pi_{t+2}) + u_t$$

	(1) CG Regression	(2) Structural Break
Revision	0.380*	0.412**
	(0.202)	(0.204)
Revision $\times \mathbb{1}_{\{t \geq t^*\}}$		-0.880**
		(0.414)
Constant	-0.183*	-0.105
	(0.102)	(0.119)
Observations	146	146

HAC robust standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Back to “Underrevision Behavior has Vanished” Back to “Back to Data”

Theory

Model in a nutshell: NK + Noisy & Dispersed Information

- Theory consistent with underreaction

- New Keynesian + noisy information
  - households and central bank NK-standard
  - firms are subject to information frictions
  - signal extraction problem: observe imprecise signal on monetary shock Communication Policy

- Endogenous forecast underreaction: shrink forecast towards prior beliefs

- Translates into inflation persistence

Consumers are NK-standard

- Continuum of infinitely-lived, ex-ante identical households
- Consume a CES bundle of $j \in [0, 1]$ goods with elasticity ϵ
- Cost-minimization: demand function $C_{jt} = \left(\frac{P_{jt}}{P_t}\right)^{-\epsilon} C_t$ and price index $P_t \equiv \left(\int P_{jt}^{1-\epsilon} dj\right)^{\frac{1}{1-\epsilon}}$
- Households maximize $\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U(C_t, N_t)$ subject to budget constraint $C_t + B_t = R_{t-1} B_{t-1} + \frac{W_t}{P_t} N_t + \mathcal{T}_t$

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- Optimality conditions under CRRA preferences

$$c_t = -\frac{1}{\sigma}\mathbb{E}_t(i_t - \pi_{t+1}) + \mathbb{E}_t c_{t+1}, \qquad w_t - p_t = \sigma c_t + \varphi n_t$$

Central Bank is NK-standard

- Central bank sets nominal interest rates following a Taylor rule

$$i_t = \phi_\pi \pi_t + \phi_y \tilde{y}_t + v_t$$

- Reacts to excess inflation π_t and output gap $\tilde{y}_t = y_t - y_t^n$

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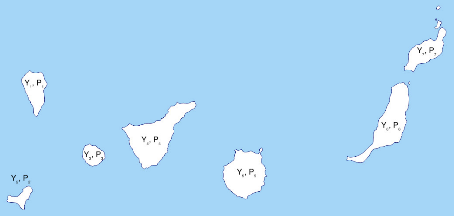
- Reacts to excess inflation π_t and output gap $\tilde{y}_t = y_t - y_t^n$
- Monetary shock v_t follows an AR(1) process

$$v_t = \rho v_{t-1} + \sigma_\varepsilon \varepsilon_t, \qquad \varepsilon_t \sim \mathcal{N}(0, 1)$$

- Key object: firms observe an imprecise signal of v_t Communication Policy

Firms: Island Model

- Island setting [Lucas (1972), Woodford (2001), Erceg & Levin (2003), Nimark (2008), Lorenzoni (2009), Angeletos & Huo (2021)]
- Know island conditions (prices, production)
- Imprecise idea of the aggregate archipielago conditions



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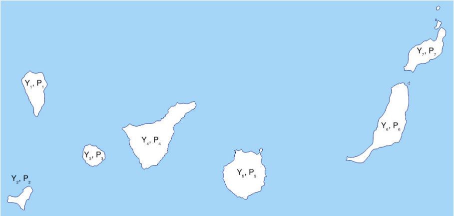

- Continuum of firms producing a differentiated intermediate good variety j
- Set price P_{jt} and face demand Y_{jt}
- Use technology $Y_{jt} = N_{jt}^{1-\alpha}$
- Nominal price rigidity: Calvo-lottery friction (at every period, each firm is able to reset price with probability $1 - \theta$)

Share of Re-setters, $1-\theta$

- Set price P_{jt}^* to maximize (real) profits while price remains effective

$$P_{jt}^* = \arg\max_{P_{jt}} \sum_{k=0}^{\infty} \theta^k \mathbb{E}_{jt} \left\{ \frac{\Lambda_{t,t+k}}{P_{t+k}} \left[P_{jt} Y_{j,t+k|t}(P_{jt}) - W_{t+k} N_{j,t+k|t}(P_{jt}) \right) \right] \right\}$$

$$\text{s.t. } Y_{j,t+k|t} = \left(\frac{P_{jt}}{P_{t+k}} \right)^{-\epsilon} C_{t+k}, \quad Y_{j,t+k|t} = N_{j,t+k|t}^{1-\alpha}$$

- $\mathbb{E}_{jt}(\cdot) :=$ firm j's expectation conditional on *its* information set at time t, stochastic discount factor $\Lambda_{t,t+k} = \beta^k \left(C_{t+k}/C_t \right)^{-\sigma}$

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- $\mathbb{E}_{jt}(\cdot) :=$ firm j's expectation conditional on *its* information set at time t, stochastic discount factor $\Lambda_{t,t+k} = \beta^k \left(C_{t+k}/C_t \right)^{-\sigma}$
- Recursive price-setting condition short derivation derivation

$$p_{jt}^* = (1-\beta\theta)\mathbb{E}_{jt} p_t + \frac{\kappa\theta}{1-\theta}\mathbb{E}_{jt}\tilde{y}_t + \beta\theta\mathbb{E}_{jt} p_{j,t+1}^*, \qquad \kappa \equiv \frac{(1-\theta)(1-\beta\theta)}{\theta} \frac{1-\alpha}{1-\alpha+\alpha\epsilon}$$

- Firm j needs to infer others' decisions: $p_t = (1-\theta)\int_{\mathcal{I}_f} p_{jt}^* \, dj + \theta p_{t-1} = (1-\theta)\sum_{k=0}^{\infty} \theta^k p_{t-k}^*$

Information Structure

- Each firm j observes noisy signal x_{jt} on the monetary shock v_t, Communication Policy

$$x_{jt} = v_t + \sigma_u u_{jt}, \quad \text{with } u_{jt} \sim \mathcal{N}(0, 1)$$

- Information on state v_t, aggregate demand $\tilde{y}_t(v_t)$ and others' actions $p_t(v_t)$
- Information is imprecise, firms do not fully react to x_{jt}

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- Information is imprecise, firms do not fully react to x_{jt}
- NK framework linear: bayesian updating (Kalman/Wiener-Hopf filter) Solving Expectations

$$\mathbb{E}_{jt}\mathbf{z}_t = \Lambda(\sigma_u)\,\mathbb{E}_{j,t-1}\mathbf{z}_{t-1} + K(\sigma_u)\,x_{jt}, \qquad \mathbf{z}_t = \begin{bmatrix} v_t & p_t & \tilde{y}_t \end{bmatrix}^{\mathsf{T}}$$

- Forecasts react sluggishly if $\Lambda \neq \mathbf{0}$!
- Noisy information generates additional persistence

Recap: In equilibrium...

- DIS curve

$$\tilde{y}_t = -\frac{1}{\sigma}(i_t - \mathbb{E}_t \pi_{t+1}) + \mathbb{E}_t \tilde{y}_{t+1}$$

- Taylor rule

$$i_t = \phi_\pi \pi_t + \phi_y \tilde{y}_t + v_t, \qquad v_t = \rho v_{t-1} + \sigma_\varepsilon \varepsilon_t, \qquad \varepsilon_t \sim \mathcal{N}(0,1)$$

- Individual price-setting:

$$p^*_{jt} = (1-\beta\theta)\mathbb{E}_{jt} p_t + \frac{\kappa\theta}{1-\theta}\mathbb{E}_{jt}\tilde{y}_t + \beta\theta\mathbb{E}_{jt} p^*_{j,t+1}$$

$$\mathbb{E}_{jt}\mathbf{z}_t = \Lambda \mathbb{E}_{j,t-1} z_{t-1} + K x_{jt}, \qquad x_{jt} = v_t + \sigma_u u_{jt}, \qquad \text{with } u_{jt} \sim \mathcal{N}(0,1)$$

Solving Expectations

Inflation Dynamics

Benchmark ($\sigma_u = 0$)

- Reduced-form: Derivation

$$\pi_t = \psi_\pi v_t$$

$$\psi_\pi = \frac{-\kappa\sigma_\varepsilon}{(1-\rho\beta)[\sigma(1-\rho)+\phi_y]+\kappa(\phi_\pi-\rho)}$$

- Structural-form:

$$\pi_t = \kappa\tilde{y}_t + \beta\mathbb{E}_t\pi_{t+1}$$

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More on δ, ξ and χ

Noisy Information

- Reduced-form: Proposition

$$\pi_t = \delta\pi_{t-1} + \xi\pi_{t-2} + \psi_\pi\chi\Delta v_t$$

$\delta(\sigma_u, \Phi)$, $\xi(\sigma_u, \Phi)$and $\chi(\sigma_u, \Phi)$are scalars endogenous to information frictions σ_u

- Structural-form: Proposition

$$\pi_t = \omega_1\pi_{t-1} + \kappa\tilde{y}_t + \omega_2\beta\mathbb{E}_t\pi_{t+1}$$

wedge Phillips curve produces identical dynamics for certain values of $(\omega_1, \omega_2) \in [0, 1]^2$

Results

Policy Experiments

- How does the change in information frictions (σ_u)/sluggishness (β_{rev}) affect (1) inflation persistence, and (2) the dynamics of the Phillips curve?

