Finance and Economics Discussion Series
Divisions of Research & Statistics and Monetary Affairs
Federal Reserve Board, Washington, D.C.

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2020-035

Please cite this paper as:
Nicolò, Giovanni (2020). "Monetary Policy, Self-Fulfilling Expectations and the U.S. Business Cycle," Finance and Economics Discussion Series 2020-035. Washington: Board of Governors of the Federal Reserve System, https://doi.org/10.17016/FEDS.2020.035.

Monetary Policy, Self-Fulfilling Expectations and the U.S. Business Cycle

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April 28, 2020

Abstract

I estimate a medium-scale New-Keynesian model and relax the conventional assumption that the central bank adopted an active monetary policy by pursuing inflation and output stability over the entire post-war period. Even after accounting for a rich structure, I find that monetary policy was passive prior to the Volcker disinflation. However, sunspot shocks did not represent quantitatively relevant sources of volatility. By contrast, such passive interest rate policy accommodated fundamental productivity and cost shocks that de-anchored inflation expectations, propagated via self-fulfilling inflation expectations and constituted the primary sources of the run-up in inflation from the 1960s through the late 1970s.

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

Keywords: Monetary policy, business cycle, expectations, indeterminacy, Bayesian methods.

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1 Introduction

Most previous studies that identify the sources of U.S. business cycles using medium-scale New-Keynesian (NK) models rely on a conventional assumption about the conduct of monetary policy. The central bank is assumed to implement an active[1] monetary policy that systematically stabilizes inflation and output during the entire post-war period.[2] This assumption cannot be easily reconciled with the behavior of the data prior to the Volcker disinflation. From the late 1950s through the 1970s, the U.S. economy experienced high volatility, and inflation was unstable and rising. Moreover, assuming that the central bank operated under an active monetary policy substantially impacts the findings about the drivers of U.S. business cycles.

I estimate the standard medium-scale NK model by Smets and Wouters (2007) (henceforth SW), in which I relax the key assumption that the central bank pursued an active monetary policy both before and after 1979. If monetary policy is passive, the model is indeterminate and characterized by multiple equilibrium paths. Two features of the model become relevant to explain the persistence and volatility of the data. First, unexpected changes in expectations constitute non-fundamental 'sunspot' disturbances that induce an additional source of volatility. Second, the propagation of structural shocks depends on self-fulfilling expectations that alter the transmission and generate additional persistence.

To the best of my knowledge, this paper is the first study that investigates the quantitative relevance of non-fundamental disturbances and the propagation of shocks based on self-fulfilling expectations for the U.S. macroeconomic instability prior to 1979. As previous studies generally adopted small-scale NK models (Clarida et al., 2000; Lubik and Schorfheide, 2004; Boivin and Giannoni, 2006; Bhattarai et al., 2016), the novelty of this paper is to address such question in the context of a medium-scale model and assess the consequences of allowing for a passive monetary policy on the identification of the sources of U.S. business

[1] The terminology of active and passive policies originated with Leeper (1991).

[2] Smets and Wouters (2003; 2007), Christiano et al. (2005), Del Negro and Eusepi (2011) and Arias et al. (2019) represent some of the key references.

cycles.

I find five main results. First, the stance of U.S. monetary policy changed in the post-war period. Monetary policy was passive between 1955 and 1979, while it pursued active inflation targeting since 1984. Compared to previous studies that use medium-scale models, this result rejects the imposed assumption that monetary policy was active before 1979.

Second, the evidence of a passive monetary policy from 1955 to 1979 substantially affects the identification of the sources of U.S. business cycles. According to the estimated model, fundamental productivity and cost shocks were the main drivers of the run-up in the inflation rate from the early 1960s through the late 1970s. Under a passive monetary regime, positive technology shocks in the 1960s de-anchored inflation expectations and generated persistent *inflationary* pressures via self-fulfilling expectations.[3] Mark-up shocks only account for the sudden inflationary episodes related to the oil crises during the 1970s.[4] On the contrary, previous studies that impose an active monetary policy before 1979 exclude the role of self-fulfilling expectations for the transmission of structural shocks. The persistent rise in inflation from the early 1960s through the 1970s would be entirely and erroneously attributed to mark-up shocks.

Third, fundamental shocks were the sources of the high volatility of inflation and output before 1979. In a passive monetary policy regime, sunspot shocks potentially lead to additional macroeconomic instability. By contrast, my estimation of the SW model shows that non-fundamental disturbances were not significant drivers of volatility between 1955 and 1979.

Fourth, I use the SW model to revisit the question on the sources of the reduction in U.S. macroeconomic volatility starting from the 1980s to 2007. I investigate whether the observed decrease in volatility is explained by a change in monetary policy to a more active stance since the early 1980s, as opposed to smaller structural shocks. Based on the SW model, I find that

[3] Fernald (2014b) and Gordon (2000) among others document that the U.S. economy experienced a period of exceptional growth in productivity since World War II until the early 1970s.

[4] As the SW model does not explicitly include oil markets, unexpected fluctuations in oil prices are captured by mark-up shocks.

the reduction in macroeconomic uncertainty was a combination of both the implementation of an active monetary policy *and* a lower volatility of the shocks, while the latter plays a relatively more important role.

Finally, I document that the propagation mechanism of the shocks depends on the conduct of monetary policy also when adopting a reduced-form approach. By estimating a medium-scale Bayesian vector autoregression (BVAR) model using the hierarchical approach, *à la* Giannone, Lenza, and Primiceri (2015), I show that the transmission of productivity and monetary policy shocks is substantially altered in the context of alternative monetary policy regimes. The reduced-form differences in the shock propagation are analogous to those resulting from the estimation of the structural SW model.

To solve the medium-scale model of SW with a passive monetary policy, I use the methodology developed in Bianchi and Nicolò (2019), which simplifies technical complexities that hamper the implementation of existing solution methods to medium-scale models (Lubik and Schorfheide, 2003; Farmer et al., 2015).

The adoption of a medium-scale model provides two advantages. First, the richer structure constitutes a suitable framework to identify and quantify the sources of business cycles in the U.S. post-war period. Second, a passive monetary policy generates an additional source of persistence via self-fulfilling expectations and an additional source of volatility via non-fundamental disturbances. In line with the insights from Beyer and Farmer (2007a), the persistence and volatility of the U.S. macroeconomy could mistakenly favor the evidence of a passive monetary policy in the context of a small-scale model because of its parsimonious *dynamic* and *stochastic* structure. Empirically, I show that the estimation of a small-scale model that does not account for the richer structure of the SW model overturns the evidence of an active monetary policy over the period between 1984 and 2007. The more parsimonious structure mistakenly interprets the persistence and volatility of the data as evidence of a passive monetary policy.

The rest of the paper is organized as follows. Section 2 highlights the contributions of the paper to the related literature. Section 3 motivates the adoption of medium-scale models to properly assess the role of U.S. monetary policy to explain business cycles. Section 4 describes the main features of the SW model and the data used to conduct the estimation using Bayesian techniques. Section 5 explains the methodology developed in Bianchi and Nicolò (2019) and its implementation to solve and estimate the SW model, allowing for indeterminacy. Section 6 presents the findings. Section 7 concludes.

2 Related Literature

A vast literature rationalizes the behavior of the data in the post-war period with changes in interest-rate policies (Clarida et al., 2000; Lubik and Schorfheide, 2004; Boivin and Giannoni, 2006; and Bhattarai et al., 2016). These papers show that U.S. monetary policy failed to implement active inflation targeting before 1979. However, they use univariate or small-scale linear rational expectations (LRE) models for which the identification and quantification of the relevant drivers of business cycles is limited. On the other hand, another strand of the literature argues that changes in business cycle fluctuations stem from the different properties of the exogenous shocks that hit the U.S. economy (Primiceri, 2005; Sims and Zha, 2006; Canova and Gambetti, 2009). In particular, Primiceri (2005) finds evidence of time variation in U.S. monetary policy, but little causal link between changes in the systematic component of monetary policy and the high inflation and unemployment rates over the post-war period. Nevertheless, the conclusion of the paper also warns that "In order to explore the true behavioral sources of these sequences of particularly bad shocks, a larger and fully structural model is needed."[5]

The contribution of this paper is to provide an interpretation of U.S. business cycle fluctuations in the United States based on the conduct of monetary policy and the role of self-fulfilling expectations. The novelty is to quantify the implications of passive monetary policy for U.S. business cycle fluctuations, especially in the period prior to 1979. Under such regime, structural shocks are accommodated by the central bank and induce self-fulfilling

[5]See Primiceri (2005), pag. 844.

expectations that alter the propagation mechanism and identify different determinants of business cycles. The upward trend in the inflation rate observed in the 1960s is attributed to persistent technology shocks that generated strong economic activity and self-fulfilling inflationary expectations. Together with an economic expansion, a productivity shock generates inflationary expectations that passive monetary policy fails to keep anchored. These inflationary pressures more than compensate the drop in marginal cost, and this mechanism thus results into a self-fulfilling inflationary effect. Moreover, I show that sunspot shocks play no quantitative role in explaining the volatility observed before 1979.[6] In section 6.5, I also provide additional empirical evidence for the difference in propagation depending on the conduct of monetary policy by estimating a BVAR with the hierarchical approach, *à la* Giannone, Lenza, and Primiceri (2015).

