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Yasuo Hirose, Takushi Kurozumi and Willem Van Zandweghe

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Monetary Policy and Macroeconomic Stability

Revisited*

Yasuo Hirose[†] Takushi Kurozumi[‡] Willem Van Zandweghe[§]

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Abstract

A large literature with canonical New Keynesian models has established that the Fed's policy change from a passive to an active response to inflation led to U.S. macroeconomic stability after the Great Inflation of the 1970s. We revisit this view by estimating a staggered price model with trend inflation using a Bayesian method that allows for equilibrium indeterminacy and adopts a sequential Monte Carlo algorithm. The model empirically outperforms a canonical New Keynesian model and demonstrates an active response to inflation even in the Great Inflation era, during which the U.S. economy was likely in the indeterminacy region of the model's parameter space. A more active response to inflation alone does not suffice for explaining the shift to determinacy after the Great Inflation, unless it is accompanied by a decline in trend inflation or a change in policy responses to the output gap and output growth.

JEL Classification: C11; C52; C62; E31; E52

Keywords: Monetary policy; Great Inflation; Equilibrium indeterminacy; Generalized New Keynesian Phillips curve; Sequential Monte Carlo algorithm

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[†]Keio University. *E-mail address:* yhirose@econ.keio.ac.jp

[‡]Bank of Japan. *E-mail address:* takushi.kurozumi@boj.or.jp

[§]Federal Reserve Bank of Kansas City. *E-mail address:* willem.vanzandweghe@kc.frb.org

1 Introduction

What led to U.S. macroeconomic stability after the Great Inflation of the 1970s? Since the seminal work by Clarida, Galí, and Gertler (2000), a large literature has regarded the Great Inflation as a consequence of self-fulfilling expectations in indeterminate equilibrium, which lasted until determinacy was restored by changes in the Federal Reserve's policy under the chairmanship of Paul Volcker and his successors.¹ In particular, this literature has established the view that the U.S. economy's shift from indeterminacy to determinacy was achieved by the Fed's policy change from a passive to an active response to inflation.² Clarida, Galí, and Gertler demonstrate this view by estimating a monetary policy rule of the sort proposed by Taylor (1993) during two periods, before and after Volcker's appointment as Fed Chairman, and combining the estimated rule with a calibrated New Keynesian (henceforth NK) model to analyze determinacy. Lubik and Schorfheide (2004) also show the validity of the view by estimating an NK model jointly with a Taylor-type rule during two periods, before 1979 and after 1982, using a full-information Bayesian approach that allows for indeterminacy and sunspot fluctuations.³

This paper revisits the literature's view on the U.S. economy's shift from indeterminacy to determinacy after the Great Inflation by estimating a staggered price model with trend inflation and a Taylor-type rule. This model differs from the canonical NK models used in the literature in that even when the trend inflation rate is non-zero, a fraction of prices is kept unchanged in each period as is consistent with micro evidence on price adjustment.⁴

¹Following this literature, the present paper explains U.S. macroeconomic stability after the Great Inflation from the perspective of monetary policy. Other explanations emphasize a decline in the volatility of shocks to the U.S. economy (e.g., Sims and Zha, 2006; Justiniano and Primiceri, 2008) or the development of inventory management (e.g., Kahn, McConnell, and Perez-Quirós, 2002).

²A policy response to inflation is called *active* if it satisfies the Taylor principle, which claims that the (nominal) interest rate should be raised by more than the increase in inflation. Otherwise, it is called *passive*.

³See also Boivin and Giannoni (2006). With a counterfactual experiment, they indicate that in order to explain U.S. macroeconomic stability after the Great Inflation, it is crucial for the Fed's policy to have changed the way it has, along with a change in shocks to the economy.

⁴For a literature review of micro evidence on price adjustment, see, e.g., Klenow and Malin (2010) and Nakamura and Steinsson (2013).

As a consequence, the NK Phillips curve, which is a key component of canonical NK models, is replaced by what is called the generalized NK Phillips curve in the recent literature reviewed by Ascari and Sbordone (2014). This new Phillips curve makes the model more susceptible to indeterminacy than canonical NK models, as indicated by Ascari and Ropele (2009), Hornstein and Wolman (2005), and Kiley (2007).⁵ Indeed, even an active monetary policy response to inflation that generates determinacy in canonical NK models can induce indeterminacy in the model.

The model is estimated during two periods, before 1979 and after 1982, with a Bayesian method based on Lubik and Schorfheide (2004).⁶ Moreover, to evaluate the empirical performance of the model, its canonical NK counterpart is also estimated. This counterpart can be derived by altering the model so that firms that keep prices unchanged in the model would update prices using indexation to trend inflation as in Yun (1996). A difficulty in the method of Lubik and Schorfheide is that when a model is estimated over determinacy and indeterminacy regions of its parameter space, the likelihood function of the model is possibly discontinuous at the boundary of each region and thereby the Random-Walk Metropolis-Hastings (henceforth RWMH) algorithm—which is the most widely used in Bayesian estimation of dynamic stochastic general equilibrium models—can get stuck near a local mode and fail to find the entire posterior distribution. To deal with this problem, our paper adopts the sequential Monte Carlo (henceforth SMC) algorithm developed by Herbst and Schorfheide (2014, 2015) in the Lubik-Schorfheide method.⁷ As illustrated by Herbst and Schorfheide, the SMC algorithm can produce more reliable estimates of model parameters than the RWMH algorithm when the posterior distribution is multimodal. This is particularly the case when the likelihood function of a model exhibits discontinuity as in our paper.

The estimation results make three main contributions to the literature. First of all, the

⁵See also Coibion and Gorodnichenko (2011), Kobayashi and Muto (2013), Kurozumi (2014, 2016), and Kurozumi and Van Zandweghe (2016, 2017).

⁶The Bayesian method of Lubik and Schorfheide (2004) has been used in previous studies, such as Arias et al. (2015), Benati and Surico (2009), Bhattarai, Lee, and Park (2012, 2016), Doko Tchatoka et al. (2016), and Hirose (2007, 2008, 2013, 2014).

⁷Creal (2007) is the first paper that uses an SMC algorithm in Bayesian estimation of a dynamic stochastic general equilibrium model.

model empirically outperforms its canonical NK counterpart by a large margin during both the pre-1979 and post-1982 periods. This result of model comparison justifies the use of the model instead of the NK counterpart in examining U.S. macroeconomic stability after the Great Inflation, which the previous literature investigates with canonical NK models. Moreover, the result suggests that the model's feature that a fraction of prices is kept unchanged in each period is not only consistent with micro evidence on price adjustment but also improves its fit to U.S. macroeconomic time series.

Second, the U.S. economy was likely in the indeterminacy region of the model's parameter space before 1979, while it was likely in the determinacy region after 1982, in line with the result obtained in the literature. However, even during the pre-1979 period, the estimated response to (current) inflation was active in the Taylor-type rule, which adjusts the policy rate in response to its past rate and current values of inflation, the output gap, and output growth.⁸ This finding contrasts sharply with the literature's view that the policy response to inflation was passive during the Great Inflation era and that the subsequent change to an active response led to the U.S. economy's shift from indeterminacy to determinacy.⁹

Last but not least, the rise in the policy response to inflation from the pre-1979 estimate to the post-1982 one alone does not suffice for explaining the U.S. economy's shift, unless it is accompanied by either the estimated fall in trend inflation or the estimated change in the policy responses to the output gap and output growth. This finding reveals that a lower rate of trend inflation (or equivalently a lower inflation target), a more dampened response to the output gap, and a more aggressive response to output growth play a key role in accounting for the shift to determinacy, along with a more active response to inflation. Thus, the last finding extends the literature by emphasizing the importance of the changes in other aspects of monetary policy than its response to inflation.

The study most closely related to ours has been done by Coibion and Gorodnichenko

⁸Regarding the policy response to *expected* inflation, Orphanides (2004) obtains active responses for both two periods, before and after 1979, by estimating a Taylor-type rule with real-time data on the Federal Reserve Board's Greenbook forecast. See also Coibion and Gorodnichenko (2011).

⁹The NK counterpart confirms the literature's view; that is, the policy response to inflation was passive and the U.S. economy was likely in the indeterminacy region before 1979, while the response was active and the economy was likely in the determinacy region after 1982.

