Inflation Persistence, Noisy Information and the Phillips Curve

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This project

1. Document a fall in inflation persistence and volatility since the mid 1980s
2. Show that the NK model cannot explain the fall in persistence
3. Document a change in information frictions in the mid 1980s
4. Build a noisy information framework
5. Implications on the (lack of) flattening in the Phillips curve

Inflation dynamics have changed since the mid 1980s

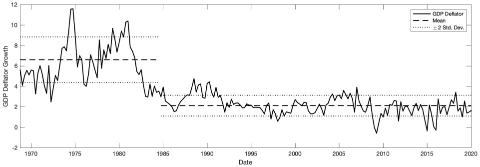


Figure: Time series of inflation, with subsample mean and standard deviation.

Table 1: Summary statistics over time.

	1968:Q4–2020:Q1	1968:Q4–1984:Q4	1985:Q1–2020:Q1
Mean	3.362	6.160	2.117
Volatility	2.400	2.234	1.016
First-Order Autocorrelation	0.880	0.754	0.505

Structural Break | Autocorrelation function | Rolling Sample Regression | Time-varying parameter regression | Unit root test | GARCH

Inflation dynamics in NK models

Inflation dynamics in NK models

- Understand the change in inflation dynamics via structural framework
- Determinants of inflation persistence and volatility
- Study 3 causal explanations: changes in...
  - Structural shocks (no change on persistence, fall in volatility)
    Benchmark | Technology & cost-push shocks
  - Monetary stance (no change on persistence, fall in volatility)
    Taylor rule | Indeterminacy | Discretion | Commitment
  - Intrinsic persistence (small change in persistence, fall in volatility)
    Price indexation | Trend inflation
- NK framework (extended in several dimensions) cannot explain the change in persistence
- Propose a noisy information environment

Noisy Information

Motivation for Noisy Information

- Federal Reserve disclosure policy over time
  - Before 1967: Fed policy decisions announced once a year in the Annual Report
  - **1967**: release the directive in the Policy Report (PR) 90 days after the decision
  - **1976**: enlarged the PR and reduced delay to 45 days
  - **1977-1993**: objectives, 'tilt', ranking of policy factors, minutes
  - **1994**: immediate release of PR if action
  - **1999**: immediate release of tilt
  - **2000**: immediate announcement after each meeting
- Quantify this increase in information using the Coibion & Gorodnickenko (AER 2015) regression design

Empirical Evidence on Dispersed Information

- Expectation data from the Survey of Professional Forecasters
  - Forecasters are asked to report their nowcast, forecast of next quarter, ..., up until a year
  - Quarterly, 1968:IV-2020:I
  - Alleviates the concern that firms could figure out Fed actions by hiring market watchers
- Measure of belief formation frictions: Coibion & Gorodnickenko (AER 2015) underrevision
  - Define $\pi_{t+3,t} = \frac{Deflator_{t+3} - Deflator_{t-1}}{Deflator_{t-1}}$
  - Denote individual i's forecast made in period t of annual inflation as $\mathbb{E}_{it}\pi_{t+3,t}$
  - Denote average forecast as $\overline{\mathbb{E}}_t \pi_{t+3,t} = \frac{1}{N_t}\sum_{i=1,\ldots,N_t} \mathbb{E}_{it}\pi_{t+3,t}$
- Structural break version of CG

$$\pi_{t+3,t} - \mathbb{E}_t\pi_{t+3,t} = \alpha + \left(\beta + \beta_{*,\mathbb{1}_{\{t\geq t^*\}}}\right)\left(\mathbb{E}_t\pi_{t+3,t} - \mathbb{E}_{t-1}\pi_{t+3,t}\right) + u_t$$

Regression Design

Table: Regression table

	(1) CG Regression	(2) 1968:IV-1984:IV	(3) 1985:I-2020:I	(4) Structural Break
Revision	1.230***	1.414***	0.169	1.501***
	(0.250)	(0.283)	(0.193)	(0.317)
Revision $\times \mathbb{1}_{\{t \geq t^*\}}$				-1.111***
				(0.379)
Constant	-0.0875	0.271	-0.317***	-0.135*
	(0.0696)	(0.185)	(0.0478)	(0.0690)
Observations	197	58	139	197

HAC robust standard errors in parentheses

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

Rolling Sample | Time-varying parameter | Livingston

Noisy Information NK model

- Assumptions:
  1. Households and the Central bank have FIRE
  2. Firms have RE but cannot observe the state of the economy
     - Monetary policy shock v_t is the only aggregate state variable
     - Each firm j observes noisy signal x_{jt} on the CB action v_t,

$$x_{jt} = v_t + u_{jt}, \quad \text{with } u_{jt} \sim \mathcal{N}(0, \sigma_u^2)$$

- Model equations:

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

$$\pi_{jt} = \kappa\theta \mathbb{E}_{jt} \tilde{y}_t + (1-\theta)\mathbb{E}_{jt}\pi_t + \beta\theta \mathbb{E}_{jt}\pi_{j,t+1}, \quad \pi_t = \int \pi_{jt}\, dj$$

$$i_t = \phi_\pi \pi_t + \phi_y \tilde{y}_t + v_t, \qquad v_t = \rho_v v_{t-1} + \varepsilon_t^v, \qquad \varepsilon_t^v \sim \mathcal{N}(0, \sigma_\varepsilon^2)$$

Derivation PC Optimal Expectations Parameters

- **Model the increase in information disclosure as a decrease in σ_u (structural break)**

Inflation dynamics in the NINK model

Proposition 1 (Full Proposition)