The adoption of a medium-scale LRE model raises two technical complexities. First, the partition of the parameter space into a determinate and indeterminate region is unknown for richer models. Second, existing methods require to construct the indeterminate solution following the seminal contribution of Lubik and Schorfheide (2003) or to rewrite the model based on the existing degree of indeterminacy (Farmer et al., 2015). Given the technical complexities, previous studies that adopt medium-scale models mainly abstract from the possibility of observing policies that lead to indeterminate outcomes and restrict *a priori* the parameter space to the unique, determinate region (Smets and Wouters, 2003; Christiano et al., 2005; Smets and Wouters, 2007; Justiniano et al., 2010; Justiniano et al., 2011; Del Negro and Eusepi, 2011; Arias et al., 2019).[7]

[6] Alternative explanations for the run-up of U.S. inflation since the early 1960s relate to the possibility that policymakers overestimated potential output (Orphanides, 2002) or underestimated both natural rate of unemployment and the persistence of inflation in the Phillips curve (Primiceri, 2005). In this paper, I focus on understanding the mechanisms through which the de-anchoring of inflation expectations due to structural shocks could have played a relevant role to explain the macroeconomic instability in the period prior to 1979.

[7] A notable exception is the work of Justiniano and Primiceri (2008) who consider changes in the role of monetary policy in a medium-scale model as a possible explanation for the Great Moderation. To solve the model under indeterminacy, they adopt the method of Lubik and Schorfheide (2004) and set the priors for the additional parameters $\tilde{M}$ around the "continuity solution" that guarantees that the impact of fundamental shocks on endogenous variables is continuous at the boundary of the indeterminacy region. However, such identification assumption could be restrictive for two reasons. First, as shown in section 6.2, the data strongly favor differences in the transmission of fundamental disturbances between the alternative monetary policy regimes. Second, section 6.1 shows that the correlation of the sunspot shocks with the mark-up shock is crucial in capturing the inflation dynamics in the pre-Volcker period. However, in Justiniano and Primiceri

In this paper, I implement the methodology we developed in Bianchi and Nicolò (2019) to relax this assumption and estimate the medium-scale model by SW over the *entire* parameter space. I find that the assumption imposed in SW is rejected for the period before 1979, during which the central bank adopted a passive monetary policy. Importantly, I verify that the assumption of a unique, determinate equilibrium has quantitative implications for the identification of the main drivers of U.S. business cycles. Moreover, I show both theoretically and empirically that the study of the conduct of monetary policy requires the adoption of a rich dynamic and stochastic structure (Beyer and Farmer, 2007a).[8]

The paper also contributes to the literature that studies the sources of the reduction in U.S. macroeconomic volatility from the early 1980s to 2007. I investigate the validity of two prominent theories that have been advocated to explain this empirical phenomenon. First, several studies show that the behavior of the data changed because of a decrease in the variance of the shocks driving the economy in the period subsequent to the Volcker disinflation (Primiceri, 2005; Sims and Zha, 2006; Justiniano and Primiceri, 2008; Justiniano et al., 2010; Fernandez-Villaverde et al., 2010; Justiniano et al., 2011). This strand of the literature finds that the reduction in volatility is not related to monetary policy and it can therefore be considered as "good luck". Second, the work of Clarida et al. (2000) and Lubik and Schorfheide (2004) among others indicates that monetary policy acted more systematically since the 1980s, therefore suggesting a view related to "good policy". In this paper, I find that the data supports both theories. Both a change in the conduct of monetary policy to a more active stance *and* a significant drop in the volatility of structural shocks account for the decrease in U.S. macroeconomic uncertainty.

Finally, the paper contributes to the literature that studies the empirical implications of dy-

(2008), the mean of the posterior distribution for the corresponding parameter, M_λ, lies on the tail of the prior distribution, potentially limiting the scope of properly fitting the inflation dynamics. Compared to Justiniano and Primiceri (2008), this paper abstracts from stochastic volatility, but by adopting the method of Bianchi and Nicolò (2019), it guarantees a flexible approach to understand the relationship between the conduct of monetary policy, the transmission of the shocks and the identification of the sources of business cycle fluctuations.

[8] A closely related literature also discusses the concerns due to model misspecification for the empirical performance of Dynamic Stochastic General Equilibrium models and provides policy analysis approaches to deal with it (Del Negro et al., 2007, Del Negro and Schorfheide, 2009).

namic indeterminacy.[9] The seminal contributions of Farmer and Guo (1994) and Farmer and Guo (1995) focus on the relevance of sunspot shocks to explain business cycle fluctuations. More recently, Lubik and Schorfheide (2004) empirically evaluate the possibility that monetary policy could lead to indeterminate outcomes, and Bhattarai et al. (2016) enrich this analysis by accounting for a nontrivial interaction between monetary and fiscal policy. This paper considers the richer dynamic and stochastic structure of the SW model to empirically study the implications of dynamic indeterminacy for U.S. business cycles in the post-war period.

While the current paper represents a first step in the quantitative assessment of the implications of a passive monetary policy for macroeconomic outcomes and the identification of the sources of business cycles, relevant questions are still open and deserve future research. In line with the work of Kiley (2007), Ascari and Ropele (2009), Coibon and Gorodnichenko (2011), Hirose et al. (2017), and Haque et al. (2019) among others, studies on the conduct of monetary policy would need to account for the positive trend inflation observed in the U.S. macroeconomic history. While the findings of these papers are based on parsimonious models, Arias et al. (2019) transparently describe the difficulties of including such analysis in the context of a medium-scale model, and possible extensions of the current work could help overcome such obstacles. Moreover, further research could address whether the adoption of a rich stochastic and dynamic structural model is also consistent with the presence of temporarily unstable paths to explain the Great Inflation, as suggested by Ascari et al. (2019) in the context of a stylized three-equation NK model. Finally, Del Negro and Eusepi (2011) point to the role of inflation expectations in the data as relevant information to discipline the understanding of the relationship between alternative interest-rate policy and the formation of expectations for macroeconomic outcomes. The current work could potentially be generalized to also address such questions.

Further extensions of this work would also explore the possibility of accounting not only for dynamic indeterminacy, but also for static indeterminacy (i.e., multiplicity of steady

[9] In this paper, I will refer to indeterminacy only as the dynamic properties of the model in the neighborhood of the unique steady state of a model.

states). Based on the cointegrating properties of the data (Beyer and Farmer, 2007b), Farmer and Platonov (2019) develop a micro-founded model that accounts for the possibility of observing multiple steady-state unemployment rates. The three-equations version of the model corresponds to the standard three-equation NK model in which the NK Phillips curve is replaced by a “belief function" that describes how agents form expectations about future nominal income growth. In Farmer and Nicolò (2018; 2019), we show that the reduced-form representation corresponds to a cointegrated vector error correction model (VECM) and the model outperforms the conventional three-equation NK model in fitting the data before and after 1979. An interesting avenue of research extends the proposed alternative framework to a medium-scale model that also displays multiplicity of steady states and therefore maps into a VECM in reduced-form. The purpose would therefore be to study whether 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.

3 Reasons for the Adoption of Medium-Scale Models

3.1 Identification Problem

Previous studies that allow for indeterminacy in U.S. monetary policy mainly adopt small-scale NK models and rationalize the empirical properties of the data before 1979 with a passive monetary policy (Clarida et al., 2000, Lubik and Schorfheide, 2004). If monetary policy is ‘passive’, two features of the model become relevant to explain the persistence in inflation dynamics and the high volatility of U.S. macroeconomic data over this period. First, the propagation of structural shocks depends on self-fulfilling expectations that alter the transmission mechanism and generate an additional source of persistence. Second, unexpected changes in expectations constitute non-fundamental ‘sunspot’ disturbances that generate an additional source of volatility.

