Monetary Policy and Macroeconomic Stability Revisited

Yasuo Hirose†  Takushi Kurozumi‡  Willem Van Zandweghe§

Abstract

A large literature has established that the Fed’s change from a passive to an active policy response to inflation led to U.S. macroeconomic stability after the Great Inflation of the 1970s. This paper revisits the literature’s view by estimating a generalized New Keynesian (NK) model using a full-information Bayesian method that allows for equilibrium indeterminacy and adopts a sequential Monte Carlo algorithm. The estimated model shows an active policy response to inflation even during the Great Inflation. Moreover, a more active policy response to inflation alone does not suffice for explaining the macroeconomic stability, unless it is accompanied by a change in either trend inflation or policy responses to the output gap and output growth. Our model empirically outperforms canonical NK models used in the literature, thus giving strong support to our view.

Keywords. Monetary policy, Great Inflation, Indeterminacy, Trend inflation, Sequential Monte Carlo

JEL Classification. C11, C52, C62, E31, E52

*The authors are grateful to Olivier Coibion, Taeyoung Doh, Mark Gertler, Yuriy Gorodnichenko, Edward Herbst, Alejandro Justiniano, Christian Matthes, Sophocles Mavroeidis, Frank Schorfheide, Mototsugu Shintani, Alexander Wolman, Raf Wouters, and seminar participants at the Bank of Japan, the Federal Reserve Bank of Kansas City, and the National Bank of Belgium for comments and discussions. The views expressed in this paper are those of the authors and do not necessarily reflect the official views of the Bank of Japan, the Federal Reserve Bank of Kansas City, or the Federal Reserve System.

†Faculty of Economics, Keio University: yhirose@econ.keio.ac.jp
‡Monetary Affairs Department, Bank of Japan: takushi.kurozumi@boj.or.jp
§Research Department, Federal Reserve Bank of Kansas City: willem.vanzandweghe@kc.frb.org
1 Introduction

What led to macroeconomic stability in the U.S. after the Great Inflation of the 1970s? 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 Fed’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 change from a passive to an active policy response to inflation.² Clarida, Galí, and Gertler (2000) 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.³ Lubik and Schorfheide (2004) confirm the view by estimating a Taylor-type rule and an NK model jointly during similar periods with a full-information Bayesian approach that allows for indeterminacy and sunspot fluctuations.⁴

This paper revisits the literature’s view by estimating a generalized NK (henceforth GNK) model jointly with a Taylor-type rule.⁵ This model differs from canonical NK (henceforth CNK) models used in the literature mainly in that, following micro evidence, each period some prices remain unchanged even under non-zero trend inflation. As a consequence, a generalized NK Phillips curve takes the place of a canonical one, and causes the GNK

¹Following the literature, this paper explains the U.S. macroeconomic stability 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.

³Mavroeidis (2010) points to a weak-identification issue in the GMM estimation of the Taylor-type rule by Clarida, Galí, and Gertler (2000), and emphasizes the need to make use of identifying assumptions that can be derived from the full structure of their model.

⁴See also Boivin and Giannoni (2006), Kimura and Kurozumi (2010), and Lubik and Matthes (2016) among others for the monetary-policy explanation of U.S. macroeconomic stability after the Great Inflation.

⁵For a literature review on GNK models, see, e.g., Ascari and Sbordone (2014).
model to be more susceptible to indeterminacy than CNK models, as indicated by Ascari and Ropele (2009), Hornstein and Wolman (2005), and Kiley (2007). Indeed, even an active policy response to inflation that generates determinacy in CNK models can induce indeterminacy in the GNK model.

Our estimation is performed using a full-information Bayesian approach based on Lubik and Schorfheide (2004). A difficulty in their approach is that when a model is estimated over both determinacy and indeterminacy regions of the model’s parameter space, its likelihood function is possibly discontinuous at the boundary of each region. As a consequence, the Random-Walk Metropolis-Hastings (henceforth RWMH) algorithm—which has been the most widely used in Bayesian estimation—can get stuck near a local mode and fail to find the entire posterior distribution for the model’s parameters. To deal with this difficulty, our paper adopts the sequential Monte Carlo (henceforth SMC) algorithm developed by Herbst and Schorfheide (2014, 2015). As they illustrate, the SMC algorithm can produce more reliable estimates of model parameters than the RWMH algorithm when the parameters’ posterior distribution is multimodal. This is particularly the case when the likelihood function of a model to be estimated exhibits discontinuity as in our paper.

Our empirical analysis makes three main contributions to the literature. First of all, the GNK model empirically outperforms CNK models used in the previous literature during both periods before and after the Volcker disinflation of 1979–1982. This finding indicates...
cates that the former model is more suitable than the latter for the analysis of what led to U.S. macroeconomic stability after the Great Inflation. In other words, the feature of the GNK model that some prices remain unchanged in each time period is not only more consistent with micro evidence on prices but also improves the model’s fit to U.S. macroeconomic time series.

Second, the U.S. economy was likely in the indeterminacy region of the (GNK) 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 inflation was active in the Taylor-type rule, which adjusts the interest rate for contemporaneous values of inflation, the output gap, and output growth in the presence of interest rate smoothing. This finding contrasts sharply with the literature’s view that the policy response to inflation was passive during the Great Inflation and that the subsequent change to an active response led to the shift from indeterminacy to determinacy.

Last but not least, the increase in the policy response to inflation from the pre-1979 to the post-1982 estimate alone does not suffice for explaining the U.S. economy’s shift, unless it is accompanied by either the estimated decline 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 in the model), 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. Therefore, the finding extends the literature by emphasizing the importance of the changes in other aspects of monetary policy than its response to inflation.

This paper is an extension of Lubik and Schorfheide (2004) and a complementary study to Coibion and Gorodnichenko (2011). Our paper strengthens the analysis of Lubik and

9Orphanides (2004) obtains active responses to expected future inflation in both periods before and after Volcker’s appointment as Fed Chairman by estimating a Taylor-type rule with real-time data on the Federal Reserve Board’s Greenbook forecast. See also Coibion and Gorodnichenko (2011).

10The CNK models confirm the previous 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.

11Arias et al. (2017) extend the analysis of Coibion and Gorodnichenko (2011) by employing a medium-
Schorfheide by adopting the SMC algorithm in their full-information Bayesian approach and estimating the GNK model (jointly with the Taylor-type rule) as well as the CNK models, which are similar to their model. Coibion and Gorodnichenko revisit the literature’s view by using a calibrated GNK model in an approach analogous to Clarida, Galí, and Gertler (2000), and offer the alternative view that the U.S. economy’s shift to determinacy after the Great Inflation is due to their estimated change in a Taylor-type rule and their calibrated fall in trend inflation.\textsuperscript{12} An advantage of our analysis is that our GNK model empirically outperforms the CNK models used in the literature, giving strong support to our view on the economy’s shift rather than the literature’s view.