In the dispersed information framework, equilibrium inflation dynamics are given by

$$\pi_t = \vartheta \pi_{t-1} - \psi_\pi \chi(\vartheta) v_t$$

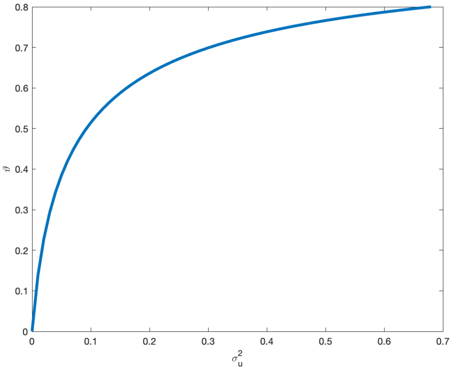
where $\vartheta(\sigma_u, \phi_\pi) \in (0, \rho_v)$ *governs information frictions, and in the limit of no info frictions* $(\sigma_u \to 0)$, $\vartheta \to 0$ *and* $\chi \to 1$

Proposition 2

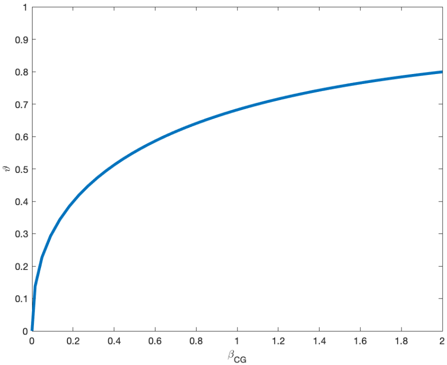
The theoretical counterpart of the coefficient β_{CG} *is given by*

$$\beta_{\mathcal{CG}} = \frac{\lambda^2\{(1-\lambda^2)\vartheta^2(1-\rho\vartheta) + [\rho(\vartheta-\lambda) - \vartheta\lambda(1-\rho\lambda)](1-\vartheta\lambda)\}}{(\rho-\lambda)(\vartheta-\lambda)(1-\vartheta\lambda)}$$

where $\lambda = \rho(1-G) \in (0,1)$



(a) Inflation persistence increasing in noise



(b) Inflation persistence increasing in CG coefficient

Persistence Result

- Calibration to match β_{CG}:

	Pre-1985	Post-1985
ϕ_π	1	2
σ_u	$\beta_{\mathcal{CG}} = 1.501$	$\beta_{\mathcal{CG}} = 0.390$

- The model produces a fall in inflation persistence: from $\vartheta_{pre} = 0.739$ to $\vartheta_{post} = 0.444$
- Data: $\rho_{\pi,pre} = 0.814$ and $\rho_{\pi,post} = 0.491$

	(1) OLS	(2) Newey
π_{t-1}	0.814***	0.814***
	(0.0481)	(0.0483)
$\pi_{t-1} \times \mathbb{1}_{\{t \geq t^*\}}$	-0.323***	-0.323***
	(0.0807)	(0.0804)
Observations	207	207

Standard errors in parentheses

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

“Inflation Disconnect” Puzzle and (lack of) flattening of Phillips Curve

"Inflation Disconnect" Puzzle

- Fall in the sensitivity of inflation wrt other (real) variables (DelNegro et al. 2020)
- Most well-known inflation dynamics in the NKPC

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

- Inflation *only* related to output *through* the slope κ
  - Literature has extensively focused on showing that κ has flattened
  - Inflation independent of any other (real) variable
- Show the "inflation disconnect" puzzle without resorting to κ
- Two tests
  - Agnostic stance in expectations
  - Using our NI framework disconnect occurs via expectation formation changes

Test 1: Agnostic stance

- Recall the individual Phillips curve for firm j

$$\pi_{jt} = \kappa\theta\mathbb{E}_{jt}\tilde{y}_t + (1-\theta)\mathbb{E}_{jt}\pi_t + \beta\theta\mathbb{E}_{jt}\pi_{j,t+1}$$

- Iterating forward and aggregating, we can write

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

- Inflation related to output via κ and *general* expectations
- Test structural break in κ *controlling for* non-standard expectations Livingston

Table: Regression table

	(1) NKPC	(2) Break Output	(3) Break
$\overline{\mathbb{E}}_t^f\tilde{y}_t$	0.108^{***} (0.0330)	0.0781^{*} (0.0451)	0.0810^{*} (0.0459)
$\overline{\mathbb{E}}_t^f\tilde{y}_{t+4}$	0.290^{***} (0.0707)	0.316^{***} (0.0793)	0.215^{**} (0.0931)
$\overline{\mathbb{E}}_t^f\pi_t$	1.252^{***} (0.0906)	1.214^{***} (0.0963)	1.205^{***} (0.119)
$\overline{\mathbb{E}}_t^f\pi_{t+4}$	-0.327^{***} (0.100)	-0.308^{***} (0.104)	-0.256^{**} (0.125)
$\overline{\mathbb{E}}_t^f\tilde{y}_t \times \mathbb{1}_{\{t\geq t^*\}}$		0.0775 (0.0596)	0.0885 (0.0593)
$\overline{\mathbb{E}}_t^f\tilde{y}_{t+4} \times \mathbb{1}_{\{t\geq t^*\}}$		-0.0846 (0.0858)	0.0990 (0.109)
$\overline{\mathbb{E}}_t^f\pi_t \times \mathbb{1}_{\{t\geq t^*\}}$			0.0305 (0.177)
$\overline{\mathbb{E}}_t^f\pi_{t+4} \times \mathbb{1}_{\{t\geq t^*\}}$			-0.262 (0.173)
Constant	-0.233^{***} (0.0581)	-0.210^{**} (0.102)	-0.160 (0.0969)

HAC robust standard errors in parentheses

Test 2: NI Phillips Curve

- Anchoring, myopia and relevance of future output gaps

Proposition 3 (Full)

The as if Phillips curve dynamics are described by

$$\pi_t = \omega_{\pi\pi}\pi_{t-1} + \kappa\tilde{y}_t + \delta_{\pi y}\mathbb{E}_t\tilde{y}_{t+1} + \delta_{\pi\pi}\beta\mathbb{E}_t\pi_{t+1}$$