I argue that the findings in earlier studies are potentially susceptible to the choice of parsimonious models (Beyer and Farmer, 2007a). Small-scale models impose restrictions on the structure of the underlying economy. By excluding richer models, the restrictions favor the result of a passive monetary policy as missing propagation mechanisms are misinterpreted as evidence of indeterminate dynamics. The identification problem relates to the possibility that a model with a richer *dynamic* and *stochastic* structure could explain the macroeconomic volatility and inflation persistence before 1979, even when monetary policy is *active*. Adopting the medium-scale NK model of SW allows me to verify whether previous findings carry over to a richer structure.[10]

In the spirit of Beyer and Farmer (2007a), the following analytic example provides an intuition of the identification problem that an econometrician faces when testing for indeterminacy. Suppose that a researcher studies the dynamics of the inflation rate using two alternative univariate LRE models. One model explains current inflation only as a function of expected inflation, $\pi_t = aE_t(\pi_{t+1})$. As the endogenous variable is expectational, the model is well specified when the associated one-step ahead forecast error is also defined $\eta_t \equiv \pi_t - E_{t-1}(\pi_t)$. Considering the case of $|a| > 1$, the model is *indeterminate*, and the solution corresponds to any process for inflation and its expectation that takes the following form

$$\begin{cases} \pi_t & = & \lambda\pi_{t-1} + \eta_t, \\ E_t\left(\pi_{t+1}\right) & = & \lambda^2\pi_{t-1} + \lambda\eta_t, \end{cases} \tag{1}$$

where $\lambda \equiv a^{-1} < 1$. According to this model, the dynamics are explained by lagged inflation rate, and the non-fundamental shock, η_t.

The alternative univariate LRE model considered by the econometrician is richer in both its dynamic and stochastic structure. The model describes current inflation as a function not

[10]Lubik and Schorfheide (2004) acknowledge that their results are sensitive to model misspecification as missing propagation mechanisms would favor the result of model indeterminacy. Their robustness check consists in comparing the fit of a small-scale NK model for the pre-Volcker period with a richer model to account for missing propagation mechanisms. However, the comparison is between two structurally different models, and the robustness check could therefore be sensitive to the choice of which propagation mechanism are included in the richer model. In this paper, I am instead considering the SW model for both the determinate and the indeterminate regions, while aiming at reducing the identification problem that is inherent to the question by considering a medium-scale model.

only of expected inflation but also of lagged inflation and a fundamental shock, ε_t, that is $\pi_t = aE_t(\pi_{t+1}) + b\pi_{t-1} + \varepsilon_t$. Given the definition of the forecast error, $\eta_t \equiv \pi_t - E_{t-1}(\pi_t)$, the dynamics of the model depend on the two roots of the model denoted by θ and λ.[11] When one root is unstable, the model has a unique, *determinate* solution. By assuming without loss of generality that $|\theta| > 1$ and $|\lambda| < 1$, the determinate solution is

$$\begin{cases} \pi_t = \lambda\pi_{t-1} + \frac{(\lambda+\theta)}{\theta}\varepsilon_t, \\ E_t(\pi_{t+1}) = \lambda^2\pi_{t-1} + \lambda\frac{(\lambda+\theta)}{\theta}\varepsilon_t. \end{cases} \tag{2}$$

The identification problem arises because of the observational equivalence of the two alternative models. Without further information about the true variance of the shocks η_t and ε_t, the *indeterminate* model in (1) and the *determinate* model in (2) are characterized by the same likelihood function.

However, the choice of a parsimonious structure affects the inference of the econometrician by erroneously favoring the indeterminate model in (1). Suppose that the true data generating process for the inflation rate is the richer, determinate model, $\pi_t = aE_t(\pi_{t+1}) + b\pi_{t-1} + \varepsilon_t$. Also, suppose the researcher chooses the parsimonious dynamic structure, $\pi_t = aE_t(\pi_{t+1})$, where lagged inflation and the exogenous shock are omitted. The inference would therefore mistakenly lead the econometrician to conclude that the data is consistent with the dynamics of the indeterminate model in (1) because of the observational equivalence.

I provide empirical relevance of this concern in section 6.1. By estimating a small-scale model that does not account for the richer dynamic and stochastic structure of the SW model, the evidence of an active monetary policy over the period between 1984:1 and 2007:3 is overturned.

[11] It can be shown that the roots of the model are related to the structural parameters of the model as follows: $a = 1/(\lambda + \theta)$ and $b = \lambda\theta/(\lambda + \theta)$.

3.2 Digging into the Mechanisms

A second advantage of adopting a medium-scale model such as SW is to provide a suitable framework to quantitatively assess the implications that a passive monetary policy has on the macroeconomy. In this section, I use a simple classical monetary model to show that, if monetary policy is passive, the dynamic and stochastic properties of the model differ in two dimensions. First, the propagation of fundamental shocks through the economy differs due to the formation of self-fulfilling expectations in response to the shocks. Second, the model is subject to non-fundamental sunspot disturbances. While small-scale models are not sufficiently detailed, medium-scale models provide a suitable framework to quantitatively assess the relative importance in the data.

To provide an intuition, I consider a classical monetary model described by the Fisher equation, $R_t = r_t + E_t(\pi_{t+1})$, and a simple Taylor rule, $R_t = \phi_\pi \pi_t$, where R_t and π_t denote the deviations of the nominal interest rate and the inflation rate from their target level.[12] I assume that the real interest rate r_t is given and follows a mean-zero Gaussian i.i.d. distribution.[13] To properly specify the model, I also define the one-step ahead forecast error associated with the expectational variable, π_t, as $\eta_t \equiv \pi_t - E_{t-1}(\pi_t)$. Combining the Fisher equation and the Taylor rule, I obtain the univariate model $E_t(\pi_{t+1}) = \phi_\pi \pi_t - r_t$.

In this simple model, the monetary authority is active if it responds to changes in the inflation rate by more than one for one. By recalling the Taylor rule, this condition can be equivalently expressed as $|\phi_\pi| > 1$. The solution in this region of the parameter space is determinate, and described by the following system

$$\begin{cases} \pi_t & = \frac{1}{\phi_\pi} r_t, \\ E_t(\pi_{t+1}) & = 0. \end{cases} \tag{3}$$

[12]For expositional purposes, I abstract from the possibility that the nominal interest rate responds to changes in output.

[13]In the classical monetary model, the real interest rate results from the equilibrium in labor and goods market and it depends on the technology shocks. I am considering an exogenous process for the technology shocks and therefore I take the process for the real interest rate as given.

The strong response of the monetary authority ensures that inflation is pinned down as a function of the exogenous real interest r_t, and the expectations that agents hold about the future inflation rate are constant at its steady state, $E_t(\pi_{t+1}) = 0$. Conversely, a passive monetary policy, $|\phi_\pi| \leq 1$, significantly affects the dynamic and stochastic properties of the model. The indeterminate solution corresponds to the following system of equations[14]

$$\begin{cases} \pi_t & = \phi_\pi \pi_{t-1} + \eta_t - r_{t-1}, \\ E_t(\pi_{t+1}) & = \phi_\pi^2 \pi_{t-1} + \phi_\pi \eta_t - (r_t + \phi_\pi r_{t-1}). \end{cases} \tag{4}$$

The comparison of the solutions in (3) and (4) shows that a change in monetary policy substantially affects the properties of the model and the interpretation of business cycle fluctuations in at least two dimensions. First, the impact and transmission of the *same* structural shock, r_t, on the dynamics of the model differs between the two specifications. While under determinacy, the inflation rate also follows an i.i.d. process, under indeterminacy, the shock de-anchors agents' expectations from the central bank's long-run target and transmits via self-fulfilling inflation expectations.[15] This is clearly not the case for the determinate solution where expectations are constant at the long-run inflation rate and play no role for the dynamics of the model.

Second, if the monetary authority is passive, the economy is subject to an additional, non-fundamental disturbance related to unexpected changes in agents' expectations, η_t. The sunspot shock therefore provides an additional source of uncertainty which could potentially help the model in matching the high volatility of the data in the period prior to the appointment of Paul Volcker as the Chairman of the Federal Reserve System.

[14]The solution is obtained by combining the definition of the forecast error, η_t, with the univariate model such that $\pi_t = E_{t-1}(\pi_t) + \eta_t = \phi_\pi \pi_{t-1} + \eta_t - r_{t-1}$. Therefore, expectations about future inflation are therefore described by $E_t(\pi_{t+1}) = \phi_\pi \pi_t - r_t = \phi_\pi^2 \pi_{t-1} + \phi_\pi \eta_t - (r_t + \phi_\pi r_{t-1})$.

[15]The structural shock to the real interest rate does not affect the inflation rate whenever it is assumed to be uncorrelated with the non-fundamental shock, η_t.

