U.S. Monetary Policy and Indeterminacy*

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Abstract

In this paper, I investigate the stance of U.S. monetary policy in the post-war period. To this end, I show that two features are key: a medium-scale structural model and, to allow for indeterminacy, the novel solution method of Bianchi and Nicolò (2021). Using data simulated with a determinate version of the medium-scale model, the estimation of a small-scale model misinterprets missing propagation mechanisms as indeterminacy. In addition, using data simulated with an indeterminate version of the medium-scale model, I correctly recover the evidence of indeterminacy if I estimate the model implementing the method of Bianchi and Nicolò (2021), although I find evidence of determinacy if I adopt existing solution methods. As a result, I estimate the medium-scale model on U.S. macroeconomic data using the method of Bianchi and Nicolò (2021). The evidence of a passive monetary policy in the period prior to 1979 is pervasive and robust to the use of alternative model specifications and data. By contrast, the evidence of an active stance after 1979 is overturned if the period of the Volcker disinflation is excluded or if the model is estimated including a time-varying inflation target, also when using data on inflation expectations.

JEL: C11, C52, C54, E31, E32, E52.

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1 Introduction

A vast literature studies the systematic conduct of U.S. monetary policy in the post-war period using univariate or small-scale linear rational expectations (LRE) models.[1] By implementing the solution method of Lubik and Schorfheide (2003, 2004), several of these papers show that U.S. monetary policy was passive during the period prior to 1979, thus failing to implement active inflation targeting and ultimately leading to indeterminacy.[2]

However, Beyer and Farmer (2007a) prove that an indeterminate model can be observationally equivalent to a determinate model with a richer dynamic and stochastic structure. Intuitively, the indeterminate specification differs from the determinate version of the same model in two aspects. First, expectations are fundamental drivers of the economy, and the resulting propagation of structural shocks is altered and *more persistent*. Second, non-fundamental 'sunspot' disturbances due to unexpected changes in expectations generate *more volatility*. In a small-scale New Keynesian (NK) model, the features of the indeterminate model can be relevant to explain the persistence and volatility of U.S. macroeconomic data.

A rich structural model can avoid that missing propagation mechanisms and structural shocks are misinterpreted as evidence of indeterminacy. Because of technical complexities associated with the implementation of existing solution methods (Lubik and Schorfheide, 2003, 2004; Farmer et al., 2015), few studies adopt such models to investigate the stance of U.S. monetary policy.[3] Justiniano and Primiceri (2008) use a rich DSGE model to rationalize the Great Moderation with a reduction in the volatility of structural disturbances, while finding little role for monetary policy. Conversely, Hirose et al. (2021) show that a change from a passive to an active monetary policy after the Volcker disinflation explains the observed decline in the persistence of the gap between inflation and its trend. However, these studies adopt the method of Lubik and Schorfheide (2003, 2004) which, as discussed below, can have implications for the findings.

In this paper, I study the systematic conduct of U.S. monetary policy over the post-war period using the medium-scale NK model of Smets and Wouters (2007) (henceforth SW) and adopting the method of Bianchi and Nicolò (2021) to allow for a passive monetary policy.

I show that the adoption of both a rich structural model and the approach of Bianchi and

[1] Among others, see Clarida et al. (2000), Lubik and Schorfheide (2004), Boivin and Giannoni (2006), Mavroeidis (2010), Bhattarai et al. (2016), Bianchi and Ilut (2017), Bianchi and Melosi (2017), Dai et al. (2020), Ettmeier and Kriwoluzky (2020), and Hirose et al. (2020).

[2] The term "indeterminacy" refers to the dynamic properties of a model in the neighborhood of its unique steady state, and the terminology of "active" and "passive" policies is borrowed from Leeper (1991).

[3] Recently, the novel approach of Bianchi and Nicolò (2021) facilitates the use of rich structural models while allowing for indeterminacy. Using this method, Albonico et al. (2020) show that accounting for rule-of-thumb consumers in a medium-scale model is irrelevant to explain U.S. business cycle fluctuations, and Hirose (2020) estimates a medium-scale DSGE model with a deflation steady state for the Japanese economy.

Nicolò (2021) are key to investigate the stance of U.S. monetary policy. Using data simulated from a determinate version of the SW model, the estimation of the small-scale model of Del Negro and Schorfheide (2004) provides incorrect evidence of indeterminacy.[4] The evidence of a passive monetary policy holds even after accounting for differences between the two models in the specification of the Taylor rules and the set of data used for the estimation. Consistent with the theoretical findings of Beyer and Farmer (2007a), the more parsimonious structure of the Del Negro and Schorfheide (2004)'s model misinterprets the persistence and volatility of the data simulated under determinacy as evidence of indeterminacy.

Additionally, using data simulated from an indeterminate version of the SW model, the estimation of the SW model with the method of Lubik and Schorfheide (2003, 2004) points to evidence of determinacy. By contrast, the estimation with the method of Bianchi and Nicolò (2021) recovers the result of indeterminacy. As discussed in Subsection 5.2, the estimation results differ under the two methods because of the alternative parameterizations of the infinite set of indeterminate solutions and the different baseline solutions that each method proposes to center the prior distribution of the parameters capturing the relationships between the sunspot shock and the exogenous shocks of the model.

After providing evidence on the relevance of adopting a rich structural model and the method of Bianchi and Nicolò (2021), I estimate the SW model using U.S. macroeconomic data to study the systematic conduct of U.S. monetary policy over the post-war period. Even when considering a rich structural model such as SW, I find that monetary policy was passive between 1955:Q4 and 1979:Q2, a result in line with previous studies in the literature and, more recently, Hirose et al. (2021).

However, whether U.S. monetary policy pursued an active inflation targeting after 1979 depends on whether the period of the Volcker disinflation is included in the data used for the model estimation. If, as in Boivin and Giannoni (2006) and Leduc et al. (2007), the Volcker-disinflation period is included in the sample, the results suggest that monetary policy adopted an aggressive stance between 1979:Q3 and 2007:Q4, thus stabilizing inflation and ensuring determinacy. By contrast, if, as in Lubik and Schorfheide (2004) and Hirose et al. (2020, 2021), the Volcker-disinflation period is excluded, the stance of monetary policy was passive between 1982:Q4 and 2007:Q4, leading to indeterminacy. The finding of indeterminacy for the post-1982 period contrasts with the result of Hirose et al. (2021) who, as discussed above, find evidence of determinacy over this period. However, several factors can explain the different outcomes. In particular, Hirose et al. (2021) adopt the method of Lubik and Schorfheide (2004), use a different model specification, and select prior distributions for the structural parameters that map into a prior model probability which favors determinacy.

[4] Del Negro and Schorfheide (2004) adapt the small-scale model of Lubik and Schorfheide (2004) to describe an economy that evolves along a balanced growth path.

I verify the robustness of the results to various model specifications and data used. A large literature points to the inclusion of a time-varying inflation target to better capture low-frequency movement in inflation.[5] Recently, Haque (2021) uses a small-scale model to show that the inclusion of a time-varying inflation target implies a stronger response of the central bank to the resulting inflation gap, thus ruling out indeterminacy over the entire post-war period. Therefore, I consider an alternative version of the SW model that allows the inflation target of the monetary authority to vary over time. Moreover, in the spirit of Aruoba and Schorfheide (2011), Del Negro and Eusepi (2011) and Del Negro and Schorfheide (2013), I also estimate this alternative specification of the SW model using data on short- or longer-term inflation expectations. Finally, I follow Orphanides (2001, 2002, 2003) and estimate the SW model using real-time data as available at the end of the pre- and post-1979 periods.

The robustness analysis confirms that the evidence of a passive monetary policy in the period prior to 1979 is pervasive and holds for all the considered specifications. By contrast, the finding of an active monetary policy during the post-1979 period is not robust and depends on the model specification and data used. With exception of the estimation of the SW model with real-time data, the results for the alternative specifications that include a time-varying inflation target and possibly use data on inflation expectations overturn the finding of an active monetary policy over the post-1979 period.[6]

To estimate the various models, I use the Hybrid Metropolis-Hastings algorithm developed in Bianchi and Nicolò (2021). This algorithm combines a standard Metropolis-Hastings random walk algorithm with a Markov chain Monte Carlo (MCMC) algorithm. The proposal distribution of the MCMC algorithm is based on a mixture of normals centered on posterior modes found in the determinate and indeterminate regions of the parameter space. In the spirit of the sequential Monte Carlo algorithm of Herbst and Schorfheide (2014), the hybrid algorithm ensures that the model is efficiently estimated over the entire parameter space.

The paper contributes to various strands of the literature. Several studies concentrate on the sources of the reduction in U.S. macroeconomic volatility from the early 1980s to 2007 and find a decrease in the variance of the shocks as the main driver (Primiceri, 2005; Sims and Zha, 2006; Justiniano and Primiceri, 2008; Canova and Gambetti, 2009; Justiniano et al., 2010; Fernandez-Villaverde et al., 2010; Justiniano et al., 2011). Alternative explanations for the run-up of U.S. inflation during the Great Inflation relate to the possibility that policymakers overestimated potential output (Orphanides, 2001, 2002, 2003) or underestimated both the

[5] For references in this literature, see Erceg and Levin (2003), Cogley and Sargent (2005a,b), Primiceri (2006), Sargent et al. (2006), Ireland (2007), Stock and Watson (2007), Cogley and Sbordone (2008), Cogley et al. (2010), and Justiniano et al. (2013) among others.

[6] I also verify that the evidence of indeterminacy for the post-1982 period holds if I incorporate a time-varying inflation target and possibly use data on inflation expectations. The results are available upon request.

natural rate of unemployment and the persistence of inflation in the Phillips curve (Primiceri, 2005). Moreover, other papers show that the behavior of the data changed since the early 1980s because monetary policy took a more systematic and aggressive stance to stabilize inflation relative to the period prior to 1979 (Clarida et al., 2000; Lubik and Schorfheide, 2004; Boivin and Giannoni, 2006; Benati and Surico, 2009). Relative to the latter branch of the literature, the current paper shows that the evidence of a passive monetary policy prior to 1979 is pervasive, while the result of the switch to a more active stance thereafter is not robust and can depend on several factors.

Results on the systematic conduct of monetary policy could also depend on the inclusion of a positive trend inflation in line with the work of Kiley (2007), Ascari and Ropele (2009), Coibon and Gorodnichenko (2011), Ascari and Sbordone (2014), Hirose et al. (2020), Haque et al. (2021) and Haque (2021) among others. The findings of these papers are based on parsimonious models, and Arias et al. (2020) describe the difficulties of such analysis in the context of a medium-scale model. Possible extensions of the current work could help overcome such obstacles likely without affecting the main results. Indeed, as shown in Ascari and Sbordone (2014), the inclusion of a positive trend inflation would increase the likelihood of indeterminacy other things being equal, further strengthening the result of a passive monetary policy before 1979 and possibly thereafter. Moreover, further research could address whether the adoption of a rich structural model is consistent with the presence of temporarily unstable paths to explain the Great Inflation (Ascari et al., 2019) or with a linear recursion representation with multiplicative noise to rationalize higher-order properties of macroeconomic time series (Dave and Sorge, 2021).

A closely related literature also discusses the implications of model misspecification for the empirical performance of DSGE models and provides approaches for policy analysis (Del Negro et al., 2007; Del Negro and Schorfheide, 2009). Recently, in addition to the joint study of identification and misspecification problems in standard NK models (Adolfson et al., 2019), this literature advanced on the identification of the sources of model misspecification (Inoue et al., 2020) and the development of approaches to deal with those issues (Canova and Matthes, 2021). This paper shows how the theoretical findings of Beyer and Farmer (2007a) on the interactions between model misspecification and conclusions about indeterminacy hold empirically when studying the stance of U.S. monetary policy.

Finally, the current paper relates to the literature that studies the empirical implications of dynamic indeterminacy (Farmer and Guo, 1994, 1995), and further extensions of this work can also account for static indeterminacy (i.e., multiplicity of steady states). Based on the evidence of Beyer and Farmer (2007b) about the cointegrating properties of the data, Farmer and Platonov (2019) develop a micro-founded model allowing for multiple steady-state unemployment rates. This three-equation model corresponds to the standard three-equation NK model in which the NK Phillips curve is replaced by a "belief function" describing how agents form expectations about future nominal income growth. Farmer and Nicolò (2018, 2019) show that the reduced-form representation corresponds to a cointegrated vector error correction model (VECM) that outperforms a standard three-equation NK model in fitting U.S. post-war data. An interesting avenue of research extends the proposed alternative framework to a medium-scale model that displays multiplicity of steady states and maps into a VECM in reduced-form. The purpose would be to study if the cointegrating properties of the proposed model would better explain the data in the post-war period relative to a baseline NK model that displays self-stabilizing properties around the unique steady state.

The rest of the paper is organized as follows. Section 2 briefly describes the SW model, and Section 3 discusses the implementation of the methodology developed in Bianchi and Nicolò (2021) to solve the SW model allowing for indeterminacy. The Hybrid Metropolis-Hastings algorithm used to estimate the model is presented in Section 4 along with a description of the data, choice of prior distributions and local-identification analysis. Section 5 shows that the adoption of both a medium-scale model and the method of Bianchi and Nicolò (2021) are key features for the study of the stance of U.S. monetary policy conducted in Section 6. In Section 7, the robustness analysis is discussed, and Section 8 concludes.

2 The Model

DSGE models are useful tools to conduct quantitative policy analysis. To this purpose, a branch of the literature focused on developing richer models that could provide a better match with the data. Based on the standard three-equation NK model, the work by Smets and Wouters (2003) and Christiano et al. (2005) expands the framework to account for relevant frictions and shocks. The model presented in Smets and Wouters (2007) now constitutes the heart of the structural DSGE models that are adopted by most central banks in advanced economies. While the reader is referred to the original paper for the details about the derivation of the model, this section describes its relevant features.

The model contains both real and nominal frictions. On the real side, households are assumed to form habit in consumption. Households face an adjustment cost when renting capital services to firms and optimally choose the capital utilization rate with an increasing cost. Firms incur a fixed cost in production and are subject to nominal price rigidities *à la* Calvo (1983), while indexing the optimized price to past inflation. The model also displays nominal wage frictions that allow for indexation to past wage inflation.

The economy follows a deterministic, balanced growth path, along which seven shocks drive the dynamics of the model. Three shocks affect the demand-side of the economy. A risk premium shock affects the household's intertemporal Euler equation by impacting the spread between the risk-free rate and the return on the risky asset. The investment-specific shock has an effect on the investment Euler equation that the household considers when choosing the amount of capital to accumulate. The third demand-side shock is an exogenous spending shock that impacts the aggregate resource constraint. Similarly, the supply-side of the economy is subject to three shocks: a productivity shock as well as a price and wage mark-up shock. Finally, the monetary authority follows a Taylor rule of the form

$$R_t = \rho R_{t-1} + (1-\rho)\left\{r_\pi \pi_t + r_y\left(y_t - y_t^p\right)\right\} + r_{\Delta y}\left[\left(y_t - y_t^p\right) - \left(y_{t-1} - y_{t-1}^p\right)\right] + u_{R,t}. \quad (1)$$

The monetary authority chooses the nominal interest rate, R_t, by allowing for some degree of interest-rate inertia, ρ, and responding to the inflation rate π_t, output gap—defined as the deviations of actual output, y_t, from its flexible price and wage counterpart, y_t^p—and changes to the output gap. Any unexpected deviation in the policy instrument is defined as a stationary AR(1) monetary policy shock, $u_{R,t}$.

3 Solution Method

The adoption of medium-scale DSGE models to study the conduct of monetary policy raises technical complexities. First, while the partition of the parameter space into a determinate and indeterminate region can be derived analytically for small-scale models, it is generally unknown for larger models. Second, the model can be characterized by regions of the parameters space associated with multiple degrees of indeterminacy. A grid point method can be used to numerically identify the region of the parameter space associated with indeterminacy, but does not provide an analytical mapping between the dynamic properties of the model and its structural parameters. Third, standard software packages do not deal with indeterminacy (Anderson and Moore, 1985; Uhlig, 1999) or the full set of indeterminate solutions (Sims, 2001). As a result, most papers rule out the possibility of indeterminacy and estimate rich structural models only in the determinate region of the parameter space. Among others, SW also adopt this approach and assume *a priori* a unique, determinate solution of the model.