Red terms endogenous to σ_u

- Model implied dynamics in the pre-1985 period $(\phi_\pi, \beta_{\mathcal{CG}}) = (1, 1.50)$

$$\pi_t = 0.562\pi_{t-1} + 0.172\tilde{y}_t + 0.000\mathbb{E}_t\tilde{y}_{t+1} + 0.405\mathbb{E}_t\pi_{t+1}$$

- Model implied dynamics in the pre-1985 period $(\phi_\pi, \beta_{\mathcal{CG}}) = (2, 0.39)$

$$\pi_t = 0.399\pi_{t-1} + 0.172\tilde{y}_t - 0.114\mathbb{E}_t\tilde{y}_{t+1} + 0.633\mathbb{E}_t\pi_{t+1}$$

- Suppose an econometrician assumes $\tilde{y}_t \sim$ AR(1):

$$0.172\tilde{y}_t - 0.114\mathbb{E}_t\tilde{y}_{t+1} = (0.172 - 0.114\rho_y)\tilde{y}_t$$

Table: Regression table

	(1) Standard NKPC	(2) Break	(3) DI NKPC	(4) Break Output	(5) Break Inflation
$\tilde{y}_t$	-0.0261	-0.114**	0.192**	0.273*	0.265**
	(0.0236)	(0.0452)	(0.0941)	(0.142)	(0.112)
π_{t+1}	0.991***	0.996***	0.677***	0.646***	0.499***
	(0.0175)	(0.0171)	(0.0740)	(0.0876)	(0.104)
π_{t-1}			0.309***	0.340***	0.481***
			(0.0743)	(0.0873)	(0.102)
$\tilde{y}_{t+1}$			-0.221**	-0.307**	-0.272**
			(0.104)	(0.142)	(0.120)
$\tilde{y}_t \times \mathbb{1}_{\{t \geq t^*\}}$		0.122**		-0.183	
		(0.0566)		(0.198)	
$\tilde{y}_{t+1} \times \mathbb{1}_{\{t \geq t^*\}}$				0.191	
				(0.196)	
$\pi_{t-1} \times \mathbb{1}_{\{t \geq t^*\}}$					-0.366*
					(0.200)
$\pi_{t+1} \times \mathbb{1}_{\{t \geq t^*\}}$					0.406*
					(0.209)
Observations	203	203	203	203	203

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

Backup Slides

Structural Break Back

- Wald test positive about a structural break in 1985:Q1
- Regress

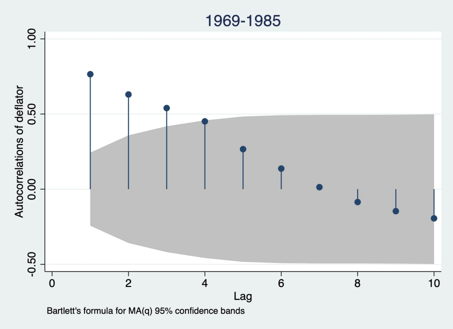
$$\pi_t = \alpha_\pi + \alpha_{\pi,*}\mathbb{1}_{\{t \geq t^*\}} + \rho_\pi \pi_{t-1} + \rho_{\pi,*}\pi_{t-1}\mathbb{1}_{\{t \geq t^*\}} + \varepsilon_t$$

	(1)	(2)	(3)	(4)	(5)	(6)
	Deflator		CPI		PCE	
π_{t-1}	0.880***	0.785***	0.738***	0.793***	0.816***	0.837***
	(0.0466)	(0.0755)	(0.0628)	(0.0827)	(0.0461)	(0.0672)
$\pi_{t-1} \times \mathbb{1}_{\{t \geq t^*\}}$		-0.287**		-0.497***		-0.434***
		(0.144)		(0.143)		(0.117)
Constant	0.400**	1.320***	1.008***	1.396**	0.618***	0.990**
	(0.166)	(0.471)	(0.262)	(0.542)	(0.182)	(0.431)
Constant$\times\mathbb{1}_{\{t \geq t^*\}}$		-0.263		0.370		0.283
		(0.543)		(0.607)		(0.477)
Observations	206	206	206	206	206	206