(2011). Like the relationship between Clarida, Galí, and Gertler (2000) and Lubik and Schorfheide (2004), our paper is a complementary study to theirs. They estimate a Taylor-type rule during two periods, before 1979 and after 1982, and combine it with a calibrated staggered price model with trend inflation to conduct a counterfactual experiment on determinacy. Within the calibrated model, their experiment shows that the U.S. economy’s shift from indeterminacy to determinacy after the Great Inflation can be explained by their calibrated fall in trend inflation along with their estimated rise in the policy response to inflation.¹⁰ Our paper confirms this novel view on the shift by estimating trend inflation and the policy response to inflation simultaneously under the cross-equation restrictions given by our model.¹¹ Moreover, 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. This view suggests that the U.S. economy’s shift was achieved by a change in the Fed’s policy responses not only to inflation but also to real economic activity. In particular, the Fed during the post-1982 period was inclined to pay less attention to the output gap—which involves great uncertainty of measurement due to unobservable potential output, as discussed by Orphanides (2001)—and put more emphasis on output growth as an indicator of real economic activity. Another key difference from Coibion and Gorodnichenko is that our model empirically outperforms its canonical NK counterpart as employed in the literature and thus the use of the former model instead of the latter is justified, whereas their paper provides no such justification. The result of model comparison empirically supports our views on the U.S. economy’s shift rather than the literature’s view.¹²

¹⁰Coibion and Gorodnichenko (2011) estimate a constant term of the Taylor-type rule, which contains trend inflation and other factors. Thus they calibrate the level of trend inflation for the two periods.

¹¹For the approach of Clarida, Galí, and Gertler (2000) who conduct limited-information estimation of a Taylor-type rule, Mavroeidis (2010) points to limitations of their approach and emphasizes the need to make use of identifying assumptions that can be derived from the full structure of their model.

¹²An independent work by Arias et al. (2015) extends the analysis of Coibion and Gorodnichenko (2011) using a medium-scale model without price or wage indexation based on Christiano, Eichenbaum, and Evans (2005). This model is estimated during the long period 1960:I–2008:II and is combined with the Taylor-type rule estimated by Coibion and Gorodnichenko to conduct a counterfactual experiment on determinacy. The experiment results confirm the conclusion of Coibion and Gorodnichenko within the estimated model.

The remainder of the paper proceeds as follows. Section 2 presents a staggered price model with trend inflation and a Taylor-type rule. Section 3 explains the estimation strategy and data. Section 4 shows results of the empirical analysis. Section 5 concludes.

2 Model

To empirically investigate sources of the U.S. economy's shift from indeterminacy of equilibrium to determinacy after the Great Inflation, this paper employs a staggered price model with trend inflation and a Taylor-type rule. This model attracts increasing attention in the recent literature reviewed by Ascari and Sbordone (2014), and has the feature that even when the trend inflation rate is non-zero, a fraction of prices is kept unchanged in each period as is consistent with micro evidence on price adjustment. This feature is not shared with canonical NK models used in previous literature. As a consequence, the model is more susceptible to indeterminacy than canonical NK models.

In the model economy there are a representative household, a representative final-good firm, a continuum of intermediate-good firms, and a central bank. These agents' behavior is described as follows.

2.1 Households

The representative household consumes final goods \tilde{C}_t , supplies labor $\{l_t(i)\}$ specific to each intermediate-good firm $i \in [0, 1]$, and purchases one-period riskless bonds B_t to maximize the utility function $E_0 \sum_{t=0}^{\infty} \beta^t \exp(z_{u,t}) \left\{ \log(\tilde{C}_t - hC_{t-1}) - [1/(1 + 1/\eta)] \int_0^1 (l_t(i))^{1+1/\eta} di \right\}$ subject to the budget constraint $P_t \tilde{C}_t + B_t = \int_0^1 P_t W_t(i) l_t(i) di + r_{t-1} B_{t-1} + T_t$, where E_t is the rational expectations operator conditional on information available in period t , $\beta \in (0, 1)$ is the subjective discount factor, $h \in [0, 1]$ is the degree of (external) habit persistence in consumption preferences, $\eta \geq 0$ is the elasticity of labor supply, P_t is the price of final goods, $W_t(i)$ is the real wage paid by intermediate-good firm i , r_t is the gross interest rate on bonds, which is assumed to equal the monetary policy rate, T_t consists of lump-sum public transfers and firm profits, and $z_{u,t}$ is a shock to current preferences.

In the presence of complete insurance markets, the first-order conditions for utility max-

imization with respect to consumption, labor supply, and bond holdings become

$$\Xi_t = \frac{\exp(z_{u,t})}{C_t - hC_{t-1}}, \quad (1)$$

$$W_t(i) = \frac{(l_t(i))^{1/\eta} \exp(z_{u,t})}{\Xi_t}, \quad (2)$$

$$1 = E_t \frac{\beta \Xi_{t+1}}{\Xi_t} \frac{r_t}{\pi_{t+1}}, \quad (3)$$

where Ξ_t is the marginal utility of consumption, C_t is aggregate consumption, and $\pi_t = P_t/P_{t-1}$ is the gross inflation rate of the final-good price.

2.2 Firms

The representative final-good firm produces homogeneous goods 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 $Y_t = \left[\int_0^1 (Y_t(i))^{(\theta-1)/\theta} di \right]^{\theta/(\theta-1)}$, where $P_t(i)$ is the price of intermediate good i and $\theta > 1$ is the price elasticity of demand for each intermediate good.

The first-order condition for profit maximization yields the final-good firm's demand curve for intermediate good i

$$Y_t(i) = Y_t \left(\frac{P_t(i)}{P_t} \right)^{-\theta}, \quad (4)$$

and thus the CES production technology leads to

$$P_t = \left[\int_0^1 (P_t(i))^{1-\theta} di \right]^{\frac{1}{1-\theta}}. \quad (5)$$

The final-good market clearing condition is given by

$$Y_t = C_t. \quad (6)$$

Each intermediate-good firm i produces one kind of differentiated good $Y_t(i)$ under monopolistic competition using the production technology

$$Y_t(i) = A_t l_t(i), \quad (7)$$

where A_t denotes the technology level and follows the stochastic process

$$\log A_t = \log a + \log A_{t-1} + z_{a,t}, \quad (8)$$

where a is the steady-state gross rate of technological change, which turns out to be equal to the steady-state gross rate of balanced growth, and $z_{a,t}$ is a (non-stationary) technology shock.

The first-order condition for cost minimization yields firm i 's real marginal cost

$$mc_t(i) = \frac{W_t(i)}{A_t}. \quad (9)$$

Prices of intermediate goods are set on a staggered basis as in Calvo (1983). In each period, a fraction $\lambda \in (0, 1)$ of firms keeps prices unchanged from previous-period ones, while the remaining fraction $1 - \lambda$ sets prices in the following two ways. As in Galí and Gertler (1999), a fraction $\omega \in (0, 1)$ of price-setting firms uses a backward-looking rule of thumb, while the remaining fraction $1 - \omega$ optimizes prices. The price set by the rule of thumb is given by

$$P_t^r = P_{t-1}^a \pi_{t-1} \quad \text{or} \quad p_t^r = \frac{P_t^r}{P_t} = \frac{(P_{t-1}^a/P_{t-1})\pi_{t-1}}{P_t/P_{t-1}} = \frac{p_{t-1}^a \pi_{t-1}}{\pi_t}, \quad (10)$$

where

$$P_t^a = (P_t^r)^\omega (P_t^o)^{1-\omega} \quad \text{or} \quad p_t^a = \frac{P_t^a}{P_t} = \left(\frac{P_t^r}{P_t}\right)^\omega \left(\frac{P_t^o}{P_t}\right)^{1-\omega} = (p_t^r)^\omega (p_t^o)^{1-\omega}, \quad (11)$$

and P_t^o is the price set by optimizing firms in period t . The price P_t^o maximizes the relevant profit function $E_t \sum_{j=0}^{\infty} \lambda^j Q_{t,t+j} (P_t(i)/P_{t+j} - mc_{t+j}(i)) Y_{t+j} (P_t(i)/P_{t+j})^{-\theta}$, where $Q_{t,t+j}$ is the stochastic discount factor between period t and period $t + j$. For this profit function to be well-defined, two conditions are assumed to be satisfied: $\beta \lambda \pi^{\theta-1} < 1$ and $\beta \lambda \pi^{\theta + \frac{\theta}{\eta}} < 1$, where π is the steady-state value of π_t and represents the gross rate of trend inflation.

