Monetary Policy and Macroeconomic Stability Revisited

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Outline

Background

- What led to U.S. macroeconomic stability after the Great Inflation of the 1970s?
- A large literature: shift from indeterminacy to determinacy of equilibrium
- Achieved by the Fed's policy change from a passive to an active response to inflation.
    - Clarida, Galí, and Gertler (2000); Lubik and Schorfheide (2004)
    - Based on canonical NK models.

Objective

- Revisit the view on the shift from indeterminacy to determinacy by estimating a staggered price model with trend inflation.
- Even when the trend inflation rate is non-zero, a fraction of prices is kept unchanged in each period.
  - Consistent with micro evidence on price adjustment.
  - A generalized NK Phillips curve replaces the canonical one.
- The model is more susceptible to indeterminacy than canonical NK models.
  - Ascari and Ropele (2009); Hornstein and Wolman (2005); Kiley (2007)
  - Even an active monetary policy response to inflation can induce indeterminacy.

Strategy

- The model is estimated during two periods, before 1979 and after 1982, allowing for both determinacy and indeterminacy.
  - Bayesian method of Lubik and Schorfheide (2004).
- To evaluate the empirical performance of the model, its canonical NK counterpart is also estimated.
  - Firms that would keep prices unchanged update prices using indexation to trend inflation as in Yun (1996).

Strategy (cont.)

- A difficulty in the method of Lubik and Schorfheide:
  - The likelihood function is possibly discontinuous at the boundary of determinacy and indeterminacy regions of the parameter space.
  - The RWMH algorithm can get stuck near a local mode and fail to find the entire posterior distribution.
- We adopt the sequential Monte Carlo (SMC) algorithm developed by Herbst and Schorfheide (2014, 2015).
  - The SMC algorithm can produce more reliable estimates than the RWMH algorithm when the posterior distribution is multimodal.

New Findings

1. The model empirically outperforms its canonical NK counterpart during both the pre-1979 and post-1982 periods.
   - Justifies the use of the model instead of the NK counterpart.
   - That some prices are unchanged in each period in the model is consistent with micro evidence and improves its fit to macro time series.
2. The US economy was likely under indeterminacy before 1979, while it was likely under determinacy after 1982.
   - In line with the literature.
   - However, even during the pre-1979 period, the estimated response to (current) inflation was active in the Taylor-type rule.
   - Contrasts with the literature's view that the policy response to inflation was passive during the Great Inflation era.

New Findings (cont.)

3. The rise in the policy response to inflation alone does not suffice for explaining the shift to determinacy.
   - Unless accompanied by either the fall in trend inflation or the change in the policy responses to the output gap and output growth.
   - Points to the importance of the changes in other aspects of monetary policy than its response to inflation.

Comparison with Coibion and Gorodnichenko (2011)

	Estimated policy rule + calibrated model	System estimation of entire model
Canonical NK	Clarida, Galí, and Gertler (2000)	Lubik and Schorfheide (2004)
Trend inflation	Coibion and Gorodnichenko (2011)	Our paper

- Coibion and Gorodnichenko (2011) shows that the shift can be explained by their calibrated fall in trend inflation along with their estimated rise in the policy response to inflation.
- Our paper confirms their view by estimating both trend inflation and the policy response parameters under cross-equation restrictions.

Comparison with Coibion and Gorodnichenko (2011) (cont.)

- Our paper offers another alternative view: the shift can be explained by a decrease in the policy response to the output gap and an increase in the response to output growth, along with a rise in the response to inflation—regardless of the fall in trend inflation.
  - The Fed during the post-1982 period was inclined to pay less attention to the output gap.
  - Orphanides (2001): Involves great uncertainty of measurement due to unobservable potential output.
- Our model empirically outperforms its canonical NK counterpart and thus the use of our model is justified.
  - Coibion and Gorodnichenko (2011) provide no such justification.