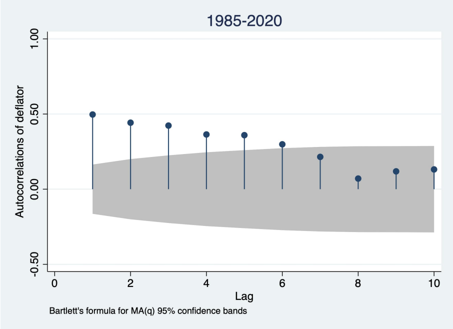
Standard errors in parentheses

Autocorrelation Function

Back



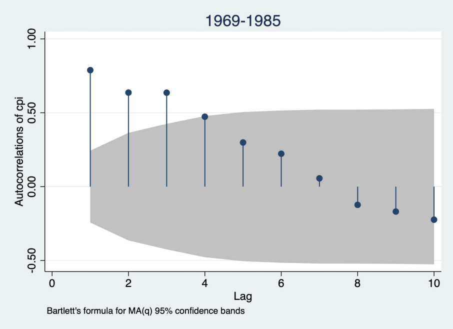
(a) GDP Deflator, 1969-1985



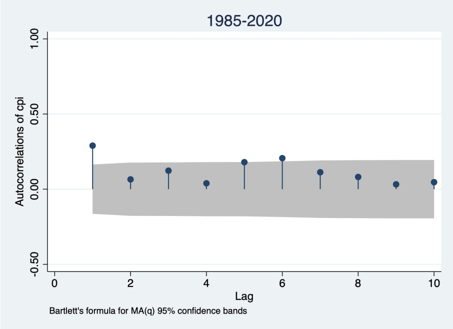
(b) GDP Deflator, 1985-2020

Figure: Autocorrelation function of GDP Deflator

Autocorrelation Function Back



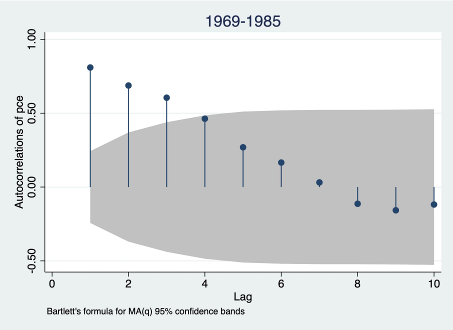
(a) CPI, 1969-1985



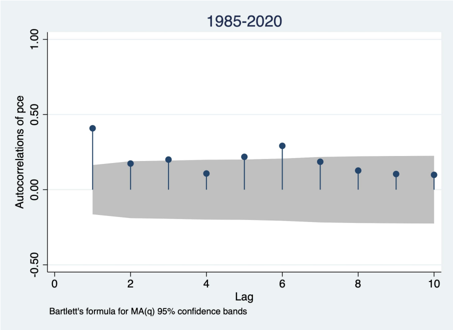
(b) CPI, 1985-2020

Figure: Autocorrelation function of CPI

Autocorrelation Function Back



(a) PCE, 1969-1985

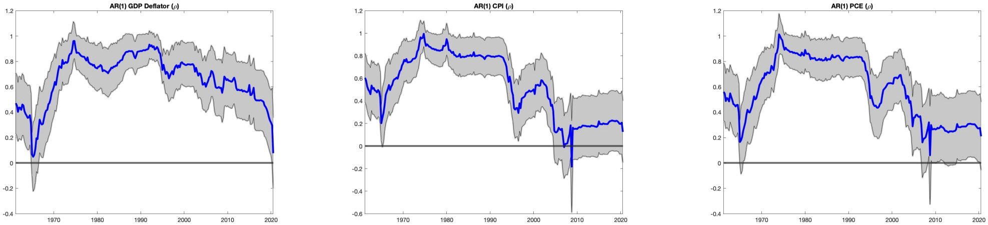


(b) PCE, 1985-2020

Figure: Autocorrelation function of PCE

Rolling-Sample Regression Back

- Regress $\pi_t = \rho_\pi \pi_{t-1} + \varepsilon_t$ using 14-year window samples



(a) GDP Deflator (b) CPI (c) PCE

Figure: First-order autocorrelation of GDP Deflator, CPI and PCE, rolling sample

Unit Root Test Back

- 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

Time-Varying Parameter Regression Back

- Consider the framework

$$\pi_t = \rho_t \pi_{t-1} + \varepsilon_t, \quad \varepsilon_t \sim \mathcal{N}(0, \sigma_\varepsilon^2)$$

- Persistence coefficient follows a random walk

$$\rho_{t+1} = \rho_t + u_t, \quad u_t \sim \mathcal{N}(0, \Sigma_u)$$

- Bayesian estimation, prior selection is standard following Nakajima (2011)

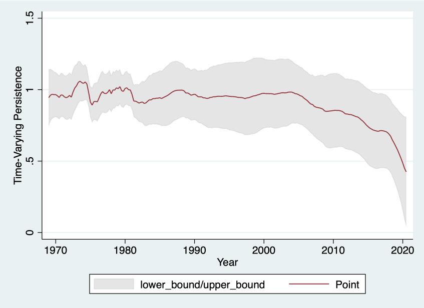


Figure: Persistence over time

Structural Break

Back

- GMM regression on
  $i_t = (\phi_\pi + \phi_{\pi,*}\mathbb{1}_{\{t \geq t^*\}})\pi_t + \phi_y y_t + \varepsilon_t$
- Instruments: four lags of
  - effective Fed funds rate
  - GDP deflator
  - CBO output gap
  - commodity price inflation
  - real M2 growth
  - spread between long-term bond rate and 3-month Treasury Bill

Table: Regression table

	(1) 1969:IV-2020:I	(2) Break
π_t	1.154^{***}	1.323^{***}
	(0.112)	(0.140)
y_t	0.353^{***}	0.309^{**}
	(0.121)	(0.128)
$\pi_t \times \mathbb{1}_{\{t \geq t^*\}}$		0.958^{***}
		(0.284)
Observations	204	204

Standard errors in parentheses.

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

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

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

- 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

$$\begin{aligned} \pi_t &= -\psi_\pi v_t \\ &= \rho_v \pi_{t-1} - \psi_\pi \varepsilon_t^v \end{aligned} \tag{4}$$

where ψ_π is decreasing in ϕ_π

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_v
- Using the AR(1) property of the v_t shock process, we can write the Taylor rule as

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

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

Persistence

$$i_t = \rho_v i_{t-1} + (\phi_\pi \pi_t + \phi_y y_t) - \rho_v (\phi_\pi \pi_{t-1} + \phi_y y_{t-1}) + \varepsilon_t^v \tag{6}$$

- As before, we rely on a structural break analysis but our results are consistent with alternative persistence measures
- First, we estimate

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

  using unrestricted GMM, where $\mathbb{1}_{\{t \geq t^*\}}$ is an indicator variable equal to 1 if the period is within the post-1985 era
- However, notice that ρ_v also interacts with lagged inflation and output gap in (6)
- To account for this, we estimate a structural break in (6) using a restricted GMM

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

	(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

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

Summary

- The full NK model cannot explain the fall in inflation persistence, since it is inherited from the monetary shock process which did not change over time
- It can rationalize the fall in inflation volatility through a contemporaneous fall in the elasticity of interest rates with respect to output and inflation

Back

Technology and Cost-push Shocks

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

$$\tilde{y}_t = -\frac{1}{\sigma}(i_t - \mathbb{E}_t \pi_{t+1}) - (1 - \rho_a)\psi_{ya} a_t + \mathbb{E}_t \tilde{y}_{t+1} \quad (7)$$