The first-order condition for the optimized relative price $p_t^o (= P_t^o/P_t)$ becomes

$$E_t \sum_{j=0}^{\infty} (\beta \lambda)^j \frac{\Xi_{t+j}}{\Xi_t} \frac{Y_{t+j}}{Y_t} \prod_{k=1}^j \pi_{t+k}^\theta \left(p_t^o \prod_{k=1}^j \frac{1}{\pi_{t+k}} - \frac{\theta}{\theta-1} mc_{t+j}^o \right) = 0, \quad (12)$$

where the insurance-market equilibrium condition $Q_{t,t+j} = \beta^j \Xi_{t+j}/\Xi_t$ is used and mc_{t+j}^o denotes period- $t + j$ real marginal cost of firms that optimize prices in period t . From (1), (2), (4), (6), (7), and (9), it follows that the marginal cost is given by

$$mc_{t+j}^o = \left(p_t^o \prod_{k=1}^j \frac{1}{\pi_{t+k}} \right)^{-\frac{\theta}{\eta}} \left(\frac{Y_{t+j}}{A_{t+j}} \right)^{\frac{1}{\eta}} \left(\frac{Y_{t+j}}{A_{t+j}} - h \frac{Y_{t+j-1}}{A_{t+j}} \right). \quad (13)$$

Under the staggered price-setting, the final-good price equation (5) can be rewritten as

$$1 = (1 - \lambda) \left[(1 - \omega)(p_t^o)^{1-\theta} + \omega (p_t^r)^{1-\theta} \right] + \lambda \pi_t^{\theta-1}. \quad (14)$$

2.3 Central bank

The central bank conducts monetary policy according to a Taylor-type rule. This rule adjusts the policy rate r_t in response to the past rate r_{t-1} , inflation π_t , the output gap x_t , and output growth Y_t/Y_{t-1} :

$$\log r_t = \phi_r \log r_{t-1} + (1 - \phi_r) \left[\log r + \phi_\pi (\log \pi_t - \log \pi) + \phi_x \log x_t + \phi_{\Delta y} \left(\log \frac{Y_t}{Y_{t-1}} - \log a \right) \right] + z_{r,t}, \quad (15)$$

where the output gap is defined as

$$x_t = \frac{Y_t}{Y_t^n}, \quad (16)$$

Y_t^n is the natural rate of output, $z_{r,t}$ is a monetary policy shock, $r \geq 1$ is the steady-state gross policy rate, $\phi_r \in [0, 1)$ is the degree of policy rate smoothing, and ϕ_π , ϕ_x , $\phi_{\Delta y}$ are the degrees of policy responses to inflation, the output gap, and output growth. By considering flexible prices (i.e., $\lambda = \omega = 0$) in the intermediate-good price equation (12) and the final-good price equation (14) and combining the resulting two equations with the marginal cost equation (13), the law of motion for the natural rate of output is given by

$$\left(\frac{Y_t^n}{A_t} \right)^{1 + \frac{1}{\eta}} = \frac{\theta - 1}{\theta} + h \left(\frac{Y_t^n}{A_t} \right)^{\frac{1}{\eta}} \frac{Y_{t-1}^n}{A_t}. \quad (17)$$

2.4 Log-linearized equilibrium conditions

The equilibrium conditions consist of (1), (3), (6), (8), (10)–(16), and (17). Combining these equilibrium conditions, rewriting the resulting equations in terms of the detrended variables $y_t = Y_t/A_t$, $y_t^n = Y_t^n/A_t$, and log-linearizing them yield

$$\hat{\pi}_t = \gamma_b \hat{\pi}_{t-1} + \gamma_f E_t \hat{\pi}_{t+1} + \kappa \left[\hat{y}_t + \frac{h}{(a-h)(1+1/\eta)} (\hat{y}_t - \hat{y}_{t-1} + z_{a,t}) \right] + \psi_t, \quad (18)$$

$$\psi_t = \beta \lambda \pi^{\theta-1} E_t \psi_{t+1} + \kappa_f (E_t \hat{y}_{t+1} - \hat{y}_t + \theta E_t \hat{\pi}_{t+1} - \hat{r}_t), \quad (19)$$

$$\hat{y}_t = \frac{h}{a+h} (\hat{y}_{t-1} - z_{a,t}) + \frac{a}{a+h} (E_t \hat{y}_{t+1} + E_t z_{a,t+1}) - \frac{a-h}{a+h} (\hat{r}_t - E_t \hat{\pi}_{t+1} + E_t z_{u,t+1} - z_{u,t}), \quad (20)$$

$$\hat{r}_t = \phi_r \hat{r}_{t-1} + (1 - \phi_r) [\phi_\pi \hat{\pi}_t + \phi_x \hat{x}_t + \phi_{\Delta y} (\hat{y}_t - \hat{y}_{t-1} + z_{a,t})] + z_{r,t}, \quad (21)$$

$$\hat{x}_t = \hat{y}_t - \hat{y}_t^n, \quad (22)$$

$$\hat{y}_t^n = \frac{h\eta}{a(1+\eta) - h} (\hat{y}_{t-1}^n - z_{a,t}), \quad (23)$$

where ψ_t is an auxiliary variable, $\gamma_b = \omega/\varphi$, $\gamma_f = \beta\lambda\pi^{\theta(1+1/\eta)}/\varphi$, $\kappa = (1 - \lambda\pi^{\theta-1})(1 - \beta\lambda\pi^{\theta(1+1/\eta)})(1 + 1/\eta)(1 - \omega)/[\varphi(1 + \theta/\eta)]$, $\kappa_f = \beta\lambda\pi^{\theta-1}(\pi^{1+\theta/\eta} - 1)(1 - \lambda\pi^{\theta-1})(1 - \omega)/[\varphi(1 + \theta/\eta)]$, $\varphi = \lambda\pi^{\theta-1} + \omega(1 - \lambda\pi^{\theta-1} + \beta\lambda\pi^{\theta(1+1/\eta)})$, and hatted variables denote log-deviations from steady-state or trend levels. Equation (18) is referred to as the generalized NK Phillips curve in recent literature.

Each of the three shocks $z_{j,t}$, $j \in \{u, a, r\}$ is assumed to follow the stationary first-order autoregressive process

$$z_{j,t} = \rho_j z_{j,t-1} + \varepsilon_{j,t}, \quad (24)$$

where $\rho_j \in [0, 1)$ is the autoregressive parameter and $\varepsilon_{j,t} \sim \text{i.i.d. } N(0, \sigma_j^2)$ is the innovation to each shock.

2.5 Canonical New Keynesian model

To evaluate the empirical performance of the model, its canonical NK counterpart is also estimated. This counterpart can be derived by altering the model so that firms that keep prices unchanged in the aforementioned setting could update prices using indexation to trend inflation as in Yun (1996). The resulting system of log-linearized equilibrium conditions consists of (20)–(24) and the NK Phillips curve

$$\hat{\pi}_t = \gamma_{b,1}\hat{\pi}_{t-1} + \gamma_{f,1}E_t\hat{\pi}_{t+1} + \kappa_1 \left[\hat{y}_t + \frac{h}{(a-h)(1+1/\eta)}(\hat{y}_t - \hat{y}_{t-1} + z_{a,t}) \right], \quad (25)$$

where the coefficients $\gamma_{b,1}$, $\gamma_{f,1}$, κ_1 correspond to γ_b , γ_f , κ with the zero trend inflation rate (i.e., $\pi = 1$). Hence, the baseline model differs from the NK counterpart only in that the NK Phillips curve (25) is replaced by the generalized NK Phillips curve (18) and the auxiliary variable equation (19). Moreover, the two models coincide only when the trend inflation rate is zero.

3 Estimation Strategy and Data

This section describes the strategy and data for estimating the two systems of log-linearized equilibrium conditions presented in the preceding section. To investigate sources of the U.S. economy's shift from indeterminacy of equilibrium to determinacy after the Great Inflation,

the systems are estimated with a full-information Bayesian approach based on Lubik and Schorfheide (2004). Specifically, each system’s likelihood function is constructed not only for the determinacy region of its parameter space but also for the indeterminacy region.¹³ Then, the likelihood function can exhibit discontinuity at the boundary of each region.¹⁴ As a consequence, the posterior distribution of parameters in the system is possibly multimodal and thus the extensively used RWMH algorithm can get stuck near a local mode and fail to find the entire posterior distribution. To deal with this problem, the SMC algorithm developed by Herbst and Schorfheide (2014, 2015) is adopted to generate the posterior distribution. The SMC algorithm can overcome the problem inherent in multimodality by building a particle approximation to the posterior distribution gradually through tempering the likelihood function.

This section begins by explaining the method for solving linear rational expectations (henceforth LRE) models under indeterminacy. It then accounts for how Bayesian inferences over both determinacy and indeterminacy regions of the parameter space are made with the SMC algorithm. Moreover, the data and prior distributions used in the estimation are presented.

3.1 Rational expectations solutions under indeterminacy

Lubik and Schorfheide (2003) derive a full set of solutions to LRE models by extending the solution algorithm developed by Sims (2002).¹⁵ Any LRE model can be written in the canonical form

$$\Gamma_0(\vartheta)s_t = \Gamma_1(\vartheta)s_{t-1} + \Psi(\vartheta)\varepsilon_t + \Pi(\vartheta)\xi_t, \quad (26)$$

¹³The full-information Bayesian approach of Lubik and Schorfheide (2004) allows for indeterminate equilibrium by including a sunspot shock and its related arbitrary coefficient matrix in solutions to linear rational expectations models. By estimating the coefficient matrix with a fairly loose prior on it, a set of particular solutions that are the most consistent with data can be selected from a full set of solutions.