Bianchi and Nicolò (2021) propose a novel solution method to solve LRE models allowing for indeterminacy. While equivalent to the methodologies of Lubik and Schorfheide (2003, 2004) and Farmer et al. (2015), the novel method provides an approach that, using the information in the data, endogenously partitions the parameter space into the determinate and indeterminate region, and deals with the possibility of multiple degrees of indeterminacy. Hence, this methodology substantially simplifies the approach to test for indeterminacy in U.S. monetary policy, especially in medium- and large-scale models.

To solve the medium-scale SW model over the entire parameter space, I implement the solution method of Bianchi and Nicolò (2021) as follows. The SW model is a LRE model that can be written in the canonical form

$$\Gamma_0(\theta)X_t = \Gamma_1(\theta)X_{t-1} + \Psi(\theta)\varepsilon_t + \Pi(\theta)\eta_t, \tag{2}$$

where $X_t \in R^k$ is the vector of endogenous variables, $\varepsilon_t \in R^\ell$ is the vector of exogenous shocks such that $\Omega_{\varepsilon\varepsilon} \equiv E_{t-1}(\varepsilon_t'\varepsilon_t)$, $\eta_t \in R^p$ collects the p one-step ahead forecast errors for the expectational variables of the model and $\theta \equiv vec(\Gamma_0, \Gamma_1, \Psi, \Omega_{\varepsilon\varepsilon})' \in \Theta$ is a vector of structural parameters as well as parameters associated with the shock processes.

I verify that the SW model has up to one degree of indeterminacy for realistic parameter values and augment the LRE model in (2) by appending the auxiliary process[7]

$$\omega_t = (1/\alpha_\omega)\,\omega_{t-1} + \nu_{\pi,t} - \eta_{\pi,t}, \qquad \eta_{\pi,t} \equiv \pi_t - E_{t-1}(\pi_t), \tag{3}$$

where $\nu_{\pi,t}$ is a newly-defined sunspot shock that can be correlated with the structural shocks ε_t and such that $E_{t-1}(\nu_{\pi,t}) = 0$. Denoting the newly-defined vector of endogenous variables $\hat{X}_t \equiv (X_t, \omega_t)'$ and the newly-defined vector of exogenous shocks $\hat{\varepsilon}_t \equiv (\varepsilon_t, \nu_{\pi,t})'$, the solution to the augmented system in (2) and (3) is

$$\hat{X}_t = \hat{\Gamma}_1(\theta)\,\hat{X}_{t-1} + \hat{\Psi}(\theta)\,\hat{\varepsilon}_t. \tag{4}$$

When the original LRE model in (2) is determinate and the auxiliary process in (3) is stationary ($|1/\alpha_\omega| < 1$), the solution of the augmented model in (4) is also determinate. In this case, ω_t constitutes a separate block of the reduced-form solution and does not affect the dynamics of the endogenous variables of the original model, X_t.

Alternatively, when the original model in (2) is indeterminate and the auxiliary process in (3) is explosive ($|1/\alpha_\omega| > 1$), the solution of the *augmented* model in (4) is still *determinate* because the Blanchard-Kahn condition is satisfied. In this case, a bounded solution requires that $\omega_0 = 0$ and $\eta_{\pi,t} = \nu_{\pi,t}$, implying that $\omega_t = 0$, $\forall t$, and the auxiliary process does not impact the dynamics of the endogenous variables X_t. In addition, given the inclusion of the forecast error for inflation, $\eta_{\pi,t}$, in the auxiliary process, the *reduced-form* solution for inflation under indeterminacy corresponds to equation (5) below[8]

$$\pi_t = E_{t-1}(\pi_t) + \nu_{\pi,t}. \tag{5}$$

[7]Bianchi and Nicolò (2021) show that the choice of which expectational error is included in (3) does not affect the indeterminate solution: a representation based on the choice of an alternative expectational error is equivalent to the representation considered in (2) and (3) up to a transformation of the correlations between the exogenous shocks and the forecast error included in the auxiliary process.

[8]In the spirit of the ARMA(1,1) solution for the univariate case under indeterminacy presented in Lubik and Schorfheide (2004), the reduced-form solution for inflation in (5) can be equivalently presented as a function of lagged inflation, π_{t-1}, lagged exogenous shocks, ε_{t-1}, and the correlated sunspot shock, $\nu_{\pi,t}$, among other terms. To this end, the reduced-form solution for inflation in (5) needs to be combined with the reduced-form solution for $E_t(\pi_{t+1})$. However, this representation cannot be derived analytically.

The full set of indeterminate solutions is parameterized by the standard deviation of the sunspot shock, σ_ν, and the correlation of the sunspot shock with the exogenous shocks, $\Omega_{\varepsilon\nu}$. Equation (5) shows that, under indeterminacy, the dynamics of inflation are predetermined, and contemporaneous movements in inflation can only be explained by sunspot shocks or by exogenous shocks that are correlated with the sunspot shock.

4 Inference

Hybrid algorithm. The estimation of a LRE model with different degrees of indeterminacy can pose several challenges (Lubik and Schorfheide, 2004). The posterior can exhibit jumps along the boundaries of the determinacy and indeterminacy regions, and the posterior distribution can present local peaks around which a Metropolis-Hastings random walk algorithm may gravitate. To overcome these challenges, several papers, such as Hirose et al. (2020, 2021), Ettmeier and Kriwoluzky (2020) and Haque (2021), adopt the sequential Monte Carlo algorithm of Herbst and Schorfheide (2014). Such algorithm can also be combined with the solution method described in Section 3.

In this paper, I adopt the Hybrid Metropolis-Hastings algorithm proposed in Bianchi and Nicolò (2021). The algorithm combines the standard Metropolis-Hastings random walk algorithm with a MCMC algorithm. The proposal distribution of the MCMC algorithm is based on a mixture of normals centered on the different posterior modes. Herbst and Schorfheide (2015) and Giordani et al. (2010) discuss the idea of using an hybrid algorithm to improve the efficiency of the standard Metropolis-Hastings random walk algorithm. Building on a specific example in An and Schorfheide (2007), the algorithm follows six key steps:

1. Using different starting values, apply a numerical optimization procedure to search for modes $\widetilde{\theta}_{(j)}$, $j = 1, ..., J$ of the posterior density. When the model allows for different degrees of indeterminacy, the search can be conditioned on determinacy or indeterminacy. This guarantees that each region has a, possibly local, posterior mode.

2. For each mode, compute the inverse of the Hessian, denoted by $\widetilde{\Sigma}_{(j)}$, $j = 1, ..., J$.

3. Let $q_j(\theta)$ be the density of a multivariate distribution obtained mixing two normals, both with mean $\widetilde{\theta}_{(j)}$, but different covariance matrices $c^s_j\widetilde{\Sigma}_{(j)}$ and $c^l_j\widetilde{\Sigma}_{(j)}$, with $c^s_j < c^l_j$. Let z^l be the probability of drawing from the normal with large variance:
$$q_j(\theta) = z^l N\left(\widetilde{\theta}_{(j)}, c^l_j\widetilde{\Sigma}_{(j)}\right) + \left(1 - z^l\right) N\left(\widetilde{\theta}_{(j)}, c^s_j\widetilde{\Sigma}_{(j)}\right).$$

4. Let π_j, $j = 1, ..., J$ be a set of probabilities and define $q(\theta)$ as:

$$q(\theta) = \sum_{j=1}^{J} \pi_j q_j(\theta).$$

5. Choose a starting value $\theta^{(0)}$ for instance by generating a draw from $q(\theta)$.

6. For $s = 1, ..., nsim$, follow these steps:

   (a) Make a draw ϑ from the following proposal distribution:

   $$\widetilde{q}(\vartheta|\theta^{(s-1)}) = w^{RW} N\left(\theta^{(s-1)}, c^{RW}\widetilde{\Sigma}_{(j)}\right) + \left(1 - w^{RW}\right) q(\theta),$$

   where w^{RW} is a number between 0 and 1 denoting the probability of using the standard random walk proposal distribution.

   (b) Accept the jump from $\theta^{(s-1)}$ to ϑ $\left(\theta^{(s)} = \vartheta\right)$ with probability $\min\left\{1, r_j\left(\theta^{(s-1)}, \vartheta|Y\right)\right\}$, otherwise reject the proposed draw and set $\theta^{(s)} = \theta^{(s-1)}$, where

   $$r_j\left(\theta^{(s-1)}, \vartheta|Y\right) = \frac{\mathcal{L}\left(\vartheta|Y\right) p\left(\vartheta\right) / \widetilde{q}(\vartheta|\theta^{(s-1)})}{\mathcal{L}\left(\theta^{(s-1)}|Y\right) p\left(\theta^{(s-1)}\right) / \widetilde{q}(\theta^{(s-1)}|\vartheta)}.$$

The hybrid algorithm collapses to a standard Metropolis-Hastings algorithm if $w^{RW} = 1$, while it becomes similar to the hybrid MCMC algorithm proposed by An and Schorfheide (2007) if $w^{RW} = 0$. The use of the mixture of normals facilitates the jump between areas of the parameter space that gravitate around different peaks of the posterior. The advantage of allowing for the standard random walk proposal distribution is to allow the algorithm to explore the parameter space around these peaks in an efficient way.

In this paper, I use the hybrid algorithm to estimate each model discussed in Section 6 and Section 7. I use 50 different starting values to apply the numerical optimization procedure in step 1 and find the conditional posterior modes in each region of (in)determinacy. Subsequently, I construct the proposal distribution as in step 6 using those posterior modes and set the initial parameterization in the "wrong" region of the parameter space—the region with the lowest posterior mode. While ensuring an acceptance rate between 25 and 35 percent, I run 10 chains of 1,000,000 draws each and keep one draw every 1,000. After combining the draws of each chain, I then keep one draw every 10 and present the estimation results based on the resulting 1,000 draws. Finally, I compute the posterior model probability as the ratio of the draws associated with determinacy relative to the total number of draws.

Data. As in SW, the measurement equation that relates the macroeconomic data, Y_t, to the endogenous variables of the model is

$$Y_t \equiv \begin{bmatrix} dlGDP_t \\ dlCONS_t \\ dlINV_t \\ dlWAG_t \\ lHours_t \\ dlP_t \\ FEDFUNDS_t \end{bmatrix} = \underbrace{\begin{bmatrix} \bar{\gamma} \\ \bar{\gamma} \\ \bar{\gamma} \\ \bar{\gamma} \\ \bar{l} \\ \bar{\pi} \\ \bar{R} \end{bmatrix}}_{\Phi_0(\theta)} + \underbrace{\begin{bmatrix} y_t - y_{t-1} \\ c_t - c_{t-1} \\ i_t - i_{t-1} \\ w_t - w_{t-1} \\ l_t \\ \pi_t \\ R_t \end{bmatrix}}_{\Phi_1(\theta)\hat{X}_t}, \tag{6}$$

where l and dl denotes 100 times log and log difference, respectively. The observables are the seven quarterly U.S. macroeconomic time series used in SW: the growth rate in real GDP, consumption, investment and wages, log hours worked, inflation rate measured by the GDP deflator, and the federal funds rate.

The deterministic balanced growth path is defined in terms of four parameters: the quarterly trend growth rate common to real GDP, consumption, investment and wages, $\bar{\gamma}$; the steady-state hours worked (normalized to zero), $\bar{l}$; the quarterly steady-state inflation rate, $\bar{\pi}$; the steady-state nominal interest rate, $\bar{R}$. Hence, the measurement equation in (6) relates the macroeconomic time series with the corresponding endogenous variables of the model: real output y_t, consumption c_t, investment i_t, wages w_t, hours worked h_t, inflation π_t and the nominal interest rate R_t.

For the estimation, I updated the U.S. quarterly time series from SW and consider three sample periods. The "Pre-1979" period starts in 1955:Q4, one year after the end of the Korean War, and ends in 1979:Q2, the date in which the chairmanship of William Miller at the Federal Reserve ends. Because, as discussed in detail in Section 6, results about the conduct of monetary policy for the period after 1979 are sensitive to the choice of the start date, I consider two alternative samples. Following Boivin and Giannoni (2006) and Leduc et al. (2007), the "Post-1979" period begins in 1979:Q3 with the appointment of Paul Volcker as chairman of the Federal Reserve, and concludes in 2007:Q3 with the onset of the Great Recession.[9] Alternatively, the "Post-1982" period starts in 1982:Q4 in line with the work of Lubik and Schorfheide (2004) and Hirose et al. (2020, 2021) and ends in 2007:Q3, the same end date of the post-1979 sample. Thus, the post-1982 sample excludes the Volcker disinflation.[10]

Calibration and prior distributions. To estimate the SW model, I calibrate the same parameters and assume the same prior distribution for the structural parameters and shock

[9] The start date of the post-1979 sample also ensures that, when estimating a version of the SW model with a time-varying inflation target in Subsection 7.2, I include all the data on 10-year-ahead inflation expectations as available starting in 1979:Q4.

[10] Bernanke and Mihov (1998) find that the main indicator of monetary policy stance is the federal funds rate for the periods before 1979 or after 1982 as opposed to nonborrowed reserves which the Fed targeted from 1979 to 1982.

processes as in SW—details in Appendix A.1. Relative to SW, the only difference relates to the prior distribution of the Taylor rule coefficient associated with the inflation response of the monetary authority, r_π. SW specify a normal distribution centered at 1.50, with standard deviation 0.25 and truncated at 1 to ensure equilibrium uniqueness. By contrast, I assume a flatter normal prior distribution centered at 1 and with standard deviation 0.35, and allow for indeterminacy by considering any positive value of r_π.

As discussed in Section 3, I use the solution method of Bianchi and Nicolò (2021) and therefore augment the SW model by appending the auxiliary process $\omega_t = (1/\alpha_\omega)\,\omega_{t-1} + \nu_{\pi,t} - \eta_{\pi,t}$, where $\eta_{\pi,t} = \pi_t - E_{t-1}(\pi_t)$. For the standard deviation of the sunspot shock, σ_ν, I assume a uniform prior distribution over the interval $[0, 1]$. To parameterize the full set of indeterminate solutions, I set a uniform prior distribution over the interval $[-1, 1]$ for the correlation of the sunspot shock with each exogenous shock i among the seven fundamental shocks of the SW model, $\rho_{\nu i}$. To ensure that the covariance matrix is always positive definite, the joint prior for the covariance matrix is effectively truncated by rejecting the parameter draws that violate this condition. Finally, to improve the efficiency of the hybrid algorithm, I choose the parameter α_ω such that the *augmented* model is determinate for each draw $\theta \in \Theta$: I set α_ω to a value greater than 1 when a draw θ is associated with determinacy of the *original* SW model and to a value in the interval $(0, 1)$ when a draw θ delivers indeterminacy.

The resulting prior probability of determinacy based on the prior distributions is 50.4 percent, thus assigning a roughly equal probability of determinacy and indeterminacy.

Local identification. To test for local identification of the estimated parameters for the augmented representation of the SW model, I use the methods of Iskrev (2010) and Qu and Tkachenko (2012) and consider both the determinate and indeterminate versions of the original SW model. For the determinate case, I test for identification by setting the Taylor rule coefficient on inflation, r_π, at 1.01 and each other parameter at the mean of their prior distribution.[11] As expected, the standard deviation of the sunspot shock and its correlation with the exogenous shocks are the only parameters that are not identified.

For the indeterminate case, I set r_π at 0.99 and keep the other parameters at their prior mean. Using both methods, the results show that all the estimated parameters are identified, including the standard deviation of the sunspot shock and its correlations with the exogenous shocks.[12] Intuitively, Section 3 shows that the resulting reduced-form solution for inflation under indeterminacy is $\pi_t = E_{t-1}(\pi_t) + \nu_{\pi,t}$, implying that its dynamics are predetermined.

[11] As in the work of SW, the prior mean of the parameters related to the autoregressiveness of the price and wage mark-up shocks—ρ_p and ρ_w respectively—is identical to the prior mean of the corresponding moving average components—μ_p and μ_w respectively—thus resulting in pairwise collinearity. For this reason, I run the identification analysis using $\mu_p = \mu_w = 0.5 + \epsilon$, where $\epsilon = 10^{-2}$.

[12] Qu and Tkachenko (2017) document that indeterminacy can help identify structural parameters and that identification properties can differ substantially between small- and medium-scale models.

Therefore, if the correlations between the sunspot shock and the exogenous shocks differ from their prior mean of zero, the exogenous shocks have a contemporaneous effect on inflation.

5 Two Key Features

This section shows that the adoption of both a rich structural model such as SW and the solution method of Bianchi and Nicolò (2021) are two key features to be accounted for when investigating the stance of U.S. monetary policy.