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Table Model parameters.

Parameter	Description	Value	Source/Target
σ	IES	1	Gali (2015)
β	Discount factor	0.99	Gali (2015)
φ	Inverse Frisch elasticity	5	Gali (2015)
$1-\alpha$	Labor share	0.75	Gali (2015)
ϵ	CES between varieties	9	Gali (2015)
θ	Calvo lottery	0.89	Hazell et al. (2022)
ρ	Monetary shock persistence	0.5	Gali (2015)
ϕ_π	Inflation coefficient Taylor rule	1.5	Gali (2015)
ϕ_y	Output gap coefficient Taylor rule	0.125	Gali (2015)
σ_ε	Volatility monetary shock	1	Gali (2015)

Results: Persistence

First Order Autocorrelation

- Inflation first-order autocorrelation ρ_1

$$\rho_1 = \frac{1}{2}\frac{(1+\rho)\delta - (1-\rho)(1+\xi)}{1-\rho\xi}$$

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- Increasing in σ_u

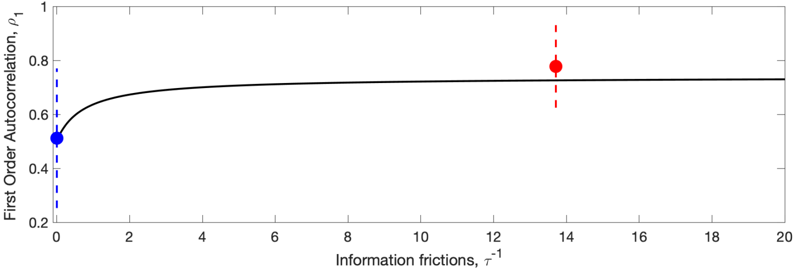

Figure First-order autocorrelation ρ_1 and information frictions $\tau^{-1} = \sigma_u^2/\sigma_\varepsilon^2$

More on δ, ξ and χ | Role of θ

Information Frictions Regression

- Forecast underrevision

$$\beta_{\text{rev}} = \frac{\mathbb{C}(\text{forecast error}_t, \text{revision}_t)}{\mathbb{V}(\text{revision}_t)} = f(\sigma_u, \Phi)$$

- Increasing in σ_u Proposition

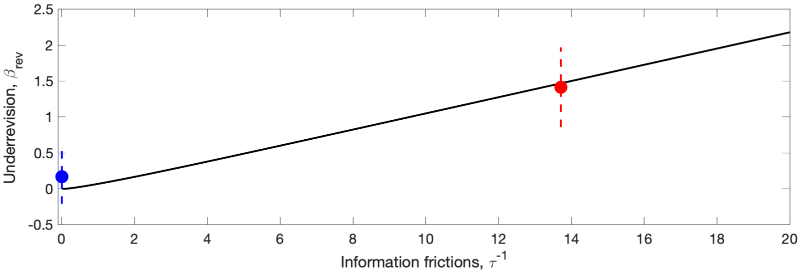

Figure β_{rev} and information frictions $\tau^{-1} = \sigma_u^2/\sigma_\varepsilon^2$

First-order Autocorrelation and Underrevision

- Inflation first-order autocorrelation $\rho_1(\sigma_u, \Phi)$ is increasing in β_{rev}

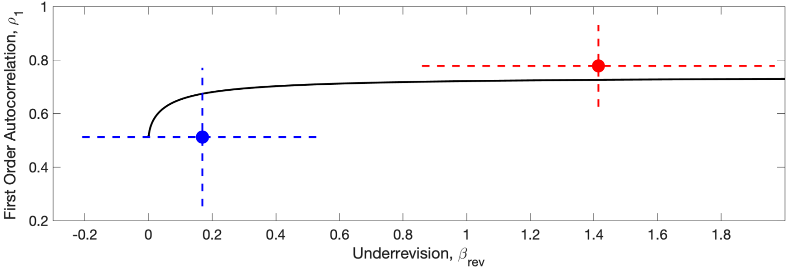

Figure Autocorrelation ρ_1 and β_{rev}

Expectations can explain inflation persistence fall!

- Calibrate signal noise σ_u to match empirical evidence on $\beta_{\text{rev}}(\sigma_u, \Phi)$

Pre-1985:

$\beta_{\text{rev}}(\sigma_u, \Phi) = 1.501$
$\sigma_u = 2.501$

Expectations can explain inflation persistence fall!

- Calibrate signal noise σ_u to match empirical evidence on $\beta_{\text{rev}}(\sigma_u, \Phi)$

Pre-1985:

$\beta_{\text{rev}}(\sigma_u, \Phi) = 1.501$
$\sigma_u = 2.501$

Post 1985:

$\beta_{\text{rev}}(\sigma_u, \Phi) = 0$
$\sigma_u = 0$

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Post 1985:

$\beta_{rev}(\sigma_u, \Phi) = 0$
$\sigma_u = 0$

Table First Order Autocorrelation ρ_1, Data vs. Model

	1968:Q4-1984:Q4	1985:Q1-2020:Q1
Data	0.757	0.497
Model	0.716	0.500

Scatter Plot | Structural Break | Unit Root

Summary

- Inflation persistence fell since mid 1980s
- Hard to understand in NK setting
- Document a new empirical result on information frictions
- A model consistent with this finding explains around 90% of its fall

Results: Phillips curve

Exercise 1: Change in Phillips curve slope

- Noisy information pre-1985: Proposition

$$\pi_t = \omega_1 \pi_{t-1} + \kappa \tilde{y}_t + \omega_2 \beta \mathbb{E}_t \pi_{t+1}$$

  - wedge Phillips curve produces identical dynamics for certain values of $(\omega_1, \omega_2) \in [0, 1]^2$
  - $\omega_1 \in (0, 1)$: anchoring
  - $\omega_2 \in (0, 1)$: myopia

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Simulated Data

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  - $\omega_1 = 0, \omega_2 = 1$

Simulated Data

Table Regression table

	Wedge Phillips Curve
π_{t-1}	0.720***
	(0.131)
$\pi_{t-1} \times \mathbb{1}_{\{t \geq t^*\}}$	-0.597**
	(0.232)
$\tilde{y}_t$	0.0566
	(0.0488)
$\tilde{y}_t \times \mathbb{1}_{\{t \geq t^*\}}$	-0.0143
	(0.0781)
π_{t+1}	0.273**
	(0.129)
$\pi_{t+1} \times \mathbb{1}_{\{t \geq t^*\}}$	0.643***
	(0.244)
Observations	202

HAC robust standard errors in parentheses
Instrument set: four lags of effective federal funds rate, CBO Output gap, GDP Deflator growth rate, Commodity inflation, M2 growth rate, spread between long and short-run interest rate and labor share.

Exercise 2: Imperfect Expectations

- Agnostic stance on belief formation
- Aggregate Phillips curve

$$\pi_t = \kappa\theta \sum_{k=0}^{\infty} (\beta\theta)^k \overline{\mathbb{E}}_t^f \tilde{y}_{t+k} + (1-\theta) \sum_{k=0}^{\infty} (\beta\theta)^k \overline{\mathbb{E}}_t^f \pi_{t+k} + \left(\overline{\mathbb{E}}_t^f p_{t-1} - p_{t-1} \right)$$

- Average firm's expectation $\overline{\mathbb{E}}_t^f(\cdot) = \int \mathbb{E}_{jt}(\cdot)\, dj$
- Have data on $\overline{\mathbb{E}}_t^f \tilde{y}_{t+k}$ and $\overline{\mathbb{E}}_t^f \pi_{t+k}$!
- Test for a break in κ *controlling for* imperfect expectations
- Set $\beta = 0.99$ and $\theta = 0.89$, truncate sums at $k = 4$:

$$\pi_t = \kappa \tilde{y}_t^e + (1-\theta)\pi_t^e + \eta_t, \quad \eta_t = \left(\overline{\mathbb{E}}_t^f p_{t-1} - p_{t-1} \right) + \text{truncation error}$$

Table Estimates of regression.