4 The Model and Data

Dynamic stochastic general equilibrium (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 as well as the measurement equations and the data used to estimate the model using Bayesian techniques.

The model contains both real and nominal frictions. On the real side, households are assumed to form habit in consumption. By renting capital services to firms, households also face an adjustment cost 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*, 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 as described in the following equation,

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

The monetary authority chooses the nominal interest rate, R_t, by allowing for some degree of interest rate inertia as measured by the parameter ρ. Changes in the inflation rate, π_t, and the output gap, defined as the deviations of actual output from its fully flexible price and wage counterpart, also generate a response by the monetary authority. The Taylor rule also accounts for changes in the output gap, while any unexpected deviation in the policy instrument is defined as a monetary policy shock, ε_t^R.[16]

To estimate the model, I use Bayesian techniques and the measurement equations that relate the macroeconomic data to the endogenous variables of the model are defined below

$$\begin{bmatrix} dlGDP_t \\ dlCONS_t \\ dlINV_t \\ dlWAG_t \\ lHours_t \\ dlP_t \\ FEDFUNDS_t \end{bmatrix} = \begin{bmatrix} \bar{\gamma} \\ \bar{\gamma} \\ \bar{\gamma} \\ \bar{\gamma} \\ \bar{l} \\ \bar{\pi} \\ \bar{R} \end{bmatrix} + \begin{bmatrix} y_t - y_{t-1} \\ c_t - c_{t-1} \\ i_t - i_{t-1} \\ w_t - w_{t-1} \\ l_t \\ \pi_t \\ R_t \end{bmatrix},$$

where *dl* denotes the percentage change measured as log difference and *l* denotes the log. The observables are the seven quarterly U.S. macroeconomic time series used in SW, and they match the number of shocks that affect the economy. The series considered are: 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.[17]

The deterministic balanced growth path is defined in terms of four parameters: $\bar{\gamma}$, the quarterly trend growth rate common to real GDP, consumption, investment and wages; $\bar{l}$, the

[16]The model also assumes that the monetary policy shock follows an autoregressive process defined by $\varepsilon_t^R = \rho_R \varepsilon_{t-1}^R + u_t^R$, where $u_t^R \overset{iid}{\sim} \mathcal{N}\left(0, \sigma_R^2\right)$. The same assumption also holds for the other structural shocks of the model.

[17]Price controls set in the early 1970s may have impacted the dynamics of the inflation rate. However, the estimation of the model successfully captures the oil price shocks that characterize this period in the U.S.

steady-state hours worked (normalized to zero); $\bar{\pi}$, the quarterly steady-state inflation rate; $\bar{R}$, the steady-state nominal interest rate. Hence, the measurement equations in (4) relate the macroeconomic time series with the corresponding endogenous variables of the model $\{y_t, c_t, i_t, w_t, l_t, \pi_t, R_t\}$, while accounting for a balanced growth path.

While the full sample of SW ends in the fourth quarter of 2004, I updated the time series and estimated the model over three subsamples. The first period starts in 1955:4, which corresponds to one year after the end of the Korean War, and it ends in 1969:4, the date in which the chairmanship of William Martin ends.[18] The second sample considers the chairmanships of both Arthur Burns and William Miller, and it spans from 1970:1 until 1979:2. As I show empirically in section 6.1, it is relevant to distinguish the first two subsamples because, in line with the evidence documented by Fernald (2014b) among others, the second period is characterized by slower productivity growth, resulting into a distinct balanced growth path. Finally, the third period begins in 1984:1, date in which Kim and Nelson (1999) identify a structural break in the U.S. business cycle. The last observation coincides with the onset of the Great Recession in 2007:3.

5 Methodology

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 could be characterized by regions of the parameters space associated with multiple degrees of indeterminacy, and the researcher has to test for the potential degrees of indeterminacy of the model.[19] Third, standard software

[18] As argued in the work of Bernanke and Blinder (1992) and Bernanke and Mihov (1998), the federal funds rate has been the main policy tool in the United States during the post-war period considered in this paper, even if the Federal Reserve varied its operational procedures.

[19] A grid point method could be used to numerically identify the region of the parameter space associated with the indeterminate solution and the degrees of indeterminacy. However, this method does not provide a mapping between the dynamic properties of the model and its structural parameters.

packages do not allow for indeterminacy.[20] In practice, most papers simply rule out the possibility of indeterminacy by estimating the model exclusively 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 (2019) develop a new method to solve and estimate LRE models allowing for indeterminacy of the model solution. While the paper builds on Lubik and Schorfheide (2003, 2004) and Farmer et al. (2015), the novelty is to provide 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.

5.1 Building the Intuition

I consider a simple analytical example to present the technical complexities that a researcher faces when dealing with indeterminacy and to provide an intuition for how the methodology developed in Bianchi and Nicolò (2019) simplifies the construction of the solution under indeterminacy. Recalling the classical monetary model in section 3.2, the corresponding univariate representation is $E_t(\pi_{t+1}) = \phi_\pi \pi_t - r_t$.

As previously described, the solution to this model depends on the conduct of monetary policy. If the monetary authority is active, $|\phi_\pi| > 1$, the determinate solution is $\pi_t = (1/\phi_\pi) r_t$. Alternatively, if the monetary authority is passive, $|\phi_\pi| \leq 1$, the indeterminate solution is any process that takes the following form $\pi_t = \phi_\pi \pi_{t-1} - r_{t-1} + \eta_t$. The problem that a researcher faces when dealing with the indeterminate solution of a LRE model is the following. The equilibrium dynamics are uniquely determined if the Blanchard-Kahn condition is satisfied (Blanchard and Kahn, 1980). The condition requires the number of expectational variables of the model to equal the number of its unstable roots. The endogenous variable, π_t, of the

[20] Examples of standard solution algorithm are the code Gensys developed by Sims (2001), the toolkit by Uhlig (1999) and the algorithm of Anderson and Moore (1985) among others.

univariate model is expectational and the dynamic properties of the model depend on the value assumed by ϕ_π. When $|\phi_\pi| > 1$, the model has a unique solution as it has a sufficient number of unstable roots to match the number of expectational variables. However, when $|\phi_\pi| \leq 1$, the model is indeterminate because it is missing one explosive root.

Bianchi and Nicolò (2019) propose to augment the original model by appending an independent process which could be either stable or unstable. The key insight consists of choosing this auxiliary process in a way to deliver the correct solution. When the original model is determinate, the auxiliary process must be stationary so that also the augmented representation satisfies the Blanchard-Kahn condition. When the model is indeterminate, the additional process should, however, be explosive so that the Blanchard-Kahn condition is satisfied for the augmented system, even if it is not for the original model.

The methodology of Bianchi and Nicolò (2019) proposes to solve the following augmented system of equations

$$\begin{cases} E_t(\pi_{t+1}) & = & \phi_\pi \pi_t - r_t, \\ \omega_t & = & \left(\frac{1}{\alpha}\right) \omega_{t-1} + \nu_t - \eta_t, \end{cases} \tag{5}$$

where ω_t is an auxiliary autoregressive process, $\alpha \in [0, 2]$, ν_t is a newly defined mean-zero sunspot shock with standard deviation σ_ν and η_t still denotes the forecast errors, $\eta_t \equiv \pi_t - E_{t-1}(\pi_t)$ as in the original model.[21]

When the original LRE model is determinate, $|\phi_\pi| > 1$, the Blanchard-Kahn condition for the augmented representation in (5) is satisfied when $|1/\alpha| \leq 1$. Indeed, the original model has the same number of unstable roots as the number of expectational variables. The methodology thus suggests to append a stable autoregressive process, and standard solution methods deliver the determinate solution $\pi_t = (1/\phi_\pi) r_t$. As the coefficient $|1/\alpha|$ is smaller than 1, the solution for the augmented representation also includes the autoregressive process ω_t. Importantly, its dynamics do not impact the endogenous variable π_t.

Considering the case of indeterminacy (i.e. $|\phi_\pi| \leq 1$), the original model has one ex-

[21]The choice of parametrizing the auxiliary process with $1/\alpha$ instead of α induces a positive correlation between ϕ_π and α that facilitates the implementation of the method when estimating a model.

pectational variable, but no unstable root, thus violating the Blanchard-Kahn condition. If the autoregressive process is explosive (i.e. $|1/\alpha| > 1$), the augmented representation satisfies the Blanchard-Kahn condition and delivers the same indeterminate solution $\pi_t = \phi_\pi \pi_{t-1} - r_{t-1} + \eta_t$. Moreover, to guarantee boundedness, the solution imposes conditions such that ω_t is always equal to zero, and the solution for π_t does not depend on the appended autoregressive process.