5.1 The Adoption of a Medium-scale Model

Several papers adopted univariate or small-scale NK models to study the conduct of U.S. monetary policy during the post-war period while allowing for indeterminacy.[13] However, it is also well known in the literature that if monetary policy is passive, two features of the model become relevant to explain the behavior of macroeconomic data. The indeterminate version of a model delivers an altered and more persistent transmission of the exogenous shocks and is subject to additional volatility due to sunspot shocks.

Beyer and Farmer (2007a) discuss the identification problem that relates to the possibility that an indeterminate small-scale model can be observationally equivalent to a determinate model with a richer dynamic and stochastic structure. Small-scale models impose restrictions on the structure of the underlying economy. By excluding richer models, the restrictions can favor the result of a passive monetary policy because missing propagation mechanisms and exogenous shocks can favor the evidence of indeterminacy.

To show that this theoretical result also has relevant empirical implications, I consider the small-scale model of Del Negro and Schorfheide (2004)—henceforth DS—who adapted the model of Lubik and Schorfheide (2004) to describe an economy that evolves along a balanced growth path. In particular, total factor productivity is assumed to follow an exogenous unit root process of the form $lnA_t = ln\gamma + lnA_{t-1} + z_t$, where $z_t = \rho_z z_{t-1} + \varepsilon_{z,t}$, and $\varepsilon_{z,t}$ can be interpreted as a technology shock. The model consists of a dynamic IS curve

$$y_t = E_t\left(y_{t+1}\right) - \tau^{-1}\left(R_t - E_t\left(\pi_{t+1}\right)\right) + (1-\rho_g)g_t + \rho_z\tau^{-1}z_t, \tag{7}$$

a NK Phillips curve

$$\pi_t = \beta E_t\left(\pi_{t+1}\right) + \kappa\left(y_t - g_t\right), \tag{8}$$

and a Taylor rule,

[13] Among others, see Clarida et al. (2000), Lubik and Schorfheide (2004), Bhattarai et al. (2016), Ettmeier and Kriwoluzky (2020), Hirose et al. (2020) and Haque (2021).

$$R_t = \rho_R R_{t-1} + (1-\rho_R)\left(\psi_\pi \pi_t + \psi_y y_t\right) + \varepsilon_{R,t}, \tag{9}$$

where $\beta = \gamma / r^*$ and r^* is the steady-state real interest rate. The demand shock, g_t, also follows a stationary AR(1) processes $g_t = \rho_g g_{t-1} + \varepsilon_{g,t}$, and the rational expectation forecast errors are defined as $\eta_{\pi,t} \equiv \pi_t - E_{t-1}(\pi_t)$ and $\eta_{y,t} \equiv y_t - E_{t-1}(y_t)$. The measurement equation for the DS model is

$$\begin{bmatrix} dlGDP_t \\ dlP_t \\ FEDFUNDS_t \end{bmatrix} = \begin{bmatrix} ln\gamma \\ ln\pi^* \\ lnr^* + ln\pi^* \end{bmatrix} + \begin{bmatrix} \Delta y_t + z_t \\ \pi_t \\ R_t \end{bmatrix}, \tag{10}$$

where the observables corresponds to three of the seven time series used for the measurement equation of the SW model, Y_t, defined in equation (6).

The DS model differs from the SW model in three important dimensions. First, the dynamic and stochastic structure of the DS model is substantially smaller than the one of the SW model. Second, differently from the Taylor rule of the DS model in (9), the monetary policy reaction function of the SW model in (1) also responds to changes in the output gap. In the context of a small-scale model, Coibon and Gorodnichenko (2011) show that a Taylor rule responding to output growth is helpful to restore determinacy for plausible inflation responses. Third, the DS model is estimated using a subset of the observables used in SW.

To empirically assess the role of each of these three differences while investigating the conduct of monetary policy, I proceed as follows. First, I simulate 10,000 observations using the SW model under the assumption of an active monetary policy leading to determinacy.[14] Then, I consider as observables the last 500 observations of the simulated growth rate in real GDP, inflation rate and federal funds rate. Finally, I estimate three alternative models:[15] i) the DS model described in equations (7) $\sim$ (10)–"DS model"; ii) a version of the DS model in which the Taylor rule in (9) also responds to output growth in the spirit of the monetary policy reaction function of the SW model in (1)—"Modified DS model"; iii) a version of the SW model estimated using the same three simulated observables as for the DS model in (10) and consequently assuming the presence of only three of the seven exogenous shocks of SW—"Modified SW model". To solve the models under indeterminacy, I adopt the method of Bianchi and Nicolò (2021) and, as for the original SW model, append the auxiliary process $\omega_t = (1/\alpha_\omega)\,\omega_{t-1} + \nu_{\pi,t} - \eta_{\pi,t}$. Using the simulated data, I estimate the models with the hybrid algorithm discussed in Section 4.

[14] To simulate the data, I use a calibration consistent with the estimates of the structural parameter and shock processes for the post-1979 period. In Section 6, I discuss the details and results of the estimation.

[15] Appendix B reports further details about the models as well as the prior and posterior distribution of the structural parameters and shock processes for each model.

For each model, Table 1 reports the conditional log-posterior mode in the determinacy and indeterminacy region resulting from the numerical optimization procedure in step 1 of the hybrid algorithm—second and third column, respectively. Moreover, the fourth column of Table 1 reports the posterior probability of determinacy obtained from step 6 and computed as the ratio of the draws associated with determinacy relative to the total number of draws. For the small-scale DS model, I find evidence of *indeterminacy*, even if the data are simulated using the SW model under determinacy. This result holds even for the Modified DS model, suggesting that allowing the Taylor rule to also respond to output growth is not enough to restore equilibrium uniqueness. By contrast, the estimation of the Modified SW model using the same three simulated observables as for the previous two models correctly shows that the data favor the specification under determinacy. The results in Table 1 empirically demonstrate that the two versions of the DS model misinterpret missing propagation mechanisms as incorrect evidence of indeterminacy and that rich structural models should be adopted to study the stance of monetary policy.

Table 1: The DS model, Modified DS model and Modified SW model

Model	Posterior mode		Prob. Determ.
	Determinacy	Indeterminacy	
DS model	-623.5	-581.7	0
Modified DS model	-621.7	-581.6	0
Modified SW model	-526.8	-541.7	1

The table reports the conditional log-posterior mode in the determinacy and indeterminacy region from the numerical optimization procedure of the hybrid algorithm as well as the posterior probability of determinacy for each of the three models: DS model, Modified DS model and Modified SW model.

5.2 The Adoption of Bianchi and Nicolò (2021)

In the literature, only few studies adopt a medium-scale model to investigate the conduct of U.S. monetary policy in the post-war period (Justiniano and Primiceri, 2008; Hirose et al., 2021). The main reason is that a researcher faces technical challenges to implement the method of Lubik and Schorfheide (2004). To overcome them, she needs to make assumptions for the construction of the indeterminate solution that, as discussed below, can be relevant for the findings, especially when adopting a rich structural model. This section shows that, even if equivalent to the method of Lubik and Schorfheide (2003, 2004), the novel method of Bianchi and Nicolò (2021) provides a valid alternative that facilitates the use of rich structural models while allowing for indeterminacy and can possibly lead to different results.

Lubik and Schorfheide (2003, 2004). This solution method is widely used in the literature and relies on three main features. To provide an intuition, I consider the case of one-degree indeterminacy for the original SW model in (2) and reported below in (11)

$$\Gamma_0(\theta)X_t = \Gamma_1(\theta)X_{t-1} + \Psi(\theta)\varepsilon_t + \Pi(\theta)\eta_t. \tag{11}$$

First, the method of Lubik and Schorfheide (2003) suggests to constructs the continuum of possible solutions under indeterminacy by appending the following additional equation

$$\underset{1\times\ell}{\widetilde{M}}\ \underset{\ell\times 1}{\varepsilon_t} + \underset{1\times 1}{M_\zeta}\ \underset{1\times 1}{\zeta_t} = \underset{1\times p}{V_2'(\theta)}\ \underset{p\times 1}{\eta_t}, \tag{12}$$

where M_ζ is normalized to 1 and the full set of indeterminate solutions is parameterized as a function of two additional sets of parameters: the standard deviation of a newly-defined sunspot shock, σ_ζ, and the vector $\widetilde{M}$ that captures the relationship between exogenous shocks and the sunspot shock. Importantly, the construction of the indeterminate solution as described in Lubik and Schorfheide (2003, 2004) does not map this relationship into correlations between exogenous shocks and the sunspot shock, implying that the domain of each parameter of $\widetilde{M}$ is *not well-defined* and *all* possible values can be considered. As a result, the choice of the baseline solution at which the indeterminate solution is centered can be critical for the peaks toward which an estimation algorithm can gravitate.

Second, Lubik and Schorfheide (2004) center the baseline solution of the indeterminate model at the "continuity solution". This solution replaces $\widetilde{M}$ with $M^*(\theta) + M$, where $M^*(\theta)$ is chosen so that the responses of the endogenous variables to the exogenous shocks are 'continuous' at the boundary between the determinacy and indeterminacy region. In medium-scale models, the condition that defines such boundary cannot be derived analytically and is a complex function of an unknown subset of the model parameters. Consequently, in the context of a NK model, the boundary is generally found by gradually increasing only the parameter that governs the response of the monetary authority to inflation, while leaving all the other parameters unchanged.

However, using alternative (subsets of) parameters affects the responses of the endogenous variables to the exogenous shocks at the boundary of the determinacy region—corresponding to the term $B_1(g(\theta))$ in equation (29) of Lubik and Schorfheide (2004), where $g(\theta)$ is an unknown function of the parameters in this case. Consequently, the selection of the parameter(s) used to find the boundary of the *determinacy* region has implications for the choice of $M^*(\theta)$ used to construct the baseline solution under *indeterminacy*.

Lastly, when estimating the model, the prior distribution of each term of the matrix M is typically a mean-zero normal distribution. However, the choice of the standard deviation of that distribution or the use of alternative prior distributions can impact which of the infinite solutions under indeterminacy are likely to be considered, especially given that the domain of the parameters defining M is not well defined.

Bianchi and Nicolò (2021). Section 3 discusses the implementation of the alternative solution method of Bianchi and Nicolò (2021) to the SW model. The solution of the augmented SW model under indeterminacy imposes conditions on the auxiliary process such that the reduced-form solution for inflation is $\pi_t = E_{t-1}(\pi_t) + \nu_{\pi,t}$.

This representation has the following three features. First, in addition to the standard deviation of the sunspot shock, σ_ν, the infinite set of indeterminate solutions is parameterized by the correlations of the sunspot shock with the exogenous shocks, $\Omega_{\varepsilon\nu}$, which have a *well-defined* domain. Second, Bianchi and Nicolò (2021) center the baseline solution by setting those correlations to zero, therefore assuming that exogenous shocks do not have a contemporaneous impact on inflation. This identification strategy is reminiscent of the zero restrictions often used in the Structural VAR (SVAR) literature and can be considered as an alternative to be tested in addition to the baseline solution of Lubik and Schorfheide (2004). Finally, because the domain of the correlations between the exogenous shocks and the sunspot shock is well defined, a uniform prior distribution over the interval $[-1, 1]$ for those correlations ensures that *all* indeterminate solutions can be explored during the estimation.

Empirical Relevance of the Adoption of Bianchi and Nicolò (2021). To show that the implementation of the solution method proposed by Bianchi and Nicolò (2021) is particularly relevant when estimating medium- and large-scale models, I simulate 10,000 observations using the SW model under the assumption of a passive monetary policy leading to indeterminacy.[16] Using the last 500 observations of the simulated data, I estimate the SW model using the two alternative methods to solve the model under indeterminacy. To construct the baseline solution using Lubik and Schorfheide (2004), I follow Justiniano and Primiceri (2008) and gradually increase only the parameter that governs the response of the monetary authority to inflation, r_π, to find the boundary of the determinacy region.

Table 2: The SW model and two alternative solution methods

Model	Posterior mode		Prob. Determ.
	Determinacy	Indeterminacy	
SW model + Lubik and Schorfheide (2004)	-2661.7	-2834.8	1
SW model + Bianchi and Nicolò (2021)	-2663.3	-2590.8	0

The table reports the conditional log-posterior mode in the determinacy and indeterminacy region from the numerical optimization procedure of the hybrid algorithm as well as the posterior probability of determinacy. The SW model is estimated using the solution method of either Lubik and Schorfheide (2004) or Bianchi and Nicolò (2021) and data simulated under indeterminacy.

For the estimation, I use the same prior distribution for the structural parameters and shock processes that are in common between the two methods. When implementing Lubik and Schorfheide (2004), the prior distribution for the sunspot shock, σ_ζ, is assumed to be an inverse gamma distribution with the same mean and standard deviation as for the other

[16] To simulate the data, I use a calibration consistent with the estimates of the structural parameter and shock processes for the pre-1979 period. In Section 6, I discuss the details and results of the estimation.

exogenous shocks. As in Lubik and Schorfheide (2004), I also use a mean-zero normal prior distribution with standard deviation equal to 1 for the each element of the M matrix.

As expected, Table 2 shows that, conditional on the region of determinacy, the numerical optimization procedure of the hybrid algorithm finds similar values for log-posterior mode of the SW model using either solution method.[17] However, the conditional log-posterior modes for the indeterminate SW model differ between the two methods. Using Lubik and Schorfheide (2004), the posterior mode under indeterminacy, -2834.8, is lower than the corresponding mode under determinacy, -2661.7. On the contrary, implementing Bianchi and Nicolò (2021), the posterior mode conditional on indeterminacy, -2590.8, is higher than its counterpart conditional on determinacy, -2663.3. The subsequent estimation of the model using step 6 of the hybrid algorithm correctly recovers the evidence that the data are simulated under indeterminacy only when the method of Bianchi and Nicolò (2021) is implemented. Instead, the adoption of the method of Lubik and Schorfheide (2004) suggests that the data are consistent with determinacy.

Table 3: The SW model and two alternative solution methods: Structural parameters

			Bianchi-Nicolò		Lubik-Schorfheide	
Coefficient	Description	Value	Mean	[5 , 95]	Mean	[5 , 95]
ϕ	Adjustment cost	4.85	5.12	[4.05,6.42]	4.74	[3.72,5.75]
σ_c	IES	1.36	1.33	[1.16,1.50]	1.32	[1.16,1.51]
h	Habit Persistence	0.59	0.58	[0.52,0.64]	0.59	[0.54,0.64]
σ_l	Labor supply elasticity	1.34	1.23	[0.72,1.81]	0.59	[0.33,0.90]
ξ_w	Wage stickiness	0.77	0.75	[0.71,0.79]	0.71	[0.68,0.74]
ξ_p	Price Stickiness	0.61	0.62	[0.58,0.67]	0.84	[0.81,0.88]
ι_w	Wage Indexation	0.43	0.45	[0.33,0.58]	0.61	[0.52,0.71]
ι_p	Price Indexation	0.27	0.26	[0.13,0.38]	0.09	[0.04,0.14]
ψ	Capacity utiliz. elasticity	0.39	0.41	[0.31,0.52]	0.35	[0.25,0.46]
Φ	Share of fixed costs	1.54	1.51	[1.43,1.58]	1.53	[1.44,1.61]
α	Share of capital	0.23	0.23	[0.21,0.24]	0.23	[0.21,0.25]
$\bar{\pi}$	S.S. inflation rate (quart.)	0.62	0.61	[0.45,0.78]	0.64	[0.49,0.80]
$100(\beta^{-1}-1)$	Discount factor	0.15	0.20	[0.12,0.28]	0.24	[0.16,0.33]
$\bar{l}$	S.S. hours worked	0.53	1.16	[0.50,1.95]	2.06	[1.03,3.02]
$\bar{\gamma}$	Trend growth rate (quart.)	0.33	0.34	[0.33,0.34]	0.34	[0.33,0.34]
r_π	Taylor rule inflation	0.86	0.88	[0.80,0.95]	0.88	[0.82,0.93]
r_y	Taylor rule output gap	0.14	0.18	[0.12,0.23]	0.20	[0.16,0.26]
$r_{\Delta y}$	Taylor rule Δ(output gap)	0.16	0.17	[0.14,0.20]	0.17	[0.14,0.19]
ρ	Taylor rule smoothing	0.85	0.87	[0.83,0.90]	0.79	[0.76,0.83]

The table compares the posterior distribution of structural parameters using the solution method of either Bianchi and Nicolò (2021) or Lubik and Schorfheide (2004) and data simulated under indeterminacy.