- Supply side:

$$\pi_t = \beta \mathbb{E}_t \pi_{t+1} + \kappa \tilde{y}_t + u_t \quad (8)$$

- 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

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

- We already documented no change in ρ_v
- 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
  - The natural real rate is given by $r_t^n = \sigma\psi_{ya}(\rho_a - 1)a_t$, which can be rewritten as

$$r_t^n = \rho_a r_{t-1}^n - \sigma\psi_{ya}(1 - \rho_a)\varepsilon_t^a \tag{9}$$

  - We use the Federal Reserve estimate of the natural interest rate series, produced by Holston (2017), as our proxy for r_t^n

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

Cost-Push Shock

- Nekarda & Ramey (2010) estimate the structural time-varying price-cost markup
- Two different measures of the cost-push shock
  - In the first, rely on a Cobb-Douglas production function in order to estimate the markup,
  - In the second, rely on a 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

Optimal Monetary Policy under Discretion

- In the pre-1985 period, inflation dynamics follow

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

- In the post-1985 period with optimal policy, the central bank minimizes the welfare losses experienced by a representative consumer,

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

where x_t is the welfare-relevant output gap, subject to the Phillips curve

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

where $\xi_t \equiv \beta \mathbb{E}_t \pi_{t+1} + u_t$ is treated as a non-policy shock

- Inflation dynamics follow

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

where $\psi_d > 0$ depends on deep parameters and inflation persistence is inherited from the cost-push shock.

- Compared to the pre-1985 dynamics there is no significant change in inflation persistence:
  - in the pre-period, model persistence is around 0.95,
  - while in the post-period persistence is around 0.96, the estimated persistence of cost-push shocks throughout both periods.
- Therefore, such change in the policy stance would have generated an *increase* in inflation persistence, which rules out this explanation.

Back

Optimal Monetary Policy under Commitment

- In the pre-1985 period, inflation dynamics follow

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

- In the post-1985 period with optimal policy, the central bank minimizes the welfare losses experienced by a representative consumer,

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

where x_t is the welfare-relevant output gap, subject to the Phillips curve

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

- Inflation dynamics follow

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

where $\psi_c > 0$ depends on deep parameters and ρ_c governs inflation persistence, which depends on deep parameters.

- Standard parameterization yields $\rho_c = 0.31$, excessive fall in inflation persistence
- Commitment implies an *as if* Taylor rule in which ϕ_π rose from 1 to 6.5, inconsistent with our empirical evidence.
- Output gap as persistent as inflation!

Back

Price Indexation

- Changes in ϕ_π and ϕ_y have no effect on inflation persistence *unless* there is aggregate anchoring
- Generate aggregate anchoring through price indexation
- A restricted firm resets its price partially indexed to past inflation: $p_{it} = p_{i,t-1} + \omega\pi_{t-1}$
- Otherwise standard
- 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 given by

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

  where ρ_ω is decreasing in ϕ_π

Back

Trend Inflation

- Ascari & Sbordone (2014) and Stock & Watson (2007) document a fall in trend inflation from 4% in the pre-1985 period to 2% afterwards
- Log-linearize the model around a steady-state with positive trend inflation
- Creates intrinsic persistence through relative price dispersion, which is a backward-looking variable that has no first-order effects in the benchmark
- Demand side unaffected, Supply side (Phillips curve) now a system of three equations

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

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

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

where ξ_t is an MA(∞) process and $\rho_{\overline{\pi}}$ is decreasing in ϕ_π and ϕ_y, and increasing in $\overline{\pi}$

Back

Regression Design

- The previous regression design is motivated by the Kalman filter
- Suppose that an agent wants to forecast an unobserved fundamental v_t,

$$v_t = \rho_v v_{t-1} + \varepsilon_t^v$$

  where $\varepsilon^v \sim \mathcal{N}(0, \sigma_\varepsilon^2)$
- Instead of observing the fundamental, agents observe a noisy signal

$$x_{it} = v_t + u_{it}$$

  with $u_i \sim \mathcal{N}(0, \sigma_u^2)$
- An agent optimal expectation (Kalman filter) takes the following form

$$\mathbb{E}_t v_t = (1 - G)\mathbb{E}_{t-1} v_t + G x_{it}$$

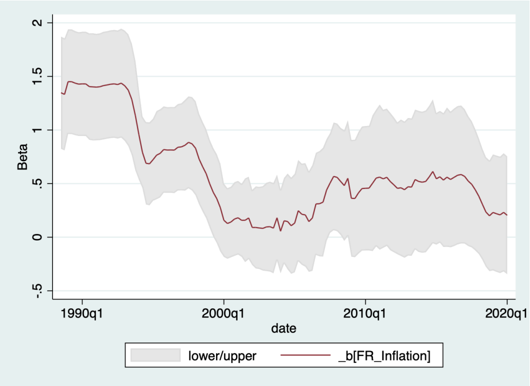
  where G is the Kalman gain, the weight that agents (optimally) assign on new information x_{it} relative to the previous forecast, which depends on σ_ε^2 and σ_u^2
- One can show

$$v_{t+1} - \mathbb{E}_t v_{t+1} = \frac{1 - G}{G}(\mathbb{E}_t v_{t+1} - \mathbb{E}_{t-1} v_{t+1}) + u_t$$

- Hence, an estimate of β pins down information frictions!