Summarizing, the choice of the additional parameter α should be made as follows. For values of $|\phi_\pi|$ outside the unit circle, the Blanchard-Kahn condition for the augmented representation is satisfied for values of $|1/\alpha|$ smaller than 1. Conversely, under indeterminacy (i.e. $|\phi_\pi| \leq 1$) the condition is satisfied when $|1/\alpha|$ is greater than 1. Also, note that under both determinacy and indeterminacy, the exact value of $1/\alpha$ is irrelevant for the law of motion of π_t. Under determinacy, the auxiliary process ω_t is stationary, but its evolution does not affect the law of motion of the model variables. Under indeterminacy, ω_t is always equal to zero. Hence, the introduction of the auxiliary processes does not affect the properties of the solution in either case. These processes only serve the purpose of providing the necessary explosive roots under indeterminacy and creating the mapping between the sunspot shocks and the expectational errors.

5.2 Implementation to Smets and Wouters (2007)

To solve and estimate indeterminate medium-scale models such as SW, a researcher faces the following technical complexities. It is not possible to derive analytically the partition of the parameter space, and the researcher does not know the exact properties of the indeterminacy region. Also, the adoption of a medium-scale model implies that a researcher does not know the degree of indeterminacy which characterizes the model.

To overcome these complexities, I implement the method proposed by Bianchi and Nicolò (2019). First, for any model with p expectational variables, the maximum degree of indeterminacy also corresponds to p. Defining $\{\eta_{i,t}\}_{i=1}^{p}$ to be the forecast error associated with each expectational variable, I augment the original LRE model by appending up to p exogenous processes $\omega_{i,t} = \left(\frac{1}{\alpha_i}\right)\omega_{i,t-1} + \nu_{i,t} - \eta_{i,t}$ for $i = 1,..,p$. Second, for a given draw of the structural parameters of the model, I wish to make draws of α_i smaller or greater than 1 with equal probabilities, as the partition of the parameter space is unknown. Therefore, I assume a uniform distribution over the interval $[0.9, 1.1]$ as a prior distribution.[22] Third, while the newly defined shocks, $\{\nu_{i,t}\}_{i=1}^{p}$, are independent, they are potentially related to the structural shocks of the model. Hence, I assume a uniform distribution over the interval $[0, 1]$ for the newly defined shocks,$\{\nu_{i,t}\}_{i=1}^{p}$, and over the interval $[-1, 1]$ for their correlations with the seven structural shocks described in section 4.[23] To estimate the model, I use the Kalman filter to generate the likelihood function and a Markov Chain Monte Carlo to explore the posterior.[24]

The data favors a specification with one degree of indeterminacy and, as proven theoretically in Bianchi and Nicolò (2019), it is without loss of generality that I include the forecast error associated with the inflation rate, $\eta_{\pi,t} \equiv \pi_t - E_{t-1}(\pi_t)$, as the non-fundamental shock in the augmented representation. Therefore, I estimate the SW model augmented with the exogenous process $\omega_t = \left(\frac{1}{\alpha}\right)\omega_{t-1} + \nu_t - \eta_{\pi,t}$. For the parameter α, I assume a uniform prior distribution over the interval $[0.9, 1.1]$ and I specify a uniform prior over the interval $[0, 1]$ for the standard deviation of the sunspot shock, σ_ν.[25] The newly defined sunspot shock, ν_t, could potentially be correlated with the seven structural shocks of the model and I set a uniform prior distribution over the interval $[-1, 1]$ for its correlations with the seven structural shocks.

Importantly, I verify that the standard deviation of the newly defined shock, ν_t, and its

[22] Any symmetric interval around 1 guarantees an equal probability of drawing α greater or smaller than 1.

[23] I refer the reader to Bianchi and Nicolò (2019) for a detailed technical discussion that shows the existence of a unique mapping between the parametrization used in this paper and the one adopted in Lubik and Schorfheide (2004) to characterize the full set of indeterminate equilibria. Therefore, by setting uniform priors over the well-defined interval $[-1, 1]$ for such correlations, the methodology of Bianchi and Nicolò (2019) accounts for the parametrization of Lubik and Schorfheide (2004) as a special case.

[24] Alternative algorithms, such as the sequential Monte Carlo of Herbst and Schorfheide (2015), could also be implemented. However, the richness of the model, the complexity of the boundary of the determinacy region as a function of the deep model parameters and the evidence of two local maxima that are interior to the determinate and indeterminate region respectively could pose technical challenges also in the implementation of such algorithms.

[25] As shown in table 3, the posterior distribution for the sunspot shock is not at the boundary but rather interior to the interval over which the uniform prior distribution.

correlations with the structural shocks are locally identified using the method proposed by Iskrev (2009).[26] Each parametrization of the correlations has strong predictions for the transmission of each shock, and the richness of the data used to estimate the SW model crucially identifies them. I find that only the correlation between the newly defined shock and the price mark-up shock statistically differs from zero, implying that the price mark-up shock has a contemporaneous effect on inflation, while the remaining shocks have a lagged impact. Hence, I report below the results of the estimation when I set the correlations with the remaining shocks to zero, as this specification is favored by the data.

6 Main Findings

6.1 U.S. Monetary Policy in the Post-War Period

I find that the conduct of monetary policy changed during the post-war period from a passive stance before 1979 to an active inflation targeting since the early 1980s. This result has two implications. First, the assumption imposed in SW about an active monetary policy both before and after 1979 is rejected. Second, the findings in previous studies that adopted small-scale models (Clarida et al., 2000; Lubik and Schorfheide, 2004) carry over to the SW model.

By considering the model and the data described in section 4, I apply the methodology presented in section 5 to estimate the SW model over three subsamples. The first period starts in 1955:4, which corresponds to one year after the end of the Korean War, and it ends in 1969:4 as the chairmanship of William Martin terminates in early 1970. The second sample considers the chairmanships of both Arthur Burns and William Miller, and it spans from 1970:1 until 1979:2. Finally, the beginning of the third period corresponds to 1984:1, in which Kim and Nelson (1999) initially identify a structural break in the U.S. business cycle,

[26] In a related paper, 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.

while the end is marked by the Great Recession in 2007:3.[27]

Appendix A reports the prior distributions for the structural parameters of the model and the exogenous processes that drive the dynamics of the economy. Relative to SW, the only difference relates to the prior distribution of the Taylor rule coefficient associated with the response of the monetary authority to changes in the inflation rate. While SW specify a normal distribution truncated at 1, centered at 1.50 and with standard deviation 0.25, I set a flatter normal prior distribution centered at 1 and with standard deviation 0.35.

Table 1 reports the results of the estimation for each subsample. Relative to SW, the novelty is to relax the *a priori* assumption of equilibrium uniqueness. The method described in section 5 allows to estimate the model over the entire parameter space. For each period, the Metropolis-Hastings algorithm finds two local maxima, one associated with the determinate solution and the other with the indeterminate representation. It is therefore possible to compute the corresponding marginal data density using the modified harmonic mean estimator proposed by Geweke (1999) and the posterior model probabilities associated with each local maxima. Focusing on the first two samples that cover the period from 1955:4 to 1979:2, the data strongly favors the representation associated with indeterminacy, therefore rejecting the assumption of equilibrium uniqueness imposed in SW. On the contrary, the period subsequent to the Volcker disinflation is associated with a determinate, unique representation.

The evidence of a change in the monetary policy stance since 1984:1 is presented in table 2, where the posterior distributions of the structural parameters in the three sub-periods are compared.[28] Considering the Taylor rule coefficient associated with the response of the monetary authority to changes in the inflation rate, r_π, it is clear that the monetary authority was passive prior to 1979, thus consistent with a weak response of the monetary authority

[27]The findings in this section for the period prior to 1979:2 are quantitatively unchanged when considering a sample spanning from 1955:4 until 1979:2. However, studying the two samples separately is relevant to understand the connection between different steady state properties between the two periods and the exceptional growth in productivity until the early 1970s documented in Fernald (2014b).

[28]I consider the posterior estimates to be unchanged when the posterior mean of a parameter estimated in either of the two sample periods is within the 90% probability interval associated with the posterior distribution obtained in the alternative sample.

Table 1: Model comparison for each sample period

		Determinacy	Indeterminacy
Martin (55Q4 - 69Q4)	Log data density	-338.1	-319.2
	Posterior Model Prob (%)	0%	100%
Burns-Miller (70Q1 - 79Q2)	Log data density	-277.9	-272.5
	Posterior Model Prob (%)	0%	100%
Post-Volcker (84Q1 - 07Q3)	Log data density	-399.7	-407.2
	Posterior Model Prob (%)	100%	0%

The table reports the (log) data densities and the posterior model probabilities obtained for each sample period.

to changes in the inflation rate. Table 2 also suggests that for the period subsequent to the Volcker disinflation, the monetary authority changed its stance and acted more aggressively to stabilize inflation, therefore ensuring equilibrium uniqueness.