To further investigate the reasons for the results shown in Table 2, I report the posterior distribution of the structural parameters and shock processes of the SW model—Table 3 and 4, respectively—under both methodologies. The tables show that the estimation of the SW

[17] The conditional log-posterior mode of the determinate SW model differs under the two methods because each method embeds different assumptions about the the prior distributions of the standard deviation of the sunspot shock and its relationship with the exogenous shocks.

model using the method of Bianchi and Nicolò (2021)—fourth and fifth columns—recovers the true values used to generate the simulated data—third column.

Table 4: The SW model and two alternative solution methods: Shock processes

			Bianchi-Nicolò		Lubik-Schorfheide	
Coefficient	Description	Value	Mean	[5 , 95]	Mean	[5 , 95]
σ_a	Technology shock	0.56	0.58	[0.54,0.62]	0.58	[0.54,0.61]
σ_b	Risk premium shock	0.17	0.18	[0.15,0.20]	0.18	[0.16,0.20]
σ_g	Government sp. shock	0.52	0.48	[0.45,0.50]	0.48	[0.45,0.50]
σ_I	Investment-specific shock	0.52	0.46	[0.41,0.51]	0.46	[0.41,0.51]
σ_r	Monetary policy shock	0.18	0.18	[0.17,0.19]	0.18	[0.17,0.20]
σ_p	Price mark-up shock	0.30	0.26	[0.23,0.30]	0.31	[0.29,0.33]
σ_w	Wage mark-up shock	0.28	0.26	[0.24,0.28]	0.26	[0.24,0.29]
σ_ν	Sunspot shock (Bianchi-Nicolò)	0.13	0.09	[0.06,0.12]	-	-
σ_ζ	Sunspot shock (Lubik-Schorfheide)	-	-	-	0.10	[0.03,0.28]
ρ_a	Persistence technology	0.98	0.98	[0.97,0.99]	0.99	[0.98,0.99]
ρ_b	Persistence risk premium	0.68	0.66	[0.58,0.73]	0.64	[0.57,0.71]
ρ_g	Persistence government sp.	0.89	0.91	[0.89,0.94]	0.92	[0.89,0.94]
ρ_I	Persistence investment-specific	0.60	0.64	[0.58,0.70]	0.64	[0.58,0.70]
ρ_r	Persistence monetary policy	0.33	0.28	[0.21,0.35]	0.39	[0.30,0.48]
ρ_p	Persistence price mark-up	0.22	0.13	[0.03,0.25]	0.98	[0.98,0.99]
ρ_w	Persistence wage mark-up	0.32	0.36	[0.15,0.58]	0.33	[0.13,0.56]
μ_p	MA price mark-up	0.54	0.61	[0.49,0.73]	0.99	[0.99,0.99]
μ_w	MA wage mark-up	0.37	0.34	[0.13,0.57]	0.32	[0.13,0.56]
ρ_{ga}	Impact of ε_a on g_t	0.62	0.58	[0.51,0.65]	0.57	[0.51,0.63]
$\rho_{\nu a}$	$Corr(\sigma_\nu, \sigma_a)$	-0.25	-0.40	[-0.60,-0.19]	-	-
$\rho_{\nu b}$	$Corr(\sigma_\nu, \sigma_b)$	-0.03	0.08	[-0.16,0.33]	-	-
$\rho_{\nu g}$	$Corr(\sigma_\nu, \sigma_g)$	-0.10	-0.30	[-0.52,-0.10]	-	-
$\rho_{\nu I}$	$Corr(\sigma_\nu, \sigma_I)$	0.03	0.34	[0.14,0.55]	-	-
$\rho_{\nu r}$	$Corr(\sigma_\nu, \sigma_r)$	0.11	0.36	[0.11,0.59]	-	-
$\rho_{\nu p}$	$Corr(\sigma_\nu, \sigma_p)$	0.60	0.22	[-0.12,0.51]	-	-
$\rho_{\nu w}$	$Corr(\sigma_\nu, \sigma_w)$	0.14	0.21	[-0.06,0.47]	-	-
$M_{\zeta a}$	Impact of ε_a on ζ_t	-	-	-	-0.13	[-1.63,1.38]
$M_{\zeta b}$	Impact of ε_b on ζ_t	-	-	-	-0.10	[-1.60,1.40]
$M_{\zeta g}$	Impact of ε_g on ζ_t	-	-	-	0.02	[-1.78,1.82]
$M_{\zeta I}$	Impact of ε_I on ζ_t	-	-	-	-0.06	[-1.56,1.38]
$M_{\zeta r}$	Impact of ε_r on ζ_t	-	-	-	0.44	[-1.08,1.80]
$M_{\zeta p}$	Impact of ε_p on ζ_t	-	-	-	0.26	[-1.25,1.77]
$M_{\zeta w}$	Impact of ε_w on ζ_t	-	-	-	-0.29	[-1.92,1.20]

The table compares the posterior distribution of the parameters associated with the shock processes using the solution method of either Bianchi and Nicolò (2021) or Lubik and Schorfheide (2004) and data simulated under indeterminacy.

By contrast, the posterior distributions obtained implementing Lubik and Schorfheide (2004) differ from the values used for the simulation in various dimension. First, while the posterior distribution of the Taylor rule coefficient on inflation is in line with its true value, the Taylor rule coefficients on the output gap and interest-rate inertia are higher and lower, respectively, likely contributing to ensure that the model is determinate. In addition, while the degree of price indexation, ι_p, is slightly lower than its true value, several other parameters differ from their corresponding true values to match the persistence of the simulated inflation dynamics: a higher price stickiness, ξ_p, and a noticeably higher persistence of the price mark-up shock, ρ_p, as well as its moving-average component, μ_p. The estimation also delivers a higher steady state of hours worked, $\bar{l}$, a lower labor supply elasticity, σ_l, and a higher degree of wage indexation, ι_w. Finally, because the standard deviation of the sunspot shock, σ_ζ, and the M matrix are not identified under determinacy, their posterior distribution roughly corresponds to their prior.

6 U.S. Monetary Policy in the Post-war Period

Having established the relevance of adopting a rich structural model and the solution method of Bianchi and Nicolò (2021), I estimate the SW model over the post-war period using the hybrid algorithm, data and prior distributions discussed in Section 4. For each sample period considered, the numerical optimization procedure described in step 1 of the hybrid algorithm finds a log-posterior mode conditional on the determinate and indeterminate region—reported in the second and third columns of Table 5 respectively. Subsequently, these modes are used to construct the proposal distribution as detailed in step 6 of the algorithm and ultimately estimate the model over the entire parameter space. The resulting posterior probability of determinacy—reported in the last column—is the ratio of the draws associated with determinacy relative to the total number of draws.

Table 5: Posterior modes and posterior probability of determinacy

	Posterior mode		Prob. Determ.
	Determinacy	Indeterminacy	
Pre-1979	-546.3	-525.1	0
Post-1979	-567.1	-584.8	1
Post-1982	-377.1	-375.3	0

The table reports the conditional log-posterior mode in the determinacy and indeterminacy region from the numerical optimization procedure of the hybrid algorithm as well as the posterior probability of determinacy for the SW model during the pre-1979, post-1979 and post-1982 periods.

Focusing on the results for pre-1979 period—reported in the first row—the data favor the representation associated with indeterminacy, therefore rejecting the assumption of equilibrium uniqueness imposed in SW. Importantly, this result provides evidence that the equilibrium was indeterminate before 1979, and the findings of Clarida et al. (2000) and Lubik and Schorfheide (2004) among others carry over to a medium-scale model. In Section 7, I analyze the sensitivity of this result and show that the evidence of a passive monetary policy in the pre-1979 period is robust to the use of alternative model specifications and data.

Table 5 also shows that conclusions about whether the U.S. monetary policy adopted an aggressive stance to stabilize inflation since 1979 depend on the choice of the sample start date. As discussed in Section 4, the post-1979 sample starts in 1979:Q3—following Boivin and Giannoni (2006) and Leduc et al. (2007)—and ends in 2007:Q4. The results reported in

Table 6: SW model: Posterior distribution of structural parameters

		Pre-1979		Post-1979		Post-1982	
Coefficient	Description	Mean	[5 , 95]	Mean	[5 , 95]	Mean	[5 , 95]
ϕ	Adjustment cost	4.83	[3.36,6.52]	5.58	[3.94,7.43]	6.65	[4.69,8.65]
σ_c	IES	1.37	[1.10,1.66]	1.46	[1.24,1.69]	1.59	[1.16,1.94]
h	Habit Persistence	0.59	[0.48,0.70]	0.70	[0.63,0.77]	0.62	[0.48,0.72]
σ_l	Labor supply elasticity	1.31	[0.45,2.37]	1.94	[0.97,2.96]	2.31	[1.38,3.35]
ξ_w	Wage stickiness	0.76	[0.68,0.83]	0.64	[0.50,0.78]	0.67	[0.49,0.84]
ξ_p	Price Stickiness	0.61	[0.51,0.72]	0.72	[0.64,0.79]	0.73	[0.60,0.84]
ι_w	Wage Indexation	0.43	[0.23,0.62]	0.47	[0.25,0.72]	0.38	[0.17,0.63]
ι_p	Price Indexation	0.27	[0.11,0.49]	0.29	[0.13,0.49]	0.22	[0.09,0.39]
ψ	Capacity utiliz. elasticity	0.40	[0.22,0.58]	0.61	[0.43,0.78]	0.68	[0.51,0.83]
Φ	Share of fixed costs	1.54	[1.43,1.66]	1.59	[1.46,1.73]	1.54	[1.37,1.71]
α	Share of capital	0.23	[0.19,0.26]	0.21	[0.18,0.24]	0.22	[0.17,0.25]
$\bar{\pi}$	S.S. inflation rate (quart.)	0.62	[0.46,0.79]	0.66	[0.53,0.80]	0.60	[0.45,0.77]
$100(\beta^{-1}-1)$	Discount factor	0.15	[0.07,0.26]	0.17	[0.08,0.27]	0.16	[0.08,0.28]
$\bar{l}$	S.S. hours worked	0.65	[-0.71,2.25]	0.77	[-0.94,2.25]	0.85	[-0.95,2.25]
$\bar{\gamma}$	Trend growth rate (quart.)	0.33	[0.28,0.38]	0.45	[0.41,0.49]	0.45	[0.40,0.50]
r_π	Taylor rule inflation	0.86	[0.68,0.97]	2.10	[1.76,2.47]	0.75	[0.34,0.96]
r_y	Taylor rule output gap	0.14	[0.08,0.21]	0.07	[0.03,0.11]	0.10	[0.03,0.18]
$r_{\Delta y}$	Taylor rule Δ(output gap)	0.16	[0.12,0.21]	0.20	[0.15,0.25]	0.14	[0.09,0.20]
ρ	Taylor rule smoothing	0.85	[0.78,0.92]	0.78	[0.73,0.82]	0.88	[0.81,0.93]

Table 7: SW model: Posterior distribution of shock processes

		Pre-1979		Post-1979		Post-1982	
Coefficient	Description	Mean	[5 , 95]	Mean	[5 , 95]	Mean	[5 , 95]
σ_a	Technology shock	0.56	[0.49,0.64]	0.39	[0.34,0.44]	0.38	[0.33,0.42]
σ_b	Risk premium shock	0.17	[0.11,0.23]	0.22	[0.19,0.26]	0.17	[0.06,0.22]
σ_g	Government sp. shock	0.52	[0.46,0.59]	0.47	[0.42,0.52]	0.40	[0.35,0.45]
σ_I	Investment-specific shock	0.52	[0.40,0.65]	0.39	[0.32,0.46]	0.38	[0.28,0.51]
σ_r	Monetary policy shock	0.18	[0.15,0.20]	0.23	[0.20,0.26]	0.12	[0.10,0.14]
σ_p	Price mark-up shock	0.30	[0.25,0.35]	0.10	[0.07,0.12]	0.14	[0.10,0.18]
σ_w	Wage mark-up shock	0.28	[0.23,0.32]	0.31	[0.25,0.37]	0.30	[0.24,0.37]
σ_ν	Sunspot shock	0.13	[0.03,0.22]	0.50	[0.05,0.95]	0.14	[0.08,0.21]
ρ_a	Persistence technology	0.98	[0.97,0.99]	0.95	[0.90,0.98]	0.93	[0.88,0.98]
ρ_b	Persistence risk premium	0.68	[0.48,0.85]	0.18	[0.05,0.33]	0.31	[0.06,0.89]
ρ_g	Persistence government sp.	0.89	[0.83,0.94]	0.97	[0.95,0.99]	0.95	[0.93,0.98]
ρ_I	Persistence investment-specific	0.60	[0.46,0.75]	0.76	[0.66,0.85]	0.65	[0.43,0.83]
ρ_r	Persistence monetary policy	0.33	[0.19,0.48]	0.12	[0.04,0.24]	0.40	[0.23,0.58]
ρ_p	Persistence price mark-up	0.22	[0.05,0.50]	0.86	[0.74,0.95]	0.55	[0.10,0.95]
ρ_w	Persistence wage mark-up	0.32	[0.11,0.59]	0.94	[0.89,0.97]	0.79	[0.51,0.94]
μ_p	MA price mark-up	0.54	[0.29,0.80]	0.63	[0.39,0.81]	0.59	[0.28,0.86]
μ_w	MA wage mark-up	0.39	[0.18,0.81]	0.75	[0.57,0.90]	0.53	[0.24,0.74]
ρ_{ga}	Impact of ε_a on g_t	0.62	[0.47,0.77]	0.48	[0.30,0.66]	0.41	[0.24,0.60]
$\rho_{\nu a}$	$Corr(\sigma_\nu, \sigma_a)$	-0.26	[-0.57,0.07]	-0.01	[-0.52,0.50]	-0.20	[-0.41,0.00]
$\rho_{\nu b}$	$Corr(\sigma_\nu, \sigma_b)$	-0.01	[-0.38,0.37]	-0.06	[-0.61,0.50]	-0.16	[-0.37,0.10]
$\rho_{\nu g}$	$Corr(\sigma_\nu, \sigma_g)$	-0.10	[-0.40,0.24]	0.03	[-0.57,0.58]	-0.16	[-0.35,0.06]
$\rho_{\nu I}$	$Corr(\sigma_\nu, \sigma_I)$	0.07	[-0.26,0.41]	0.05	[-0.52,0.59]	-0.19	[-0.40,0.04]
$\rho_{\nu r}$	$Corr(\sigma_\nu, \sigma_r)$	0.11	[-0.29,0.45]	-0.03	[-0.51,0.56]	0.00	[-0.26,0.23]
$\rho_{\nu p}$	$Corr(\sigma_\nu, \sigma_p)$	0.60	[0.06,0.88]	0.02	[-0.53,0.54]	0.70	[0.45,0.87]
$\rho_{\nu w}$	$Corr(\sigma_\nu, \sigma_w)$	0.13	[-0.26,0.50]	0.03	[-0.50,0.56]	0.26	[0.03,0.47]

the second row of Table 5 suggest that the post-1979 period is associated with determinacy and indicative of the fact that the conduct of monetary policy changed during the post-war period from a passive stance before 1979 to an active inflation targeting thereafter.

However, the evidence of determinacy for the post-1979 period is overturned when the Volcker-disinflation period is excluded. In line with the work of Lubik and Schorfheide (2004) and Hirose et al. (2020) among others, the post-1982 period uses 1982:Q4 as an alternative start date relative to the post-1979 sample, but keeps the same end date. The third row of Table 5 indicates that the log-posterior mode conditional on determinacy (-377.1) is lower than the corresponding mode under indeterminacy (-375.3) and that the probability of indeterminacy resulting from the model estimation is 1. In Section 7, I show that the finding of an active monetary policy stance in the post-1979 period is also sensitive to the inclusion of a time-varying inflation target in the model, even when using data on short- or longer-term inflation expectations for the estimation.

Table 6 and 7 report the posterior distribution of the structural parameters and shock processes, respectively, for the three sample periods. The estimates for the pre-1979 period—third and fourth column—display five important differences compared to the corresponding estimates for the post-1979 period—fifth and sixth column.[18] First, in the post-1979 period, the monetary authority responded more actively to inflation and more moderately to output gap than in the pre-1979 period, and the federal funds rate was less persistent as indicated by a lower degree of inertia. Second, the growth rate of the economy, $\bar{\gamma}$, is slightly higher in the post-1979 period, likely due to the high productivity growth that the U.S. economy experienced since the mid-1990s to the early 2000s (Fernald, 2015).