Outline

Household

- The representative household maximizes the utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t \exp(z_{u,t}) \left\{ \log(\tilde{C}_t - hC_{t-1}) - \frac{1}{1+\frac{1}{\eta}} \int_0^1 l_t(i)^{1+\frac{1}{\eta}} di \right\},$$

subject to the budget constraint

$$P_t \tilde{C}_t + B_t = \int_0^1 P_t W_t(i) l_t(i) di + r_{t-1} B_{t-1} + T_t.$$

- Preference shock:

$$z_{u,t} = \rho_u z_{u,t-1} + \varepsilon_{u,t}, \qquad \varepsilon_{u,t} \sim N(0, \sigma_u).$$

Final-Good Firm

- The representative final-good firm produces output Y_t by choosing a combination of intermediate inputs $\{Y_t(i)\}$ to maximize profit

$$P_t Y_t - \int_0^1 P_t(i) Y_t(i)\, di,$$

subject to the CES production technology

$$Y_t = \left[\int_0^1 Y_t(i)^{\frac{\theta-1}{\theta}} di \right]^{\frac{\theta}{\theta-1}} .$$

Intermediate-Good Firms

- Each intermediate-good firm i produces one kind of differentiated good $Y_t(i)$ subject to the production function

$$Y_t(i) = A_t l_t(i),$$

where A_t is the technology level and follows the stochastic process

$$\log A_t = \log a + \log A_{t-1} + z_{a,t}.$$

- Technology shock:

$$z_{a,t} = \rho_a z_{a,t-1} + \varepsilon_{a,t}, \qquad \varepsilon_{a,t} \sim N(0, \sigma_a).$$

Intermediate-Good Firms (cont.)

- Set prices on a staggered basis as in Calvo (1983).
  - In each period, a fraction $\lambda \in (0,1)$ of firms keeps prices unchanged, while the remaining fraction $1-\lambda$ sets prices in the following two ways:
    1. A fraction $\omega \in [0,1)$ of price-setting firms uses a backward-looking rule of thumb, as in Galí and Gertler (1999).
    2. The remaining fraction $1-\omega$ optimizes prices.

- The firms that optimize their prices maximize expected profit

$$E_t \sum_{j=0}^{\infty} \lambda^j Q_{t,t+j} \left(\frac{P_t(i)}{P_{t+j}} - mc_{t+j}(i) \right) Y_{t+j} \left(\frac{P_t(i)}{P_{t+j}} \right)^{-\theta}.$$

Central Bank

- Monetary policy rule:

$$\log r_t = \phi_r \log r_{t-1} + (1-\phi_r)\left[\begin{array}{c} \log r + \phi_\pi(\log \pi_t - \log \pi) \\ +\phi_x \log x_t + \phi_{\Delta y}\left(\log \frac{Y_t}{Y_{t-1}} - \log a\right) \end{array}\right] + z_{r,t}$$

  - $x_t = \frac{Y_t}{Y_t^n}$ is the output gap, where Y_t^n is the natural output.

- Monetary policy shock:

$$z_{r,t} = \rho_r z_{r,t-1} + \varepsilon_{r,t}, \qquad \varepsilon_{r,t} \sim N(0, \sigma_r).$$

Log-Linearized Equilibrium Conditions

$$\hat{\pi}_t = \gamma_b \hat{\pi}_{t-1} + \gamma_f E_t \hat{\pi}_{t+1} + \kappa \left[\hat{y}_t + \frac{h\eta}{(a-h)(1+\eta)} (\hat{y}_t - \hat{y}_{t-1} + z_{a,t}) \right] + \psi_t, \tag{1}$$

$$\psi_t = \beta \lambda \pi^{\theta - 1} E_t \psi_{t+1} + \kappa_f (E_t \hat{y}_{t+1} - \hat{y}_t + \theta E_t \hat{\pi}_{t+1} - \hat{r}_t), \tag{2}$$