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

\section{Generalized New Keynesian Model}

This paper investigates the source of the U.S. economy’s shift from indeterminacy of equilibrium to determinacy after the Great Inflation by estimating a GNK model jointly with a Taylor-type rule. This model differs from CNK models used in previous literature mainly in that, following micro evidence, each period a fraction of prices remains unchanged even under non-zero trend inflation.

In the model there are a representative household, a representative final-good firm, a continuum of intermediate-good firms, and a central bank. The model introduces (external) habit formation in the household’s consumption preferences, backward-looking price-setters among intermediate-good firms, and interest-rate smoothing in the Taylor-type rule so that output, inflation, and the interest rate can exhibit persistence.\textsuperscript{13} This is because our estimationscale GNK model based on Christiano, Eichenbaum, and Evans (2005), which is estimated during a post-1984 period within the determinacy region of the model’s parameter space.

\textsuperscript{12}In the estimation of the Taylor-type rule by Coibion and Gorodnichenko (2011), its constant term contains not only trend inflation but also other factors. They thus calibrate the level of trend inflation.

\textsuperscript{13}Backward-looking price-setters are incorporated as in Galí and Gertler (1999) not only to embed intrinsic inertia of inflation but also to keep a fraction of prices unchanged in each period.
tion is conducted with a full-information Bayesian approach based on Lubik and Schorfheide (2004), which may have a bias toward indeterminacy unless the model can generate sufficient persistence, as argued by Beyer and Farmer (2007).

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 $B_t$ so as to maximize the utility function

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

subject to the budget constraint $P_t \tilde{C}_t + B_t = \int_0^1 P_i W_t(i) l_t(i) di + r_{t-1} B_{t-1} + T_t$, 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 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 rate paid by intermediate-good firm $i$, $r_t$ is the (gross) interest rate on bonds and is assumed to equal the monetary policy rate, $T_t$ consists of lump-sum taxes and transfers and firm profits received, and $z_{u,t}$ is a shock to current preferences.

The first-order conditions for utility maximization 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 $\Xi_t$ 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 combining intermediate goods $\{Y_t(i)\}$ so as to maximize profit $P_t Y_t - \int_0^1 P_t(i) Y_t(i) di$ subject to the CES aggregator

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

where $P_t(i)$ is the price of intermediate good $i$ and $\theta > 1$ is the elasticity of substitution between intermediate goods.
The first-order condition for profit maximization yields the final-good firm’s demand curve for intermediate good \( i \)

\[
Y_t(i) = Y_t \left( \frac{P_t(i)}{P_t} \right)^{-\theta},
\]

and thus the CES aggregator leads to

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

The final-good market clearing condition is given by

\[
Y_t = C_t.
\]

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

\[
Y_t(i) = A_t l_t(i),
\]

where \( A_t \) denotes the technology level and follows the stochastic process

\[
\log A_t = \log a + \log A_{t-1} + z_{a,t},
\]

where \( \log a \) is the steady-state rate of technological change, which turns out to be equal to the steady-state 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

\[
mc_t(i) = \frac{W_t(i)}{A_t}.
\]

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, 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 backward-looking rule of thumb is given by

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

where

\[
P_t^a = (P_t^r)^{\omega} (P_t^o)^{1-\omega} \quad \text{or} \quad p_t^a = \frac{P_t^a}{P_t} = \left( \frac{P_t^r}{P_t} \right)^{\omega} \left( \frac{P_t^o}{P_t} \right)^{1-\omega} = (P_t^r)^{\omega} (P_t^o)^{1-\omega},
\]
and $P^o_t$ is the price set by optimizing firms in period $t$. The price $P^o_t$ maximizes the relevant profit function $E_t \sum_{j=0}^{\infty} \lambda^j Q_{t,t+j} \left( P_t(i)/P_{t+j} - mc_{t+j}(i) \right) Y_{t+j}(P_t(i)/P_{t+j})^{-\theta}$, where $Q_{t,t+j}$ is the stochastic discount factor between period $t$ and period $t+j$.

The first-order condition for the optimized price $P^o_t$ becomes

$$E_t \sum_{j=0}^{\infty} (\beta \lambda)^j \Xi_{t+j} Y_{t+j}^\theta \prod_{k=1}^{j} \frac{1}{\pi_{t+k}} m_{c_t+j}^\theta = 0, \quad (12)$$

where the equilibrium condition $Q_{t,t+j} = \beta^j \Xi_{t+j}/\Xi_t$ is used and $mc_{t+j}$ 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

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

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

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

### 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 inflation $\pi_t$, the output gap $x_t$, and output growth $Y_t/Y_{t-1}$ in the presence of policy rate smoothing:

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

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, $\pi$ is the steady-state value of $\pi_t$ and represents the (gross) rate of trend inflation, $\phi_r \in [0, 1)$ is the degree of policy rate smoothing, and $\phi_\pi, \phi_x, \phi_{\Delta y}$ 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), we can derive the law of motion for the natural rate of output
\[
\left(\frac{Y_t^n}{A_t}\right)^{1+\frac{1}{\theta}} = \frac{\theta - 1}{\theta} + h \left(\frac{Y_{t-1}^n}{A_t}\right) Y_{t-1}^n.
\]

(17)

2.4 Equilibrium conditions

The equilibrium conditions consist of (1), (3), (6), (8), (10)–(16), and (17). For the steady state to be well defined, the following condition is assumed:
\[
\lambda \max(\pi^{\theta-1}, \beta \pi^{\theta(1+1/\eta)}) < 1.
\]

(18)

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

(19)

\[
\psi_t = \gamma_b E_t \psi_{t+1} + \kappa_\psi (E_t \hat{y}_{t+1} - \hat{y}_t + \theta E_t \hat{\pi}_{t+1} - \hat{r}_t),
\]

(20)

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

(21)

\[
\hat{r}_t = \phi, \hat{r}_{t-1} + (1 - \phi) \left[ \phi_\pi \hat{\pi}_t + \phi_x \hat{x}_t + \phi_{\Delta y}(\hat{y}_t - \hat{y}_{t-1} + z_{a,t}) \right] + z_{r,t},
\]

(22)

\[
\hat{x}_t = \hat{y}_t - \hat{y}_{t}^n,
\]

(23)

\[
\hat{y}_{t}^n = \frac{h \eta}{a(1+\eta) - h} (\hat{y}_{t-1} - z_{a,t}),
\]

(24)

where hatted variables denote log-deviations from steady-state values, \(\psi_t\) is an auxiliary variable, and the coefficients in (19) and (20) are given by \(\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 - \omega)/\varphi][(1 + 1/\eta)/(1 + \theta/\eta)], \gamma_\psi = \beta \lambda \pi^{\theta-1}, \kappa_\psi = \gamma_\psi (\pi^{1+\theta/\eta} - 1)(1 - \lambda \pi^{\theta-1})(1 - \omega)/[\varphi(1 + \theta/\eta)], \text{ and } \varphi = \lambda \pi^{\theta-1} + \omega(1 - \lambda \pi^{\theta-1} + \beta \lambda \pi^{\theta(1+1/\eta)}).