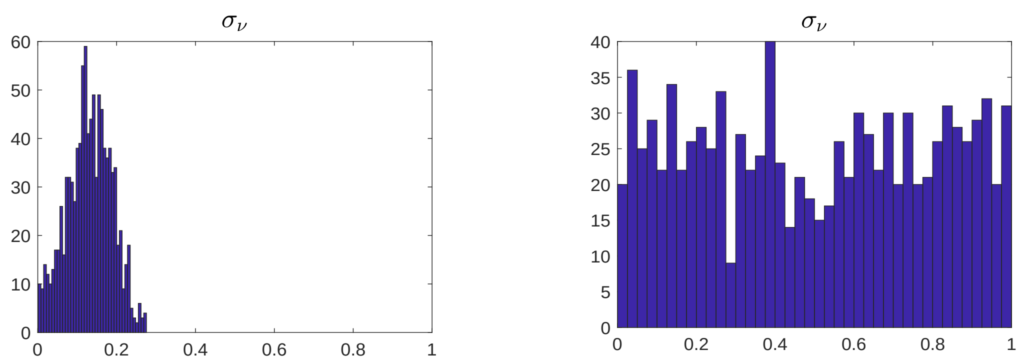
Third, the post-1979 period is characterized by a mildly higher degree of price stickiness, ξ_p, and a more persistent process of the price mark-up shock, ρ_p, in line with the evidence of an increase in the average price duration over this period because of the lower and more stable inflation rate (Galí and Gertler, 1999). Fourth, the volatility of the technology, investment-specific and price mark-up shocks is notably smaller in the second sample, a finding supported by Stock and Watson (2003), Primiceri (2005) and Sims and Zha (2006). By contrast, the volatility of the risk premium and monetary policy shocks is slightly higher mainly because of the inclusion of the Volcker-disinflation period in the sample, as further discussed below.

Finally, the estimation also delivers the posterior distribution of the standard deviation of the sunspot shock and its correlation with the exogenous shocks. As expected, these parameters are not identified in the post-1979 period when the evidence of determinacy prevails. The right panel of Figure 1 shows that the posterior distribution of the standard deviation of the sunspot shock corresponds to its uniform prior distribution over the interval [0,1]. Table 7 also

[18] Appendix A.2 shows the corresponding plots of the posterior distributions.

shows that the posterior distributions of the correlations between the sunspot shock and the exogenous shocks are symmetric around 0. However, these distributions do not correspond to their uniform prior distribution because, as explained in Section 4, the joint prior for the covariance matrix results to be truncated to ensure that the matrix is always positive definite. The standard deviation of the sunspot shock and its correlations are however identified in the pre-1979 period when the passive monetary policy stance led to indeterminacy. The left panel of Figure 1 shows that the standard deviation is tightly estimated. Similarly, Table 7 suggests that the correlation between the sunspot and price mark-up shock, $\rho_{\nu p}$, is well identified and positive, thus capturing the contemporaneous impact of mark-up shocks on inflation over this period.

Figure 1: Posterior distribution: Standard deviation of the sunspot shock



(a) Pre-1979 (b) Post-1979

This figure plots the posterior distribution of the standard deviation of the sunspot shock, σ_ν, for the pre-1979 period in panel (a) and for the post-1979 period in panel (b).

The estimates of the structural parameters and shock processes for the post-1982 period are roughly equivalent to those for the post-1979 period with three important distinctions. The Taylor-rule coefficients indicate a weaker response to inflation and a higher degree of interest rate inertia than suggested by the corresponding coefficient for the post-1979 period. However, the estimates of the Taylor-rule parameters for the post-1982 are similar to those for the pre-1979 period. Additionally, because of the exclusion of the Volcker-disinflation period, the standard deviation of both the risk premium and monetary policy shocks are smaller for the post-1982 period than for the post-1979 period. In particular, the volatility of the monetary policy shock is also smaller than its counterpart for the pre-1979. Finally, the standard deviation of the sunspot shock and its correlation with the exogenous shocks are identified for the post-1982 period given the evidence of a passive monetary policy, leading to indeterminacy. Also, their posterior estimates are similar to those for the pre-1979 period, suggesting a positive correlation between the sunspot and price mark-up shocks.

7 Robustness Analysis

This section verifies the robustness of the results obtained in Section 6 about the systematic conduct of U.S. monetary policy. Subsection 7.1 and 7.2 test if the inclusion of a time-varying inflation target for the central bank affects the estimation results, while possibly using data on short- or longer-run inflation expectations. Subsection 7.3 uses the latest vintage of real-time data available at the end of the pre- and post-1979 periods to estimate the SW model.

For the pre-1979 period, the results show that the evidence of indeterminacy is robust to the various specifications. However, this conclusion does not apply to the post-1979 sample for which the determinacy result is overturned if a time-varying inflation target is included, possibly also using data on short- or longer-term inflation expectations to estimate the model.

7.1 Time-varying Inflation Target

Low-frequency movements in inflation during the post-war period are difficult to capture in models which assume that the monetary authority has a constant inflation target. To improve the empirical fit of these models, a large literature highlights the importance of explicitly accounting for a time-varying inflation target.[19] Recently, Haque (2021) includes of a time-varying inflation target in a small-scale NK model with positive trend inflation and shows that the response of the monetary authority to the resulting inflation gap is stronger, ruling out indeterminacy for both periods before and after the Volcker disinflation.

In addition to verify the robustness of the results presented in Section 6, this section seeks to assess whether the conclusions of Haque (2021) carry over to a SW model with a time-varying inflation target. I follow Del Negro and Schorfheide (2013) and modify the Taylor rule in equation (1) for the SW model as follows

$$R_t = \rho R_{t-1} + (1-\rho)\left\{r_\pi\left(\pi_t - \pi_t^*\right) + r_y\left(y_t - y_t^p\right)\right\} + r_{\Delta y}\left[\left(y_t - y_t^p\right) - \left(y_{t-1} - y_{t-1}^p\right)\right] + u_{R,t}, \tag{13}$$

where the time-varying inflation target is a stationary AR(1) process $\pi_t^* = \rho_{\pi^*}\pi_{t-1}^* + \varepsilon_{\pi^*,t}$ with $0 < \rho_{\pi^*} < 1$, as in Erceg and Levin (2003). The process for π_t^* is assumed to be highly persistent, and the prior for ρ_{π^*} is centered at 0.95. Moreover, as in Del Negro and Schorfheide (2013), the prior for the standard deviation of the inflation-target shock, σ_{π^*}, is an inverse gamma distribution with mean 0.03 and standard deviation 6.

Table 8 reports the log-posterior mode conditional on determinacy and indeterminacy as well as the posterior probability of determinacy of the baseline SW model and alternative

[19] Among others, see Cogley and Sargent (2005a,b), Primiceri (2006), Sargent et al. (2006), Ireland (2007), Stock and Watson (2007), Cogley and Sbordone (2008), Cogley et al. (2010), Aruoba and Schorfheide (2011) and Justiniano et al. (2013).

specifications for both the pre- and post-1979 samples. The first row reports the same results obtained for the baseline model and shown in Table 5. The second row focuses on the version of the SW model which incorporates the time-varying inflation target and labeled "SWπ^*". For both the pre- and post-1979 periods, relaxing the assumption that the inflation target is constant improves the fit of the model compared to the baseline SW model as shown by overall higher posterior modes.[20] While the result of indeterminacy for the pre-1979 period is robust to this version, the evidence of determinacy for the post-1979 period is overturned because the improvement in the fit of the specification with a flexible inflation target relative to the baseline SW model is noticeably larger under indeterminacy than under determinacy.

Table 8: The baseline SW model and alternative specifications

Model	Pre-1979			Post-1979		
	Posterior mode		Prob.Det.	Posterior mode		Prob.Det.
	Det.	Indet.		Det.	Indet.	
SW model	-546.3	-525.1	0	-567.1	-584.8	1
SWπ^*	-534.4	-520.5	0	-564.4	-557.1	0
SWπ^* + $\pi^{e,4}$	-584.8	-571.1	0	-485.2	-451.0	0
SWπ^* + $\pi^{e,40}$	-	-	-	-472.2	-466.6	0
SW model + Real-time data	-543.9	-522.8	0	-598.2	-605.7	1

The table reports the conditional log-posterior mode in the determinacy and indeterminacy region from the numerical optimization procedure of the hybrid algorithm as well as the posterior probability of determinacy of the SW model and alternative specifications for the pre- and post-1979 samples.

In contrast to the findings of Haque (2021), these results show that a time-varying inflation target does not rule out indeterminacy not only for the pre-1979 period but also for the post-1979 period. This conclusion is relevant in light of the three main facts. First, as shown in Subsection 5.1, the adoption of a rich model that explicitly accounts for propagation mechanisms and exogenous shocks is key for conclusions about the conduct of monetary policy. Second, Haque (2021) adopts the solution method of Lubik and Schorfheide (2004) which, as shown in Subsection 5.2, can lead to different conclusions relative to those resulting from the implementation of the method of Bianchi and Nicolò (2021). Finally, while the model in Haque (2021) has a positive trend inflation, the SW model assumes no trend inflation, thus reducing the likelihood of indeterminacy all else being equal (Ascari and Sbordone, 2014). Therefore, the introduction of a positive trend inflation in the SW model would further strengthen the results presented herein.

[20] Appendix C reports the posterior distributions of the structural parameters and shock processes associated with the results presented in Subsection 7.1 and 7.2.

7.2 Time-varying Inflation Target and Inflation Expectations

To better capture the low-frequency dynamics of inflation, several papers not only incorporate a time-varying inflation target in the model but also use data on inflation expectations (Leduc et al., 2007; Aruoba and Schorfheide, 2011; Del Negro and Eusepi, 2011; Del Negro and Schorfheide, 2013). I follow the approach of Del Negro and Schorfheide (2013) who, in addition to adopting a time-varying inflation target as discussed in Subsection 7.1, augment the set of measurement equations in (6) with equation (14) below

$$\begin{aligned}\pi_t^{e,J} &= \bar{\pi} + \mathbb{E}_t\left[\frac{1}{J}\sum_{k=1}^{J}\pi_{t+k}\right] \\ &= \bar{\pi} + \frac{1}{J}\Phi_1(\theta)_{(\pi,\cdot)}\left(I-\hat{\Gamma}_1(\theta)\right)^{-1}\left(I-\left[\hat{\Gamma}_1(\theta)\right]^J\right)\hat{\Gamma}_1(\theta)\hat{X}_t,\end{aligned} \tag{14}$$

where $\pi_t^{e,J}$ represents observed inflation expectations averaged over the next J quarters. The right-hand side of (14) represents the corresponding expectations from the SW model and computed using the reduced-form solution of the model in (4) and the measurement equation for inflation in (6)—$\Phi_1(\theta)_{(\pi,\cdot)}$ denotes the row of $\Phi_1(\theta)$ associated with inflation.

I estimate the specification of the SW model with a time-varying inflation target by using short- or longer-term inflation expectations in addition to the observables in (6).[21] Following Del Negro and Eusepi (2011), the short-run inflation expectations are obtained from the Survey of Professional Forecasters (SPF) available from the FRB Philadelphia's Real-Time Data Research Center. Specifically, these expectations correspond to average inflation—measured by the GDP price index—over the next four quarters (i.e. $J = 4$ in (14)) and are available since 1970:Q2.

I follow Del Negro and Schorfheide (2013) to construct a time series for longer-run inflation expectations from the SPF and the Blue Chip Economic Indicators survey—also available from the Real-Time Data Research Center. I use the 10-year CPI inflation expectations (i.e. $J = 40$ in (14)) from the Blue Chip survey—available twice a year from 1979:Q4 to 1991:Q4—and those from the SPF—available each quarter starting from 1991:Q4.[22] To combine the measures, I subtract from the 10-year CPI inflation expectations the average difference between CPI and GDP annualized inflation over the period from 1979:Q4 to 2007:Q3.

Using the short-run inflation expectations, I estimate the SW model with a time-varying inflation target—labeled "SWπ^* + $\pi^{e,4}$"—over both the pre- and post-1979 period. As shown in the third row of Table (8), the results further support the findings obtained when estimating the SW model with time-varying inflation target but without data on inflation

[21] Both short- and longer-run inflation expectations are expressed at quarterly rates.
[22] To treat missing observations, I adjust the measurement equation of the Kalman filter accordingly.

expectations: the evidence of indeterminacy holds for both samples. Finally, due to data availability, the estimation of the SW model with longer-run inflation expectations—labeled "SWπ^* + $\pi^{e,40}$"—is conducted only over the post-1979 sample period. Even in this case, the results show that evidence of indeterminacy persists—fourth row of Table (8).

7.3 Real-Time Data

In Section 6, the estimation of the SW model uses the most recent data available. However, Orphanides (2001) demonstrates that policy-rate recommendations based on real-time data can vary compared to those based on revised data. Orphanides (2002, 2003) shows that, while systematically adopting an active and forward-looking approach, policymakers overestimated potential output in real time during the 1970s and therefore implemented expansionary policy decisions that led to the Great Inflation.

Using real-time data available from the FRB Philadelphia's Real-Time Data Research Center, I estimate the SW model over the pre- and post-1979 periods using the vintage available at the end of each sample period—1979:Q2 and 2007:Q4, respectively. I use real-time data on real output (ROUTPUT), real personal consumption expenditure (RCON), real non-residential private domestic investment (RINVBF) and the price index for output (P).[23] Because real-time data are not available for the remaining time series used to construct the dataset as in SW, I consider the most recent data for these series.

Table 8 indicates that the results obtained using the most recent data—reported in the first column—are robust to the use of real-time data—shown in the last column. In the pre-1979 period, the posterior mode under indeterminacy (-522.8) is considerably higher than that under determinacy (-543.9), and the posterior probability of determinacy obtained from the hybrid algorithm is zero.[24] Similarly, the results for the post-1979 period still provide evidence of determinacy, suggesting that the use of real-time data does not affect the results based on the most recent data.[25]

8 Conclusions

In this paper, I argue that two features need to be adopted when investigating the stance of U.S. monetary policy: a rich structural model and the novel method of Bianchi and

[23] Real-time data on real output corresponds to real-time data on real GNP before 1992 and real GDP since 1992.

[24] Appendix D reports the corresponding posterior distribution of the structural parameters and exogenous shocks for the pre- and post-1979 periods.

[25] I also verify that the evidence of indeterminacy for the post-1982 period obtained using the most recent data holds if I estimate the SW model using real-time data as available at the end of the sample. The results are available upon request.

Nicolò (2021). Using data simulated from a determinate version of the SW model, I find that the estimated small-scale model of Del Negro and Schorfheide (2004) misinterprets missing propagation mechanisms as evidence of indeterminacy. This finding holds even after accounting for differences between the two models in the specification of the Taylor rules or the set of data used. Moreover, using simulated data from an indeterminate version of the SW model, the estimation of the SW model implementing the approach of Bianchi and Nicolò (2021) correctly points to evidence of determinacy, while the adoption of the method of Lubik and Schorfheide (2003, 2004) leads to evidence of indeterminacy.

As a result, I estimate the medium-scale NK model of SW using the novel solution method of Bianchi and Nicolò (2021) to allow for a passive monetary policy. The evidence of indeterminacy in the pre-1979 period is pervasive and robust to various model specifications and data used. By contrast, the result of an active monetary policy since 1979 is overturned if the Volcker-disinflation period is excluded or if the SW model is modified to incorporate a time-varying inflation target for the central bank and is possibly estimated by also including data on inflation expectations.

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A SW model

A.1 SW model: Calibration and prior distributions

Following SW, I adopt the same calibration for five parameters. The depreciation rate δ is fixed to 0.025, the exogenous spending-GDP ratio g_y to 18 percent, the steady state mark-up in the labor market λ_w to 1.5 and the curvature parameters of the Kimball aggregators in the food and labor market, ε_p and ε_w respectively, are both set at 10. The prior distribution of the structural parameters and the shock processes of the SW model are reported in Table 9 and 10, respectively. The prior probability of determinacy based on the prior distributions is 50.4 percent, thus assigning a roughly equal probability to the determinate and indeterminate regions of the parameter space.