$$\begin{aligned} \hat{y}_t = {} & \frac{h}{a+h} (\hat{y}_{t-1} - z_{a,t}) + \frac{a}{a+h} (E_t \hat{y}_{t+1} + E_t z_{a,t+1}) \\ & - \frac{a-h}{a+h} (\hat{r}_t - E_t \hat{\pi}_{t+1} + E_t z_{u,t+1} - z_{u,t}), \end{aligned} \tag{3}$$

$$\hat{r}_t = \phi_r \hat{r}_{t-1} + (1 - \phi_r)[\phi_\pi \hat{\pi}_t + \phi_x \hat{x}_t + \phi_{\Delta y} (\hat{y}_t - \hat{y}_{t-1} + z_{a,t})] + z_{r,t}, \tag{4}$$

$$\hat{x}_t = \hat{y}_t - \hat{y}_t^n, \tag{5}$$

$$\hat{y}_t^n = \frac{h\eta}{a(1+\eta) - h} (\hat{y}_{t-1}^n - z_{a,t}), \tag{6}$$

where $\gamma_b = \frac{\omega}{\varphi}$, $\varphi = \lambda \pi^{\theta - 1} + \omega(1 - \lambda \pi^{\theta - 1} + \beta \lambda \pi^{\theta(1 + \frac{1}{\eta})})$, $\gamma_f = \beta \lambda \pi^{\theta(1 + \frac{1}{\eta})} / \varphi$,
$\kappa = (1 - \lambda \pi^{\theta - 1})(1 - \beta \lambda \pi^{\theta(1 + \frac{1}{\eta})})(1 + \frac{1}{\eta})(1 - \omega) / [\varphi(1 + \frac{\theta}{\eta})]$,
$\kappa_f = \beta \lambda \pi^{\theta - 1} (\pi^{1 + \frac{\theta}{\eta}} - 1)(1 - \lambda \pi^{\theta - 1})(1 - \omega) / [\varphi(1 + \frac{\theta}{\eta})]$.

Canonical New Keynesian Model

- To evaluate the empirical performance of the model, its canonical NK counterpart is also estimated.
- Firms that would keep prices unchanged update prices using indexation to trend inflation as in Yun (1996).
- The generalized NK Phillips curve (1) and the auxiliary variable equation (2) is replaced with

$$\hat{\pi}_t = \gamma_{b,1}\hat{\pi}_{t-1} + \gamma_{f,1}E_t\hat{\pi}_{t+1} + \kappa_1\left[\hat{y}_t + \frac{h\eta}{(a-h)(1+\eta)}(\hat{y}_t - \hat{y}_{t-1} + z_{a,t})\right],$$

where $\gamma_{b,1}$, $\gamma_{f,1}$, κ_1 correspond to γ_b, γ_f, κ with $\pi = 1$.

Outline

Rational expectations solutions under indeterminacy

- A full set of LRE solutions (Lubik and Schorfheide, 2003):

$$s_t = \Phi_x(\vartheta) s_{t-1} + \Phi_\varepsilon(\vartheta, \tilde{M}) \varepsilon_t + \Phi_\zeta(\vartheta) \zeta_t,$$

  1. $\zeta_t \sim N(0, \sigma_\zeta^2)$: Sunspot shock
  2. $\tilde{M}$: Arbitrary matrix represents multiplicity of fundamental solutions

  - Case of determinacy: $s_t = \Phi_x^D(\vartheta) s_{t-1} + \Phi_\varepsilon^D(\vartheta) \varepsilon_t$.

- Components of the arbitrary matrix $\tilde{M}$ are estimated, following Lubik and Schorfheide (2004).
  - Construct a prior that is centered on a particular solution $M^*(\vartheta)$.
    - Replace $\tilde{M}$ with $M^*(\vartheta) + M$ and estimate M with prior mean zero.
    - Select $M^*(\vartheta)$ so that $\partial s_t / \partial \varepsilon_t$ is continuous at the boundary between determinacy and indeterminacy regions of the parameter space.