¹⁴With a univariate model, Lubik and Schorfheide (2004) illustrate discontinuity of the model’s likelihood function that is constructed for both determinacy and indeterminacy regions of its parameter space.

¹⁵Sims (2002) generalizes the solution algorithm of Blanchard and Kahn (1980) and characterizes one particular solution in the case of indeterminacy. In this solution, the contribution of fundamental shocks and sunspot shocks to forecast errors is orthogonal.

where $\Gamma_0(\vartheta)$, $\Gamma_1(\vartheta)$, $\Psi(\vartheta)$, and $\Pi(\vartheta)$ are coefficient matrices that depend on model parameters ϑ , s_t is a vector of endogenous variables including those expected at time t , ε_t is a vector of fundamental shocks, and ξ_t is a vector of forecast errors. Specifically, in our model, these vectors are given by

$$\begin{aligned} s_t &= [\hat{y}_t, \hat{\pi}_t, \hat{r}_t, \hat{y}_t^n, \hat{x}_t, \psi_t, z_{u,t}, z_{a,t}, z_{r,t}, E_t \hat{y}_{t+1}, E_t \hat{\pi}_{t+1}, E_t \psi_{t+1}]', \\ \varepsilon_t &= [\varepsilon_{u,t}, \varepsilon_{a,t}, \varepsilon_{r,t}]', \\ \xi_t &= [(\hat{y}_t - E_{t-1} \hat{y}_t), (\hat{\pi}_t - E_{t-1} \hat{\pi}_t), (\psi_t - E_{t-1} \psi_t)]'. \end{aligned}$$

According to Lubik and Schorfheide (2003), a full set of solutions to the LRE model (26) is of the form

$$s_t = \Phi_x(\vartheta) s_{t-1} + \Phi_\varepsilon(\vartheta, \tilde{M}) \varepsilon_t + \Phi_\zeta(\vartheta) \zeta_t, \quad (27)$$

where $\Phi_x(\vartheta)$, $\Phi_\varepsilon(\vartheta, \tilde{M})$, and $\Phi_\zeta(\vartheta)$ are coefficient matrices, \tilde{M} is an arbitrary matrix, and ζ_t is a reduced-form sunspot shock, which is a non-fundamental disturbance.¹⁶ For estimation, it is assumed that $\zeta_t \sim \text{i.i.d. } N(0, \sigma_\zeta^2)$. In the case of determinacy, the solution (27) is reduced to

$$s_t = \Phi_x^D(\vartheta) s_{t-1} + \Phi_\varepsilon^D(\vartheta) \varepsilon_t. \quad (28)$$

The solution (27) shows two key features under indeterminacy. First, the dynamics of the LRE model is driven not only by the fundamental shocks ε_t but also by the sunspot shock ζ_t . Second, the solution cannot be unique due to the presence of the arbitrary matrix \tilde{M} , that is, the LRE model induces indeterminate solutions. Thus, to specify the law of motion of the endogenous variables s_t , the matrix \tilde{M} must be pinned down.

The arbitrary matrix \tilde{M} is inferred from data used in estimation, following Lubik and Schorfheide (2004). To this end, we construct a prior distribution for \tilde{M} that is centered on $M^*(\vartheta)$ given in a particular solution. That is, \tilde{M} is replaced with $M^*(\vartheta) + M$, and M is estimated with prior mean zero. The matrix $M^*(\vartheta)$ is selected so that the contemporaneous

¹⁶Lubik and Schorfheide (2003) originally express the last term in (27) as $\Phi_\zeta(\theta, M_\zeta) \zeta_t$, where M_ζ is an arbitrary matrix and ζ_t is a vector of sunspot shocks. For identification, Lubik and Schorfheide (2004) impose the normalization $M_\zeta = 1$ with the dimension of the sunspot shock vector being unity. Such a normalized shock is referred to as a ‘‘reduced-form sunspot shock’’ in that it contains beliefs associated with all the expectational variables.

impulse responses of endogenous variables to fundamental shocks (i.e., $\partial s_t/\partial \varepsilon_t$) are continuous at the boundary between determinacy and indeterminacy regions of the parameter space. More specifically, for each set of ϑ , the procedure searches for a vector ϑ^* that lies on the boundary of the determinacy region and then selects $M^*(\vartheta)$ that minimizes the discrepancy between $\partial s_t/\partial \varepsilon_t(\vartheta, M^*(\vartheta))$ and $\partial s_t/\partial \varepsilon_t(\vartheta^*)$, using a least-squares criterion. In the search for ϑ^* , the procedure numerically finds ϑ^* by perturbing the parameter ϕ_π in the monetary policy rule (21), given the other parameters in ϑ .

3.2 Bayesian inference with sequential Monte Carlo algorithm

The LRE model is estimated using a Bayesian method that extends the model's likelihood function to the indeterminacy region of the parameter space. Following Lubik and Schorfheide (2004), the likelihood function for a sample of observations $X^T = [X_1, \dots, X_T]'$ is given by

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

where Θ^D, Θ^I are the determinacy and indeterminacy regions of the parameter space, $1\{\vartheta \in \Theta^i\}$, $i \in \{D, I\}$ is the indicator function that equals one if $\vartheta \in \Theta^i$ and zero otherwise, and $p^D(X^T|\vartheta)$, $p^I(X^T|\vartheta, M)$ are the likelihood functions of the state-space models that consist of observation equations and the determinacy solution (28) or the indeterminacy solution (27). Then, by Bayes' theorem, updating a prior distribution $p(\vartheta, M)$ with the sample X^T leads to the posterior distribution

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

To approximate the posterior distribution, this paper exploits the generic SMC algorithm with likelihood tempering described in Herbst and Schorfheide (2014, 2015). In the algorithm, a sequence of tempered posteriors are defined as

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

The tempering schedule $\{\tau_n\}_{n=0}^{N_\tau}$ is determined by $\tau_n = (n/N_\tau)^\chi$, where χ is a parameter that controls the shape of the tempering schedule. The SMC algorithm generates parameter

draws and associated importance weights—which are called particles—from the sequence of posteriors $\{\varpi_n\}_{n=1}^{N_\tau}$; that is, at each stage, $\varpi_n(\vartheta)$ is represented by a swarm of particles $\{\vartheta_n^i, w_n^i\}_{i=1}^N$, where N denotes the number of particles. For $n = 0, \dots, N_\tau$, the algorithm sequentially updates the swarm of particles $\{\vartheta_n^i, w_n^i\}_{i=1}^N$ through importance sampling.¹⁷ Posterior inferences about estimated parameters are made based on the particles $\{\vartheta_{N_\tau}^i, w_{N_\tau}^i\}_{i=1}^N$ from the final importance sampling. The SMC-based approximation of the marginal data density is given by

$$p(X^T) = \prod_{n=1}^{N_\tau} \left(\frac{1}{N} \sum_{i=1}^N \tilde{w}_n^i w_{n-1}^i \right),$$

where \tilde{w}_n^i is the incremental weight defined as $\tilde{w}_n^i = [p(X^T | \vartheta_{n-1}^i, M)]^{\tau_n - \tau_{n-1}}$.

In the subsequent empirical analysis, the SMC algorithm uses $N = 10,000$ particles and $N_\tau = 200$ stages. The parameter that controls the tempering schedule is set at $\chi = 2$ following Herbst and Schorfheide (2014, 2015).

3.3 Data

The systems of the log-linearized equilibrium conditions are estimated using three U.S. quarterly time series: the per-capita real GDP growth rate ($100\Delta \log Y_t$), the inflation rate of the GDP implicit price deflator ($100 \log \pi_t$), and the federal funds rate ($100 \log r_t$). The observation equations that relate the data to model variables are given by

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

where $\bar{a} = 100(a - 1)$, $\bar{\pi} = 100(\pi - 1)$, and $\bar{r} = 100(r - 1)$.

To examine the shift from indeterminacy to determinacy after the Great Inflation of the 1970s, the systems are estimated during two periods: the pre-1979 period from 1966:I to 1979:II and the post-1982 period from 1982:IV to 2008:IV. Following Lubik and Schorfheide (2004), the Volcker disinflation period from 1979:III to 1982:III is excluded. The post-1982 period ends in 2008:IV, as the estimation strategy is not able to deal with the nonlinearity that arises from the zero lower bound on the (nominal) interest rate.

¹⁷This process includes one step of a single-block RWMH algorithm.