Table 9: SW model: Prior distribution of structural parameters

Coefficient	Description	Distr.	Mean	Std. Dev
ϕ	Adjustment cost	Normal	4.00	1.50
σ_c	IES	Normal	1.50	0.37
h	Habit Persistence	Beta	0.70	0.10
σ_l	Labor supply elasticity	Normal	2.00	0.75
ξ_w	Wage stickiness	Beta	0.50	0.10
ξ_p	Price Stickiness	Beta	0.50	0.10
ι_w	Wage Indexation	Beta	0.50	0.15
ι_p	Price Indexation	Beta	0.50	0.15
ψ	Capacity utilization elasticity	Beta	0.50	0.15
Φ	Share of fixed costs	Normal	1.25	0.12
α	Share of capital	Normal	0.30	0.05
$\bar{\pi}$	S.S. inflation rate (quart.)	Gamma	0.62	0.10
$100(\beta^{-1}-1)$	Discount factor	Gamma	0.25	0.10
$\bar{l}$	S.S. hours worked	Normal	0.00	2.00
$\bar{\gamma}$	Trend growth rate	Normal	0.40	0.10
r_π	Taylor rule inflation	Normal	***1.00***	***0.35***
r_y	Taylor rule output gap	Normal	0.12	0.05
$r_{\Delta y}$	Taylor rule Δ(output gap)	Normal	0.12	0.05
ρ	Taylor rule smoothing	Beta	0.75	0.10

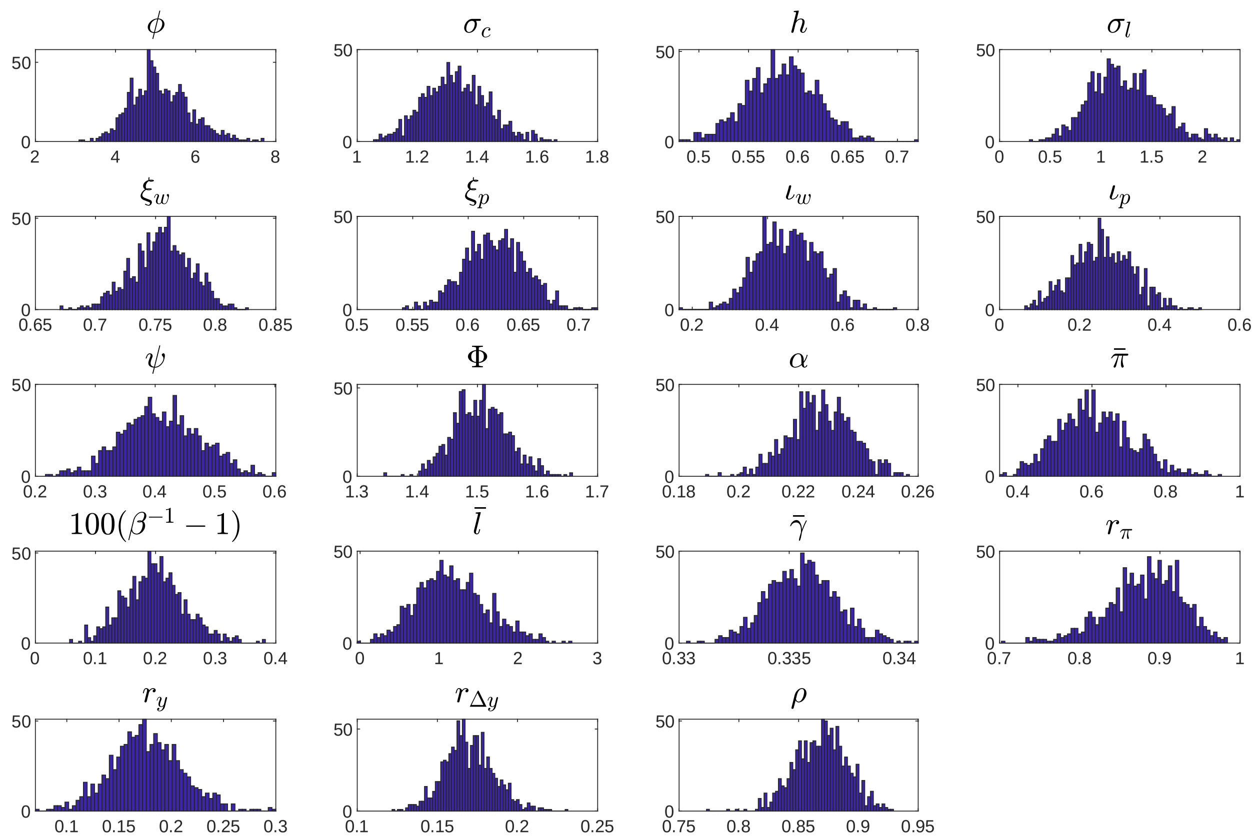
Table 10: SW model: Prior distribution of shock processes

Coefficient	Description	Distr.	Mean	Std. Dev
σ_a	Technology shock	Invgamma	0.10	2.00
σ_b	Risk premium shock	Invgamma	0.10	2.00
σ_g	Government sp. shock	Invgamma	0.10	2.00
σ_I	Investment-specific shock	Invgamma	0.10	2.00
σ_r	Monetary policy shock	Invgamma	0.10	2.00
σ_p	Price mark-up shock	Invgamma	0.10	2.00
σ_w	Wage mark-up shock	Invgamma	0.10	2.00
σ_ν	Sunspot shock	Uniform[0,1]	0.50	0.29
ρ_a	Persistence technology	Beta	0.50	0.20
ρ_b	Persistence risk premium	Beta	0.50	0.20
ρ_g	Persistence government sp.	Beta	0.50	0.20
ρ_I	Persistence investment-specific	Beta	0.50	0.20
ρ_r	Persistence monetary policy	Beta	0.50	0.20
ρ_p	Persistence price mark-up	Beta	0.50	0.20
ρ_w	Persistence wage mark-up	Beta	0.50	0.20
μ_p	Mov. Avg. term, price mark-up	Beta	0.50	0.20
μ_w	Mov. Avg. term, wage mark-up	Beta	0.50	0.20
ρ_{ga}	Impact of ε_a on g_t	Normal	0.50	0.25
$\rho_{\nu a}$	$Corr(\sigma_\nu, \sigma_p)$	Uniform[-1,1]	0.00	0.57
$\rho_{\nu b}$	$Corr(\sigma_\nu, \sigma_p)$	Uniform[-1,1]	0.00	0.57
$\rho_{\nu g}$	$Corr(\sigma_\nu, \sigma_p)$	Uniform[-1,1]	0.00	0.57
$\rho_{\nu I}$	$Corr(\sigma_\nu, \sigma_p)$	Uniform[-1,1]	0.00	0.57
$\rho_{\nu r}$	$Corr(\sigma_\nu, \sigma_p)$	Uniform[-1,1]	0.00	0.57
$\rho_{\nu p}$	$Corr(\sigma_\nu, \sigma_p)$	Uniform[-1,1]	0.00	0.57
$\rho_{\nu w}$	$Corr(\sigma_\nu, \sigma_p)$	Uniform[-1,1]	0.00	0.57

A.2 SW model: Posterior distributions

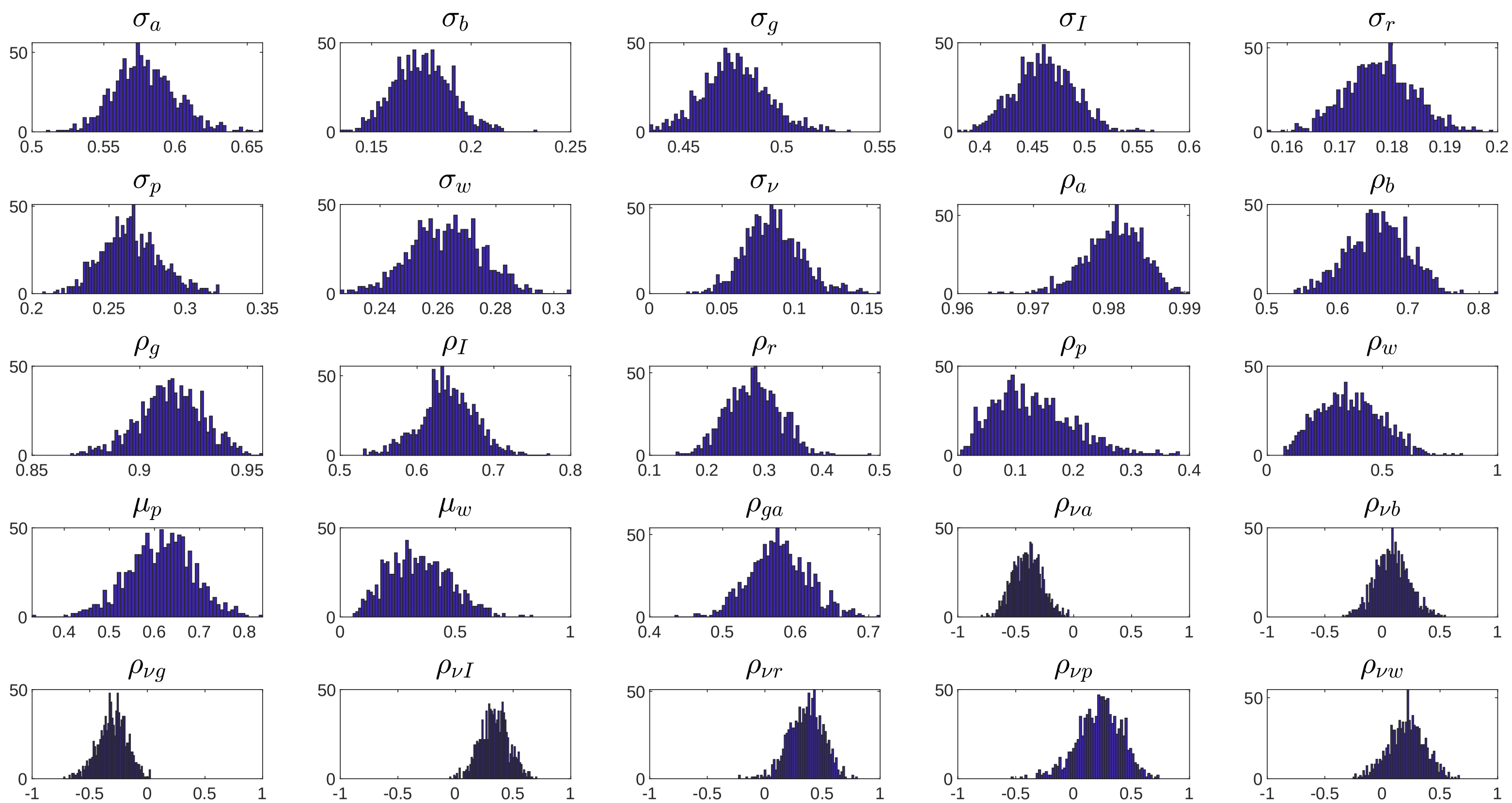
The next four figures plot the posterior distribution of the structural parameters and shock processes of the SW model. Figure 2 and 3 plot the respective posterior distributions for the pre-1979 period, while Figure 4 and 5 for the post-1979 period.

Figure 2: Posterior distributions for pre-1979 period: Structural parameters



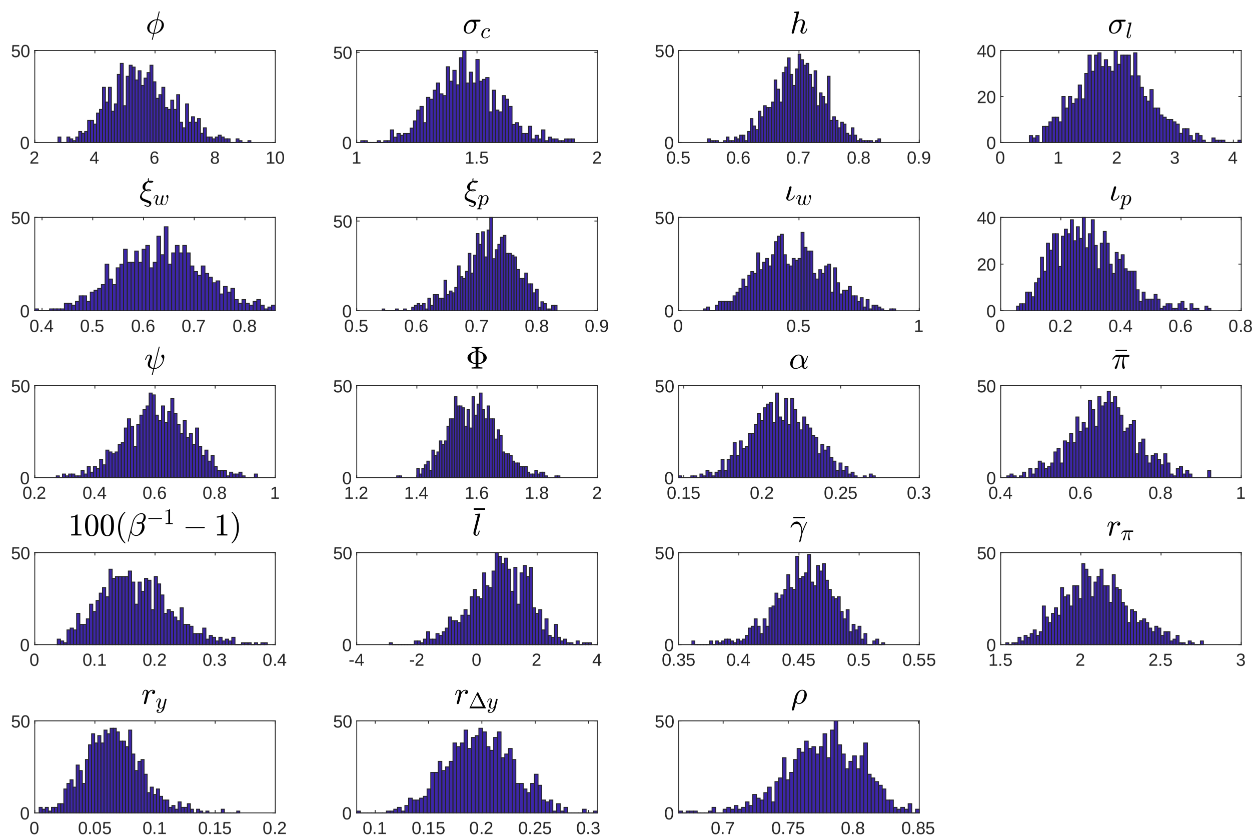
The figure plots the posterior distribution of the structural parameters of the SW model for the pre-1979 period.

Figure 3: Posterior distributions for pre-1979 period: Shock processes



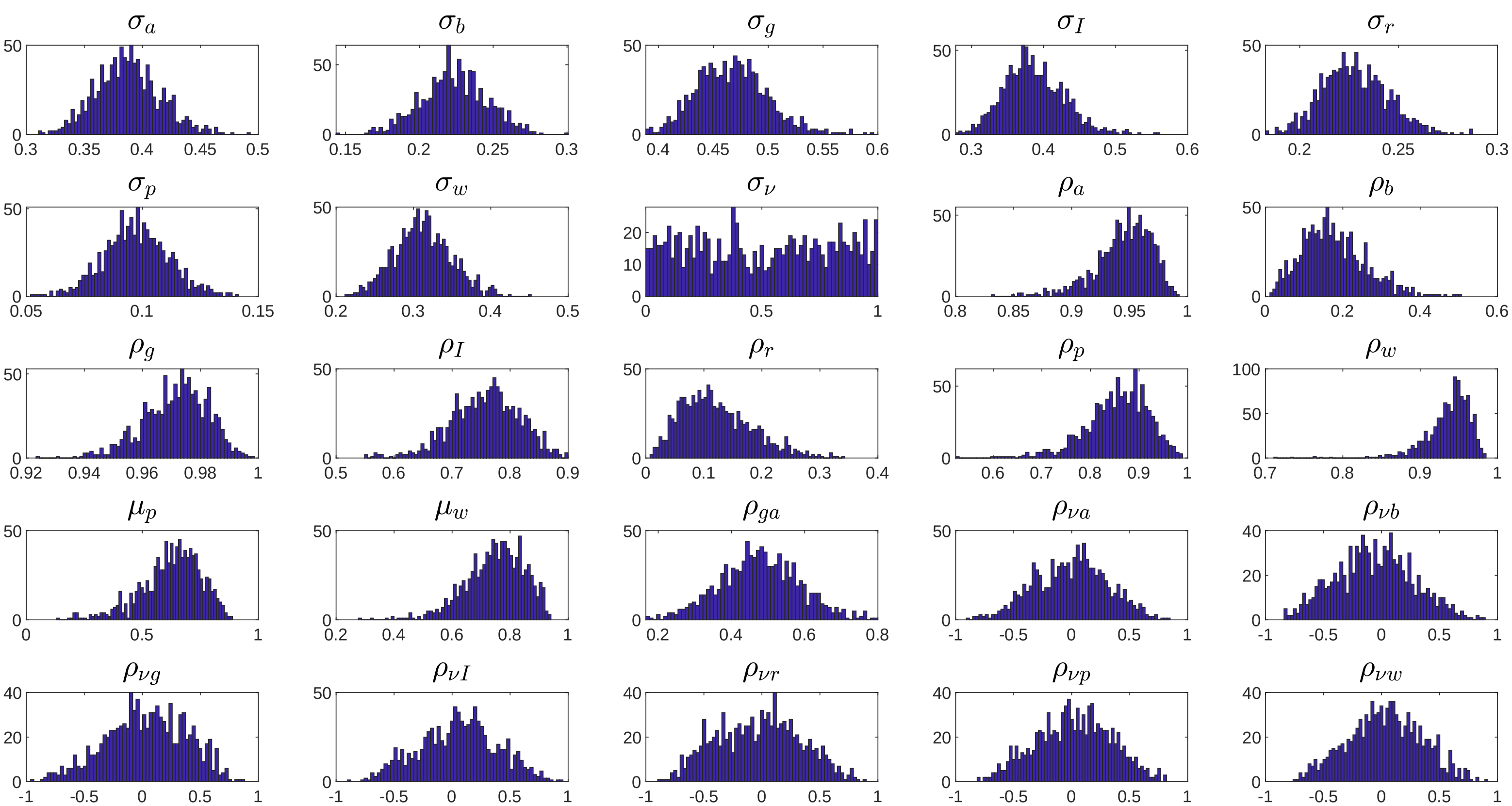
The figure plots the posterior distribution of the parameters associated with the shock processes of the SW model for the pre-1979 period.