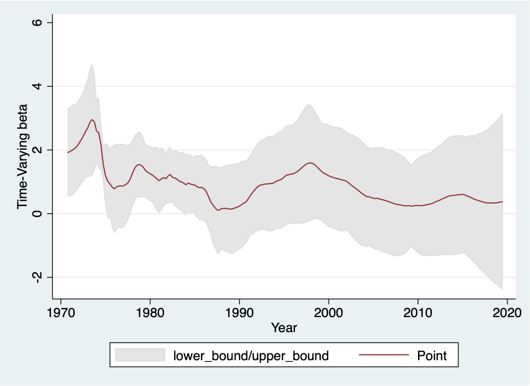
Back

Rolling Sample Back



Time-Varying Parameter Regression Back

$$\pi_{t+3,t} - \mathbb{E}_t \pi_{t+3,t} = \beta_t (\mathbb{E}_t \pi_{t+3,t} - \mathbb{E}_{t-1} \pi_{t+3,t}) + u_t$$



Back

Livingston Survey Back

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

$$\pi_{t+2,t} - \mathbb{E}_t\pi_{t+2,t} = \alpha_{CG} + \left(\beta_{CG} + \beta_{CG*}\mathbb{1}_{\{t\geq t^*\}}\right)\left(\mathbb{E}_t\pi_{t+2,t} - \mathbb{E}_{t-2}\pi_{t+2,t}\right) + u_t \qquad (10)$$

Table: Regression table

	(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

Standard errors in parentheses

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

Derivation Phillips curve

- Continuum of firms indexed by $j \in \mathcal{I}_f = [0, 1]$
- Each firm is a monopolist producing a differentiated intermediate-good variety, producing output Y_{jt} and setting nominal price P_{jt} and making real profit D_{jt}
- Production function

$$Y_{jt} = N_{jt}^{1-\alpha} \tag{11}$$

- Firm j's program

$$P_{jt}^* = \arg\max_{P_{jt}} \sum_{k=0}^{\infty} \theta^k \mathbb{E}_{jt} \left\{ \Lambda_{t,t+k} \frac{1}{P_{t+k}} \left[P_{jt} Y_{j,t+k|t} - \mathcal{C}_{t+k}(Y_{j,t+j|t}) \right] \right\}$$

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

where

- $\Lambda_{t,t+k} \equiv \beta^k \left(\frac{C_{t+k}}{C_t} \right)^{-\sigma}$ is the stochastic discount factor,
- $\mathcal{C}_t(\cdot)$ is the (nominal) cost function,
- $Y_{j,t+k|t}$ denotes output in period $t + k$ for a firm j that last reset its price in period t.

- FOC

$$\sum_{k=0}^{\infty} \theta^k \mathbb{E}_{jt} \left[\Lambda_{t,t+k} Y_{j,t+k|t} \frac{1}{P_{t+k}} \left(P_{jt}^* - \mathcal{M} \Psi_{j,t+k|t} \right) \right] = 0$$

where

  - $\Psi_{j,t+k|t} \equiv \mathcal{C}'_{t+k}(Y_{j,t+j|t})$ denotes the (nominal) marginal cost for firm j,
  - $\mathcal{M} = \frac{\epsilon}{\epsilon - 1}$.

- Log-linearizing around the zero inflation steady-state, we obtain the familiar price-setting rule

$$p_{jt}^* = (1 - \beta\theta) \sum_{k=0}^{\infty} (\beta\theta)^k \mathbb{E}_{jt} \left(\psi_{j,t+k|t} + \mu \right) \tag{12}$$

where

  - $\psi_{j,t+k|t} = \log \Psi_{j,t+k|t}$
  - $\mu = \log \mathcal{M}$.

- The (log) marginal cost for firm j at time $t+k|t$ is

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

where
  - $mpn_{j,t+k|t}$ denotes (log) marginal product of labor for a firm that last reset its price at time t,
  - $n_{j,t+k|t}$ denotes (log) employment in period $t+k$ for a firm that last reset its price at time t
- Let $\psi_t \equiv \int_{\mathcal{I}_f} \psi_{jt}$ denote the (log) average marginal cost

$$\psi_t = w_t - [\log(1-\alpha) - \alpha n_t]$$

- The following relation holds

$$\begin{aligned}\psi_{j,t+k|t} &= \psi_{t+k} + \alpha(n_{jt+k|t} - n_{t+k}) \\ &= \psi_{t+k} + \frac{\alpha}{1-\alpha}(y_{jt+k|t} - y_{t+k}) \\ &= \psi_{t+k} - \frac{\alpha\epsilon}{1-\alpha}(p^*_{jt} - p_{t+k}) \qquad (13)\end{aligned}$$

- Introducing (13) into (12), we can rewrite the firm price-setting condition as

$$p^*_{jt} = (1 - \beta\theta) \sum_{k=0}^{\infty} (\beta\theta)^k \mathbb{E}_{jt} \left(p_{t+k} - \Theta \hat{\mu}_{t+k} \right)$$

  where
  - $\hat{\mu} = \mu_t - \mu$ is the deviation between the average and desired markups,
  - $\mu_t = -(\psi_t - p_t)$,
  - $\Theta = \frac{1-\alpha}{1-\alpha+\alpha\epsilon}$
- Suppose that firms observe the aggregate prices up to period $t-1$, p^{t-1}
- Then we can restate the above condition as

$$p^*_{jt} - p_{t-1} = -(1 - \beta\theta)\Theta \sum_{k=0}^{\infty} (\beta\theta)^k \mathbb{E}_{jt} \hat{\mu}_{t+k} + \sum_{k=0}^{\infty} (\beta\theta)^k \mathbb{E}_{jt} \pi_{t+k}$$

- Define the firm-specific inflation rate as $\pi_{jt} = (1 - \theta)(p^*_{jt} - p_{t-1})$
- Then we can write the above expression as

$$\pi_{jt} = -(1 - \theta)(1 - \beta\theta)\Theta \mathbb{E}_{jt} \hat{\mu}_t + (1 - \theta)\mathbb{E}_{jt} \pi_t + \beta\theta \mathbb{E}_{jt} \pi_{j,t+1}$$

  where $\pi_t = \int_{\mathcal{I}_f} \pi_{jt} \, dj$.