3.4 Fixed parameters and prior distributions

Before estimation, the elasticity of labor supply and the price elasticity of demand are fixed at $\eta = 1$ and $\theta = 9.32$ to avoid an identification issue. The former value is a standard one in macroeconomics literature, while the latter is the estimate of Ascari and Sbordone (2014). All the other parameters are estimated.¹⁸ Their prior distributions are shown in Table 1. The priors of the steady-state (quarterly) rates of output growth, inflation, and interest $\bar{a}, \bar{\pi}, \bar{r}$ are distributed around their averages over the period from 1966:I to 2008:IV. The prior distributions of the structural and policy parameters— h (spending habit persistence), ω (fraction of rule-of-thumb price-setting), λ (probability of no price change¹⁹), ϕ_r (policy rate smoothing), ϕ_π (policy response to inflation), ϕ_x (policy response to the output gap), $\phi_{\Delta y}$ (policy response to output growth)—are based on Smets and Wouters (2007). For the model, these distributions generate the prior probability of determinacy of 0.482, which is almost even and suggests that there is a priori no substantial bias toward determinacy or indeterminacy. For the NK counterpart, the prior mean of ϕ_π is set at 1.1 (as in Lubik and Schorfheide, 2004), so that the prior probability of determinacy is 0.485.

Regarding the structural shocks, the prior distributions of the autoregressive parameters $\rho_i, i \in \{u, a, r\}$ are beta distributions with mean of 0.5 and standard deviation of 0.2, while those of the standard deviations of the shock innovations $\sigma_i, i \in \{u, a, r\}$ are inverse gamma distributions with mean of 0.63 and standard deviation of 0.33. As for the indeterminacy solution, the prior distribution of the coefficients $M_i, i \in \{u, a, r\}$ are normal distributions with mean zero and standard deviation of unity, while that of the standard deviation of the sunspot shock σ_ζ is the same as those of the structural shocks.

4 Results of Empirical Analysis

This section presents the results of the empirical analysis. First, the estimation results are explained. Then, the main question of what led to the U.S. economy's shift from indeterminacy of equilibrium to determinacy after the Great Inflation is addressed.

¹⁸For the subjective discount factor β , the steady-state condition $\beta = \pi a/r$ is used in estimation.

¹⁹In the NK counterpart, λ represents the probability of price-setting by indexation to trend inflation.

4.1 Estimation results

This subsection begins by comparing the empirical performance of the model with that of its canonical NK counterpart. Table 2 presents the estimation results of these two models in the pre-1979 and post-1982 periods. The second to last row of the table reports the log marginal data density $\log p(X^T)$ and shows that its value for the baseline model in each period is much greater than that for the NK counterpart, i.e., $-127.10 > -133.24$ in the pre-1979 period and $-67.51 > -77.51$ in the post-1982 period. Therefore, the model empirically outperforms the NK counterpart during both the pre-1979 and post-1982 periods. This result of model comparison justifies the use of the model instead of the NK counterpart in addressing the question of what led to U.S. macroeconomic stability after the Great Inflation, which has been investigated with canonical NK models in the previous literature. Moreover, the result suggests that the model's feature that a fraction of prices is kept unchanged in each quarter is not only consistent with micro evidence on price adjustment but also ameliorates its fit to the U.S. macroeconomic time series.

The last row of Table 2 reports the posterior probability of determinacy of equilibrium $\mathbb{P}\{\vartheta \in \Theta^D | X^T\}$, which can be calculated as the posterior distribution's probability mass assigned to the determinacy region. For both the model and the NK counterpart, the probability of determinacy is (almost) zero in the pre-1979 period, whereas it is unity in the post-1982 period. Hence, these two models share the estimation result that the U.S. economy was likely in the indeterminacy region of the parameter space before 1979, while the economy was likely in the determinacy region after 1982, in line with the result obtained in the previous literature. However, there is an important difference between the estimation results of the two models. In the NK counterpart, the policy response to inflation ϕ_π was passive (i.e., less than unity) during the pre-1979 period and became active (i.e., greater than unity) during the post-1982 period. This result is consistent with that of the previous literature, and thus the NK counterpart confirms the literature's view that ascribes the U.S. economy's shift from indeterminacy to determinacy after the Great Inflation to the Fed's policy change from a passive to an active response to inflation. By contrast, in the baseline model, the policy response to inflation was active even during the pre-1979 period, in addition to the post-1982 period. Thus, the literature's view does not hold in the model.

Because the model outperforms the NK counterpart during both periods in terms of its fit to the data, our finding is more compelling than the literature’s view.²⁰

Before investigating the sources of the U.S. economy’s shift, the remainder of this subsection examines whether abstracting from some properties of the model can improve the fit of the model even further. In light of the result of Cogley and Sbordone (2008) that there is 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., $\omega = 0$. As presented in the second to last row of Table 3, the log marginal data density of the model with $\omega = 0$ is -120.20 for the pre-1979 period and -55.59 for the post-1982 period. These values are substantially greater than those of the model without such a restriction shown in the second to last row of Table 2 (i.e., -127.10 for the pre-1979 period and -67.51 for the post-1982 period), which demonstrates that the data favors the model with $\omega = 0$, and confirms the result of Cogley and Sbordone.

In the model with no intrinsic inflation inertia (i.e., $\omega = 0$), Table 3 shows that four of the estimated parameters changed substantially between the pre-1979 and post-1982 periods. First, the policy response to inflation ϕ_π more than doubled from the pre-1979 to the post-1982 period. Second, trend inflation $\bar{\pi}$ fell by more than half. Third, the policy response to output growth $\phi_{\Delta y}$ increased by a factor of almost five. These three changes are significant in that the 90 percent credible intervals of the three parameters do not overlap between the two periods. Last but not least, the policy response to the output gap ϕ_x decreased considerably. To examine whether this decrease suggests virtually no response to the output gap, the model is further estimated with the additional restriction that the response is fixed at zero, i.e., $\phi_x = 0$. The second to last row of the table shows that the model with $\omega = \phi_x = 0$ fits the data better during the post-1982 period than the model with only $\omega = 0$ but does not during the pre-1979 period, indicating that the policy response to the output gap diminished from the estimate of 0.37 in the pre-1979 period to 0 in the post-1982 period.

²⁰Orphanides (2004) obtains an active response to inflation—which is expected inflation but not current inflation—in a Taylor-type rule estimated for the pre-1979 period, thereby claiming that self-fulfilling expectations cannot be the source of instability in the Great Inflation era. This claim, however, does not always hold for the model of the present paper, since an active policy response to inflation is not a sufficient condition for equilibrium determinacy, as also stressed by Coibion and Gorodnichenko (2011).

4.2 Sources of the U.S. economy’s shift from indeterminacy to determinacy

This subsection addresses the main question of what led to the U.S. economy’s shift from indeterminacy to determinacy after the Great Inflation. In light of the estimation results in the preceding subsection, we examine sources of the shift by focusing on the changes in trend inflation and the policy responses to inflation, the output gap, and output growth from the pre-1979 estimates in the model with $\omega = 0$ to the post-1982 estimates in the model with $\omega = \phi_x = 0$.

Figure 1 illustrates how the determinacy region of the parameter space for the annualized trend inflation rate $4\bar{\pi}$ and the policy response to inflation ϕ_π expands with changes in the other parameters. In each panel of the figure, the mark “ \times ”, “ $*$ ”, and “ o ” respectively represent the pair of $(4\bar{\pi}^{pre79}, \phi_\pi^{pre79})$, $(4\bar{\pi}^{pre79}, \phi_\pi^{post82})$, and $(4\bar{\pi}^{post82}, \phi_\pi^{post82})$, where $\bar{\pi}^{pre79}$, ϕ_π^{pre79} denote the mean estimates of the trend inflation rate and the policy response to inflation during the pre-1979 period presented in the second column of Table 3 and $\bar{\pi}^{post82}$, ϕ_π^{post82} denote those during the post-1982 period presented in the eighth column of the table.

Panel (a) shows the case in which all the model parameters (except trend inflation and the policy response to inflation) are fixed at the pre-1979 estimates (presented in the second column of Table 3). In this panel, the pair of the pre-1979 estimates of trend inflation and the policy response to inflation $(4\bar{\pi}^{pre79}, \phi_\pi^{pre79})$ —which is represented by “ \times ”—lies in the indeterminacy region of the parameter space, as shown in the estimation result that the posterior probability of determinacy during the pre-1979 period is (almost) zero. The panel also demonstrates that the pair of the pre-1979 estimate of trend inflation and the post-1982 estimate of the policy response to inflation $(4\bar{\pi}^{pre79}, \phi_\pi^{post82})$ —which is denoted by “ $*$ ”—is located within the indeterminacy region. That is, the rise in the policy response to inflation from the pre-1979 estimate ϕ_π^{pre79} to the post-1982 estimate ϕ_π^{post82} alone does not suffice for explaining the shift from indeterminacy to determinacy. Moreover, the pair of the post-1982 estimates of trend inflation and the policy response to inflation $(4\bar{\pi}^{post82}, \phi_\pi^{post82})$ —which is represented by “ o ”—lies inside the determinacy region, which suggests that the shift can be explained by the fall in trend inflation from the pre-1979 estimate $4\bar{\pi}^{pre79}$ to the post-1982 estimate $4\bar{\pi}^{post82}$ along with the rise in the policy response to inflation. This view on the

shift is consistent with the one advocated by Coibion and Gorodnichenko (2011), who pursue a different approach from ours.