Equation (19) is called the generalized NK Phillips curve.

Each of the three shocks \(z_{j,t}, j \in \{u, a, r\}\) is assumed to follow the stationary first-order autoregressive process
\[
z_{j,t} = \rho_j z_{j,t-1} + \varepsilon_{j,t},
\]

(25)

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 models

We compare the empirical performance of the GNK model with that of two types of CNK models. Moreover, the estimation of the CNK models enables us to confirm the literature’s view on the U.S. economy’s shift from indeterminacy to determinacy after the Great Inflation and to compare that view with ours.

One type of CNK model incorporates price indexation to past inflation as in Smets and Wouters (2007). This model, called the SW-CNK model, can be derived by altering the GNK model so that each period a fraction \( \lambda \) of firms updates prices using indexation to recent past inflation \( \pi_{t-1} \) and trend inflation \( \pi \) with the relative past-inflation weight \( \omega_{sw} \in [0,1] \), while the remaining fraction \( 1-\lambda \) sets prices optimally. The resulting system of log-linearized equilibrium conditions consists of (21)–(25) and the NK Phillips curve

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

where \( \gamma_{b,cnk} = \omega_{sw}/\varphi_{sw} \), \( \gamma_{f,cnk} = \beta/\varphi_{sw} \), \( \kappa_{cnk} = [(1-\lambda)(1-\beta\lambda)/(\lambda\varphi_{sw})][(1+1/\eta)/(1+\theta/\eta)] \), and \( \varphi_{sw} = 1 + \beta \omega_{sw} \).

The other type is based on Galí and Gertler (1999) and is a CNK counterpart to the GNK model. This model, referred to as the GG-CNK model, can be derived by altering the GNK model so that firms that keep prices unchanged in the aforementioned setting update prices using indexation to trend inflation \( \pi \) as in Yun (1996). The GG-CNK model differs from the SW-CNK model only in the coefficients of the NK Phillips curve (26), \( \gamma_{b,cnk}, \gamma_{f,cnk}, \kappa_{cnk} \), which correspond to those of the generalized NK Phillips curve (19), \( \gamma_b, \gamma_f, \kappa \), with zero trend inflation (i.e., \( \pi = 1 \)), that is, \( \gamma_{b,cnk} = \omega/\varphi_1 \), \( \gamma_{f,cnk} = \beta\lambda/\varphi_1 \), \( \kappa_{cnk} = [(1-\lambda)(1-\beta\lambda)(1-\omega)/\varphi_1][(1+1/\eta)/(1+\theta/\eta)] \), and \( \varphi_1 = \lambda + \omega(1-\lambda+\beta\lambda) \). This implies that the GNK model and its CNK counterpart (i.e., the GG-CNK model) coincide only when trend inflation is zero, so that the GNK model does not literally generalize the CNK counterpart.

Thus, we also consider an NK model that nests the GNK model and its CNK counterpart, by altering the GNK model so that firms that keep prices unchanged in the model update prices using indexation to trend inflation \( \pi \) with the degree \( \alpha \in [0,1] \). This model, called the nested model, differs from the GNK model only in the coefficients of the generalized NK Phillips curve (19) and the auxiliary-variable equation (20), which are given by \( \gamma_b = \omega/\varphi \), \( \gamma_f = \beta\lambda\pi^{\alpha(1+1/\eta)(1-\alpha)}/\varphi \), \( \kappa = [(1-\lambda\pi^{(\theta-1)(1-\alpha)})(1-\beta\lambda\pi^{(1+1/\eta)(1-\alpha)})(1-\omega)/\varphi][(1+1/\eta)/(1+\theta/\eta)] \),
\[ \gamma_{\psi} = \beta \lambda \pi^{(\theta-1)(1-\alpha)}, \quad \kappa_{\psi} = \gamma_{\psi}(\pi^{(1+\theta/\eta)(1-\alpha)} - 1)(1 - \lambda \pi^{(\theta-1)(1-\alpha)})(1 - \omega)/[\varphi(1 + \theta/\eta)], \] and

\[ \varphi = \lambda \pi^{(\theta-1)(1-\alpha)} + \omega(1 - \lambda \pi^{(\theta-1)(1-\alpha)} + \beta \lambda \pi^{(\theta(1+1/\eta)(1-\alpha))}). \] The nested model includes the GNK model and the GG-CNK model as the special cases of \( \alpha = 0 \) and \( \alpha = 1 \), respectively.

### 3 Estimation Strategy and Data

This section describes the strategy and data for estimating the GNK model, the two types of CNK models, and the nested model presented in the preceding section. These models are estimated using a full-information Bayesian approach based on Lubik and Schorfheide (2004). Specifically, each model’s likelihood function is constructed not only for the determinacy region of the model’s parameter space but also for the indeterminacy region.\(^{14}\) The likelihood function can then exhibit discontinuity at the boundary of each region.\(^ {15}\) As a consequence, the posterior distribution for parameters in the model 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 for the parameters. To deal with this problem, the SMC algorithm developed by Herbst and Schorfheide (2014, 2015) is adopted to generate the posterior distribution.\(^ {16}\) 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, it presents the data and prior distributions used in estimation.

---

\(^{14}\) The 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, a set of particular solutions that are the most consistent with data can be selected from a full set of solutions.

\(^{15}\) With 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.

\(^{16}\) Creal (2007) is the first paper that uses an SMC algorithm in Bayesian estimation of a dynamic stochastic general equilibrium model.
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).\(^{17}\) Any LRE model can be written in the canonical form

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

(27)

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

\[ s_t = [\hat{y}_t, \hat{\pi}_t, \hat{r}_t, \hat{y}_{tn}, \hat{x}_t, \psi_t, z_{tu, t}, z_{ta, t}, z_{tr, t}, E_t\hat{y}_t + 1, E_t\hat{\pi}_t + 1, E_t\psi + 1]' \]

\[ \varepsilon_t = [\varepsilon_{u, t}, \varepsilon_{a, t}, \varepsilon_{r, t}]' \]

\[ \xi_t = [(\hat{y}_t - E_{t-1}\hat{y}_t), (\hat{\pi}_t - E_{t-1}\hat{\pi}_t), (\psi_t - E_{t-1}\psi_t)]' \]

According to Lubik and Schorfheide (2003), a full set of solutions to the LRE model (27) is of the form

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

(28)

where \(\Phi_x(\vartheta), \Phi_\varepsilon(\vartheta, \tilde{M}),\) and \(\Phi_\zeta(\vartheta)\) are coefficient matrices, \(\tilde{M}\) is an arbitrary matrix, and \(\zeta_t\) is a reduced-form sunspot shock, which is a non-fundamental disturbance.\(^{18}\) 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 (28) is reduced to

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

(29)

The solution (28) shows two key features under indeterminacy. First, the dynamics of the LRE model is driven not only by the fundamental shocks \(\varepsilon_t\) but also by the sunspot shock

\(--\)

\(^{17}\)Sims (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 to forecast errors of fundamental shocks and that of sunspot shocks are orthogonal.