Table 2: Posterior distribution of structural parameters

		1955:4-1969:4		1970:1-1979:2		1984:1-2007:3	
Coefficient	Description	Mean	[5 , 95]	Mean	[5 , 95]	Mean	[5 , 95]
ϕ	Adjustment cost	4.75	[2.90,6.63]	3.41	[2.01,4.69]	6.92	[5.04,8.79]
σ_c	IES	1.11	[0.86,1.37]	0.91	[0.67,1.12]	1.58	[1.36,1.85]
h	Habit Persistence	0.62	[0.49,0.74]	0.62	[0.48,0.76]	0.64	[0.56,0.73]
σ_l	Labor supply elasticity	1.98	[0.89,3.07]	1.27	[0.25,2.14]	2.30	[1.29,3.24]
ξ_w	Wage stickiness	0.74	[0.63,0.85]	0.70	[0.59,0.81]	0.68	[0.53,0.83]
ξ_p	Price Stickiness	0.60	[0.50,0.67]	0.58	[0.50,0.65]	0.75	[0.67,0.83]
ι_w	Wage Indexation	0.33	[0.13,0.53]	0.56	[0.35,0.77]	0.44	[0.20,0.68]
ι_p	Price Indexation	0.30	[0.12,0.47]	0.47	[0.24,0.70]	0.28	[0.10,0.44]
ψ	Capacity utiliz. elasticity	0.52	[0.31,0.74]	0.47	[0.24,0.71]	0.71	[0.57,0.86]
Φ	Share of fixed costs	1.59	[1.46,1.71]	1.34	[1.18,1.51]	1.60	[1.46,1.75]
α	Share of capital	0.24	[0.20,0.29]	0.18	[0.13,0.23]	0.22	[0.19,0.26]
$\bar{\pi}$	S.S. inflation rate (quart.)	0.60	[0.44,0.76]	0.62	[0.46,0.78]	0.69	[0.55,0.80]
$100(\beta^{-1}-1)$	Discount factor	0.17	[0.06,0.26]	0.20	[0.08,0.31]	0.13	[0.05,0.21]
$\bar{l}$	S.S. hours worked	1.33	[0.17,2.54]	-2.42	[-3.63,-1.17]	1.52	[0.36,2.80]
$\bar{\gamma}$	Trend growth rate (quart.)	0.57	[0.38,0.76]	0.36	[0.31,0.41]	0.45	[0.42,0.48]
r_π	Taylor rule inflation	0.64	[0.35,0.99]	0.75	[0.54,0.99]	1.83	[1.44,2.24]
r_y	Taylor rule output gap	0.13	[0.05,0.20]	0.16	[0.09,0.23]	0.09	[0.04,0.15]
$r_{\Delta y}$	Taylor rule Δ(output gap)	0.11	[0.07,0.15]	0.18	[0.12,0.24]	0.15	[0.10,0.19]
ρ	Taylor rule smoothing	0.87	[0.81,0.94]	0.73	[0.61,0.86]	0.84	[0.80,0.88]

The table compares the posterior estimates of structural parameters under indeterminacy for the pre-Volcker period and under determinacy for the post-Volcker period.

Importantly, these results provide evidence that, even when accounting for the richer propagation mechanisms, 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. Appendix B reports predictive checks, further supporting these findings, and shows that the imposition of an active monetary policy, as in the original paper by SW, is not innocuous and delivers erroneous estimates of the structural parameters.

Table 2 also provides evidence in support of Fernald (2014b) who documents that the U.S. economy experienced a period of exceptional growth in productivity in the post-war period until the early 1970s. Both the trend growth rate of the economy, $\bar{\gamma}$, and the (steady state) hours worked, $\bar{l}$, drop significantly in the period between 1970 until 1979 relative to the previous period. The posterior distributions also show that the post-Volcker period is characterized by a mildly higher degree of price stickiness, ξ_p, and a more persistent process of the price-markup shock measured by ρ_p in table 3. This finding is supported by Galí and Gertler (1999), who provide evidence of an increased average price duration over this period due to the lower and more stable inflation rate. Also, the post-Volcker period is associated with a larger adjustment cost faced by the representative agent that chooses a higher degree of capital utilization rate.

The comparison in table 3 of the properties of the exogenous processes between the period before and after 1979 provides an additional finding. In line with a large literature, the volatility of the shocks driving macroeconomic fluctuations are significantly smaller starting from the mid-1980s (Stock and Watson, 2003; Primiceri, 2005; and Sims and Zha, 2006). This result and the evidence of the change in the conduct of monetary policy are clearly linked to the discussion on the possible explanations for the sources of the reduction in U.S. macroeconomic volatility from the early 1980s to 2007. In section 6.4, I show that, according to the SW model, both the change in the monetary policy stance *and* the lower size of the shocks explain this empirical observation for U.S. macro data. In line with the results of the local identification test by Iskrev (2009) described in section 5.2, the posterior distribution for the standard deviation of the sunspot shock, σ_ν, and its correlation with the mark-up shock, $\rho_{\nu p}$, are both tightly estimated, even when assuming a uniform distribution as a prior.

Table 3: Posterior distribution of exogenous processes

		1955:4-1969:4		1970:1-1979:2		1984:1-2007:3	
Coefficient	Description	Mean	[5 , 95]	Mean	[5 , 95]	Mean	[5 , 95]
σ_a	Technology shock	0.52	[0.44,0.61]	0.56	[0.45,0.67]	0.36	[0.31,0.40]
σ_b	Risk premium shock	0.19	[0.11,0.27]	0.17	[0.11,0.23]	0.18	[0.14,0.22]
σ_g	Government sp. shock	0.50	[0.42,0.58]	0.55	[0.44,0.65]	0.41	[0.36,0.46]
σ_I	Investment-specific shock	0.61	[0.42,0.79]	0.38	[0.24,0.51]	0.35	[0.28,0.43]
σ_r	Monetary policy shock	0.11	[0.09,0.12]	0.22	[0.18,0.27]	0.12	[0.10,0.14]
σ_p	Price mark-up shock	0.24	[0.20,0.28]	0.31	[0.23,0.39]	0.09	[0.07,0.11]
σ_w	Wage mark-up shock	0.24	[0.18,0.28]	0.31	[0.23,0.38]	0.31	[0.24,0.37]
σ_ν	Sunspot shock	0.14	[0.07,0.21]	0.19	[0.06,0.33]	-	-
ρ_a	Persistence technology	0.95	[0.92,0.99]	0.74	[0.60,0.87]	0.92	[0.87,0.96]
ρ_b	Persistence risk premium	0.58	[0.34,0.83]	0.77	[0.62,0.92]	0.22	[0.05,0.35]
ρ_g	Persistence government sp.	0.86	[0.77,0.94]	0.85	[0.77,0.94]	0.96	[0.94,0.98]
ρ_I	Persistence investment-specific	0.50	[0.30,0.70]	0.66	[0.47,0.84]	0.66	[0.52,0.78]
ρ_r	Persistence monetary policy	0.50	[0.31,0.69]	0.31	[0.11,0.51]	0.35	[0.19,0.51]
ρ_p	Persistence price mark-up	0.24	[0.04,0.41]	0.37	[0.11,0.65]	0.83	[0.72,0.95]
ρ_w	Persistence wage mark-up	0.62	[0.34,0.90]	0.43	[0.14,0.68]	0.81	[0.66,0.95]
μ_p	MA price mark-up	0.64	[0.43,0.85]	0.68	[0.45,0.95]	0.66	[0.48,0.84]
μ_w	MA wage mark-up	0.50	[0.25,0.74]	0.55	[0.25,0.88]	0.62	[0.38,0.82]
ρ_{ga}	$Cov(\sigma_a, \sigma_g)$	0.57	[0.38,0.76]	0.62	[0.40,0.84]	0.40	[0.22,0.57]
$\rho_{\nu p}$	$Corr(\sigma_\nu, \sigma_p)$	0.92	[0.82,0.99]	0.66	[0.29,0.99]	-	-

The table compares the posterior estimates of the parameters associated with the exogenous processes under indeterminacy for the pre-Volcker period and under determinacy for the post-Volcker period.

Finally, I show that by estimating a small-scale model that does not account for the richer structure of the SW model, the evidence of an active monetary policy over the period between 1984:1 and 2007:3 is overturned. This result is consistent with the identification problem described in section 3.1 for which missing propagation mechanisms could be misinterpreted as evidence of indeterminacy.