Figure 4: Posterior distributions for post-1979 period: Structural parameters



The figure plots the posterior distribution of the structural parameters of the SW model for the post-1979 period.

Figure 5: Posterior distributions for post-1979 period: Shock processes



The figure plots the posterior distribution of the parameters associated with the shock processes of the SW model for the post-1979 period.

B DS model, Modified DS model and Modified SW model

B.1 DS model and Modified DS model

Table 11 reports the prior distribution of the structural parameters and shock processes of the DS model. The prior distributions are equivalent to those in Del Negro and Schorfheide (2004), with three exceptions. First, to ensure that $\beta \in (0,1)$, I estimate this coefficient directly—by assuming a beta prior distribution with mean 0.9 and standard deviation 0.08—and, by also estimating lnr^*, I obtain $\gamma = \beta r^*$. Second, I assume that the prior distribution for the Taylor rule response to inflation, ψ_π, is a normal distribution with mean 0.95 and standard deviation 0.45. Given the prior distributions, the prior probability of determinacy for the DS model is 51.4 percent. Third, I assume the same uniform prior distributions for the standard deviation of the sunspot shock and its correlations with the exogenous shocks as in the SW model.

Table 11: DS model: Prior distribution of structural parameters and shock processes

Coefficient	Distribution	Mean	Std. Dev
ψ_π	Normal	0.950	0.450
ψ_y	Gamma	0.125	0.100
ρ_R	Beta	0.500	0.200
β	Beta	0.900	0.080
$ln\pi^*$	Normal	1.000	0.500
lnr^*	Gamma	0.500	0.250
κ	Gamma	0.300	0.150
τ	Gamma	2.000	0.500
ρ_g	Beta	0.800	0.100
ρ_z	Beta	0.300	0.100
σ_R	Invgamma	0.251	0.139
σ_g	Invgamma	0.630	0.323
σ_z	Invgamma	0.875	0.430
σ_ν	Uniform[0,1]	0.500	0.290
$\rho_{R\nu}$	Uniform[-1,1]	0.000	0.570
$\rho_{g\nu}$	Uniform[-1,1]	0.000	0.570
$\rho_{z\nu}$	Uniform[-1,1]	0.000	0.570

All the equations of the Modified DS model are equivalent to those of the DS model, except for the Taylor rule which allows for the response to output growth and takes the following form

$$R_t = \rho_R R_{t-1} + (1-\rho_R)\left(\psi_\pi \pi_t + \psi_y y_t\right) + \psi_{\Delta y}\left(y_t - y_{t-1}\right) + \varepsilon_{R,t}. \tag{15}$$

The prior distributions of the Modified DS model are the same as those reported in Table 11. In addition, the prior distribution for the parameter governing the Taylor rule response to output growth, $\psi_{\Delta y}$, is a normal distribution centered at 0.125 and with standard deviation 0.05, in line with the prior distribution for the corresponding parameter of the SW model, $r_{\Delta y}$. For the Modified DS model, the resulting prior probability of determinacy is 50.8 percent.

Table 12 reports the posterior mean and 90-percent probability interval of the structural parameters and shock processes of the DS model—second and third columns—and the Modified DS model—fourth and fifth columns.

Table 12: DS model and Modified DS model: Posterior distributions

	DS Model		Modified DS model	
Coefficient	Mean	[5 , 95]	Mean	[5 , 95]
ψ_π	0.26	[0.06,0.48]	0.27	[0.05,0.52]
ψ_y	0.42	[0.30,0.57]	0.39	[0.26,0.55]
ρ_R	0.58	[0.50,0.66]	0.60	[0.50,0.68]
$\psi_{\Delta y}$	-	-	0.07	[0.01,0.14]
β	0.92	[0.81,0.99]	0.92	[0.81,0.99]
lnr^*	0.61	[0.49,0.73]	0.60	[0.48,0.73]
$ln\pi^*$	1.28	[0.74,1.87]	1.27	[0.71,1.89]
κ	0.07	[0.03,0.13]	0.07	[0.03,0.13]
τ	4.41	[3.45,5.40]	4.27	[3.37,5.26]
ρ_g	0.83	[0.76,0.89]	0.84	[0.78,0.91]
ρ_z	0.61	[0.51,0.71]	0.57	[0.46,0.68]
σ_R	0.20	[0.19,0.22]	0.21	[0.19,0.23]
σ_g	0.65	[0.54,0.77]	0.63	[0.51,0.76]
σ_z	0.56	[0.48,0.65]	0.60	[0.51,0.71]
σ_ν	0.25	[0.23,0.26]	0.25	[0.23,0.26]
$\rho_{R\nu}$	-0.08	[-0.19,0.02]	-0.19	[-0.35,-0.05]
$\rho_{g\nu}$	-0.14	[-0.33,0.04]	-0.13	[-0.33,0.07]
$\rho_{z\nu}$	-0.44	[-0.58,-0.29]	-0.48	[-0.62,-0.31]

B.2 Modified SW model

To estimate the SW model using the same three observables of the DS model, I modify the stochastic structure of the SW model. Following Del Negro and Schorfheide (2013), I keep the government spending shock, the price mark-up shock and the monetary policy shock, while eliminating the remaining shocks of the SW model. In addition, as in the DS model, I assume that the monetary policy shocks are independent and identically distributed. I also set to zero the moving-average parameter of the price mark-up shock in SW, μ_p, so that the shock follows a stationary AR(1) process as in DS. Finally, for the remaining parameters, I use the same prior distributions as for the SW model.

Table 13 and 14 report the values used for the simulation of the SW model—third column—and the posterior distribution of the structural parameters and shock processes of the estimated Modified SW model—fourth and fifth columns.

Table 13: Modified SW model: Structural parameters

Coefficient	Description	Value	Modified SW Mean	[5 , 95]
ϕ	Adjustment cost	5.55	6.91	[3.94,9.37]
σ_c	IES	1.45	1.67	[1.48,1.84]
h	Habit Persistence	0.70	0.74	[0.63,0.88]
σ_l	Labor supply elasticity	1.91	2.81	[1.80,3.84]
ξ_w	Wage stickiness	0.64	0.47	[0.35,0.63]
ξ_p	Price Stickiness	0.72	0.85	[0.77,0.91]
ι_w	Wage Indexation	0.48	0.51	[0.25,0.76]
ι_p	Price Indexation	0.29	0.18	[0.11,0.25]
ψ	Capacity utiliz. elasticity	0.60	0.30	[0.08,0.71]
Φ	Share of fixed costs	1.59	1.29	[1.13,1.47]
α	Share of capital	0.21	0.22	[0.08,0.32]
$\bar{\pi}$	S.S. inflation rate (quart.)	0.66	0.65	[0.57,0.73]
$100(\beta^{-1}-1)$	Discount factor	0.17	0.10	[0.05,0.16]
$\bar{l}$	S.S. hours worked	0.78	-	-
$\bar{\gamma}$	Trend growth rate (quart.)	0.46	0.46	[0.45,0.46]
r_π	Taylor rule inflation	2.08	1.76	[1.47,2.04]
r_y	Taylor rule output gap	0.07	0.04	[0.03,0.06]
$r_{\Delta y}$	Taylor rule Δ(output gap)	0.20	0.13	[0.10,0.17]
ρ	Taylor rule smoothing	0.78	0.74	[0.71,0.78]

The table reports the values of the structural parameters used for the simulation—third column—and their posterior estimates using the simulated data–fourth and fifth columns.

Table 14: Modified SW model: Shock processes

Coefficient	Description	Value	Modified SW Mean	[5 , 95]
σ_a	Technology shock	0.39	-	-
σ_b	Risk premium shock	0.22	-	-
σ_g	Government sp. shock	0.47	0.60	[0.49,0.72]
σ_I	Investment-specific shock	0.39	-	-
σ_r	Monetary policy shock	0.23	0.24	[0.22,0.25]
σ_p	Price mark-up shock	0.10	0.05	[0.04,0.06]
σ_w	Wage mark-up shock	0.31	-	-
σ_ν	Sunspot shock	0.43	0.40	[0.04,0.93]
ρ_a	Persistence technology	0.94	-	-
ρ_b	Persistence risk premium	0.17	-	-
ρ_g	Persistence government sp.	0.97	0.92	[0.89,0.95]
ρ_I	Persistence investment-specific	0.75	-	-
ρ_r	Persistence monetary policy	0.13	-	-
ρ_p	Persistence price mark-up	0.85	0.86	[0.80,0.92]
ρ_w	Persistence wage mark-up	0.94	-	-
μ_p	MA price mark-up	0.62	-	-
μ_w	MA wage mark-up	0.75	-	-
ρ_{ga}	Impact of ε_a on g_t	0.48	-	-
$\rho_{\nu a}$	$Corr(\sigma_\nu, \sigma_a)$	0.04	-	-
$\rho_{\nu b}$	$Corr(\sigma_\nu, \sigma_b)$	0.01	-	-
$\rho_{\nu g}$	$Corr(\sigma_\nu, \sigma_g)$	0.04	-0.03	[-0.82,0.73]
$\rho_{\nu I}$	$Corr(\sigma_\nu, \sigma_I)$	-0.02	-	-
$\rho_{\nu r}$	$Corr(\sigma_\nu, \sigma_r)$	-0.03	0.05	[-0.52,0.64]
$\rho_{\nu p}$	$Corr(\sigma_\nu, \sigma_p)$	-0.02	0.02	[-0.75,0.76]
$\rho_{\nu w}$	$Corr(\sigma_\nu, \sigma_w)$	-0.02	-	-

The table reports the values of the parameters associated with the shock processes used for the simulation—third column—and their posterior estimates using the simulated data—fourth and fifth columns.

C Time-varying Inflation Target with and without Inflation Expectations

This Appendix reports the posterior distribution of the structural parameters and shock processes of the SW model and several alternative specifications: the SW model with time-varying inflation target and estimated over the same data as the original SW data (SWπ^*) and the version of the SW model with time-varying inflation target estimated using either short-term inflation expectations (SWπ^* + $\pi^{e,4}$) or with longer-term inflation expectations (SWπ^* + $\pi^{e,40}$). The results for the pre-1979 period are reported in Appendix C.1, and those for the post-1979 period in Appendix C.2.

C.1 Pre-1979

Table 15: Posterior distribution of structural parameters for the pre-1979 period

	SW model		SWπ^*		SWπ^*+ $\pi^{e,4}$	
Coefficient	Mean	[5 , 95]	Mean	[5 , 95]	Mean	[5 , 95]
ϕ	4.83	[3.36,6.52]	4.78	[3.32,6.35]	5.15	[3.61,6.79]
σ_c	1.37	[1.10,1.66]	1.35	[1.08,1.67]	1.45	[1.18,1.76]
h	0.59	[0.48,0.70]	0.60	[0.48,0.71]	0.70	[0.59,0.79]
σ_l	1.31	[0.45,2.37]	1.38	[0.57,2.43]	1.29	[0.44,2.53]
ξ_w	0.76	[0.68,0.83]	0.77	[0.70,0.83]	0.75	[0.67,0.83]
ξ_p	0.61	[0.51,0.72]	0.61	[0.50,0.72]	0.52	[0.42,0.64]
ι_w	0.43	[0.23,0.62]	0.43	[0.24,0.64]	0.50	[0.30,0.70]
ι_p	0.27	[0.11,0.49]	0.25	[0.10,0.45]	0.15	[0.06,0.27]
ψ	0.40	[0.22,0.58]	0.39	[0.23,0.57]	0.37	[0.21,0.54]
Φ	1.54	[1.43,1.66]	1.53	[1.42,1.65]	1.52	[1.40,1.64]
α	0.23	[0.19,0.26]	0.23	[0.19,0.26]	0.23	[0.19,0.26]
$\bar{\pi}$	0.62	[0.46,0.79]	0.63	[0.47,0.79]	0.62	[0.48,0.78]
$100(\beta^{-1}-1)$	0.15	[0.07,0.26]	0.16	[0.08,0.28]	0.17	[0.08,0.27]
$\bar{l}$	0.65	[-0.71,2.25]	0.07	[-1.27,1.38]	-0.34	[-1.69,1.05]
$\bar{\gamma}$	0.33	[0.28,0.38]	0.35	[0.30,0.40]	0.35	[0.29,0.41]
r_π	0.86	[0.68,0.97]	0.84	[0.62,0.97]	0.78	[0.53,0.96]
r_y	0.14	[0.08,0.21]	0.15	[0.09,0.22]	0.15	[0.09,0.22]
$r_{\Delta y}$	0.16	[0.12,0.21]	0.16	[0.11,0.20]	0.14	[0.10,0.18]
ρ	0.85	[0.78,0.92]	0.83	[0.75,0.91]	0.80	[0.70,0.89]

The table reports the posterior distribution of the structural parameters of the SW model and the SW model with a time-varying inflation target estimated both without inflation expectations (SWπ^*) and with short-run inflation expectations (SWπ^* + $\pi^{e,4}$) over the pre-1979 period.