Bayesian Inference

- Estimate LRE model with full-information Bayesian approach of Lubik and Schorfheide (2004).
- Likelihood function is constructed for the indeterminacy region and determinacy region of the parameter space:

$$p(X^T|\vartheta, M) = 1\{\vartheta \in \Theta^D\}\, p^D(X^T|\vartheta) + 1\{\vartheta \in \Theta^I\}\, p^I(X^T|\vartheta, M).$$

- Updating a prior distribution $p(\vartheta, M)$ with the sample X^T leads to the posterior distribution:

$$\begin{aligned} p(\vartheta, M|X^T) &= \frac{p(X^T|\vartheta, M)p(\vartheta, M)}{p(X^T)} \\ &= \frac{p(X^T|\vartheta, M)p(\vartheta, M)}{\int p(X^T|\vartheta, M)p(\vartheta, M)d\vartheta \cdot dM}. \end{aligned}$$

Sequential Monte Carlo Algorithm

- The likelihood function is possibly discontinuous at the boundary of determinacy and indeterminacy regions.
  - The posterior distribution is possibly multimodal.
  - The RWMH algorithm can get stuck near a local mode and fail to find the entire posterior distribution.
- Adopt the SMC algorithm developed by Herbst and Schorfheide (2014, 2015) to generate the posterior distribution.
  - Overcome the problem by building a particle approximation to the posterior gradually through tempering the likelihood function.
  - Sequence of tempered posteriors:

$$\varpi_n(\vartheta) = \frac{[p(X^T|\vartheta, M)]^{\tau_n} p(\vartheta, M)}{\int [p(X^T|\vartheta, M)]^{\tau_n} p(\vartheta, M) d\vartheta \cdot dM}, \qquad n = 0, ..., N_\tau.$$

    - Tempering schedule: $\tau_n = (n/N_\tau)^\chi$ with $N_\tau = 200$ and $\chi = 2$.
    - $N = 10,000$ particles

Data

- Data: real GDP growth rate; inflation rate of the GDP price deflator; federal funds rate
- Observation equations:

$$\begin{bmatrix} 100\Delta\log Y_t \\ 100\log \pi_t \\ 100\log r_t \end{bmatrix} = \begin{bmatrix} \bar{a} \\ \bar{\pi} \\ \bar{r} \end{bmatrix} + \begin{bmatrix} \hat{y}_t - \hat{y}_{t-1} + z_{a,t} \\ \hat{\pi}_t \\ \hat{r}_t \end{bmatrix},$$

  where $\bar{a} = 100(a-1)$, $\bar{\pi} = 100(\pi - 1)$, and $\bar{r} = 100(r-1)$.
- Estimated for two periods:
  1. Pre-1979 period (1966:I–1979:II)
  2. Post-1982 period (1982:IV–2008:IV)
  - The Volcker disinflation period (1979:III–1982:III) is excluded, following Lubik and Schorfheide (2004).

Priors

Parameter	Distribution	Mean	St. dev.
$\bar{a}$	Normal	0.370	0.150
$\bar{\pi}$	Normal	0.985	0.750
$\bar{r}$	Gamma	1.597	0.250
h	Beta	0.700	0.100
ω	Beta	0.500	0.150
λ	Beta	0.500	0.050
ϕ_r	Beta	0.750	0.100
ϕ_π	Gamma	1.500/1.100	0.750
ϕ_x	Gamma	0.125	0.100
$\phi_{\Delta y}$	Gamma	0.125	0.100
ρ_u, ρ_a, ρ_r	Beta	0.500	0.200
$\sigma_u, \sigma_a, \sigma_r, \sigma_\zeta$	Inverse gamma	0.627	0.328
M_u, M_a, M_r	Normal	0.000	1.000