Panel (b) displays the case in which the policy responses to the output gap and output growth, ϕ_x and $\phi_{\Delta y}$, are set at the post-1982 estimates (presented in the eighth column of Table 3), keeping the other model parameters fixed at the pre-1979 estimates. As the difference between panels (a) and (b) shows, the change in the policy responses to the output gap and output growth from the pre-1979 estimates to the post-1982 ones expands the determinacy region significantly. As a consequence, in panel (b), the pair of the pre-1979 estimates of trend inflation and the policy response to inflation ($4\bar{\pi}^{pre79}, \phi_{\pi}^{pre79}$) is located near the boundary between the indeterminacy and determinacy regions, whereas the pair of the pre-1979 estimate of trend inflation and the post-1982 estimate of the policy response to inflation ($4\bar{\pi}^{pre79}, \phi_{\pi}^{post82}$) lies inside the determinacy region. This indicates that the decrease in the policy response to the output gap and the increase in the response to output growth, along with the rise in the response to inflation, can account for the shift from indeterminacy to determinacy, regardless of the fall in trend inflation.²¹ This view on the shift is novel in the literature and suggests that the Fed during the post-1982 period was inclined to disregard the output gap—which involves great uncertainty about the measurement of unobservable potential output, as discussed by Orphanides (2001)—and put more emphasis on output growth as an indicator of real economic activity.

Panel (c) presents the case in which all the model parameters are set at the post-1982 estimates. In this panel, the pair of post-1982 estimates of trend inflation and the policy response to inflation ($4\bar{\pi}^{post82}, \phi_{\pi}^{post82}$) is located inside the determinacy region, consistent with the estimation result that the posterior probability of determinacy during the post-1982 period is unity. Panel (c) is not so different from panel (b), suggesting that the change in all the model parameters other than trend inflation and the policy responses to inflation, the output gap, and output growth from the pre-1979 estimates to the post-1982 ones plays a minor role in accounting for the shift from indeterminacy to determinacy.

These panels demonstrate that the rise in the policy response to inflation from the pre-

²¹In a calibrated staggered price model with trend inflation, the destabilizing role of the policy response to the output gap is indicated by Ascari and Ropele (2009), while the stabilizing role of the one to output growth is pointed out by Coibion and Gorodnichenko (2011).

1979 estimate to the post-1982 one alone does not suffice for explaining the U.S. economy's shift from indeterminacy to determinacy after the Great Inflation, without either the estimated fall in trend inflation or the estimated change in the policy responses to the output gap and output growth. Taking into consideration that trend inflation is equivalent to the central bank's inflation target in the model, this finding indicates that the Fed's policy changes in its implicit inflation target and its responses to real economic activity have played a key role in the U.S. economy's shift to determinacy, in addition to its more active response to inflation.

5 Conclusion

This paper has revisited a large literature's view that U.S. macroeconomic stability after the Great Inflation of the 1970s was achieved by the Fed's policy change from a passive to an active response to inflation. Instead of the canonical NK models used in the literature, the paper has employed a staggered price model with trend inflation and a Taylor-type rule, and has estimated it during two periods, before 1979 and after 1982, with a full-information Bayesian approach that allows for equilibrium indeterminacy and uses an SMC algorithm.

The paper has shown that the model empirically outperforms its canonical NK counterpart during both periods, which justifies the use of the model rather than the NK counterpart. According to the estimated model, the U.S. economy was likely in the indeterminacy region of the parameter space before 1979, while it was likely in the determinacy region after 1982, in line with the result obtained in the literature. However, the policy response to (current) inflation was active even during the pre-1979 period, in addition to the post-1982 period, which contrasts sharply with the literature's view that the response to inflation was passive during the Great Inflation era and that the subsequent change to an active response led to the shift from indeterminacy to determinacy. This paper has demonstrated that the rise in the policy response to inflation from the pre-1979 estimate to the post-1982 one alone does not suffice for explaining the shift, unless trend inflation or the policy responses to the output gap and output growth change from the pre-1979 estimates to the post-1982 ones. This finding extends the literature on the role of monetary policy in achieving U.S. macroeconomic stability after the Great Inflation by emphasizing the importance of the changes in the Fed's implicit inflation target and responses to real economic activity.

References

- [1] **Arias, Jonas E., Guido Ascari, Nicola Branzoli, and Efrem Castelnuovo.** 2015. “Monetary Policy, Trend Inflation and the Great Moderation: An Alternative Interpretation – Comment.” International Finance Discussion Papers, No. 1127, Board of Governors of the Federal Reserve System.
- [2] **Ascari, Guido, and Tiziano Ropele.** 2009. “Trend Inflation, Taylor Principle and Indeterminacy.” *Journal of Money, Credit and Banking*, 41(8): 1557–1584.
- [3] **Ascari, Guido, and Argia M. Sbordone.** 2014. “The Macroeconomics of Trend Inflation.” *Journal of Economic Literature*, 52(3): 679–739.
- [4] **Benati, Luca, and Paolo Surico.** 2009. “VAR Analysis and the Great Moderation.” *American Economic Review*, 99(4): 1636–1652.
- [5] **Bhattarai, Saroj, Jae Won Lee, and Woong Yong Park.** 2012. “Monetary-Fiscal Policy Interactions and Indeterminacy in Postwar US Data.” *American Economic Review*, 102(3): 173–178.
- [6] **Bhattarai, Saroj, Jae Won Lee, and Woong Yong Park.** 2016. “Policy Regimes, Policy Shifts, and U.S. Business Cycles.” *Review of Economics and Statistics*, 98(5): 968–983.
- [7] **Blanchard, Olivier Jean, and Charles M. Kahn.** 1980. “The Solution of Linear Difference Models under Rational Expectations.” *Econometrica*, 48(5): 1305–1311.
- [8] **Boivin, Jean, and Marc P. Giannoni.** 2006. “Has Monetary Policy Become More Effective?” *Review of Economics and Statistics*, 88(3): 445–462.
- [9] **Calvo, Guillermo A.** 1983. “Staggered Prices in a Utility-Maximizing Framework.” *Journal of Monetary Economics*, 12(3): 383–398.
- [10] **Christiano, Lawrence J., Martin Eichenbaum, and Charles L. Evans.** 2005. “Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy.” *Journal of Political Economy*, 113(1): 1–45.

- [11] **Clarida, Richard, Jordi Galí, and Mark Gertler.** 2000. “Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory.” *Quarterly Journal of Economics*, 115(1): 147–180.
- [12] **Cogley, Timothy, and Argia M. Sbordone.** 2008. “Trend Inflation, Indexation, and Inflation Persistence in the New Keynesian Phillips Curve.” *American Economic Review*, 98(5): 2101–2126.
- [13] **Coibion, Olivier, and Yuriy Gorodnichenko.** 2011. “Monetary Policy, Trend Inflation, and the Great Moderation: An Alternative Interpretation.” *American Economic Review*, 101(1): 341–370.
- [14] **Creal, Drew.** 2007. “Sequential Monte Carlo Samplers for Bayesian DSGE Models.” Working paper, Vrije Universiteit.
- [15] **Doko Tchatoka, Firmin, Nicolas Groshenny, Qazi Haque, and Mark Weder.** 2016. “Monetary Policy and Indeterminacy after the 2001 Slump.” School of Economics Working Papers 2016-09, University of Adelaide.
- [16] **Galí, Jordi, and Mark Gertler.** 1999. “Inflation Dynamics: A Structural Econometric Analysis.” *Journal of Monetary Economics*, 44(2): 195–222.
- [17] **Herbst, Edward, and Frank Schorfheide.** 2014. “Sequential Monte Carlo Sampling for DSGE Models.” *Journal of Applied Econometrics*, 29(7): 1073–1098.
- [18] **Herbst, Edward, and Frank Schorfheide.** 2015. *Bayesian Estimation of DSGE Models*, Princeton: Princeton University Press.
- [19] **Hirose, Yasuo.** 2007. “Sunspot Fluctuations under Zero Nominal Interest Rates.” *Economics Letters*, 97(1): 39–45.
- [20] **Hirose, Yasuo.** 2008. “Equilibrium Indeterminacy and Asset Price Fluctuation in Japan: A Bayesian Investigation.” *Journal of Money, Credit and Banking*, 40(5): 967–999.
- [21] **Hirose, Yasuo.** 2013. “Monetary Policy and Sunspot Fluctuations in the United States and the Euro Area.” *Macroeconomic Dynamics*, 17(1): 1–28.