\(^{18}\)Lubik and Schorfheide (2003) originally express the last term in (28) as \(\Phi_\zeta(\theta, M_\zeta)\zeta_t\), where \(M_\zeta\) is an arbitrary matrix and \(\zeta_t\) 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.
ζ. 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 the data used in estimation, following Lubik and Schorfheide (2004). The prior distribution for \( \tilde{M} \) is set so that it is centered around the matrix \( M^*(\vartheta) \) 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 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 \( \vartheta \), the procedure searches for a vector \( \vartheta^* \) that lies on the boundary of the determinacy region, and 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 \( \vartheta^* \), the procedure numerically finds \( \vartheta^* \) by perturbing the parameter \( \phi_\pi \) in the monetary policy rule (22), given the other parameters in \( \vartheta \).

### 3.2 Bayesian inference with a sequential Monte Carlo algorithm

The LRE model is estimated using a full-information Bayesian approach 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 \( X^T = [X_1, ..., X_T]' \) 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 \( \Theta^D \) and \( \Theta^I \) 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 \( p^D(X^T|\vartheta) \) and \( p^I(X^T|\vartheta, M) \) are the likelihood functions of the state-space models that consist of observation equations and either the determinacy solution (29) or the indeterminacy solution (28). 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

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

The tempering schedule \( \{\tau_n\}_{n=0}^{N_r} \) is determined by \( \tau_n = (n/N_r)^\chi \), where \( \chi \) 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 \( \{\varpi_n\}_{n=1}^{N_r} \); that is, at each stage, \( \varpi_n(\vartheta) \) is represented by a swarm of particles \( \{\vartheta_{in}, w_{in}\}_{i=1}^{N} \), where \( N \) denotes the number of particles. For \( n = 0, ..., N_r \), the algorithm sequentially updates the swarm of particles \( \{\vartheta_{in}, w_{in}\}_{i=1}^{N} \) through importance sampling.\(^\text{19}\)

Posterior inferences about parameters to be estimated are made based on the particles \( \{\vartheta_{N_r}, w_{N_r}\}_{i=1}^{N} \) from the final importance sampling. The SMC-based approximation of the marginal data density is given by

\[ p(X^T) = \prod_{n=1}^{N_r} \left( \frac{1}{N} \sum_{i=1}^{N} \tilde{w}_{in}^{i} w_{n-1}^{i} \right), \]

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

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

### 3.3 Data

Our estimation is performed using three U.S. quarterly 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

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

\(^{19}\)This process includes one step of a single-block RWMH algorithm.
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, estimation is conducted in 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.

3.4 Fixed parameters and prior distributions

Before estimation, the elasticity of labor supply and the elasticity of substitution between intermediate goods are fixed at \( \eta = 1 \) and \( \theta = 9.32 \) to avoid an identification issue. The former value is a standard one in the macroeconomic literature, while the latter is the estimate of Ascari and Sbordone (2014). All the other parameters are estimated; their prior distributions are shown in Table 1.\(^{20}\)

The prior mean of the steady-state (quarterly) rates of output growth, inflation, and interest \( \bar{a}, \bar{\pi}, \bar{r} \) is set at their respective averages over the period from 1966:I to 2008:IV. The prior distributions for the structural and policy parameters—\( h \) (spending habit persistence), \( \omega \) (fraction of backward-looking price-setters) or \( \omega_{sw} \) (relative weight on past inflation in price indexation), \( \lambda \) (probability of no price change or price-setting by indexation), \( \phi_r \) (policy rate smoothing), \( \phi_\pi \) (policy response to inflation), \( \phi_x \) (policy response to the output gap), \( \phi_{\Delta y} \) (policy response to output growth)—are based on Smets and Wouters (2007).\(^{21}\) For the GNK model, these distributions generate the prior probability of equilibrium determinacy of 0.482, which is almost even, thus indicating that there is a priori no substantial bias toward determinacy or indeterminacy.\(^{22}\) In the same vein, for the SW-CNk model, the GG-CNk model, and the nested model, the prior mean of \( \phi_\pi \) is set at 1.125, 1.1, and 1.245, so that

\(^{20}\)For the subjective discount factor \( \beta \), the steady-state condition \( \beta = \pi a/r \) is used in estimation.

\(^{21}\)For \( \alpha \) (degree of price indexation to trend inflation in the nested model), the prior is the uniform distribution between zero and unity.

\(^{22}\)The prior probability of equilibrium determinacy can be computed as the prior distributions’ probability mass assigned to the determinacy region of the parameter space.
the prior probability of determinacy is 0.481, 0.485, and 0.484, respectively.

Regarding the structural shocks, the prior distributions for 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 for 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 priors for the coefficients \( M_i, i \in \{u, a, r\} \) are normal distributions with mean zero and standard deviation of unity, while that for the standard deviation of the sunspot shock \( \sigma_\zeta \) is the same as those for the standard deviations of the structural shock innovations.

## 4 Results of Empirical Analysis

This section presents the results of the empirical analysis. First, the estimation results are discussed. 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.

### 4.1 Estimation results

This subsection begins by comparing the empirical performance among the GNK model, the two types of CNK models, and the nested model. Tables 2 and 3 report the posterior estimates of these four models in the pre-1979 and post-1982 periods, respectively. The second to last row of each table presents the log marginal data densities \( \log p(X^T) \) and shows that the value for the GNK model (i.e., \(-127.10\)) is the largest in the pre-1979 period, while that for the SW-CNK model (i.e., \(-64.43\)) is the greatest in the post-1982 period. Besides, in both periods, the GG-CNK model has the smallest values, and the values for the nested model are intermediate between those for the GNK model and for the GG-CNK model. Thus we focus on the GNK model and the SW-CNK model in the subsequent analysis.