- Fixed parameters: $\theta = 9.32$ (Ascari and Sbordone, 2014); $\eta = 1$
- Prior probability of determinacy: 0.482 (0.485 for NK counterpart)

Outline

Posterior Estimates: Pre-1979 Period

	Baseline model		NK counterpart	
Parameter	Mean	90% interval	Mean	90% interval
$\bar{a}$	0.353	[0.156, 0.572]	0.387	[0.172, 0.619]
$\bar{\pi}$	1.512	[1.189, 1.836]	1.349	[0.900, 1.794]
$\bar{r}$	1.663	[1.395, 1.941]	1.585	[1.270, 1.914]
h	0.550	[0.439, 0.653]	0.548	[0.426, 0.669]
ω	0.143	[0.050, 0.222]	0.110	[0.039, 0.180]
λ	0.521	[0.450, 0.594]	0.513	[0.428, 0.595]
ϕ_r	0.707	[0.591, 0.833]	0.692	[0.573, 0.814]
ϕ_π	1.028	[0.399, 1.640]	0.401	[0.083, 0.696]
ϕ_x	0.313	[0.095, 0.562]	0.163	[0.002, 0.320]
$\phi_{\Delta y}$	0.119	[0.003, 0.235]	0.125	[0.003, 0.243]
$\log p(X^T)$	-127.100		-133.240	
$\mathbb{P}\{\vartheta \in \Theta^D \mid X^T\}$	0.000		0.002	

Posterior Estimates: Post-1982 Period

	Baseline model		NK counterpart	
Parameter	Mean	90% interval	Mean	90% interval
$\bar{a}$	0.399	[0.211, 0.584]	0.410	[0.223, 0.576]
$\bar{\pi}$	0.701	[0.537, 0.880]	0.679	[0.491, 0.873]
$\bar{r}$	1.442	[1.168, 1.741]	1.385	[1.119, 1.672]
h	0.625	[0.540, 0.713]	0.605	[0.523, 0.682]
ω	0.064	[0.024, 0.102]	0.069	[0.026, 0.110]
λ	0.458	[0.389, 0.534]	0.435	[0.365, 0.503]
ϕ_r	0.678	[0.602, 0.768]	0.617	[0.530, 0.701]
ϕ_π	2.730	[1.924, 3.574]	2.358	[1.795, 2.893]
ϕ_x	0.114	[0.001, 0.229]	0.085	[0.002, 0.168]
$\phi_{\Delta y}$	0.466	[0.269, 0.673]	0.409	[0.239, 0.565]
$\log p(X^T)$	-67.513		-77.511	
$\mathbb{P}\{\vartheta \in \Theta^D \| X^T\}$	1.000		1.000	

Model Selection: No Inflation Inertia?

- Examine whether abstracting from some properties of the model can improve the fit of the model even further.
- Cogley and Sbordone (2008): No empirical support for intrinsic inertia of inflation in their generalized NK Phillips curve
  - Our model is estimated in the absence of rule-of-thumb price-setting, i.e., $\omega = 0$.

	Pre-1979 period		Post-1982 period	
	Baseline	$\omega = 0$	Baseline	$\omega = 0$
$\log p(X^T)$	-127.1	-120.2	-67.5	-55.6
$\mathbb{P}\{\vartheta \in \Theta^D \mid X^T\}$	0.000	0.001	1.000	1.000

Posterior Estimates: $\omega = 0$

	Pre-1979		Post-1982	
Parameter	Mean	90% interval	Mean	90% interval
$\bar{a}$	0.379	[0.193, 0.555]	0.392	[0.221, 0.560]
$\bar{\pi}$	1.447	[1.116, 1.768]	0.700	[0.560, 0.839]
$\bar{r}$	1.641	[1.359, 1.920]	1.446	[1.173, 1.722]
h	0.568	[0.430, 0.700]	0.598	[0.520, 0.682]
λ	0.530	[0.455, 0.601]	0.458	[0.390, 0.522]
ϕ_r	0.702	[0.583, 0.819]	0.690	[0.607, 0.776]
ϕ_π	1.179	[0.260, 2.065]	2.989	[2.228, 3.792]
ϕ_x	0.370	[0.106, 0.620]	0.125	[0.001, 0.252]
$\phi_{\Delta y}$	0.106	[0.003, 0.212]	0.526	[0.322, 0.746]

Model Selection: No Response to Output Gap?