	Unemployment		Real GDP Growth	
	Full Sample	Structural Break	Full Sample	Structural Break
$\tilde{y}_t^e$	-0.00519***	-0.0231***	-0.0128	0.0245
	(0.00171)	(0.00679)	(0.0133)	(0.0224)
$\tilde{y}_t^e \times \mathbb{1}_{\{t \geq t^*\}}$		0.0133***		-0.0403**
		(0.00493)		(0.0201)
π_t^e	0.282***	0.342***	0.258***	0.251***
	(0.0109)	(0.0261)	(0.00999)	(0.0108)
Observations	199	199	199	199

HAC (1 lag) robust standard errors in parentheses. Instrument set: four lags of forecasts of annual real GDP growth and annual GDP Deflator growth.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

- Modest fall in κ, consistent with Hazell et al. (2022)

Conclusion

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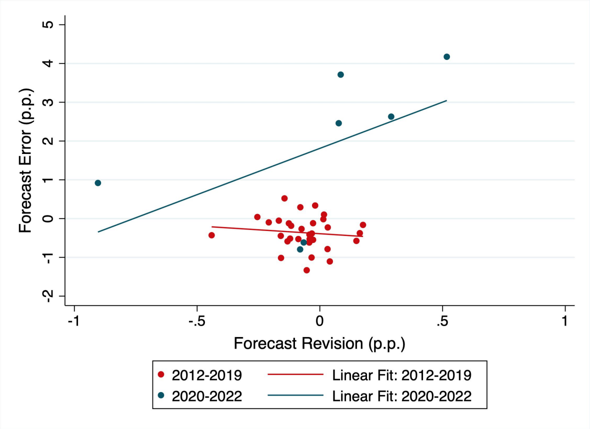
  - modest flattening after controlling for imperfect expectations
- **Will the 2020-22 inflation be persistent?** Fed should pay attention to forecast underrevision!

Will the 2020-22 inflation be persistent? (speculative) yes...



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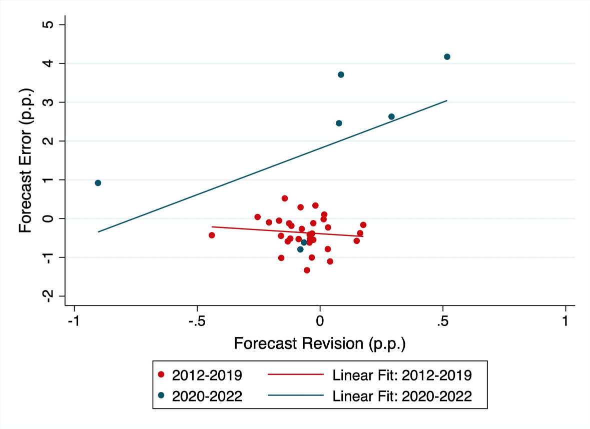
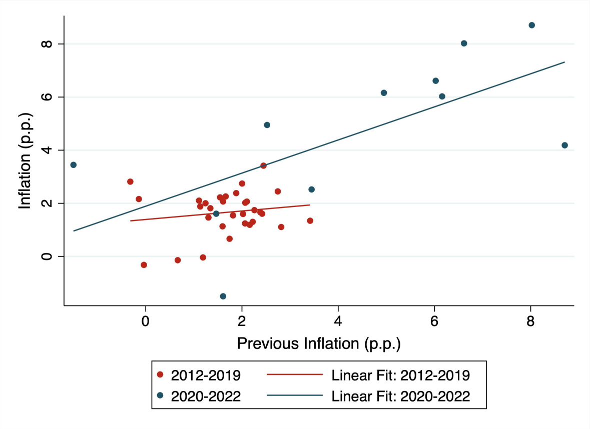




Thank you!

Structural Break Test

1985

Table Structural break

	F-Statistic	p-value
Error vs. Revision		
1980:Q3	11.25	0.00
1985:Q1	7.96	0.01
Inflation Persistence		
1991:Q1	32.03	0.00
1985:Q1	28.22	0.00

Back to "What I Do" Back to "Underrevision Behavior has Vanished" Back to "Back to Data"

Benchmark NK

Benchmark

- Dynamic IS curve

$$\tilde{y}_t = -\frac{1}{\sigma}\left(i_t - \mathbb{E}_t \pi_{t+1}\right) + \mathbb{E}_t \tilde{y}_{t+1} \tag{1}$$

- NK Phillips curve

$$\pi_t = \kappa \tilde{y}_t + \beta \mathbb{E}_t \pi_{t+1} \tag{2}$$

- Monetary policy rule

$$i_t = \phi_\pi \pi_t + \phi_y y_t + v_t, \qquad v_t = \rho v_{t-1} + \varepsilon_t^v, \qquad \varepsilon_t^v \sim \mathcal{N}(0, \sigma_\varepsilon^2) \tag{3}$$

- Introducing (3) into (1), we can write (1)-(2) as a system of two first-order forward-looking stochastic equations
- Inflation dynamics are given by

$$\begin{aligned} \pi_t &= -\psi_\pi v_t \\ &= \rho \pi_{t-1} - \psi_\pi \varepsilon_t^v \end{aligned}$$

Measuring the Shock Process

- Problem: v_t is unobservable, but we have estimates on monetary policy shocks ε_t^v from Romer and Romer (2004), updated until 2007 by Wieland & Yang (2020)
- Solution: indirect estimation on ρ
- Using the AR(1) property of the v_t shock process, we can write the Taylor rule as

$$i_t = \rho i_{t-1} + \left(\phi_\pi \pi_t + \phi_y y_t\right) - \rho\left(\phi_\pi \pi_{t-1} + \phi_y y_{t-1}\right) + \varepsilon_t^v \tag{4}$$

- An estimate of the first autoregressive coefficient identifies monetary policy persistence

Persistence

$$i_t = \rho i_{t-1} + \left(\phi_\pi \pi_t + \phi_y y_t\right) - \rho\left(\phi_\pi \pi_{t-1} + \phi_y y_{t-1}\right) + \varepsilon_t^v \qquad (5)$$

- Structural break analysis
- Estimate using unrestricted GMM

$$i_t = \alpha_i + \alpha_{i,*}\mathbb{1}_{\{t \geq t^*\}} + \rho_i i_{t-1} + \rho_{i,*} i_{t-1}\mathbb{1}_{\{t \geq t^*\}} + \gamma \mathbf{X}_{t,t-1} + u_t$$

- Notice: ρ also interacts with lagged inflation and output gap in (5)
- Estimate structural break in (5), restricted GMM

$$i_t = \alpha_i + \alpha_{i,*}\mathbb{1}_{\{t\geq t^*\}} + \rho_i i_{t-1} + \rho_{i,*} i_{t-1}\mathbb{1}_{\{t\geq t^*\}} + \gamma \mathbf{X}_{t,t-1} + u_t$$

	(1)	(2)	(3)	(4)
	Unrestricted GMM		Restricted GMM	
i_{t-1}	0.941***	0.939***	0.972***	0.931***
	(0.0184)	(0.0448)	(0.0119)	(0.0365)
$i_{t-1} \times \mathbb{1}_{\{t\geq t^*\}}$		−0.00261		−0.0537
		(0.0591)		(0.0632)
Constant	0.122	0.305	0.0770*	0.851**
	(0.118)	(0.473)	(0.0467)	(0.373)
Constant$\times \mathbb{1}_{\{t\geq t^*\}}$		−0.123		−0.813
		(0.436)		(0.559)
Observations	203	203	203	203

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

- Benchmark NK model cannot explain the fall in inflation persistence
- Inherited from monetary shock process, did not change

Back to “Inflation Persistence: the First Puzzle”

Technology and Cost-push Shocks

- Extend the basic framework to demand (technology) and supply (cost-push) shocks, a_t and u_t
- Demand side:

$$\tilde{y}_t = -\frac{1}{\sigma}(i_t - \mathbb{E}_t \pi_{t+1}) - (1 - \rho_a)\psi_{ya} a_t + \mathbb{E}_t \tilde{y}_{t+1}$$

- Supply side:

$$\pi_t = \beta \mathbb{E}_t \pi_{t+1} + \kappa \tilde{y}_t + u_t$$

- a_t and u_t follow AR(1) processes with persistence ρ_a and ρ_u
- Inflation dynamics follow

$$\pi_t = \psi_{\pi v} v_t + \psi_{\pi a} a_t + \psi_{\pi u} u_t$$

- First-order autocorrelation coefficient ρ_1 depends critically on the ρ_x's

$$\rho_1 = \frac{\rho \frac{\psi_{\pi v}^2 \sigma_{\varepsilon v}^2}{1-\rho_v^2} + \rho_a \frac{\psi_{\pi a}^2 \sigma_{\varepsilon a}^2}{1-\rho_a^2} + \rho_u \frac{\psi_{\pi u}^2 \sigma_{\varepsilon u}^2}{1-\rho_u^2}}{\frac{\psi_{\pi v}^2 \sigma_{\varepsilon v}^2}{1-\rho_v^2} + \frac{\psi_{\pi a}^2 \sigma_{\varepsilon a}^2}{1-\rho_a^2} + \frac{\psi_{\pi u}^2 \sigma_{\varepsilon u}^2}{1-\rho_u^2}}$$

- We already documented no change in ρ
- Find evidence on a structural break in ρ_a and ρ_u