In light of the empirical result of Cogley and Sbordone (2008) that there is no need for backward-looking components in an NK Phillips curve when drift in trend inflation is taken into account, we estimate the GNK model and the SW-CNK model with the restriction of no intrinsic inertia in inflation, that is, \( \omega = 0 \) in the GNK model and \( \omega_{sw} = 0 \) in the SW-CNK model. The second to fourth columns of Tables 4 and 5 show the posterior estimates of
the SW-CNK model and the GNK model with the restriction in the pre-1979 and post-1982 periods, respectively. The log marginal data densities $\log p(X^T)$ shown in the second to last row of each table indicate two findings. First, the GNK and SW-CNK models without intrinsic inertia of inflation exhibit higher densities than those with it in both periods: for the GNK (SW-CNK) model, $-120.20 > -127.10$ ($-124.62 > -130.43$) in the pre-1979 period and $-55.59 > -67.51$ ($-56.87 > -64.43$) in the post-1982 period. Second, the GNK model with $\omega = 0$ has larger densities than the SW-CNK model with $\omega_{sw} = 0$ in both periods. Therefore, the GNK model with no intrinsic inflation inertia is more suitable than any other model considered for the analysis of what led to U.S. macroeconomic stability after the Great Inflation, which has been examined using CNK models in previous literature. In other words, the feature of the GNK model that some prices remain unchanged in each quarter is not only more consistent with micro evidence on prices but also improves the model’s fit to the U.S. macroeconomic time series.

The posterior probability of equilibrium determinacy $\mathbb{P}\{\vartheta \in \Theta^D | X^T\}$ is reported in the last row of Tables 4 and 5. For both the GNK model with $\omega = 0$ and the (SW-)CNK model (with $\omega_{sw} = 0$), the probability of determinacy is almost zero in the pre-1979 period, whereas it is unity in the post-1982 period. Hence, both 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 previous literature. However, there is an important difference between the estimation results of the two models. In the CNK model, the policy response to inflation $\phi_{\pi}$ was passive (i.e., less than unity: $0.44 < 1$) in the pre-1979 period and then became active (i.e., greater than unity: $2.85 > 1$) in the post-1982 period. This result is consistent with that obtained in previous literature, and thus the CNK model 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 change from a passive to an active policy response to inflation. On the other hand, the GNK model shows that the policy response to inflation was already active (i.e., $1.18 > 1$) during the pre-1979 period, in sharp contrast with the literature’s view.24

---

23 The posterior probability of equilibrium determinacy can be calculated as the posterior distribution’s probability mass assigned to the determinacy region of the parameter space.

24 The posterior probability of the policy response to inflation $\phi_{\pi}$ being active is 0.56. For an estimated
Because the GNK model outperforms the CNK model during both periods in terms of its fit to the data, our finding is more compelling than the literature’s view.

In the GNK model with $\omega = 0$, the fourth to fifth columns of Tables 4 and 5 show that four of the estimated parameters changed substantially between the pre-1979 and post-1982 periods. First, the policy response to inflation more than doubled from $\phi_\pi = 1.18$ in the pre-1979 period to $\phi_\pi = 2.99$ in the post-1982 period. Second, trend inflation fell by more than half from $\bar{\pi} = 1.45$ to $\bar{\pi} = 0.70$ in quarterly terms. Third, the policy response to output growth increased by a factor of almost five from $\phi_{\Delta y} = 0.11$ to $\phi_{\Delta y} = 0.53$. These three changes are significant in that the 90 percent highest posterior density intervals of the three parameters do not overlap between the two periods. Last but not least, the policy response to the output gap $\phi_x$ decreased considerably. To examine whether this decrease suggests virtually no response to the output gap, the GNK model is further estimated with the additional restriction that the response is fixed at zero, i.e., $\phi_x = 0$. The second to last rows of the tables show that the GNK model with $\omega = \phi_x = 0$ fits the data better than the model with only $\omega = 0$ in the post-1982 period but not in the pre-1979 period. This result indicates that the policy response to the output gap $\phi_x$ diminished from the estimate of 0.37 in the pre-1979 period to zero in the post-1982 period. It suggests that the Fed in 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.

4.2 **Source 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 Taylor-type rule, Orphanides (2004) obtains an active response to expected future inflation in the pre-1979 period, thus claiming that self-fulfilling expectations cannot be the source of U.S. macroeconomic instability during the Great Inflation. This claim, however, does not necessarily hold for the GNK model, since an active policy response to inflation is not a sufficient condition for equilibrium determinacy, as also stressed by Coibion and Gorodnichenko (2011).
the preceding subsection, the present analysis examines the source 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 GNK 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 GNK model’s parameter space for the annualized trend inflation rate $4\bar{\pi}$ and the policy response to inflation $\phi_\pi$ expands with changes in the other model parameters. In each panel of the figure, the marks “×”, “∗”, and “o” respectively represent the pairs of $(4\bar{\pi}_{pre79}, \phi_{\pi pre79})$, $(4\bar{\pi}_{pre79}, \phi_{\pi post82})$, and $(4\bar{\pi}_{post82}, \phi_{\pi post82})$, where $\bar{\pi}_{pre79}$ and $\phi_{\pi pre79}$ denote the posterior mean estimates of the trend inflation rate and the policy response to inflation during the pre-1979 period presented in the fourth to last column of Table 4 and $\bar{\pi}_{post82}$ and $\phi_{\pi post82}$ denote those during the post-1982 period presented in the second to last column of Table 5.

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 fourth to last column of Table 4). 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 “×”—lies in the indeterminacy region of the parameter space, in line with 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. This indicates that the increase in the policy response to inflation from the pre-1979 estimate $\phi_{\pi pre79}$ to the post-1982 estimate $\phi_{\pi post82}$ 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. This finding 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 increase in the policy response to inflation.

Panel (b) displays the case in which the policy responses to the output gap and output growth, $\phi_x$ and $\phi_{\Delta y}$, are set at the post-1982 estimates (presented in the second to last column of Table 5), 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 to the post-1982 estimates significantly expands the determinacy region. As a consequence, in panel (b), the pair of the pre-1979 estimates of trend inflation and the policy response to inflation \((4\bar{\pi}_{\text{pre79}}, \phi_{\pi \text{pre79}})\) 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 \((4\bar{\pi}_{\text{pre79}}, \phi_{\pi \text{post82}})\) lies inside the determinacy region. This finding 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.

Panel (c) presents the case in which all the model parameters are set at the post-1982 estimates. In this panel, the pair of the post-1982 estimates of trend inflation and the policy response to inflation \((4\bar{\pi}_{\text{post82}}, \phi_{\pi \text{post82}})\) is located inside the determinacy region, in line 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 from the pre-1979 to the post-1982 estimates of all the model parameters other than trend inflation and the policy responses to inflation, the output gap, and output growth plays a minor role in accounting for the shift from indeterminacy to determinacy.