To this purpose, I estimate the small-scale model in Del Negro and Schorfheide (2004), who adapted the model by Lubik and Schorfheide (2004) to account for a balanced growth path.[29] Table 4 reports the (log) data densities and the corresponding posterior model probabilities for the determinate and indeterminate representations using the two alternative models. The first row shows that by estimating the small-scale model of Del Negro and Schorfheide (2004) using the post-Volcker data from SW, the evidence of *indeterminacy* is pervasive. Nevertheless, the conclusion is reversed once richer and more relevant propagation

[29] Appendix C reports the details about the model, the data, the prior and the posterior distributions of the model parameters of the model by Del Negro and Schorfheide (2004).

Table 4: Model comparison: Del Negro and Schorfheide (2004) and SW

Sample: 1984:1-2007:3		Determinacy	Indeterminacy
Del Negro and Schorfheide (2004) model	Log data density	-58.09	-26.56
	Posterior Model Prob (%)	0%	100%
SW model	Log data density	-399.670	-407.16
	Posterior Model Prob (%)	100%	0%

The table reports the (log) data densities and the posterior model probabilities for the Del Negro and Schorfheide (2004) model and the SW model over the period 1984:1-2007:3.

mechanisms and structural shocks are included. According to the SW model, monetary policy was active and consistent with a determinate equilibrium over the period between 1984:1 and 2007:3.

6.2 Monetary Policy, Expectations, and the Propagation Mechanism

In this section, I document the effects of a change in monetary policy on the dynamics of the economy and the transmission of structural shocks. When monetary policy is passive, the propagation of structural disturbances is altered and more persistent due to the formation of self-fulfilling expectations in response to shocks. In particular, I study the propagation of three shocks that, as highlighted in section 6.3, explain most of U.S. business cycle fluctuations in the period prior to 1979: productivity, risk-premium and monetary policy shocks.[30] Importantly, the results presented in this section are further supported by the empirical evidence in section 6.5 that also documents the differences in the transmission of shocks depending on the conduct of monetary policy by estimating a BVAR model, *à la* Giannone, Lenza, and Primiceri (2015).

6.2.1 Productivity Shock

The impact of a productivity shock has implications that differ depending on the conduct of U.S. monetary policy. The four panels on the right of figure 1 show the transmission of a

[30] As discussed in section 5.2, the data favors a specification in which the non-fundamental shock, ν_t, is correlated only with the markup shock. This implies that the inflation rate responds on impact only to a markup shock while with a lag to all the remaining fundamental shocks, including those analyzed in this section.

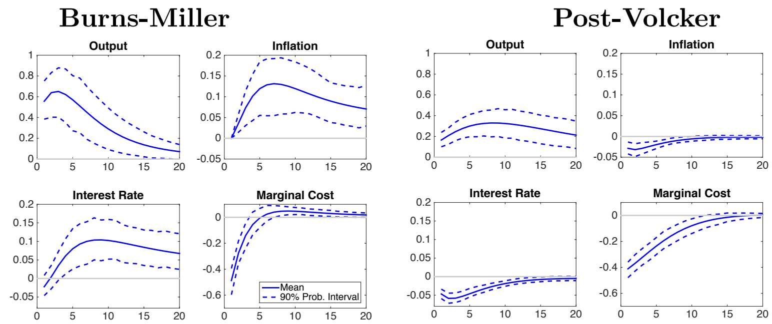

Figure 1: Productivity shock

Mean impulse responses to a productivity shock are denoted by solid lines, while dashed lines represent the associated 90% probability intervals.

(one standard deviation) productivity shock in the post-Volcker period on output, inflation rate, nominal interest rate, and marginal cost incurred by firms.[31] The shock generates economic activity and deflationary pressures because of a drop in marginal cost. Under the active inflation targeting, the monetary authority responds by lowering the policy rate by more than one-for-one. Conversely, the four panels on the left are associated with the passive monetary policy of the Burns and Miller chairmanship.[32] The shock still results into a drop in marginal cost and an economic expansion. However, the productivity shock also generates inflationary expectations that are accommodated by the passive monetary authority. Firms observe a contemporaneous drop in marginal cost, but also expect future marginal costs to be persistently higher than the steady state level. This mechanism thus results into a self-fulfilling rise of the inflation rate. The corresponding increase in the nominal interest rate is gradual and not aggressive enough to anchor inflation expectations and stabilize the inflation rate, therefore allowing for persistent effects on the economy.

6.2.2 Risk-Premium Shock

The risk-premium shock represents a wedge between the policy rate set by the central bank and the return that households receive to hold their assets. As figure 2 suggests, the shock

[31] The size of the shock depends on the standard deviation estimated in each of the two samples. As found in table 3, the size of the shock in the two samples before 1979 is larger than the standard deviation estimated for the post-Volcker period.

[32] I obtain similar results for the period that covers the Martin chairmanship.

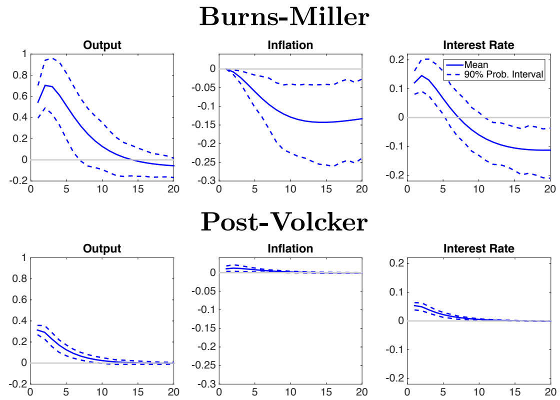

Figure 2: Risk-premium shock

Mean impulse responses to a risk-premium shock are denoted by solid lines, while dashed lines represent the associated 90% probability intervals.

has similar effects on the real economy regardless of the conduct of monetary policy. A (one standard deviation) negative shock increases consumption as the required rate of return on assets is lower. Also, the decrease in the cost of capital further stimulates economic activity due to larger investments by firms. However, the inflation response to the risk-premium shock depends on the conduct of monetary policy. When monetary policy is active, firms face a higher marginal cost that maps into inflationary pressures. When monetary policy is passive, agents observe a rise in the real interest rate and form self-fulfilling deflationary expectations that more than offset the increase in marginal cost. In this case, the risk-premium shock therefore generates deflationary effects.

6.2.3 Monetary Policy Shock

The bottom three panels of figure 3 describe the predictions of a contractionary monetary policy shock under the active regime of the post-Volcker period. Output and inflation drop and revert to the steady state of the economy. When monetary policy is indeterminate, the responses to a contractionary monetary policy shock are reported in the top three panels. Economic activity is depressed. However, in line with the empirical findings of Lubik and Schorfheide (2004), the unexpected tightening of monetary policy is associated with a persistent inflationary effect due to self-fulfilling inflationary expectations. Therefore, figure 3

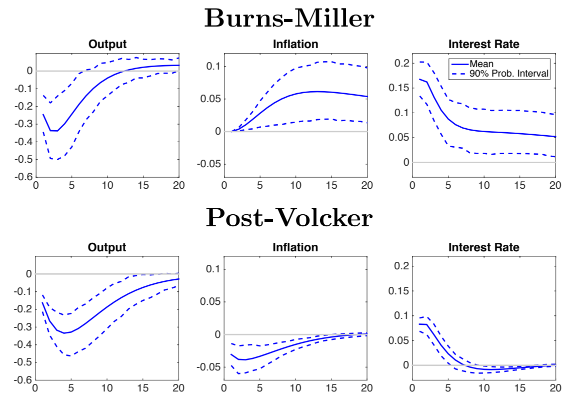

Figure 3: Monetary policy shock

Mean impulse responses to a monetary policy shock are denoted by solid lines, while dashed lines represent the associated 90% probability intervals.

highlights the differences in the impact and the transmission of structural shocks such as an unexpected monetary policy tightening.

6.3 The History of U.S. Business Cycles

The interpretation of U.S. business cycle fluctuations relies on the conduct of monetary policy. The passive interest rate policy in the period from 1955 to 1979 meant that monetary policy accommodated the transmission of fundamental shocks and failed to insulate the inflation rate from persistent deviations relative to the target. Persistent technology shocks explain the initial upward trend in the inflation rate observed since the early 1960s. This result is supported by the evidence of Fernald (2014b), according to whom the U.S. economy experienced a period of exceptional growth in productivity since World War II until the oil crisis in 1973. Mark-up shocks account for the sudden inflationary episodes related to the oil price shocks during the 1970s but do not explain the persistent rise in the inflation rate. Sunspot shocks play a minor role to explain the high macroeconomic volatility observed before 1979. These findings indicate that the strong evidence of a passive monetary policy before 1979 lies in the distinctive transmission mechanism of structural shocks because of self-fulfilling expectations rather than in the quantitative relevance of non-fundamental disturbances. Regarding the period after the Volcker disinflation, the results are in line with previous findings in the literature and reported in appendix E.