Technology Shock

- Use three data series used in the literature
- Fernald (2014) estimates directly (log) technology a_t
- Francis et al. (2014) and Justiniano et al. (2011) estimate the technology shock ε_t^a
  - Indirect estimation of ρ_a using the natural real interest rate process
  - Natural real rate $r_t^n = -\sigma\psi_{ya}(1-\rho_a)a_t$,

$$r_t^n = \rho_a r_{t-1}^n - \sigma\psi_{ya}(1-\rho_a)\varepsilon_t^a$$

  - Fed estimate of natural rate, produced by Holston (2017)

	(1) Technology	(2) SB	(3) Natural rate	(4) SB	(5) Natural rate	(6) SB
(Log) TFP_{t-1}	0.998***	0.990***				
	(0.00454)	(0.00860)				
(Log) TFP_{t-1} change		0.00323				
		(0.00339)				
Natural rate_{t-1}			0.951***	0.945***	0.963***	0.957***
			(0.0317)	(0.0327)	(0.0367)	(0.0404)
Technology shock in Francis et al. (2014)			0.0511**	0.0514**		
			(0.0234)	(0.0237)		
Natural rate_{t-1} change				−0.0106		−0.00863
				(0.0129)		(0.0141)
Technology shock in Justiniano et al. (2011)					0.0191	0.0195
					(0.0278)	(0.0280)
Constant	0.00360	0.00743*	0.128	0.162	0.0878	0.123
	(0.00327)	(0.00445)	(0.0968)	(0.109)	(0.114)	(0.140)
Observations	186	186	163	163	160	160

Robust standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Back to "Inflation Persistence: the First Puzzle"

Cost-Push Shock

- Nekarda & Ramey (2010) estimate the structural time-varying price-cost markup
- Two different measures of the cost-push shock
  - Assume Cobb-Douglas production function
  - Assume CES production function, estimating labor-augmented technology using long-run restrictions as in Gali (1999)

	(1) Cobb-Douglas	(2) SB	(3) CES	(4) SB
Markup_{t-1}	0.945***	0.938***	0.963***	0.947***
	(0.0246)	(0.0305)	(0.0234)	(0.0252)
Markup_{t-1} change		0.00187		0.00472
		(0.00436)		(0.00419)
Constant	0.0280**	0.0307**	0.0189	0.0252**
	(0.0125)	(0.0146)	(0.0117)	(0.0120)
Observations	195	195	195	195

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Back to "Inflation Persistence: the First Puzzle"

Optimal Monetary Policy under Discretion

- Pre-1985, inflation dynamics

$$\pi_t = \psi_{\pi v} v_t + \psi_{\pi a} a_t + \psi_{\pi u} u_t$$

- Post-1985 with optimal policy, CB minimizes welfare losses

$$\mathbb{E}_0 \sum_{k=0}^{\infty} \beta^t \left(\pi_t^2 + \frac{\kappa}{\epsilon} x_t^2 \right)$$

$x_t \equiv$ welfare-relevant output gap, subject to Phillips curve

$$\pi_t = \kappa x_t + \xi_t,$$

$\xi_t \equiv \beta \mathbb{E}_t \pi_{t+1} + u_t$ non-policy shock

- Inflation dynamics

$$\pi_t = \rho_u \pi_{t-1} + \psi_d \varepsilon_t^u$$

- Persistence inherited from cost-push shock
- No significant change in persistence: pre-1985 persistence around 0.95, post around 0.96

Optimal Monetary Policy under Commitment

- Pre-1985 period inflation dynamics

$$\pi_t = \psi_{\pi v} v_t + \psi_{\pi a} a_t + \psi_{\pi u} u_t$$

- Post-1985 with optimal policy, CB minimizes welfare losses

$$\mathbb{E}_0 \sum_{k=0}^{\infty} \beta^t \left(\pi_t^2 + \frac{\kappa}{\epsilon} x_t^2 \right)$$

$x_t \equiv$ welfare-relevant output gap, subject to Phillips curve

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

- Inflation dynamics

$$\pi_t = \rho_c \pi_{t-1} + \psi_c \Delta u_t$$

- ρ_c depends on deep parameters
- Commitment requires change ϕ_π from 1 to 6.5, inconsistent with empirical evidence

Price Indexation

- Generate intrinsic persistence through price indexation
- Restricted firms reset price indexed to past inflation: $p_{it} = p_{i,t-1} + \omega\pi_{t-1}$
- Phillips curve modified to

$$\Delta_t = \kappa\tilde{y}_t + \beta\mathbb{E}_t\Delta_{t+1},$$

  where $\Delta_t := \pi_t - \omega\pi_{t-1}$
- Inflation dynamics

$$\pi_t = \rho_\omega\pi_{t-1} + \psi_\omega v_t$$

Back to "Inflation Persistence: the First Puzzle"

Trend Inflation

- Ascari & Sbordone (2014), Stock & Watson (2007): fall in trend inflation from 4% to 2%
- Log-linearize around positive trend inflation
- Phillips curve now a system of three equations

$$\pi_t = \Xi_1 \psi_t + \Xi_2 y_t + \Xi_3 \mathbb{E}_t \psi_{t+1} + \Xi_4 \mathbb{E}_t \pi_{t+1}$$
$$\psi_t = \Gamma_1 s_t + \Gamma_2 y_t + \Gamma_3 \mathbb{E}_t \psi_{t+1} + \Gamma_4 \mathbb{E}_t \pi_{t+1}$$
$$s_t = \Lambda_1 \pi_t + \Lambda_2 s_{t-1}$$

- $\Lambda_2(\overline{\pi})$ increasing in $\overline{\pi}$
- Inflation dynamics

$$\pi_t = \rho_{\overline{\pi}} \pi_{t-1} + \psi_{\overline{\pi}} v_t + \xi_t,$$

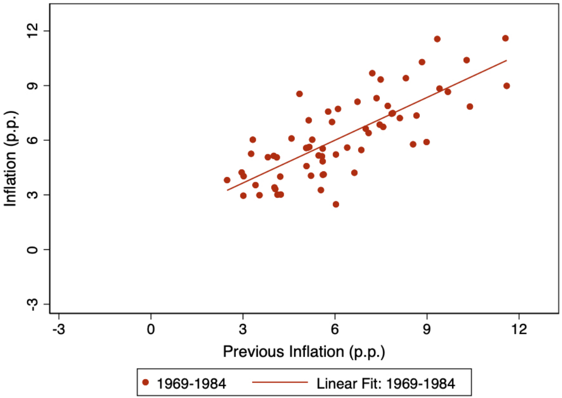
where ξ_t MA(∞) process and $\rho_{\overline{\pi}}$ increasing in $\overline{\pi}$

Back to "Inflation Persistence: the First Puzzle"

Inflation Persistence

Inflation Persistence, Scatter Plot

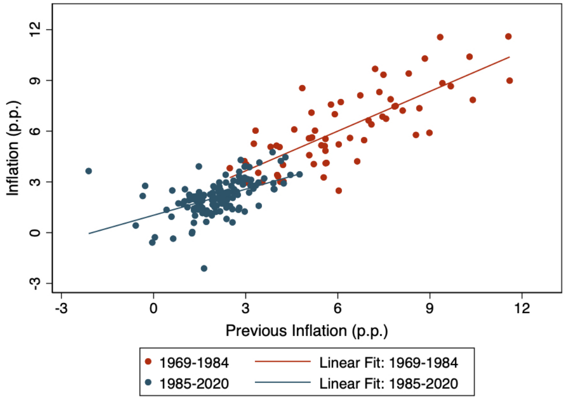
Figure Inflation Persistence, 1969-1984



Back to “Inflation Persistence: the First Puzzle”
Back to “Expectations can Explain...”

Inflation Persistence, Scatter Plot

Figure Inflation Persistence, 1969-1984 and 1985-2020



Back to "Inflation Persistence: the First Puzzle"   Back to "Expectations can Explain..."

Structural Break

Table $\pi_t = \alpha_\pi + \alpha_{\pi,*}\mathbb{1}_{\{t \geq t^*\}} + (\rho_\pi + \rho_{\pi,*}\mathbb{1}_{\{t \geq t^*\}})\pi_{t-1} + \varepsilon_t^\pi$

	All Sample	Structural Break
π_{t-1}	0.880***	0.785***
	(0.0466)	(0.0755)
$\pi_{t-1} \times \mathbb{1}_{\{t \geq t^*\}}$		-0.287**
		(0.144)
Constant	0.400**	1.320***
	(0.166)	(0.471)
Constant$\times \mathbb{1}_{\{t \geq t^*\}}$		-0.263
		(0.543)
Observations	206	206

HAC robust standard errors in parenthesis,

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Back to "Inflation Persistence: the First Puzzle" Back to "Expectations can Explain..."

Unit Root Test

- Cross-sample unit root analysis
  - Augmented Dickie-Fuller
  - Phillips-Perron
- Null hypothesis (unit root) cannot be rejected in the pre-1985 sample
- Strong rejection of the null in the post-1985 sample

p-values, null = series has unit root		
1969-2020		
Variable	ADF	Phillips-Perron
GDP Deflator	0.23	0.02
CPI	0.11	0.00
PCE	0.16	0.00
1969-1985		
Variable	ADF	Phillips-Perron
GDP Deflator	0.15	0.07
CPI	0.17	0.09
PCE	0.055	0.09
1985-2020		
Variable	ADF	Phillips-Perron
GDP Deflator	0.07	0.00
CPI	0.00	0.00
PCE	0.01	0.00

Back to "Inflation Persistence: the First Puzzle"   Back to "Expectations can Explain..."