These panels demonstrate that the increase in the policy response to inflation from the pre-1979 to the post-1982 estimate alone does not suffice for explaining the U.S. economy’s shift from indeterminacy to determinacy after the Great Inflation, 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. Taking into consideration that trend inflation is equivalent to the central bank’s inflation target in the model, this finding indicates that the changes in the Fed’s implicit inflation target and policy responses to real economic activity have played a key role in the shift to determinacy, in addition to its more active response to inflation.

\[25\]

In a GNK model with a Taylor-type rule, the destabilizing role of the policy response to the output gap is indicated by Ascari and Ropele (2009), while the stabilizing role of the policy response to output growth is pointed out by Coibion and Gorodnichenko (2011).
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 change from a passive to an active policy response to inflation. The paper has estimated a GNK model jointly with a Taylor-type rule during two periods, before and after the Volcker disinflation of 1979–1982, by adopting an SMC algorithm in a full-information Bayesian approach based on Lubik and Schorfheide (2004). It has shown that the GNK model (with no intrinsic inertia in inflation) empirically outperforms CNK models used in previous literature during both periods. This indicates that the former model is more suitable than the latter for analyzing the source of U.S. macroeconomic stability.

According to the estimated GNK model, the U.S. economy was likely in the equilibrium-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, 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 and that the subsequent change to an active response led to the U.S. economy’s shift from indeterminacy to determinacy. This paper has demonstrated that the increase in the policy response to inflation from the pre-1979 to the post-1982 estimate alone does not suffice for explaining the shift, unless it is accompanied by the change from the pre-1979 to the post-1982 estimates of either trend inflation or the policy responses to the output gap and output growth. This finding extends the literature on the role of monetary policy in achieving macroeconomic stability in the U.S. 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


Table 1: Prior distributions for parameters of the GNK model, the two types of CNK models, and the nested model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Distribution</th>
<th>Mean</th>
<th>St. dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{a}$</td>
<td>Normal</td>
<td>0.370</td>
<td>0.150</td>
</tr>
<tr>
<td>$\bar{\pi}$</td>
<td>Normal</td>
<td>0.985</td>
<td>0.750</td>
</tr>
<tr>
<td>$\bar{r}$</td>
<td>Gamma</td>
<td>1.597</td>
<td>0.250</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Beta</td>
<td>0.700</td>
<td>0.100</td>
</tr>
<tr>
<td>$\omega$</td>
<td>Beta</td>
<td>0.500</td>
<td>0.150</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Beta</td>
<td>0.500</td>
<td>0.050</td>
</tr>
<tr>
<td>$\phi_r$</td>
<td>Beta</td>
<td>0.750</td>
<td>0.100</td>
</tr>
<tr>
<td>$\phi_\pi$</td>
<td>Gamma</td>
<td>1.5/1.125/1.1/1.245</td>
<td>0.750</td>
</tr>
<tr>
<td>$\phi_x$</td>
<td>Gamma</td>
<td>0.125</td>
<td>0.100</td>
</tr>
<tr>
<td>$\phi_{\Delta y}$</td>
<td>Gamma</td>
<td>0.125</td>
<td>0.100</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Uniform</td>
<td>0.500</td>
<td>0.289</td>
</tr>
<tr>
<td>$\rho_u$</td>
<td>Beta</td>
<td>0.500</td>
<td>0.200</td>
</tr>
<tr>
<td>$\rho_a$</td>
<td>Beta</td>
<td>0.500</td>
<td>0.200</td>
</tr>
<tr>
<td>$\rho_r$</td>
<td>Beta</td>
<td>0.500</td>
<td>0.200</td>
</tr>
<tr>
<td>$\sigma_u$</td>
<td>Inverse gamma</td>
<td>0.627</td>
<td>0.328</td>
</tr>
<tr>
<td>$\sigma_a$</td>
<td>Inverse gamma</td>
<td>0.627</td>
<td>0.328</td>
</tr>
<tr>
<td>$\sigma_r$</td>
<td>Inverse gamma</td>
<td>0.627</td>
<td>0.328</td>
</tr>
<tr>
<td>$\sigma_\zeta$</td>
<td>Inverse gamma</td>
<td>0.627</td>
<td>0.328</td>
</tr>
<tr>
<td>$M_u$</td>
<td>Normal</td>
<td>0.000</td>
<td>1.000</td>
</tr>
<tr>
<td>$M_a$</td>
<td>Normal</td>
<td>0.000</td>
<td>1.000</td>
</tr>
<tr>
<td>$M_r$</td>
<td>Normal</td>
<td>0.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Notes: The prior mean of the policy response to inflation $\phi_\pi$ is set at 1.5 for the GNK model, 1.125 for the SW-CNK model, 1.1 for the GG-CNK model, and 1.245 for the nested model. The prior probability of equilibrium determinacy is then 0.482 for the GNK model, 0.481 for the SW-CNK model, 0.485 for the GG-CNK model, and 0.484 for the nested model. 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 estimates of the GNK model, the two types of CNK models, and the nested model in the pre-1979 period

<table>
<thead>
<tr>
<th>Parameter</th>
<th>GNK model</th>
<th>SW-CNK model</th>
<th>GG-CNK model</th>
<th>Nested model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>90% interval</td>
<td>Mean</td>
<td>90% interval</td>
</tr>
<tr>
<td>$\bar{a}$</td>
<td>0.353</td>
<td>[0.156, 0.572]</td>
<td>0.382</td>
<td>[0.170, 0.602]</td>
</tr>
<tr>
<td>$\bar{\pi}$</td>
<td>1.512</td>
<td>[1.189, 1.836]</td>
<td>1.350</td>
<td>[0.917, 1.760]</td>
</tr>
<tr>
<td>$h$</td>
<td>0.550</td>
<td>[0.439, 0.653]</td>
<td>0.550</td>
<td>[0.427, 0.683]</td>
</tr>
<tr>
<td>$\omega/\omega_{sw}$</td>
<td>0.143</td>
<td>[0.050, 0.222]</td>
<td>0.213</td>
<td>[0.071, 0.342]</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>0.521</td>
<td>[0.450, 0.594]</td>
<td>0.496</td>
<td>[0.411, 0.585]</td>
</tr>
<tr>
<td>$\phi_r$</td>
<td>0.707</td>
<td>[0.591, 0.833]</td>
<td>0.680</td>
<td>[0.554, 0.810]</td>
</tr>
<tr>
<td>$\phi_\pi$</td>
<td>1.028</td>
<td>[0.399, 1.640]</td>
<td>0.483</td>
<td>[0.051, 0.826]</td>
</tr>
<tr>
<td>$\phi_x$</td>
<td>0.313</td>
<td>[0.095, 0.562]</td>
<td>0.157</td>
<td>[0.003, 0.307]</td>
</tr>
<tr>
<td>$\phi_\Delta y$</td>
<td>0.119</td>
<td>[0.003, 0.235]</td>
<td>0.118</td>
<td>[0.002, 0.231]</td>
</tr>
<tr>
<td>$\alpha$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\rho_a$</td>
<td>0.414</td>
<td>[0.125, 0.711]</td>
<td>0.497</td>
<td>[0.162, 0.815]</td>
</tr>
<tr>
<td>$\rho_a$</td>
<td>0.741</td>
<td>[0.492, 0.943]</td>
<td>0.399</td>
<td>[0.097, 0.697]</td>
</tr>
<tr>
<td>$\rho_r$</td>
<td>0.424</td>
<td>[0.200, 0.655]</td>
<td>0.432</td>
<td>[0.244, 0.617]</td>
</tr>
<tr>
<td>$\sigma_a$</td>
<td>0.968</td>
<td>[0.252, 2.194]</td>
<td>0.919</td>
<td>[0.247, 2.024]</td>
</tr>
<tr>
<td>$\sigma_a$</td>
<td>0.726</td>
<td>[0.351, 1.075]</td>
<td>1.691</td>
<td>[0.889, 2.522]</td>
</tr>
<tr>
<td>$\sigma_r$</td>
<td>0.282</td>
<td>[0.229, 0.333]</td>
<td>0.276</td>
<td>[0.224, 0.321]</td>
</tr>
<tr>
<td>$\sigma_\xi$</td>
<td>0.387</td>
<td>[0.286, 0.475]</td>
<td>0.479</td>
<td>[0.305, 0.621]</td>
</tr>
<tr>
<td>$M_a$</td>
<td>0.010</td>
<td>[−0.479, 0.477]</td>
<td>−0.054</td>
<td>[−0.844, 0.784]</td>
</tr>
<tr>
<td>$M_a$</td>
<td>−0.263</td>
<td>[−0.786, 0.376]</td>
<td>−0.288</td>
<td>[−0.835, 0.077]</td>
</tr>
<tr>
<td>$M_r$</td>
<td>0.102</td>
<td>[−0.475, 0.708]</td>
<td>1.032</td>
<td>[0.107, 2.006]</td>
</tr>
</tbody>
</table>