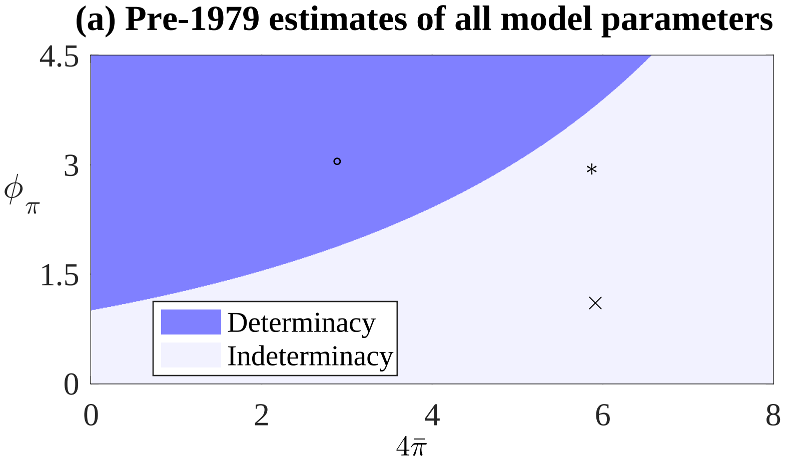
- Policy response to the output gap ϕ_x decreased considerably.
- Examine whether this decrease suggests virtually no response to the output gap.
  - The model with $\omega = 0$ is further estimated by fixing $\phi_x = 0$.

	Pre-1979 period		Post-1982 period	
	$\omega = 0$	$\omega = \phi_x = 0$	$\omega = 0$	$\omega = \phi_x = 0$
$\log p(X^T)$	-120.2	-124.0	-55.6	-54.2
$\mathbb{P}\{\vartheta \in \Theta^D \| X^T\}$	0.001	0.168	1.000	1.000

Posterior Estimates for Subsequent Analysis

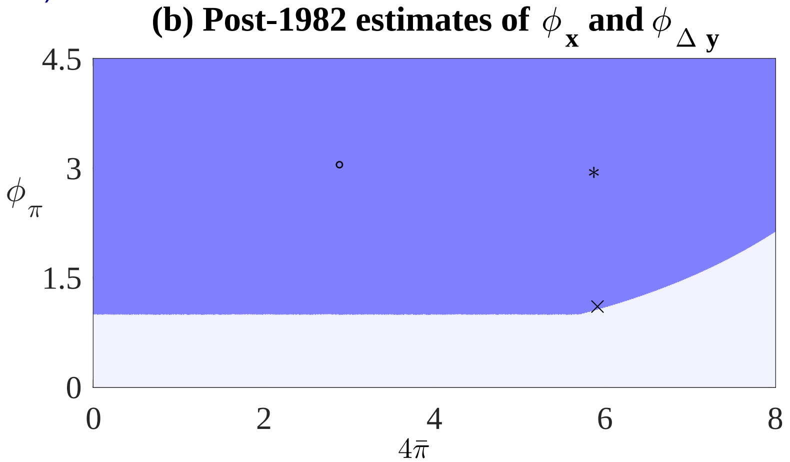
	Pre-1979		Post-1982	
	$\omega = 0$		$\omega = \phi_x = 0$	
Parameter	Mean	90% interval	Mean	90% interval
$\bar{a}$	0.379	[0.193, 0.555]	0.404	[0.231, 0.578]
$\bar{\pi}$	1.447	[1.116, 1.768]	0.699	[0.556, 0.841]
$\bar{r}$	1.641	[1.359, 1.920]	1.452	[1.173, 1.713]
h	0.568	[0.430, 0.700]	0.582	[0.500, 0.664]
λ	0.530	[0.455, 0.601]	0.462	[0.398, 0.535]
ϕ_r	0.702	[0.583, 0.819]	0.678	[0.588, 0.762]
ϕ_π	1.179	[0.260, 2.065]	3.013	[2.143, 3.825]
ϕ_x	0.370	[0.106, 0.620]	0	–
$\phi_{\Delta y}$	0.106	[0.003, 0.212]	0.525	[0.302, 0.725]
$\mathbb{P}\{\vartheta \in \Theta^D \| X^T\}$		0.001		1.000