Literature Review on Persistence

- Barsky (1987): historical analysis (1839-1979) documenting time-varying persistence
- Pivetta & Reis (2007): within decade variation in persistence
- Benati (2008): international analysis, inflation targeting reduces inflation persistence
- Cogley & Sbordone (2008): inflation gap persistence falls after 1983
- Cogley, Primiceri & Sargent (2010): inflation gap persistence fell after the Volcker Disinflation (1980)
- Fuhrer (2010): inflation persistence fell since 1985
- Goldstein & Gorodnichenko (2020): forecast-*implied* persistence fell gradually since 1968

Table First Order Autocorrelation, Inflation (Q-to-Q).

	1968:Q4–1984:Q4	1985:Q1–2020:Q1
GDP Deflator	0.7572	0.4968
CPI	0.7856	0.2898
PCE	0.8047	0.4086

Back to "Inflation Persistence: the First Puzzle"

Forecast Underrevision

Interpretation

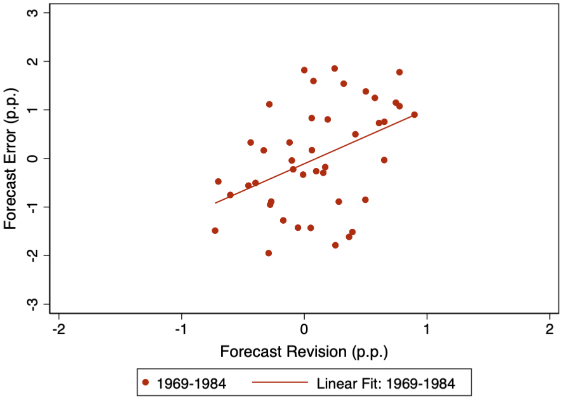
$$\text{forecast error}_t = \beta_{\text{rev}}\ \text{revision}_t + e_t$$

- Econometrician does not know what exactly happened between $t-1$ and t
- Can observe the forecast revision
- Suppose $\text{revision}_t > 0$
- $\beta_{\text{rev}} > 0$ implies that $\text{forecast error}_t > 0$
- $\pi_{t+4} - \mathbb{F}_t \pi_{t+4} > 0$

Back to "What I Find" Back to "Evidence on Expectations"

Outliers

Figure First-Vintage inflation and forecasts



Back to "Underrevision Behavior has Vanished"

Outliers

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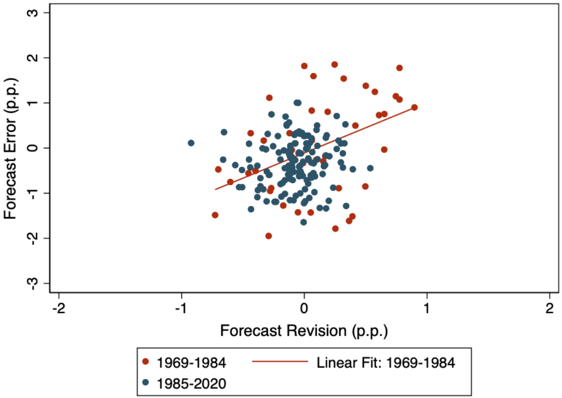
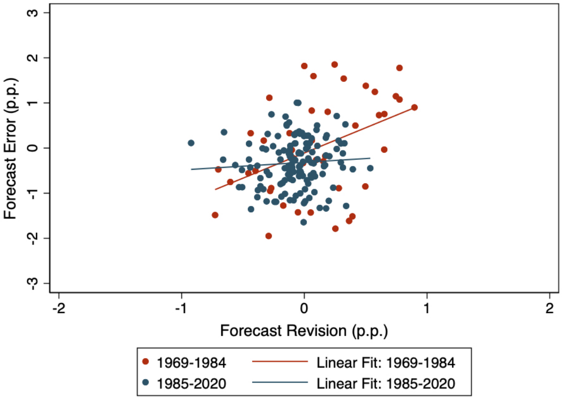


Back to "Underrevision Behavior has Vanished"

Outliers

Figure First-Vintage inflation and forecasts



Back to “Underrevision Behavior has Vanished”

Structural Break

Table forecast error$_t = \alpha + (\beta_{rev} + \beta_{rev,*} \times \mathbb{1}_{\{t \geq t^*\}})$ revision$_t + \epsilon_t^{rev}$

	Full Sample	1968:Q4-1984:Q4	1985:Q1-2020:Q1	Structural Break	
Revision	1.230***	1.414***	0.169	1.501***	1.414***
	(0.250)	(0.283)	(0.193)	(0.317)	(0.281)
Revision $\times \mathbb{1}_{\{t \geq t^*\}}$				-1.111***	-1.245***
				(0.379)	(0.341)
Constant	-0.0875	0.271	-0.317***	-0.135*	0.271
	(0.0696)	(0.185)	(0.0478)	(0.0690)	(0.184)
Constant $\times \mathbb{1}_{\{t \geq t^*\}}$					-0.587***
					(0.190)
Observations	197	58	139	197	197

Robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Back

Table forecast error$_t = \alpha + (\beta_{rev} + \beta_{rev,*} \times \mathbb{1}_{\{t \geq t^*\}})$ revision$_t + (\gamma + \gamma_* \times \mathbb{1}_{\{t \geq t^*\}})\pi_{t-1,t-5} + \epsilon_t^{rev}$

	(1) CG Regression	(2) Structural Break	(3) Structural Break
Revision	1.220***	1.489***	1.476***
	(0.248)	(0.316)	(0.296)
Revision × $\mathbb{1}_{\{t \geq t^*\}}$		-1.114***	-1.232***
		(0.376)	(0.355)
$\pi_{t-1,t-5}$	0.00819	0.0103	-0.0482
	(0.0340)	(0.0350)	(0.0352)
$\pi_{t-1,t-5} \times \mathbb{1}_{\{t \geq t^*\}}$			-0.253***
			(0.0585)
Observations	197	197	197

Robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Back to "Underrevision Behavior has Vanished" Back to "Back to Data"

Individual

- Kohlhas & Walther (2021): correct for unbalancedness, number of forecasters

$$\text{forecast error}_{jt} = \pi_{t+4} - \mathbb{F}_{jt}\pi_{t+4}$$
$$\text{revision}_{t} = \mathbb{F}_{t}\pi_{t+4} - \mathbb{F}_{t-1}\pi_{t+4}$$

- Regress

$$\text{forecast error}_{jt} = \beta_{\text{rev,ind}}\ \text{revision}_{t} + u_{jt}$$

Table forecast $\text{error}_{jt} = \alpha_{\text{ind}} + \beta_{\text{rev,ind}}\ \text{revision}_t + u_{jt}$

	(1) All Sample	(2) 1968:IV-1984:IV	(3) 1985:I-2020:I	(4) Structural Break	(5)
revision	1.703***	1.131***	-0.0854	1.850***	1.131***
	(0.153)	(0.200)	(0.138)	(0.188)	(0.199)
revision$\times \mathbb{1}_{\{t \geq t^*\}}$				-0.833***	-1.216***
				(0.264)	(0.243)
Observations	6688	2294	4394	6688	6688

Robust standard errors in parentheses

Constant included

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Back to "Evidence on Expectations" Back to "Underrevision Behavior has Vanished" Back to "Back to Data"

Table forecast $\text{error}_{jt} = \alpha_{\text{ind}} + \beta_{\text{rev,ind}} \text{ revision}_t + u_{jt}$

	(1)	(2)	(3)	(4)	(5)
	All Sample	1968:IV-1984:IV	1985:I-2020:I	Structural Break	
revision	1.703***	1.131***	-0.0854	1.850***	1.131***
	(0.153)	(0.200)	(0.138)	(0.188)	(0.199)
revision $\times \mathbb{1}_{\{t \geq t^*\}}$				-0.833***	-1.216***
				(0.264)	(0.243)
Constant	-0.0392**	0.438***	-0.329***	-0.0719***	0.438***
	(0.0183)	(0.0554)	(0.0138)	(0.0213)	(0.0554)
Constant $\times \mathbb{1}_{\{t \geq t^*\}}$					-0.767***
					(0.0571)
Observations	6688	2294	4394	6688	6688

Robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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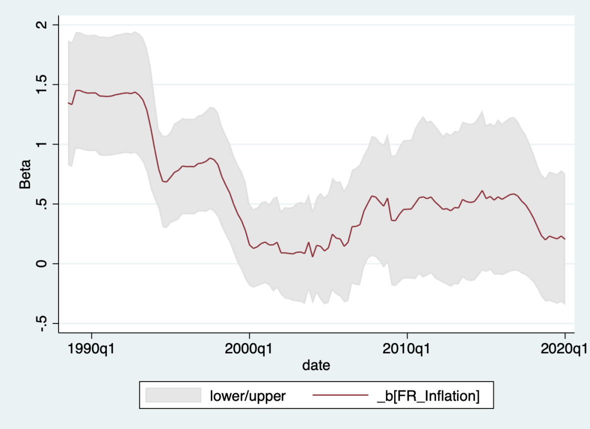
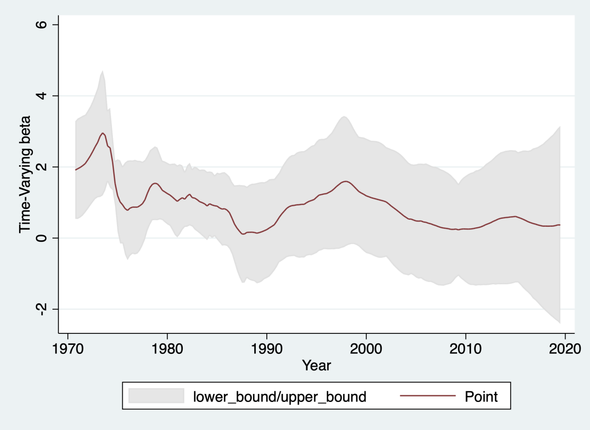
Rolling Sample



Back to “Underrevision Behavior has Vanished”
Back to “Back to Data”

Time-Varying Parameter Regression

$$\pi_{t+4} - \mathbb{E}_t \pi_{t+4} = \beta_t (\mathbb{E}_t \pi_{t+4} - \mathbb{E}_{t-1} \pi_{t+4}) + u_t$$



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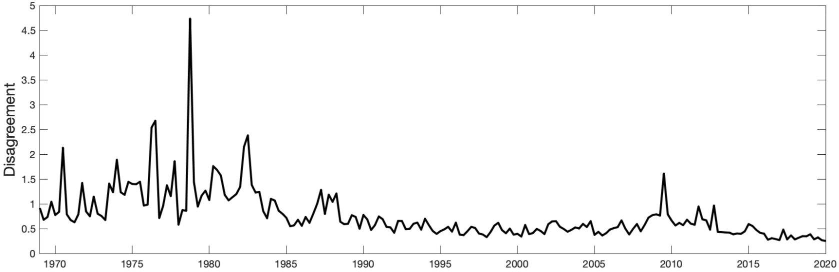
Disagreement

- Time series of "disagreement"
- Define *disagreement* at time t as the cross-sectional standard deviation of forecasts at time t

$$disagreement_t = \sigma_i(\mathbb{F}_{it}\pi_{t+4})$$

- Disagreement fell around the mid-80s



Disagreement

- Concern: correlated with inflation level
- Show that for forecasters the inflation level is irrelevant
  - Underlying AR(p) inflation dynamics: individual

$$\mathbb{F}_{it}\pi_{t+3} = \rho_1 \mathbb{F}_{it}\pi_{t+2} + \rho_2 \mathbb{F}_{it}\pi_{t+1} + \rho_3 \mathbb{F}_{it}\pi_t + \gamma \pi_{t-1,t-5} + u_t$$

  - Underlying AR(p) inflation dynamics: average

$$\overline{\mathbb{F}}_t\pi_{t+3} = \rho_1 \overline{\mathbb{F}}_t\pi_{t+2} + \rho_2 \overline{\mathbb{F}}_t\pi_{t+1} + \rho_3 \overline{\mathbb{F}}_t\pi_t + \gamma \pi_{t-1,t-5} + u_t$$

  - Forecast error and revision

$$\text{forecast error}_t = \beta \text{revision}_t + \gamma \pi_{t-1,t-5} + u_t$$

  - Forecast error autocorrelation

$$\text{forecast error}_t = \beta \text{forecast error}_{t-1} + \gamma \pi_{t-1,t-5} + u_t$$

Table Regression table

	Individual forecasts			Average forecast			Error	Error
	AR(1)	AR(2)	AR(3)	AR(1)	AR(2)	AR(3)		
$\mathbb{F}_t \pi_{t+2}$	1.284***	1.435***	1.417***	1.356***	1.870***	1.749***		
	(0.0162)	(0.0476)	(0.0482)	(0.0190)	(0.0707)	(0.0739)		
$\mathbb{F}_t \pi_{t+1}$		-0.232***	-0.0992		-0.775***	-0.390***		
		(0.0652)	(0.0874)		(0.102)	(0.139)		
$\mathbb{F}_t \pi_t$			-0.214***			-0.414***		
			(0.0697)			(0.097)		
$revision_t$							1.220***	
							(0.248)	
$error_{t-1}$								0.881***
								(0.0592)
$\pi_{t-1,t-5}$	0.00705	0.0119	0.0137*	-0.0299**	-0.0182	-0.0169	0.00819	-0.0163
	(0.00909)	(0.00859)	(0.00819)	(0.0124)	(0.0115)	(0.0108)	(0.0340)	(0.0131)
Observations	7,751	7,750	7,750	205	205	205	197	203

HAC robust standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Back to "Underrevision Behavior has Vanished" Back to "Back to Data"

Firm Problem

Short Derivation

- FOC wrt P_{jt} and log-linearizing around the zero inflation steady-state

$$p^*_{jt} = (1-\beta\theta)\sum_{k=0}^{\infty}(\beta\theta)^k \mathbb{E}_{jt}\left(mc_{j,t+k|t} + \mu\right), \qquad \mu = \log\frac{\epsilon}{\epsilon-1}$$

- Price equal to desired markup over (weighted) average of expected marginal costs
- In equilibrium
  * Individual marginal cost as a function of aggregate marginal cost:

$$mc_{j,t+k|t} = mc_{t+k} - \frac{\alpha\epsilon}{1-\alpha}(p^*_{jt} - p_{t+k})$$

  * Aggregate demand = supply: $c_t = y_t$
  * Aggregate labor supply: $w_t - p_t = (\sigma+\varphi)y_t$
  * Output in gap term, difference from natural rate: $\mu = -(\sigma+\varphi)y^n_t$, $\tilde{y}_t = y_t - y^n_t$
- Recursive price-setting condition

$$p^*_{jt} = (1-\beta\theta)\mathbb{E}_{jt}p_t + \frac{\kappa\theta}{1-\theta}\mathbb{E}_{jt}\tilde{y}_t + \beta\theta\mathbb{E}_{jt}p^*_{j,t+1}$$

Firm Problem Solution

- Marginal cost: cost of each unit of labor (wage) times labor needed to produce an additional unit of output

$$\begin{aligned} \mathrm{mc}_{j,t+k|t} &= w_{t+k} - mpn_{j,t+k|t} \\ &= w_{t+k} + \alpha n_{j,t+k|t} - \log(1-\alpha) \end{aligned}$$

- Define average marginal cost: $\mathrm{mc}_{t+k} = \int_{\mathcal{I}_f} \mathrm{mc}_{j,t+k}\, dj$

$$\begin{aligned} \mathrm{mc}_{t+k} &= w_{t+k} - mpn_{t+k} \\ &= w_{t+k} + \alpha n_{t+k} - \log(1-\alpha) \end{aligned}$$

Firm Problem Solution

- We can write

$$\begin{aligned} \text{mc}_{j,t+k|t} &= \text{mc}_{t+k} + (w_{t+k} - w_{t+k}) + \alpha(n_{j,t+k|t} - n_{t+k}) \\ &= \text{mc}_{t+k} + \frac{\alpha}{1-\alpha}(y_{j,t+k|t} - y_{t+k}) \\ &= \text{mc}_{t+k} - \frac{\alpha\epsilon}{1-\alpha}(p^*_{jt} - p_{t+k}) \end{aligned}$$

- Inserting into price-setting condition,

$$\begin{aligned} p^*_{jt} &= (1-\beta\theta)\sum_{k=0}^{\infty}(\beta\theta)^k \mathbb{E}_{jt}\left[p_{t+k} + \frac{1-\alpha}{1-\alpha+\alpha\epsilon}\left(\text{mc}_{t+k} - p_{t+k} + \mu\right)\right] \\ &= (1-\beta\theta)\mathbb{E}_{jt}p_t + (1-\beta\theta)\frac{1-\alpha}{1-\alpha+\alpha\epsilon}\mathbb{E}_{jt}\left(\text{mc}_t - p_t + \mu\right) + \beta\theta\mathbb{E}_{jt}p^*_{j,t+1} \end{aligned}$$

Firm Problem Solution

- We can write

$$
\begin{aligned}
mc_t - p_t &= w_t + \alpha n_t - \log(1-\alpha) \\
&= \sigma c_t + (\varphi + \alpha) n_t - \log(1-\alpha) \\
&= \left(\sigma + \frac{\varphi + \alpha}{1-\alpha}\right) y_t - \log(1-\alpha)
\end{aligned}
$$