$\log p(X^T)$ \hspace{1cm} −127.100 \hspace{1cm} −130.434 \hspace{1cm} −133.240 \hspace{1cm} −127.995

$\mathbb{P}\{\vartheta \in \Theta^D|X^T\}$ \hspace{1cm} 0.000 \hspace{1cm} 0.070 \hspace{1cm} 0.002 \hspace{1cm} 0.000

Notes: 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 log marginal data density and $\mathbb{P}\{\vartheta \in \Theta^D|X^T\}$ denotes the posterior probability of equilibrium determinacy.
Table 3: Posterior estimates of the GNK model, the two types of CNK models, and the nested model in the post-1982 period

<table>
<thead>
<tr>
<th>Parameter</th>
<th>GNK model</th>
<th>SW-CNK model</th>
<th>GG-CNK model</th>
<th>Nested model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>90% interval</td>
<td>Mean</td>
<td>90% interval</td>
</tr>
<tr>
<td>$\bar{a}$</td>
<td>0.399</td>
<td>[0.211, 0.584]</td>
<td>0.410</td>
<td>[0.238, 0.574]</td>
</tr>
<tr>
<td>$\bar{\pi}$</td>
<td>0.701</td>
<td>[0.537, 0.880]</td>
<td>0.692</td>
<td>[0.533, 0.837]</td>
</tr>
<tr>
<td>$h$</td>
<td>0.625</td>
<td>[0.540, 0.713]</td>
<td>0.590</td>
<td>[0.510, 0.665]</td>
</tr>
<tr>
<td>$\omega/\omega_{sw}$</td>
<td>0.064</td>
<td>[0.024, 0.102]</td>
<td>0.136</td>
<td>[0.051, 0.220]</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>0.458</td>
<td>[0.389, 0.534]</td>
<td>0.434</td>
<td>[0.367, 0.497]</td>
</tr>
<tr>
<td>$\phi_{r}$</td>
<td>0.678</td>
<td>[0.602, 0.768]</td>
<td>0.675</td>
<td>[0.590, 0.764]</td>
</tr>
<tr>
<td>$\phi_{x}$</td>
<td>0.114</td>
<td>[0.001, 0.229]</td>
<td>0.115</td>
<td>[0.002, 0.236]</td>
</tr>
<tr>
<td>$\phi_{\Delta y}$</td>
<td>0.466</td>
<td>[0.269, 0.673]</td>
<td>0.533</td>
<td>[0.316, 0.716]</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>$\rho_{u}$</td>
<td>0.905</td>
<td>[0.868, 0.947]</td>
<td>0.915</td>
<td>[0.882, 0.949]</td>
</tr>
<tr>
<td>$\rho_{a}$</td>
<td>0.133</td>
<td>[0.014, 0.241]</td>
<td>0.088</td>
<td>[0.014, 0.156]</td>
</tr>
<tr>
<td>$\rho_{r}$</td>
<td>0.660</td>
<td>[0.579, 0.748]</td>
<td>0.629</td>
<td>[0.543, 0.726]</td>
</tr>
<tr>
<td>$\sigma_{r}$</td>
<td>0.233</td>
<td>[0.177, 0.286]</td>
<td>0.232</td>
<td>[0.183, 0.281]</td>
</tr>
</tbody>
</table>

$\log p(X^T) = -67.513$  
$\mathbb{P}\{\theta \in \Theta^D | X^T\} = 1.000$

Notes: 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 log marginal data density and $\mathbb{P}\{\theta \in \Theta^D | X^T\}$ denotes the posterior probability of equilibrium determinacy.
Table 4: Posterior estimates of the GNK model and the SW-CNK model with parameter restrictions in the pre-1979 period