Sources of Shift from Indeterminacy to Determinacy



$\times$: $(4\bar{\pi}^{pre79}, \phi_\pi^{pre79})$; $*$: $(4\bar{\pi}^{pre79}, \phi_\pi^{post82})$; $\circ$: $(4\bar{\pi}^{post82}, \phi_\pi^{post82})$

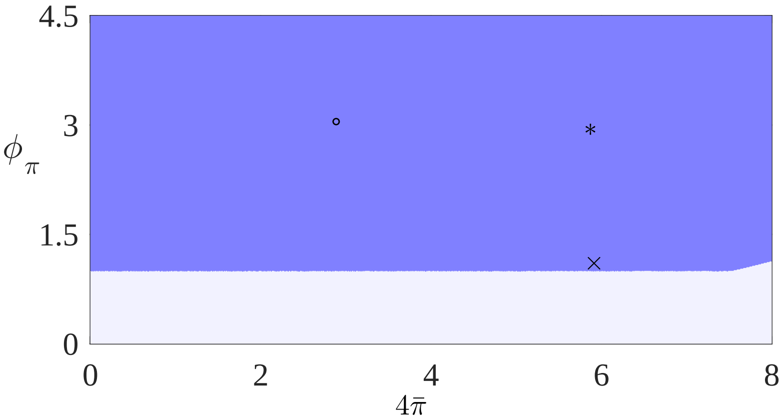
Sources of Shift from Indeterminacy to Determinacy (cont.)



$\times$: $(4\bar{\pi}^{pre79}, \phi_\pi^{pre79})$; $\ast$: $(4\bar{\pi}^{pre79}, \phi_\pi^{post82})$; $\circ$: $(4\bar{\pi}^{post82}, \phi_\pi^{post82})$

Sources of Shift from Indeterminacy to Determinacy (cont.)

(c) Post-1982 estimates of all model parameters



$\times$: $(4\bar{\pi}^{pre79}, \phi_\pi^{pre79})$; $\ast$: $(4\bar{\pi}^{pre79}, \phi_\pi^{post82})$; $\circ$: $(4\bar{\pi}^{post82}, \phi_\pi^{post82})$

Outline

Conclusion

- Revisited the view that US macroeconomic stability after the Great Inflation was achieved by the Fed's policy change from a passive to an active response to inflation.
- Estimated a staggered price model with trend inflation and a Taylor-type rule during two periods, before 1979 and after 1982.
  - Full-information Bayesian approach that allows for indeterminacy
  - SMC algorithm
- The model empirically outperforms its canonical NK counterpart.
- U.S. economy was likely under indeterminacy before 1979, while it was likely under determinacy after 1982.

Conclusion (cont.)

- The policy response to inflation was active even during the pre-1979 period, in addition to the post-1982 period.
- The rise in the response to inflation from the pre-1979 estimate to the post-1982 one alone does not suffice for explaining the shift.
  - Without changes in trend inflation or the policy responses to the output gap and output growth.
- Extends the literature by emphasizing the importance of the changes in the Fed's target inflation and responses to real economic activity in achieving US macroeconomic stability.