- $\mu \equiv$ markup under flexible prices

$$
\begin{aligned}
\mu &= p_t - mc_t \\
&= -w_t - \alpha n_t^n + \log(1-\alpha) \\
&= -\left(\sigma + \frac{\varphi + \alpha}{1-\alpha}\right) y_t^n + \log(1-\alpha)
\end{aligned}
$$

- Defining $\tilde{y}_t = y_t - y_t^n$

$$
p_{jt}^* = (1-\beta\theta)\mathbb{E}_{jt} p_t + (1-\beta\theta)\frac{1-\alpha}{1-\alpha+\alpha\epsilon}\left(\sigma + \frac{\varphi+\alpha}{1-\alpha}\right)\mathbb{E}_{jt}\tilde{y}_t + \beta\theta\mathbb{E}_{jt} p_{j,t+1}^*
$$

Solving Expectations

Obtaining Expectations

- Need to obtain expectations of output and price level
- Guess output and price dynamics

$$\tilde{y}_t = a_y p_{t-1} + b_y p_{t-2} + c_y v_t$$
$$p_t = a_p p_{t-1} + b_p p_{t-2} + c_p v_t$$
$$p^*_{jt} = a_p p^*_{j,t-1} + b_p p^*_{j,t-2} + \frac{c_p}{1-\theta} x_{jt} - \frac{c_p \theta}{1-\theta} x_{j,t-1}$$

- Using guesses, rewrite firm j's policy function as beauty contest!

$$p^*_{jt} = \frac{\kappa\theta c_y}{1-\theta}\mathbb{E}_{jt} v_t + \frac{\kappa\theta b_y}{1-\theta}\mathbb{E}_{jt} p_{t-2} + \frac{\kappa\theta a_y}{1-\theta}\mathbb{E}_{jt} p_{t-1} + (1-\beta\theta)\mathbb{E}_{jt} p_t + \beta\theta\mathbb{E}_{jt} p^*_{j,t+1}$$

- Firm j's action depends on her forecast of the fundamental, but also on my predictions of others' actions

Obtaining Expectations

- State-space representation

$$\mathbf{Z}_t = \mathbf{F}\mathbf{Z}_{t-1} + \breve{\ }\mathbf{S}_{jt}, \quad x_{jt} = \mathbf{H}\mathbf{Z}_t + \bar{\ }\mathbf{S}_{jt}$$

$$\mathbf{Z}_t = \begin{bmatrix} v_t & p_t & p_{t-1} & p_{t-2} \end{bmatrix}', \quad \mathbf{S}_{jt} = \begin{bmatrix} \varepsilon_t & u_{jt} \end{bmatrix}'$$

$$\mathbf{F} = \begin{bmatrix} \rho & 0 & 0 & 0 \\ \rho c_p & a_p & b_p & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}, \breve{\ } = \begin{bmatrix} \sigma_\varepsilon & 0 \\ \sigma_\varepsilon c_p & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}, \mathbf{H} = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}', \bar{\ } = \begin{bmatrix} 0 \\ \sigma_u \end{bmatrix}'$$

Obtaining Expectations

- Kalman filter

$$\mathbb{E}_{jt}\mathbf{Z}_t = \tilde{}\,\mathbb{E}_{j,t-1}\mathbf{Z}_{t-1} + \mathbf{K}x_{jt} \tag{6}$$

$$\tilde{} = \begin{bmatrix} \lambda & 0 & 0 & 0 \\ \left(\rho - \frac{\rho-\lambda}{1-\lambda(a_p+\lambda b_p)}\right)c_p & a_p & b_p & 0 \\ -\frac{\lambda(\rho-\lambda)c_p}{1-\lambda(a_p+\lambda b_p)} & 1 & 0 & 0 \\ -\frac{\lambda(\rho-\lambda)c_p}{1-\lambda(a_p+\lambda b_p)} & 0 & 1 & 0 \end{bmatrix}, \quad \mathbf{K} = \begin{bmatrix} 1 - \frac{\lambda}{\rho} \\ \frac{(\rho-\lambda)c_p}{\rho(1-\lambda a_p-\lambda^2 b_p)} \\ \frac{\lambda(\rho-\lambda)c_p}{\rho(1-\lambda a_p-\lambda^2 b_p)} \\ \frac{\lambda(\rho-\lambda)c_p}{\rho(1-\lambda a_p-\lambda^2 b_p)} \end{bmatrix}$$

and λ is the inside root of the following quadratic polynomial $\mathcal{Q}(z) = (z-\rho^{-1})(z-\rho) - \frac{\sigma_\varepsilon^2}{\rho\sigma_u^2}z$

Obtaining Expectations

- Using the lag operator, we can write (6) as

$$\mathbb{E}_{jt}\mathbf{Z}_t = (\mathbf{I} - \tilde{\ }L)^{-1}\mathbf{K}x_{jt}$$
$$= \tilde{\tilde{\ }}(L)x_{jt}$$

$$\tilde{\tilde{\ }}(L) = \begin{bmatrix} \frac{\rho-\lambda}{\rho(1-\lambda L)} \\ \frac{(\rho-\lambda)[1-\lambda(\rho a_p-(1-\rho\lambda)b_p)]c_p}{\rho(1-\lambda L)(1-a_pL-b_pL^2)(1-a_p\lambda-b_p\lambda^2)} \\ \frac{(\rho-\lambda)[\lambda+(1-\rho\lambda+\lambda a_p)L-\lambda^2\rho b_pL^2]c_p}{\rho(1-\lambda L)(1-a_pL-b_pL^2)(1-a_p\lambda-b_p\lambda^2)} \\ \frac{(\rho-\lambda)[\lambda^2+(1-\rho\lambda+\lambda a_p)L+((1-\rho\lambda)(1-\lambda a_p)-\lambda^2 b_p)L^2]c_p}{\rho(1-\lambda L)(1-a_pL-b_pL^2)(1-a_p\lambda-b_p\lambda^2)} \end{bmatrix}$$

Obtaining Expectations

- Still need to find unknown (a_p, b_p, c_p)!
- Recall firm j price-setting condition

$$p_{jt}^* = \frac{\kappa\theta c_y}{1-\theta}\mathbb{E}_{jt}v_t + \frac{\kappa\theta b_y}{1-\theta}\mathbb{E}_{jt}p_{t-2} + \frac{\kappa\theta a_y}{1-\theta}\mathbb{E}_{jt}p_{t-1} + (1-\beta\theta)\mathbb{E}_{jt}p_t + \beta\theta\mathbb{E}_{jt}p_{j,t+1}^*$$

- Have every necessary object since

$$\mathbb{E}_{jt}p_{j,t+1}^* = a_p p_{jt}^* + b_p p_{j,t-1}^* + \frac{c_p}{1-\theta}\rho\mathbb{E}_{jt}v_t - \frac{c_p\theta}{1-\theta}\mathbb{E}_{jt}v_t$$

- Plugging in our last result and the obtained expectations $\mathbb{E}_{jt}\mathbf{Z}_t$ we obtain a system of 3 equations that must hold $\forall x_{jt}$
- Obtain triplet (a_p, b_p, c_p)!
- Given price dynamics, verify $\tilde{y}_t$ dynamics and solve for triplet (a_y, b_y, c_y)

Back to "Information Structure" Back to "Recap"

Model Dynamics

Inflation dynamics

Proposition

Noisy information: inflation dynamics

$$\pi_t = \delta \pi_{t-1} + \xi \pi_{t-2} + \psi_\pi \chi \Delta v_t$$

where $\delta(\sigma_u, \Phi)$, $\xi(\sigma_u, \Phi)$ *and* $\chi(\sigma_u, \Phi)$ *are scalars endogenous to information frictions* σ_u

Corollary

In the frictionless limit ($\sigma_u \to 0$), $\delta \to 1$, $\xi \to 0$ *and* $\chi \to 1$

Back to "Inflation Dynamics" Full Proposition

Proposition

Under noisy information price level dynamics are given by

$$p_t = (\vartheta_1 + \vartheta_2)p_{t-1} - \vartheta_1\vartheta_2 p_{t-2} - \psi_\pi \chi_\pi(\vartheta_1, \vartheta_2)v_t \tag{7}$$

where ϑ_1 and ϑ_2 are the reciprocals of the two outside roots of the quartic polynomial

$$\begin{aligned}\mathcal{P}(z) = &-(\beta\theta - z)(1-\theta z)(z-\rho)\,(1-\rho z)\\ &-\tau z\Bigg[(\beta\theta - z)(1-\theta z) + z(1-\theta)(1-\beta\theta)\\ &+ z^2\kappa\theta\frac{\vartheta_1[\sigma(1-\vartheta_2)+\phi_y](\vartheta_1+\vartheta_2-1-\phi_\pi)+(1-\vartheta_2)(\phi_\pi-\vartheta_2)(\sigma+\phi_y)}{[\sigma(1-\vartheta_1)+\phi_y][\sigma(1-\vartheta_2)+\phi_y]}\\ &+ z^3\kappa\theta\frac{\vartheta_1\vartheta_2[\sigma(1-\vartheta_1)(1-\vartheta_2)-(\vartheta_1+\vartheta_2-1-\phi_\pi)\phi_y]}{[\sigma(1-\vartheta_1)+\phi_y][\sigma(1-\vartheta_2)+\phi_y]}\Bigg]\end{aligned}$$

and χ_π is a scalar endogenous to information frictions.