- Using the aggregate household's labor supply condition we can write

$$\hat{\mu}_t = -\left(\sigma + \frac{\varphi + \alpha}{1-\alpha}\right)\tilde{y}_t$$

- Finally, we can write the individual Phillips curve as

$$\begin{aligned}\pi_{jt} &= (1-\theta)(1-\beta\theta)\Theta\left(\sigma + \frac{\varphi+\alpha}{1-\alpha}\right)\mathbb{E}_{jt}\tilde{y}_t + (1-\theta)\mathbb{E}_{jt}\pi_t + \beta\theta\mathbb{E}_{jt}\pi_{i,t+1} \\ &= \kappa\theta\mathbb{E}_{jt}\tilde{y}_t + (1-\theta)\mathbb{E}_{jt}\pi_t + \beta\theta\mathbb{E}_{jt}\pi_{i,t+1}\end{aligned} \tag{14}$$

where $\kappa = \frac{(1-\theta)(1-\beta\theta)}{\theta}\Theta\left(\sigma + \frac{\varphi+\alpha}{1-\alpha}\right)$, and the aggregate Phillips curve can be written as

$$\pi_t = \kappa\theta\sum_{k=0}^{\infty}(\beta\theta)^k\overline{\mathbb{E}}_t^f\tilde{y}_{t+k} + (1-\theta)\sum_{k=0}^{\infty}(\beta\theta)^k\overline{\mathbb{E}}_t^f\pi_{t+k} \tag{15}$$

Back

Parameter Values

Parameter	Description	Value	Source/Target
σ	IES	1	Galí (2015)
β	Discount factor	0.99	Galí (2015)
φ	Inv. Frisch Elas.	5	Galí (2015)
$1-\alpha$	Labor share	0.75	Galí (2015)
θ	Calvo lottery	0.75	Galí (2015)
ϵ	Elas. Subs. between goods	9	Galí (2015)
ρ_v	Monetary shock process persistence	0.94	Estimated
ϕ_y	Output coefficient Taylor rule	0.5	Estimated
$\phi_{\pi,\text{pre}}$	Inflation coefficient Taylor rule pre-1985	1	Estimated
$\phi_{\pi,\text{post}}$	Inflation coefficient Taylor rule post-1985	2	Estimated
$\sigma^2_{u,\text{pre}}$	Signal innovation variance pre-1985	0.445	$\beta_{CG,\text{pre}}$ in Estimated
$\sigma^2_{u,\text{post}}$	Signal innovation variance post-1985	0.095	$\beta_{CG,\text{post}}$ in Estimated

Back

Optimal expectations

- Aggregate inflation persistence depends on individual expectation's anchoring
- Guessing (and verifying) dynamics for $\tilde{y}_t$ and π_t, we can rewrite the firm problem as

$$\pi_{jt} = -\frac{1 + \rho_v \chi \left(\psi_\pi + \frac{\sigma \psi_y}{1 - \frac{\vartheta}{\rho_v}}\right)}{\sigma + \phi_y} \kappa \theta \mathbb{E}_{jt} v_t + \left[1 - \theta - \kappa\theta \frac{\phi_\pi - \vartheta}{\sigma(1 - \vartheta) + \phi_y}\right] \mathbb{E}_{jt} \pi_t + \beta\theta \mathbb{E}_{jt} \pi_{j,t+1}$$

Proposition 4

Firm i's nowcast of the monetary policy shock process is

$$\mathbb{E}_{it} v_t = \mathbb{E}_{i,t-1} v_t + G(x_{it} - \mathbb{E}_{i,t-1} v_t) \tag{16}$$

where the Kalman gain is given by $G(\rho, \sigma_\varepsilon, \sigma_u) = 1 - \frac{\lambda}{\rho}$. *Firm i's expectations of current aggregate output and individual future inflation as*

$$\mathbb{E}_{it} \pi_t = \mathbb{E}_{i,t-1} \pi_t + G_1(x_{it} - \mathbb{E}_{i,t-1} v_t)$$
$$\mathbb{E}_{it} \pi_{i,t+1} = \mathbb{E}_{i,t-1} \pi_{i,t+1} + G_2(x_{it} - \mathbb{E}_{i,t-1} v_t)$$

where $G_k(\beta, \sigma, \theta, \kappa, \phi_\pi, \phi_y, \rho, \sigma_\varepsilon, \sigma_u)$ *for* $k = \{1, 2\}$, *satisfying* $G_1 < G_2 < G$.

Optimal expectations

- Exogenous variable forecast: expectations will only update by a factor $G \in (0, 1)$, a firm does not need to infer others' decision
  - agents only need to rely on their private information, since others' actions do not determine the forecasted variable
- Forecasts of endogenous variables depend on others' actions, giving rise to higher-order beliefs
  - degree of anchoring is higher at each belief order
  - larger anchoring in expectations of endogenous aggregates

Back

Table: Regression table

	(1) NKPC	(2) Break Output	(3) Break
$\overline{\mathbb{E}}_t^f \tilde{y}_{t+2,t}$	1.014***	1.402***	1.079**
	(0.262)	(0.438)	(0.418)
$\overline{\mathbb{E}}_t^f \tilde{y}_{t+4,t+2}$	-0.0717	-0.680	-0.354
	(0.335)	(0.553)	(0.533)
$\overline{\mathbb{E}}_t^f \pi_{t+2,t}$	-0.0552	-0.0352	-0.264***
	(0.0652)	(0.0602)	(0.0836)
$\overline{\mathbb{E}}_t^f \pi_{t+4,t+2}$	-0.0375	-0.123	0.237
	(0.151)	(0.147)	(0.180)
$\overline{\mathbb{E}}_t^f \tilde{y}_{t+2,t} \times \mathbb{1}_{\{t \geq t*\}}$		-0.892*	-0.598
		(0.526)	(0.509)
$\overline{\mathbb{E}}_t^f \tilde{y}_{t+4,t+2} \times \mathbb{1}_{\{t \geq t*\}}$		0.882	0.555
		(0.662)	(0.641)
$\overline{\mathbb{E}}_t^f \pi_{t+2,t} \times \mathbb{1}_{\{t \geq t*\}}$			0.303***
			(0.0955)
$\overline{\mathbb{E}}_t^f \pi_{t+4,t+2} \times \mathbb{1}_{\{t \geq t*\}}$			-0.486**
			(0.191)
Constant	-0.115	0.388	0.479
	(0.250)	(0.398)	(0.460)
Observations	99	99	99