- [22] **Hirose, Yasuo.** 2014. “An Estimated DSGE Model with a Deflation Steady State.” Centre for Applied Macroeconomic Analysis Working Paper 52/2014, Australian National University.
- [23] **Hirose, Yasuo, Takushi Kurozumi, and Willem Van Zandweghe.** 2015. “Monetary Policy, Trend Inflation, and the Great Moderation: An Alternative Interpretation: Comment Based on System Estimation.” Research Working Paper, No. 15-17, Federal Reserve Bank of Kansas City.
- [24] **Hornstein, Andreas, and Alexander L. Wolman.** 2005. “Trend Inflation, Firm-Specific Capital, and Sticky Prices.” *Federal Reserve Bank of Richmond Economic Quarterly*, Fall.
- [25] **Justiniano, Alejandro, and Giorgio E. Primiceri.** 2008. “The Time-Varying Volatility of Macroeconomic Fluctuations.” *American Economic Review*, 98(3): 604–41.
- [26] **Kahn, James A., Margaret M. McConnell, and Gabriel Perez-Quiros.** 2002. “On the Causes of the Increased Stability of the U.S. Economy.” *Federal Reserve Bank of New York Economic Policy Review*, 8(1): 183–202.
- [27] **Kiley, Michael T.** 2007. “Is Moderate-to-High Inflation Inherently Unstable?” *International Journal of Central Banking*, 3(2): 173–201.
- [28] **Klenow, Peter J., and Benjamin A. Malin.** 2010. “Microeconomic Evidence on Price-Setting.” In *Handbook of Monetary Economics*, Vol. 3, eds. Benjamin M. Friedman and Michael Woodford, 231–84. Amsterdam: Elsevier, North-Holland.
- [29] **Kobayashi, Teruyoshi, and Ichiro Muto.** 2013. “A Note on Expectational Stability under Nonzero Trend Inflation.” *Macroeconomic Dynamics*, 17(3): 681–93.
- [30] **Kurozumi, Takushi.** 2014. “Trend Inflation, Sticky Prices, and Expectational Stability.” *Journal of Economic Dynamics and Control*, 42: 175–87.
- [31] **Kurozumi, Takushi.** 2016. “Endogenous Price Stickiness, Trend Inflation, and Macroeconomic Stability.” *Journal of Money, Credit and Banking*, 48(6): 1267–91.

- [32] **Kurozumi, Takushi, and Willem Van Zandweghe.** 2016. “Kinked Demand Curves, the Natural Rate Hypothesis, and Macroeconomic Stability.” *Review of Economic Dynamics*, 20, 240–57.
- [33] **Kurozumi, Takushi, and Willem Van Zandweghe.** 2017. “Trend Inflation and Equilibrium Stability: Firm-Specific versus Homogeneous Labor.” *Macroeconomic Dynamics*, forthcoming.
- [34] **Lubik, Thomas A., and Frank Schorfheide.** 2003. “Computing Sunspot Equilibria in Linear Rational Expectations Models.” *Journal of Economic Dynamics and Control*, 28(2): 273–85.
- [35] **Lubik, Thomas A., and Frank Schorfheide.** 2004. “Testing for Indeterminacy: An Application to U.S. Monetary Policy.” *American Economic Review*, 94(1): 190–217.
- [36] **Mavroeidis, Sophocles.** 2010. “Monetary Policy Rules and Macroeconomic Stability: Some New Evidence.” *American Economic Review*, 100(1): 491–503.
- [37] **Nakamura, Emi, and Jon Steinsson.** 2013. “Price Rigidity: Microeconomic Evidence and Macroeconomic Implications.” *Annual Review of Economics*, 5: 133–63.
- [38] **Orphanides, Athanasios.** 2001. “Monetary Policy Rules Based on Real-Time Data.” *American Economic Review*, 91(4): 964–85.
- [39] **Orphanides, Athanasios.** 2004. “Monetary Policy Rules, Macroeconomic Stability, and Inflation: A View from the Trenches.” *Journal of Money, Credit and Banking*, 36(2): 151–75.
- [40] **Sims, Christopher A.** 2002. “Solving Linear Rational Expectations Models.” *Computational Economics*, 20(1-2): 1–20.
- [41] **Sims, Christopher A., and Tao Zha.** 2006. “Were There Regime Switches in U.S. Monetary Policy?” *American Economic Review*, 96(1): 54–81.
- [42] **Smets, Frank, and Rafael Wouters.** 2007. “Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach.” *American Economic Review*, 97(3): 586–606.

- [43] **Taylor, John B.** 1993. “Discretion Versus Policy Rules in Practice.” *Carnegie-Rochester Conference Series on Public Policy*, 39(1): 195–214.
- [44] **Yun, Tack.** 1996. “Nominal Price Rigidity, Money Supply Endogeneity, and Business Cycles.” *Journal of Monetary Economics*, 37(2-3): 345–70.

Table 1: Prior distributions of parameters of the model and the NK counterpart

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	Beta	0.500	0.200
ρ_a	Beta	0.500	0.200
ρ_r	Beta	0.500	0.200
σ_u	Inverse gamma	0.627	0.328
σ_a	Inverse gamma	0.627	0.328
σ_r	Inverse gamma	0.627	0.328
σ_ζ	Inverse gamma	0.627	0.328
M_u	Normal	0.000	1.000
M_a	Normal	0.000	1.000
M_r	Normal	0.000	1.000

Notes: The prior mean of the policy response to inflation ϕ_π is 1.5 for the model and 1.1 for the NK counterpart. The prior probability of determinacy of equilibrium is 0.482 for the model and 0.485 for the NK counterpart. Inverse gamma distributions are of the form $p(\sigma|\nu, s) \propto \sigma^{-\nu-1} e^{-\nu s^2/2\sigma^2}$, where $\nu = 4$ and $s = 0.5$.

Table 2: Posterior distributions of parameters of the model and the NK counterpart

Parameter	Pre-1979 period			Post-1982 period				
	Baseline model		NK counterpart	Baseline model		NK counterpart		
	Mean	90% interval	Mean	90% interval	Mean	90% interval		
\bar{a}	0.353	[0.156, 0.572]	0.387	[0.172, 0.619]	0.399	[0.211, 0.584]	0.410	[0.223, 0.576]
$\bar{\pi}$	1.512	[1.189, 1.836]	1.349	[0.900, 1.794]	0.701	[0.537, 0.880]	0.679	[0.491, 0.873]
\bar{r}	1.663	[1.395, 1.941]	1.585	[1.270, 1.914]	1.442	[1.168, 1.741]	1.385	[1.119, 1.672]
h	0.550	[0.439, 0.653]	0.548	[0.426, 0.669]	0.625	[0.540, 0.713]	0.605	[0.523, 0.682]
ω	0.143	[0.050, 0.222]	0.110	[0.039, 0.180]	0.064	[0.024, 0.102]	0.069	[0.026, 0.110]
λ	0.521	[0.450, 0.594]	0.513	[0.428, 0.595]	0.458	[0.389, 0.534]	0.435	[0.365, 0.503]
ϕ_r	0.707	[0.591, 0.833]	0.692	[0.573, 0.814]	0.678	[0.602, 0.768]	0.617	[0.530, 0.701]
ϕ_π	1.028	[0.399, 1.640]	0.401	[0.083, 0.696]	2.730	[1.924, 3.574]	2.358	[1.795, 2.893]
ϕ_x	0.313	[0.095, 0.562]	0.163	[0.002, 0.320]	0.114	[0.001, 0.229]	0.085	[0.002, 0.168]
$\phi_{\Delta y}$	0.119	[0.003, 0.235]	0.125	[0.003, 0.243]	0.466	[0.269, 0.673]	0.409	[0.239, 0.565]
ρ_u	0.414	[0.125, 0.711]	0.459	[0.124, 0.762]	0.905	[0.868, 0.947]	0.914	[0.881, 0.949]
ρ_a	0.741	[0.492, 0.943]	0.428	[0.123, 0.731]	0.133	[0.014, 0.241]	0.095	[0.011, 0.167]
ρ_r	0.424	[0.200, 0.655]	0.439	[0.252, 0.626]	0.660	[0.579, 0.748]	0.672	[0.598, 0.753]
σ_u	0.968	[0.252, 2.194]	0.681	[0.252, 1.131]	2.032	[1.407, 2.712]	1.974	[1.405, 2.512]
σ_a	0.726	[0.351, 1.075]	1.737	[1.010, 2.487]	1.456	[1.139, 1.761]	1.410	[1.137, 1.685]
σ_r	0.282	[0.229, 0.333]	0.272	[0.226, 0.319]	0.233	[0.177, 0.286]	0.255	[0.193, 0.319]
σ_ζ	0.387	[0.286, 0.475]	0.471	[0.315, 0.610]	1.196	[0.267, 2.402]	0.689	[0.314, 1.039]
M_u	0.010	[-0.479, 0.477]	0.043	[-0.838, 0.784]	-0.608	[-2.243, 1.202]	-0.906	[-1.903, 0.100]
M_a	-0.263	[-0.786, 0.376]	-0.266	[-0.559, 0.009]	-0.751	[-2.202, 0.730]	-0.327	[-1.353, 0.655]
M_r	0.102	[-0.475, 0.708]	1.025	[0.118, 1.897]	0.055	[-1.596, 1.817]	-0.473	[-1.658, 0.705]
$\log p(X^T)$		-127.100		-133.240		-67.513		-77.511
$\mathbb{P}\{\vartheta \in \Theta^D X^T\}$		0.000		0.002		1.000		1.000