Back to "Inflation Dynamics" | Proposition Output Gap

Proposition

Under noisy information output gap and price level dynamics are given by

$$\tilde{y}_t = \frac{\vartheta_1[\sigma(1-\vartheta_2)+\phi_y](\vartheta_1+\vartheta_2-1-\phi_\pi)+(1-\vartheta_2)(\phi_\pi-\vartheta_2)(\sigma+\phi_y)}{[\sigma(1-\vartheta_1)+\phi_y][\sigma(1-\vartheta_2)+\phi_y]}p_{t-1} + \frac{\vartheta_1\vartheta_2[\sigma(1-\vartheta_1)(1-\vartheta_2)-(\vartheta_1+\vartheta_2-1-\phi_\pi)\phi_y]}{[\sigma(1-\vartheta_1)+\phi_y][\sigma(1-\vartheta_2)+\phi_y]}p_{t-2} - \psi_y\chi_y(\vartheta_1,\vartheta_2)v_t \tag{8}$$

where ϑ_1 and ϑ_2 are the reciprocals of the two outside roots of the quartic polynomial $\mathcal{P}(z)$ and χ_y is a scalar endogenous to information frictions.

Back to "Inflation Dynamics"

Information Frictions

$\delta \in (1, \rho + \theta), \quad \delta'(\sigma_u) > 0,$

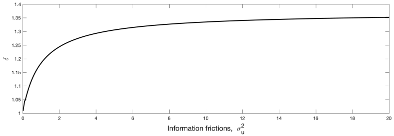


Figure δ and information frictions σ_u^2

$\xi \in (-\rho\theta, 0), \quad \xi'(\sigma_u) < 0$

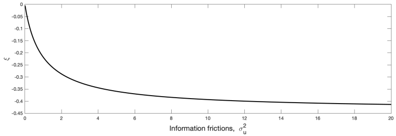


Figure ξ and information frictions σ_u^2

$\chi \in (0, 1), \quad \xi'(\sigma_u) < 0$

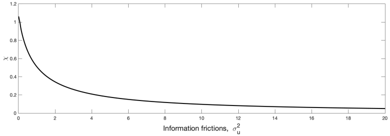


Figure χ and information frictions σ_u^2

Back to “Inflation Dynamics” Back to “First-Order Autocorrelation”

The role of θ

- Information frictions affect ϑ_1 and ϑ_2 in opposing ways
- Want $\vartheta_2 \in (\theta, 1)$ not very sensitive
- Large value of θ limits this sensitivity
- Calvo price rigidity $\theta = 0.872$ implies a mean price duration of 7.8 quarters, upper range
- Micro-data: between 4.5-11 months [Bils & Klenow (2004), Klenow & Kryvtsov (2008), Nakamura & Steinsson (2008), Goldberg & Hellerstein (2009)]
- Macro-data: between 1-3.5 years [Gali (2015), Auclert, Rognlie & Straub (2020)]

The role of θ

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- Macro-data: between 1-3.5 years [Gali (2015), Auclert, Rognlie & Straub (2020)]
- Depending on θ: can explain 40%-100% of persistence fall

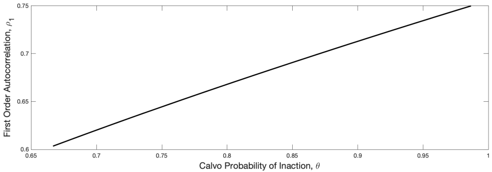

Figure First-order autocorrelation ρ_1 and price friction θ

Back to "First-Order Autocorrelation"

Information frictions regression

Proposition

The theoretical counterpart of the coefficient β_{rev} is given by

$$\beta_{rev} = \frac{\lambda^3\rho(1-\vartheta_1\lambda)(1-\vartheta_2\lambda)}{(1-\lambda^4)(\rho-\lambda)}\left\{\frac{\lambda(\lambda-\xi_1)(\lambda-\xi_2)(\lambda-\xi_3)(\lambda-\xi_4)}{(\lambda-\vartheta_1)(\lambda-\vartheta_2)} - (1-\lambda^2)\left[\frac{\vartheta_1(\vartheta_1-\xi_1)(\vartheta_1-\xi_2)(\vartheta_1-\xi_3)(\vartheta_1-\xi_4)}{(1-\lambda\vartheta_1)(\lambda-\vartheta_1)(\vartheta_1-\vartheta_2)} + \frac{\vartheta_2(\vartheta_2-\xi_1)(\vartheta_2-\xi_2)(\vartheta_2-\xi_3)(\vartheta_2-\xi_4)}{(1-\lambda\vartheta_2)(\lambda-\vartheta_2)(\vartheta_1-\vartheta_2)}\right]\right\}$$

where

- $\delta = \vartheta_1 + \vartheta_2$ *and* $\xi = -\vartheta_1\vartheta_2$
- λ *is the inside root of the quadratic polynomial* $\mathcal{Q}_1(z) = (1-\rho z)(z-\rho) + \frac{\sigma_\varepsilon^2}{\sigma_u^2}z$
- $\{\xi_1, \xi_2, \xi_3, \xi_4\}$ *are the reciprocals of the roots of the quartic polynomial* $\mathcal{Q}_2(z) = \phi_0 + \phi_1 z + \phi_2 z^2 + \phi_3 z^3 + \phi_4 z^4$, *where* $\phi_0 = c_p$, $\phi_1 = \left(\frac{1}{\lambda} - \frac{1}{\rho}\right)c_p$, $\phi_2 = \frac{(\rho-\lambda)c_p}{\lambda^2\rho}$,
  $\phi = \frac{(\rho-\lambda)c_p[\lambda^3-\vartheta_1-\vartheta_2+\lambda\vartheta_1\vartheta_2]}{\cdots}$ *and* $\phi = \frac{-\lambda^3+\lambda^4\vartheta_2+\lambda^4\vartheta_1-\vartheta_1\vartheta_2[\lambda-(1-\lambda^4)\rho]}{\cdots}$

Information frictions regression

Proposition

The theoretical counterpart of the coefficient β_{rev} *is given by*

$$\beta_{rev} = \frac{\lambda}{\rho-\lambda}\left[(1+\lambda)(\delta+\lambda\xi)-1-\frac{(\rho-\lambda)}{1-\lambda(\delta+\lambda\xi)}\left[\lambda\xi+\frac{\delta+\lambda\xi-1}{1-\lambda}\right]\right]$$

where λ *is the inside root of the following quadratic polynomial*

$$\mathcal{Q}(z) = (1-\rho z)(z-\rho) + \frac{\sigma_\varepsilon^2}{\sigma_u^2} z$$

Back

Wedge Phillips Curve

- Noisy information pre-1985

Proposition

Suppose we want to reproduce the noisy information dynamics in a FIRE setting. Guess that inflation dynamics follow

$$\pi_t = \omega_1 \pi_{t-1} + \omega_2 \kappa \tilde{y}_t + \omega_3 \beta \mathbb{E}_t \pi_{t+1}$$

The above wedge Phillips curve produces identical dynamics for certain values of $(\omega_1, \omega_2, \omega_3) \in [0, 1]^3$

- $\omega_1 \in (0, 1)$: anchoring
- $\omega_3 \in (0, 1)$: myopia

Wedge Phillips Curve

- Noisy information pre-1985

Proposition

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- $\omega_3 \in (0, 1)$: myopia
- Post 1985: $\omega_1 = 0$, $\omega_2 = \omega_3 = 1$

$$\pi_t = \kappa \tilde{y}_t + \beta \mathbb{E}_t \pi_{t+1}$$

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Simulated Wedge Phillips Curve

Table Simulated Wedge Phillips Curve

	(1) Simulated Wedge Phillips Curve
π_{t-1}	0.458***
	(0.0130)
$\tilde{y}_t$	-0.00000774
	(0.000110)
π_{t+1}	0.657***
	(0.0169)
Observations	8995

HAC Robust standard errors in parentheses

Instruments: four lags of inflation and output gap

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table Regression table

	Real GDP growth		Unemployment	
	(1)	(2)	(3)	(4)
	Full Sample	Structural Break	Full Sample	Structural Break
Revision	0.726***	1.092***	0.734***	0.599*
	(0.272)	(0.414)	(0.184)	(0.306)
Revision $\times \mathbb{1}_{\{t \geq t^*\}}$		-0.814		0.239
		(0.498)		(0.391)
Constant	-0.198*	-0.206**	-0.0453	-0.0420
	(0.101)	(0.102)	(0.0465)	(0.0473)
Observations	197	197	197	197

Robust standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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