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Proposition 5 (Back)

In the dispersed information framework, equilibrium output gap and inflation dynamics are given by

$$\tilde{y}_t = -\frac{\vartheta(\phi_\pi - \vartheta)}{\sigma(1-\vartheta)+\phi_y}\pi_{t-1} - \psi_y \frac{\chi(\vartheta)}{1-\vartheta/\rho} v_t$$

$$\pi_t = \vartheta \pi_{t-1} - \psi_\pi \chi(\vartheta) v_t$$

where

$$\chi(\vartheta) = \left(1 - \frac{\frac{\kappa\sigma\vartheta(\phi_\pi - \vartheta)}{\sigma(1-\vartheta)+\phi_y}}{(1-\rho\beta)[\sigma(1-\rho)+\phi_y] + \kappa(\phi_\pi - \rho) + \frac{\kappa\sigma\vartheta(\phi_\pi-\vartheta)}{\sigma(1-\vartheta)+\phi_y}}\right)\left(1-\frac{\vartheta}{\rho}\right) \in (0,1)$$

and ϑ is a scalar that is given by the reciprocal of the largest root of the following cubic

$$\mathcal{P}(z) = (\beta\theta - z)(z-\rho^{-1})(z-\rho) - \frac{\sigma_\varepsilon^2}{\rho\sigma_u^2} z\theta \left[\beta - z\left(1 + \frac{\kappa(\phi_\pi - \vartheta)}{\sigma(1-\vartheta)+\phi_y}\right)\right] \qquad (17)$$

Proposition 6 (Back)

The ad-hoc hybrid dynamics (**??**) *produces identical dynamics to the dispersed information model if*

$$B - \boldsymbol{\varphi} = \boldsymbol{\omega}_f \boldsymbol{\delta}(AB + \rho B)$$
$$\boldsymbol{\omega}_b = (I_2 - \boldsymbol{\omega}_f \boldsymbol{\delta} A)A$$

for certain matrices $\boldsymbol{\omega}_b$ *and* $\boldsymbol{\omega}_f$

$$\boldsymbol{\omega}_b = \begin{bmatrix} \omega_{b,11} & \omega_{b,12} \\ \omega_{b,21} & \omega_{b,22} \end{bmatrix} \quad \text{and} \quad \boldsymbol{\omega}_f = \begin{bmatrix} \omega_{f,11} & \omega_{f,12} \\ \omega_{f,21} & \omega_{f,22} \end{bmatrix}$$

where

$$A = \begin{bmatrix} 0 & -\frac{\vartheta(\phi_\pi - \vartheta)}{\sigma(1-\vartheta)+\phi_y} \\ 0 & \vartheta \end{bmatrix} \quad \text{and} \quad B = \begin{bmatrix} -\psi_y \\ -\psi_\pi \left(1 - \frac{\vartheta}{\rho}\right) \end{bmatrix} \chi(\vartheta)$$

Corollary 1 (Back)

The as if DIS and Phillips curve dynamics are described by

$$\tilde{y}_t = \frac{\omega_{y\pi}}{\sigma}\pi_{t-1} - \frac{1}{\sigma}\mathbb{E}_t r_t + \frac{\delta_{yy}}{\sigma}\mathbb{E}_t\tilde{y}_{t+1} + \frac{\delta_{y\pi} - 1}{\sigma}\mathbb{E}_t\pi_{t+1}$$
$$\pi_t = \omega_{\pi\pi}\pi_{t-1} + \kappa y_t + \delta_{\pi y}\mathbb{E}_t\tilde{y}_{t+1} + \delta_{\pi\pi}\beta\mathbb{E}_t\pi_{t+1}$$

where

$$\omega_{y\pi} = (\sigma + \phi_y)\omega_{b,12} + \phi_\pi\omega_{b,22}$$
$$\omega_{\pi\pi} = \omega_{b,22} - \kappa\omega_{b,12}$$
$$\delta_{yy} = \frac{\sigma}{\sigma + \phi_y + \kappa\phi_\pi}\left[(\sigma + \phi_y)(\omega_{f,11} + \kappa\omega_{f,12}) + \phi_\pi(\omega_{f,21} + \kappa\omega_{f,22})\right]$$
$$\delta_{y\pi} = \frac{1}{\sigma + \phi_y + \kappa\phi_\pi}\left\{(1 - \beta\phi_\pi)[(\sigma + \phi_y)\omega_{f,11} + \phi_\pi\omega_{f,21}] + (\kappa + \beta\sigma + \beta\phi_y)[(\sigma + \phi_y)\omega_{f,12} + \phi_\pi\omega_{f,22})]\right\}$$
$$\delta_{\pi y} = \frac{\sigma}{\sigma + \phi_y + \kappa\phi_\pi}\left[(\omega_{f,21} - \kappa\omega_{f,11}) + \kappa\left(\omega_{f,22} - \kappa\omega_{f,12}\right)\right]$$
$$\delta_{\pi\pi} = \frac{1}{\sigma + \phi_y + \kappa\phi_\pi}\left\{(1 - \beta\phi_\pi)(\omega_{f,21} - \kappa\omega_{f,11}) + [\kappa + \beta(\sigma + \phi_y)]\left(\omega_{f,22} - \kappa\omega_{f,12}\right)\right\}$$