Table 16: Posterior distribution of shock processes for the pre-1979 period

	SW model		$SW\pi^*$		$SW\pi^* + \pi^{e,4}$	
Coefficient	Mean	[5 , 95]	Mean	[5 , 95]	Mean	[5 , 95]
σ_a	0.62	[0.49,0.64]	0.56	[0.49,0.64]	0.56	[0.49,0.64]
σ_b	0.17	[0.11,0.23]	0.16	[0.11,0.23]	0.25	[0.18,0.33]
σ_g	0.52	[0.46,0.59]	0.52	[0.46,0.59]	0.52	[0.46,0.59]
σ_I	0.52	[0.40,0.65]	0.51	[0.39,0.64]	0.56	[0.43,0.70]
σ_r	0.18	[0.15,0.20]	0.17	[0.15,0.20]	0.17	[0.15,0.20]
σ_p	0.30	[0.25,0.35]	0.30	[0.25,0.35]	0.25	[0.21,0.29]
σ_w	0.28	[0.23,0.32]	0.27	[0.23,0.32]	0.27	[0.23,0.32]
σ_ν	0.13	[0.03,0.22]	0.13	[0.04,0.23]	0.34	[0.30,0.38]
ρ_a	0.98	[0.97,0.99]	0.98	[0.96,0.99]	0.98	[0.97,0.99]
ρ_b	0.68	[0.48,0.85]	0.70	[0.47,0.86]	0.41	[0.17,0.68]
ρ_g	0.89	[0.83,0.94]	0.89	[0.83,0.94]	0.89	[0.84,0.94]
ρ_I	0.60	[0.46,0.75]	0.61	[0.46,0.76]	0.56	[0.42,0.71]
ρ_r	0.33	[0.19,0.48]	0.32	[0.18,0.47]	0.34	[0.19,0.49]
ρ_p	0.22	[0.05,0.50]	0.23	[0.06,0.53]	0.68	[0.38,0.90]
ρ_w	0.32	[0.11,0.59]	0.32	[0.12,0.57]	0.35	[0.14,0.63]
μ_p	0.54	[0.29,0.80]	0.53	[0.30,0.78]	0.52	[0.22,0.76]
μ_w	0.39	[0.18,0.81]	0.36	[0.17,0.59]	0.34	[0.14,0.58]
ρ_{ga}	0.62	[0.47,0.77]	0.62	[0.47,0.78]	0.63	[0.49,0.79]
$\rho_{\nu a}$	-0.26	[-0.57,0.07]	-0.24	[-0.56,0.08]	-0.13	[-0.26,-0.01]
$\rho_{\nu b}$	-0.01	[-0.38,0.37]	-0.08	[-0.43,0.29]	-0.08	[-0.23,0.05]
$\rho_{\nu g}$	-0.09	[-0.40,0.24]	-0.09	[-0.42,0.27]	0.14	[0.02,0.25]
$\rho_{\nu I}$	0.07	[-0.26,0.41]	0.04	[-0.29,0.35]	0.07	[-0.05,0.20]
$\rho_{\nu r}$	0.09	[-0.29,0.45]	0.05	[-0.32,0.41]	-0.06	[-0.15,0.04]
$\rho_{\nu p}$	0.61	[0.06,0.88]	0.58	[0.13,0.86]	0.83	[0.72,0.92]
$\rho_{\nu w}$	0.13	[-0.26,0.50]	0.15	[-0.17,0.50]	0.20	[0.05,0.34]
σ_{π^*}	-	-	0.03	[0.01,0.08]	0.03	[0.01,0.07]
ρ_{π^*}	-	-	0.95	[0.89,0.99]	0.96	[0.90,0.99]
$\rho_{\nu\pi^*}$	-	-	-0.02	[-0.47,0.44]	-0.01	[-0.37,0.37]

The table reports the posterior distribution of the parameters associated with the shock processes of the SW model and the SW model with a time-varying inflation target estimated both without inflation expectations ($SW\pi^*$) and with short-run inflation expectations ($SW\pi^* + \pi^{e,4}$) over the pre-1979 period.

C.2 Post-1979

Table 17: Posterior distribution of structural parameters for the post-1979 period

	SW model		$SW\pi^*$		$SW\pi^* + \pi^{e,4}$		$SW\pi^* + \pi^{e,40}$	
Coefficient	Mean	[5 , 95]	Mean	[5 , 95]	Mean	[5 , 95]	Mean	[5 , 95]
ϕ	5.58	[3.94,7.43]	5.40	[3.63,7.33]	5.61	[4.02,7.40]	6.01	[4.36,7.92]
σ_c	1.46	[1.24,1.69]	1.44	[1.22,1.67]	1.41	[1.21,1.61]	1.43	[1.23,1.64]
h	0.70	[0.63,0.77]	0.68	[0.59,0.76]	0.70	[0.63,0.77]	0.74	[0.67,0.80]
σ_l	1.94	[0.97,2.96]	2.14	[1.16,3.18]	2.09	[1.13,3.19]	2.19	[1.19,3.33]
ξ_w	0.64	[0.50,0.78]	0.73	[0.57,0.89]	0.73	[0.56,0.88]	0.81	[0.71,0.89]
ξ_p	0.72	[0.64,0.79]	0.78	[0.71,0.84]	0.75	[0.69,0.82]	0.81	[0.76,0.86]
ι_w	0.47	[0.25,0.72]	0.38	[0.17,0.62]	0.36	[0.15,0.61]	0.40	[0.20,0.63]
ι_p	0.29	[0.13,0.49]	0.26	[0.11,0.44]	0.11	[0.04,0.20]	0.13	[0.05,0.22]
ψ	0.61	[0.43,0.78]	0.56	[0.38,0.73]	0.68	[0.51,0.83]	0.58	[0.40,0.76]
Φ	1.59	[1.46,1.73]	1.59	[1.45,1.72]	1.57	[1.44,1.71]	1.57	[1.44,1.70]
α	0.21	[0.18,0.24]	0.21	[0.18,0.25]	0.22	[0.18,0.25]	0.21	[0.17,0.24]
$\bar{\pi}$	0.66	[0.53,0.80]	0.63	[0.47,0.81]	0.62	[0.47,0.80]	0.62	[0.46,0.79]
$100(\beta^{-1}-1)$	0.17	[0.08,0.27]	0.14	[0.07,0.24]	0.15	[0.07,0.25]	0.13	[0.06,0.22]
$\bar{l}$	0.77	[-0.94,2.25]	2.13	[0.72,3.56]	0.72	[-0.95,2.35]	2.05	[0.55,3.60]
$\bar{\gamma}$	0.45	[0.41,0.49]	0.46	[0.43,0.49]	0.44	[0.39,0.49]	0.46	[0.42,0.50]
r_π	2.10	[1.76,2.47]	0.89	[0.76,0.96]	0.70	[0.40,0.93]	0.70	[0.47,0.88]
r_y	0.07	[0.03,0.11]	0.14	[0.09,0.19]	0.14	[0.08,0.21]	0.13	[0.08,0.18]
$r_{\Delta y}$	0.20	[0.15,0.25]	0.20	[0.15,0.26]	0.21	[0.15,0.27]	0.18	[0.13,0.24]
ρ	0.78	[0.73,0.82]	0.72	[0.63,0.80]	0.79	[0.71,0.86]	0.74	[0.65,0.82]

The table reports the posterior distribution of the structural parameters of the SW model and the SW model with a time-varying inflation target estimated without inflation expectations ($SW\pi^*$), with short-run inflation expectations ($SW\pi^* + \pi^{e,4}$) and with longer-run inflation expectations ($SW\pi^* + \pi^{e,40}$) over the post-1979 period.

Table 18: Posterior distribution of shock processes for the post-1979 period

	SW model		SWπ^*		SWπ^*+ $\pi^{e,4}$		SWπ^*+ $\pi^{e,40}$	
Coefficient	Mean	[5 , 95]	Mean	[5 , 95]	Mean	[5 , 95]	Mean	[5 , 95]
σ_a	0.39	[0.34,0.44]	0.39	[0.35,0.44]	0.38	[0.34,0.43]	0.39	[0.35,0.44]
σ_b	0.22	[0.19,0.26]	0.21	[0.16,0.25]	0.23	[0.19,0.27]	0.23	[0.19,0.27]
σ_g	0.47	[0.42,0.52]	0.47	[0.42,0.53]	0.47	[0.42,0.52]	0.47	[0.42,0.53]
σ_I	0.39	[0.32,0.46]	0.39	[0.32,0.47]	0.46	[0.37,0.57]	0.41	[0.33,0.50]
σ_r	0.23	[0.20,0.26]	0.22	[0.20,0.25]	0.22	[0.20,0.25]	0.23	[0.20,0.26]
σ_p	0.10	[0.07,0.12]	0.15	[0.13,0.18]	0.17	[0.15,0.20]	0.10	[0.08,0.12]
σ_w	0.31	[0.25,0.37]	0.29	[0.23,0.35]	0.30	[0.24,0.36]	0.31	[0.25,0.38]
σ_ν	0.50	[0.05,0.95]	0.12	[0.07,0.18]	0.23	[0.21,0.25]	0.19	[0.17,0.21]
ρ_a	0.95	[0.90,0.98]	0.92	[0.87,0.95]	0.94	[0.90,0.97]	0.93	[0.88,0.97]
ρ_b	0.18	[0.05,0.33]	0.28	[0.11,0.51]	0.18	[0.05,0.36]	0.19	[0.076,0.36]
ρ_g	0.97	[0.95,0.99]	0.98	[0.96,0.99]	0.96	[0.93,0.98]	0.98	[0.96,0.99]
ρ_I	0.76	[0.66,0.85]	0.75	[0.64,0.85]	0.60	[0.47,0.74]	0.68	[0.55,0.80]
ρ_r	0.12	[0.04,0.24]	0.12	[0.04,0.24]	0.12	[0.03,0.23]	0.13	[0.04,0.25]
ρ_p	0.86	[0.74,0.95]	0.24	[0.05,0.58]	0.79	[0.53,0.92]	0.85	[0.76,0.93]
ρ_w	0.94	[0.89,0.97]	0.86	[0.55,0.97]	0.82	[0.50,0.96]	0.81	[0.56,0.93]
μ_p	0.63	[0.39,0.81]	0.57	[0.29,0.83]	0.72	[0.43,0.87]	0.70	[0.49,0.85]
μ_w	0.75	[0.57,0.90]	0.71	[0.38,0.87]	0.63	[0.28,0.84]	0.74	[0.44,0.92]
ρ_{ga}	0.48	[0.30,0.66]	0.47	[0.30,0.66]	0.48	[0.30,0.65]	0.48	[0.31,0.65]
$\rho_{\nu a}$	-0.01	[-0.52,0.50]	-0.15	[-0.37,0.06]	-0.08	[-0.13,-0.03]	-0.10	[-0.15,-0.02]
$\rho_{\nu b}$	-0.06	[-0.61,0.50]	0.08	[-0.17,0.33]	0.07	[0.02,0.13]	0.01	[-0.06,0.08]
$\rho_{\nu g}$	0.03	[-0.57,0.58]	0.11	[-0.15,0.35]	-0.04	[-0.10,0.03]	0.08	[0.01,0.16]
$\rho_{\nu I}$	0.05	[-0.52,0.59]	0.05	[-0.19,0.28]	0.05	[-0.01,0.10]	0.07	[-0.01,0.13]
$\rho_{\nu r}$	-0.03	[-0.51,-0.56]	-0.52	[-0.74,-0.26]	-0.01	[-0.06,0.05]	-0.19	[-0.26,-0.12]
$\rho_{\nu p}$	0.02	[0.53,0.54]	0.54	[0.23,0.78]	0.93	[0.91,0.95]	0.91	[0.87,0.94]
$\rho_{\nu w}$	0.03	[-0.50,0.56]	0.18	[-0.03,0.38]	0.02	[-0.05,0.08]	0.18	[0.09,0.26]
σ_{π^*}	-	-	0.06	[0.01,0.15]	0.15	[0.02,0.38]	0.04	[0.01,0.11]
ρ_{π^*}	-	-	0.94	[0.91,0.97]	0.95	[0.89,0.98]	0.93	[0.88,0.96]
$\rho_{\nu\pi^*}$	-	-	-0.18	[-0.51,0.22]	-0.22	[-0.33,-0.10]	-0.23	[-0.27,-0.18]

The table reports the posterior distribution of the parameters associated with the shock processes of the SW model and the SW model with a time-varying inflation target estimated without inflation expectations (SWπ^*), with short-run inflation expectations (SW$\pi^* + \pi^{e,4}$) and with longer-run inflation expectations (SW$\pi^* + \pi^{e,40}$) over the post-1979 period.

D Real-time Data

This Appendix reports the posterior distribution of the structural parameters and shock processes of the SW model for the pre- and post-1979 period using real-time data as available at the end of each sample period.

Table 19: SW model and real-time data: Structural parameters

		Pre-1979		Post-1979	
Coefficient	Description	Mean	[5 , 95]	Mean	[5 , 95]
ϕ	Adjustment cost	3.86	[2.59,5.51]	5.75	[3.84,7.81]
σ_c	IES	1.05	[0.88,1.24]	1.04	[0.77,1.33]
h	Habit Persistence	0.59	[0.47,0.71]	0.73	[0.61,0.82]
σ_l	Labor supply elasticity	1.47	[0.58,2.59]	2.05	[1.14,3.07]
ξ_w	Wage stickiness	0.73	[0.61,0.83]	0.64	[0.51,0.78]
ξ_p	Price Stickiness	0.50	[0.36,0.64]	0.73	[0.65,0.80]
ι_w	Wage Indexation	0.35	[0.17,0.56]	0.48	[0.27,0.72]
ι_p	Price Indexation	0.23	[0.09,0.43]	0.34	[0.16,0.58]
ψ	Capacity utiliz. elasticity	0.50	[0.34,0.67]	0.44	[0.25,0.64]
Φ	Share of fixed costs	1.48	[1.36,1.61]	1.46	[1.32,1.60]
α	Share of capital	0.20	[0.16,0.24]	0.16	[0.13,0.20]
$\bar{\pi}$	S.S. inflation rate (quart.)	0.62	[0.47,0.79]	0.74	[0.60,0.88]
$100(\beta^{-1}-1)$	Discount factor	0.16	[0.07,0.28]	0.29	[0.16,0.43]
$\bar{l}$	S.S. hours worked	-1.36	[-2.52,-0.17]	-1.01	[-2.35,0.30]
$\bar{\gamma}$	Trend growth rate (quart.)	0.37	[0.33,0.41]	0.39	[0.36,0.42]
r_π	Taylor rule inflation	0.80	[0.50,0.98]	2.16	[1.80,2.52]
r_y	Taylor rule output gap	0.14	[0.07,0.21]	0.08	[0.04,0.12]
$r_{\Delta y}$	Taylor rule Δ(output gap)	0.17	[0.12,0.22]	0.21	[0.15,0.26]
ρ	Taylor rule smoothing	0.86	[0.78,0.93]	0.77	[0.73,0.82]

The table compares the posterior distribution of structural parameters for the pre- and post-1979 period using real-time data.

Table 20: SW model and real-time data: Shock processes

		Pre-1979		Post-1979	
Coefficient	Description	Mean	[5 , 95]	Mean	[5 , 95]
σ_a	Technology shock	0.51	[0.44,0.58]	0.40	[0.35,0.45]
σ_b	Risk premium shock	0.20	[0.13,0.30]	0.16	[0.10,0.23]
σ_g	Government sp. shock	0.58	[0.51,0.65]	0.49	[0.43,0.55]
σ_I	Investment-specific shock	0.56	[0.44,0.70]	0.40	[0.30,0.52]
σ_r	Monetary policy shock	0.19	[0.16,0.21]	0.23	[0.20,0.26]
σ_p	Price mark-up shock	0.28	[0.22,0.34]	0.12	[0.09,0.15]
σ_w	Wage mark-up shock	0.26	[0.21,0.31]	0.31	[0.25,0.36]
σ_ν	Sunspot shock	0.24	[0.13,0.32]	0.51	[0.05,0.96]
ρ_a	Persistence technology	0.96	[0.93,0.98]	0.84	[0.75,0.94]
ρ_b	Persistence risk premium	0.65	[0.38,0.82]	0.55	[0.26,0.81]
ρ_g	Persistence government sp.	0.92	[0.87,0.97]	0.96	[0.94,0.98]
ρ_I	Persistence investment-specific	0.45	[0.31,0.60]	0.75	[0.61,0.89]
ρ_r	Persistence monetary policy	0.31	[0.16,0.45]	0.13	[0.04,0.27]
ρ_p	Persistence price mark-up	0.47	[0.11,0.83]	0.80	[0.64,0.91]
ρ_w	Persistence wage mark-up	0.48	[0.18,0.81]	0.90	[0.82,0.95]
μ_p	MA price mark-up	0.51	[0.21,0.89]	0.60	[0.33,0.80]
μ_w	MA wage mark-up	0.37	[0.13,0.64]	0.70	[0.51,0.84]
ρ_{ga}	Impact of ε_a on g_t	0.52	[0.33,0.69]	0.54	[0.34,0.73]
$\rho_{\nu a}$	$Corr(\sigma_\nu, \sigma_a)$	-0.04	[-0.24,0.16]	-0.02	[-0.55,0.51]
$\rho_{\nu b}$	$Corr(\sigma_\nu, \sigma_b)$	-0.01	[-0.26,0.27]	0.02	[-0.53,0.59]
$\rho_{\nu g}$	$Corr(\sigma_\nu, \sigma_g)$	-0.02	[-0.24,0.20]	0.02	[-0.51,0.55]
$\rho_{\nu I}$	$Corr(\sigma_\nu, \sigma_I)$	0.29	[0.07,0.52]	0.06	[-0.50,0.59]
$\rho_{\nu r}$	$Corr(\sigma_\nu, \sigma_r)$	-0.04	[-0.33,0.20]	-0.02	[-0.57,0.51]
$\rho_{\nu p}$	$Corr(\sigma_\nu, \sigma_p)$	0.69	[0.37,0.89]	-0.01	[-0.52,0.58]
$\rho_{\nu w}$	$Corr(\sigma_\nu, \sigma_w)$	0.25	[-0.03,0.51]	-0.02	[-0.57,0.54]

The table compares the posterior distribution of the parameters associated with the shock processes for the pre- and post-1979 period using real-time data.