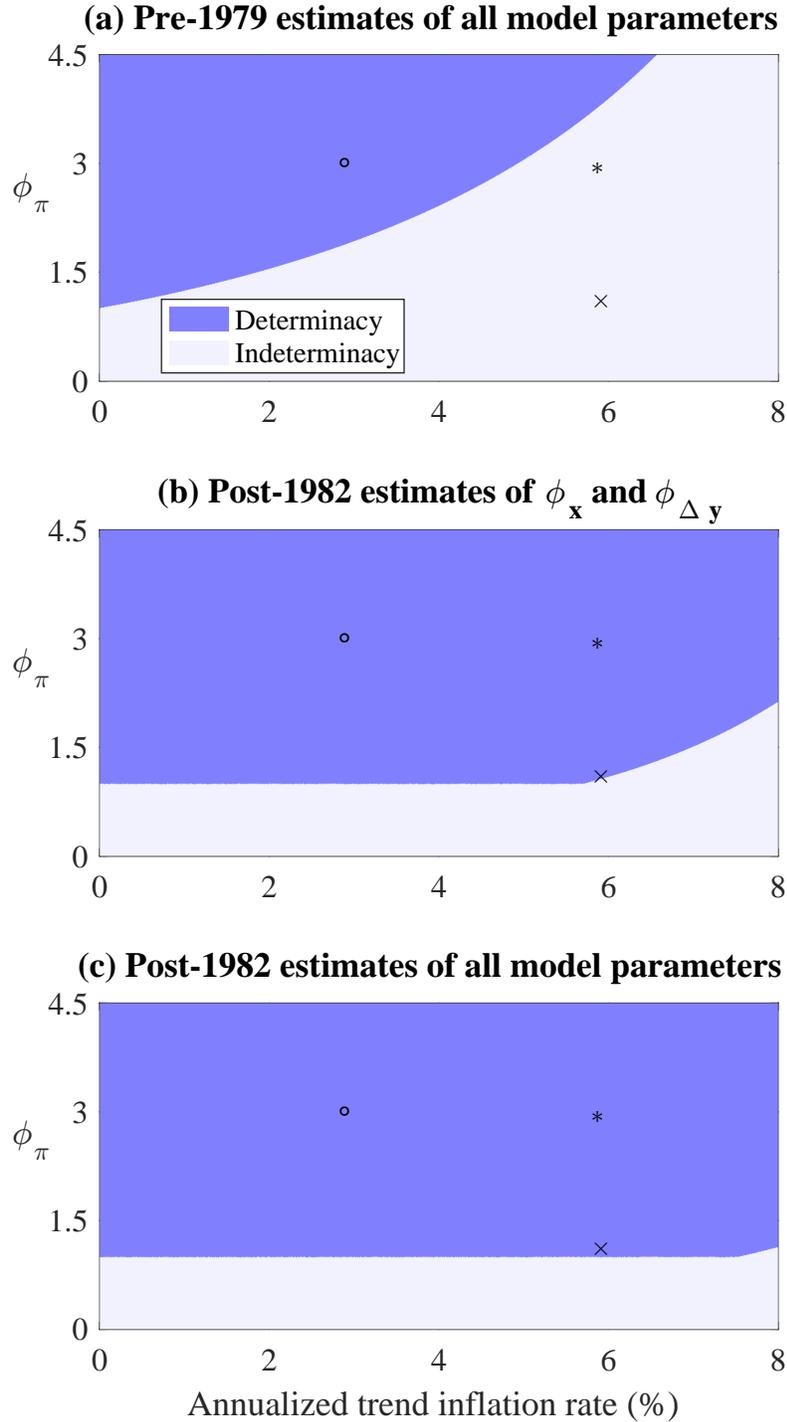
Note: This table shows the posterior mean and 90 percent highest posterior density intervals based on 10,000 particles from the final importance sampling in the SMC algorithm. In the table, $\log p(X^T)$ represents the SMC-based approximation of the log marginal data density and $\mathbb{P}\{\vartheta \in \Theta^D | X^T\}$ denotes the posterior probability of determinacy of equilibrium.

Table 3: Posterior distributions of parameters of the model with no intrinsic inertia of inflation

Parameter	Pre-1979 period			Post-1982 period		
	$\omega = 0$		$\omega = \phi_x = 0$	$\omega = 0$		$\omega = \phi_x = 0$
	Mean	90% interval	Mean	90% interval	Mean	90% interval
\bar{a}	0.379	[0.193, 0.555]	0.374	[0.141, 0.606]	0.392	[0.221, 0.560]
$\bar{\pi}$	1.447	[1.116, 1.768]	1.431	[1.125, 1.766]	0.700	[0.560, 0.839]
\bar{r}	1.641	[1.359, 1.920]	1.632	[1.329, 1.928]	1.446	[1.173, 1.722]
h	0.568	[0.430, 0.700]	0.574	[0.458, 0.705]	0.598	[0.520, 0.682]
ω	0	-	0	-	0	-
λ	0.530	[0.455, 0.601]	0.503	[0.415, 0.585]	0.458	[0.390, 0.522]
ϕ_r	0.702	[0.583, 0.819]	0.651	[0.515, 0.790]	0.690	[0.607, 0.776]
ϕ_π	1.179	[0.260, 2.065]	0.720	[0.143, 1.563]	2.989	[2.228, 3.792]
ϕ_x	0.370	[0.106, 0.620]	0	-	0.125	[0.001, 0.252]
$\phi_{\Delta y}$	0.106	[0.003, 0.212]	0.214	[0.007, 0.406]	0.526	[0.322, 0.746]
ρ_u	0.456	[0.178, 0.731]	0.521	[0.174, 0.866]	0.923	[0.887, 0.962]
ρ_a	0.554	[0.207, 0.900]	0.597	[0.251, 0.893]	0.146	[0.035, 0.263]
ρ_r	0.412	[0.195, 0.624]	0.410	[0.231, 0.591]	0.608	[0.521, 0.705]
σ_u	1.859	[0.287, 3.333]	0.738	[0.252, 1.359]	2.323	[1.365, 3.318]
σ_a	0.651	[0.291, 0.990]	1.207	[0.470, 2.053]	1.340	[1.066, 1.583]
σ_r	0.282	[0.213, 0.343]	0.289	[0.219, 0.355]	0.240	[0.185, 0.297]
σ_ζ	0.385	[0.284, 0.482]	0.449	[0.260, 0.589]	0.640	[0.263, 1.036]
M_u	-0.013	[-0.370, 0.316]	0.044	[-0.702, 0.834]	0.146	[-1.436, 1.785]
M_a	-0.102	[-0.711, 0.629]	0.092	[-0.734, 0.656]	-0.089	[-1.612, 1.554]
M_r	0.093	[-0.546, 0.704]	-0.467	[-1.886, 0.702]	-0.065	[-1.698, 1.554]
$\log p(X^T)$	-120.200		-124.040		-55.590	
$\mathbb{P}\{\vartheta \in \Theta^D X^T\}$	0.001		0.168		1.000	
						-54.214
						1.000

Note: This table shows the posterior mean and 90 percent highest posterior density intervals based on 10,000 particles from the final importance sampling in the SMC algorithm. In the table, $\log p(X^T)$ represents the SMC-based approximation of the log marginal data density and $\mathbb{P}\{\vartheta \in \Theta^D | X^T\}$ denotes the posterior probability of determinacy of equilibrium.

Figure 1: Equilibrium determinacy region of the parameter space



Notes: The figure shows the equilibrium determinacy region of the model parameter space of the annualized trend inflation rate $4\bar{\pi}$ and the policy response to inflation ϕ_π . In each panel, the mark “×”, “*”, and “o” respectively represent the pair of $(4\bar{\pi}^{pre79}, \phi_\pi^{pre79})$, $(4\bar{\pi}^{pre79}, \phi_\pi^{post82})$, and $(4\bar{\pi}^{post82}, \phi_\pi^{post82})$, where $\bar{\pi}^{pre79}$, $\bar{\pi}^{post82}$, and ϕ_π^{post82} denote the mean estimates of the trend inflation rate and the policy response to inflation during the pre-1979 and post-1982 periods.