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SW-CNK model: $\omega_{sw} = 0$</th>
<th>GNK model: $\omega = 0$</th>
<th>GNK model: $\omega = \phi_x = 0$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean 90% interval</td>
<td>Mean 90% interval</td>
<td>Mean 90% interval</td>
</tr>
<tr>
<td>$\bar{a}$</td>
<td>0.381 [0.159, 0.606]</td>
<td>0.379 [0.193, 0.555]</td>
<td>0.374 [0.141, 0.606]</td>
</tr>
<tr>
<td>$\bar{\pi}$</td>
<td>1.365 [0.970, 1.778]</td>
<td>1.447 [1.116, 1.768]</td>
<td>1.431 [1.125, 1.766]</td>
</tr>
<tr>
<td>$\bar{r}$</td>
<td>1.586 [1.254, 1.872]</td>
<td>1.641 [1.359, 1.920]</td>
<td>1.632 [1.329, 1.928]</td>
</tr>
<tr>
<td>$h$</td>
<td>0.540 [0.422, 0.669]</td>
<td>0.568 [0.430, 0.700]</td>
<td>0.574 [0.458, 0.705]</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>0.502 [0.419, 0.585]</td>
<td>0.530 [0.455, 0.601]</td>
<td>0.503 [0.415, 0.585]</td>
</tr>
<tr>
<td>$\phi_r$</td>
<td>0.686 [0.562, 0.816]</td>
<td>0.702 [0.583, 0.819]</td>
<td>0.651 [0.515, 0.790]</td>
</tr>
<tr>
<td>$\phi_x$</td>
<td>0.436 [0.069, 0.737]</td>
<td>1.179 [0.260, 2.065]</td>
<td>0.720 [0.143, 1.563]</td>
</tr>
<tr>
<td>$\phi_{\Delta y}$</td>
<td>0.167 [0.002, 0.334]</td>
<td>0.370 [0.106, 0.620]</td>
<td>0</td>
</tr>
<tr>
<td>$\rho_u$</td>
<td>0.123 [0.002, 0.238]</td>
<td>0.106 [0.003, 0.212]</td>
<td>0.214 [0.007, 0.406]</td>
</tr>
<tr>
<td>$\rho_a$</td>
<td>0.469 [0.142, 0.795]</td>
<td>0.456 [0.178, 0.731]</td>
<td>0.521 [0.174, 0.866]</td>
</tr>
<tr>
<td>$\rho_r$</td>
<td>0.432 [0.148, 0.724]</td>
<td>0.554 [0.207, 0.900]</td>
<td>0.597 [0.251, 0.893]</td>
</tr>
<tr>
<td>$\sigma_u$</td>
<td>0.441 [0.253, 0.633]</td>
<td>0.412 [0.195, 0.624]</td>
<td>0.410 [0.231, 0.591]</td>
</tr>
<tr>
<td>$\sigma_a$</td>
<td>0.717 [0.232, 1.345]</td>
<td>1.859 [0.287, 3.333]</td>
<td>0.738 [0.252, 1.359]</td>
</tr>
<tr>
<td>$\sigma_r$</td>
<td>1.565 [0.909, 2.300]</td>
<td>0.651 [0.291, 0.990]</td>
<td>1.207 [0.470, 2.053]</td>
</tr>
<tr>
<td>$\sigma_\zeta$</td>
<td>0.275 [0.225, 0.318]</td>
<td>0.282 [0.213, 0.343]</td>
<td>0.289 [0.219, 0.355]</td>
</tr>
<tr>
<td>$M_u$</td>
<td>0.431 [0.307, 0.545]</td>
<td>0.385 [0.284, 0.482]</td>
<td>0.449 [0.260, 0.589]</td>
</tr>
<tr>
<td>$M_a$</td>
<td>-0.061 [-0.765, 0.620]</td>
<td>-0.013 [-0.370, 0.316]</td>
<td>0.044 [-0.702, 0.834]</td>
</tr>
<tr>
<td>$M_r$</td>
<td>-0.204 [-0.519, 0.054]</td>
<td>-0.102 [-0.711, 0.629]</td>
<td>0.092 [-0.734, 0.656]</td>
</tr>
<tr>
<td>$\log p(X^T)$</td>
<td>-124.619</td>
<td>-120.200</td>
<td>-124.040</td>
</tr>
<tr>
<td>$P{\theta \in \Theta</td>
<td>X^T}$</td>
<td>0.023</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Notes: 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 log marginal data density and $P\{\theta \in \Theta | X^T\}$ denotes the posterior probability of equilibrium determinacy.
Table 5: Posterior estimates of the GNK model and the SW-CNK model with parameter restrictions in the post-1982 period

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SW-CNK model: $\omega_{sw} = 0$</th>
<th>GNK model: $\omega = 0$</th>
<th>GNK model: $\omega = \phi_x = 0$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>90% interval</td>
<td>Mean</td>
</tr>
<tr>
<td>$\bar{a}$</td>
<td>0.408</td>
<td>[0.243, 0.578]</td>
<td>0.392</td>
</tr>
<tr>
<td>$\bar{\pi}$</td>
<td>0.690</td>
<td>[0.546, 0.824]</td>
<td>0.700</td>
</tr>
<tr>
<td>$\bar{r}$</td>
<td>1.433</td>
<td>[1.171, 1.691]</td>
<td>1.446</td>
</tr>
<tr>
<td>$h$</td>
<td>0.584</td>
<td>[0.497, 0.663]</td>
<td>0.598</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>0.451</td>
<td>[0.386, 0.515]</td>
<td>0.458</td>
</tr>
<tr>
<td>$\phi_r$</td>
<td>0.685</td>
<td>[0.602, 0.774]</td>
<td>0.690</td>
</tr>
<tr>
<td>$\phi_x$</td>
<td>0.129</td>
<td>[0.001, 0.260]</td>
<td>0.125</td>
</tr>
<tr>
<td>$\phi_{\Delta y}$</td>
<td>0.534</td>
<td>[0.308, 0.738]</td>
<td>0.526</td>
</tr>
<tr>
<td>$\rho_u$</td>
<td>0.916</td>
<td>[0.883, 0.949]</td>
<td>0.923</td>
</tr>
<tr>
<td>$\rho_a$</td>
<td>0.111</td>
<td>[0.023, 0.195]</td>
<td>0.146</td>
</tr>
<tr>
<td>$\rho_r$</td>
<td>0.608</td>
<td>[0.514, 0.704]</td>
<td>0.608</td>
</tr>
<tr>
<td>$\sigma_u$</td>
<td>2.073</td>
<td>[1.489, 2.736]</td>
<td>2.323</td>
</tr>
<tr>
<td>$\sigma_a$</td>
<td>1.323</td>
<td>[1.068, 1.568]</td>
<td>1.340</td>
</tr>
<tr>
<td>$\sigma_r$</td>
<td>0.235</td>
<td>[0.183, 0.288]</td>
<td>0.240</td>
</tr>
</tbody>
</table>

Notes: 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 log marginal data density and $\mathbb{P}\{\vartheta \in \Theta^D|X^T\}$ denotes the posterior probability of equilibrium determinacy.
Notes: For the annualized trend inflation rate $\bar{\pi}$ and the policy response to inflation $\phi_\pi$, the figure illustrates the equilibrium-determinacy region of the GNK model’s parameter space. In each panel, the marks “×”, “∗”, and “◦” respectively represent the pairs of $(\bar{\pi}^{pre79}, \phi_\pi^{pre79})$, $(\bar{\pi}^{pre79}, \phi_\pi^{post82})$, and $(\bar{\pi}^{post82}, \phi_\pi^{post82})$, where $\bar{\pi}^{pre79}$ ($\bar{\pi}^{post82}$) and $\phi_\pi^{pre79}$ ($\phi_\pi^{post82}$) denote the mean estimates of the trend inflation rate and the policy response to inflation in the pre-1979 (post-1982) period.