6.3.1 Martin and the Post-Korean War Period

I first focus on the post-Korean War period that starts in 1955 and during which William Martin has been the Chairman of the Fed until the beginning of 1970.

Figure 4 plots the historical decomposition of the deviations of the inflation rate from its long run for two alternative specifications.[33] The left panel plots the decomposition under indeterminacy that is favored by the data.[34] While sunspot shocks could have potentially contributed for the model to better match the high volatility in the inflation rate, the historical decomposition indicates that they played no quantitative role. The rise in inflation since the early 1960s is associated with a sequence of productivity shocks. In line with the analysis in section 6.2, the left panel indicates that the cumulated impact of positive productivity shocks explains the upward trend in the inflation rate.[35] As discussed below, this result is supported by the empirical evidence presented in Fernald (2014b) among others.[36]

The right panel reports the decomposition that results by imposing equilibrium uniqueness as conducted in SW. A comparison with the left panel suggests that the assumption substantially affects the interpretation of the data.[37] The upward trend in the inflation rate during the 1960s is erroneously attributed to mark-up shocks. However, the results in section 6.1

[33]The historical decomposition of output growth for the two sample periods prior to 1979 is provided in appendix D and shows minor differences between the determinate and the indeterminate representation.

[34]To conduct the historical decompositions, I use the posterior means estimated for the pre-Volcker period for each of the two local maxima found during the estimation and that are reported in table 2 and 3. Also, to simplify the analysis, I group the exogenous spending shock, the investment-specific shock and the risk-premium shock as "demand" shocks. Similarly, price and wage mark-up shocks are grouped as "mark-up" shocks.

[35]Monetary policy shocks had a minor impact that resulted into mildly deflationary pressures during the early 1960s. It is useful to recall that the historical decomposition cumulates the effect of a given shock on the inflation rate until a given date. Given the persistence of the monetary policy shocks under indeterminacy, as described in section 6.2, a monetary policy shock can be identified as the change in the contribution to explain the dynamics.

[36]While the SW model does not account for a fiscal block explicitly, it is relevant to note that government spending shocks possibly associated with the Vietnam War are not quantitatively relevant to explain inflation dynamics over this time period.

[37]Minor differences in the historical decomposition at a given year across the two panels are explained by differences in the contribution of the initial conditions for each representation.

reject the assumption of determinacy, thus indicating that the correct interpretation relies on the left panel.

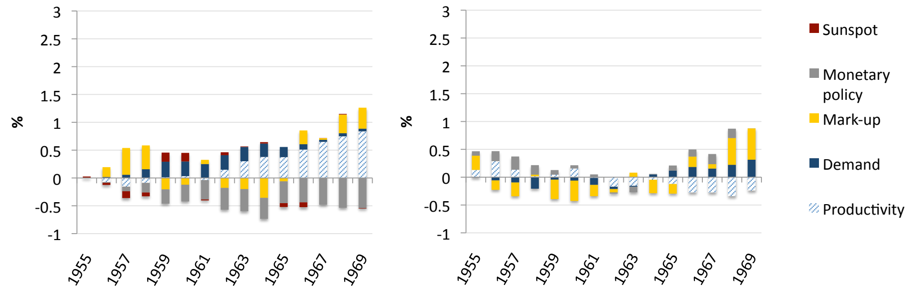

Figure 4: Historical decomposition of the inflation rate (1955–1969)

Historical decomposition of the inflation rate under indeterminacy (left) and determinacy (right) at quarterly rates.

The evidence that the U.S. economy experienced exceptional growth in productivity prior to the early 1970s is documented by Fernald (2014b) among others[38]. This literature points to a wave of technological innovations as the source of a rise in productivity growth and therefore economic activity. In particular, when considering the quarterly time series for total factor productivity produced by Fernald (2014a), the resulting (standardized) series is plotted in figure 5 together with the smoothed productivity shocks estimated using the SW model. The comparison indicates that the estimation of the SW model successfully identifies the sequence of positive productivity shocks that the U.S. economy experienced starting from the early 1960s.[39] Importantly, in a passive monetary policy regime, productivity shocks generate persistent inflationary expectations that are consistent with the observed upward trend in inflation.

6.3.2 The Burns and Miller Chairmanships

The second period begins with the chairmanship of Arthur Burns in 1970 and ends in 1979 with the conclusion of the chairmanship of William Miller. Figure 6 presents the historical

[38]Other work that supports this view is provided by Fernald (2014a), Gordon (2000), Davig and Wright (2000), and Field (2003).

[39]The correlation between the two sequences of productivity shocks is 0.74, suggesting that the model does remarkably well in extracting productivity shocks that are in line with Fernald (2014a).

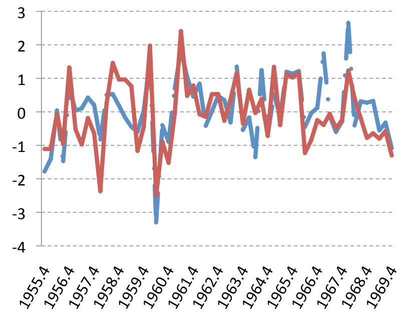

Figure 5: Total factor productivity

Sample 1955:4–1969:4. Quarterly (standardized) series of total factor productivity (solid) from Fernald (2014a) and of the smoothed productivity shocks from SW model (dashed) in percentages at quarterly rates.

decomposition of the inflation rate over this sample period according to alternative monetary policy regimes. The left panel presents the decomposition associated with indeterminacy, as supported by the data, while the right panel is obtained by imposing the assumption that monetary policy was active. As explained in section 6.2, the conduct of a passive monetary policy is such that positive risk-premium shocks have a contractionary effect on the economy but also lead agents to form inflationary expectations that are self-fulfilling and persistent. Hence, a combination of demand shocks and positive productivity shocks sustained the high inflation observed in the late 1970s, while the spike in 1979 is attributed to mark-up shocks.[40] Even for this sample period, sunspot shocks have no quantitative relevance for U.S. business cycles. Conversely, the right panel shows that the assumption of an active monetary policy mistakenly attributes the fluctuations in the inflation rate exclusively to mark-up shocks.

6.4 What Changed in the Early 1980s?

The work of Kim and Nelson (1999) and McConnell and Perez-Quiros (2000) first documented the lower volatility of U.S. real GDP since the early 1980s. Extensive research has been conducted to provide explanations for the reduction in U.S. macroeconomic volatility. Using the SW model, I investigate the validity of two prominent theories that have been advocated

[40]While figure 6 generally refers to demand shocks, the break down for each demand shock shows that the contribution of the risk-premium shock is the most relevant as opposed to the government spending or investment-specific shocks.

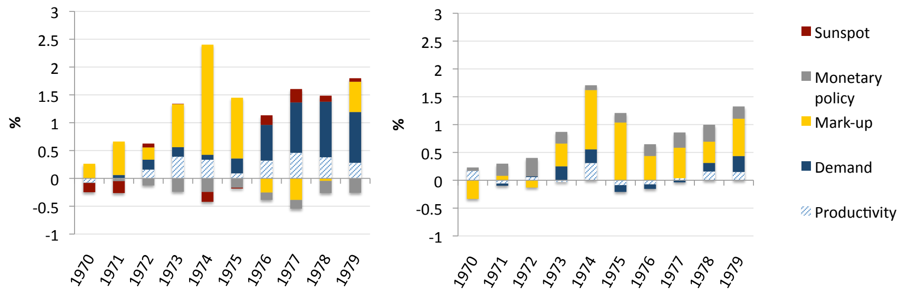

Figure 6: Historical decomposition of the inflation rate (1970–1979)

Historical decomposition of the deviation of the inflation rate from its steady state under indeterminacy (left) and determinacy (right) at quarterly rates.

to explain this empirical fact. The work by Sims and Zha (2006) suggests that the behavior of the data changed because of a decrease in the variance of the structural shocks since the Volcker disinflation. Primiceri (2005) finds evidence that policy also changed, but the role played by structural disturbances is more relevant. According to this strand of the literature, the reduction in volatility of U.S. macroeconomic data is not related to monetary policy and it can therefore be considered as "good luck".

An alternative theory has been supported by the work of Clarida et al. (2000) and Lubik and Schorfheide (2004), among others who find evidence of an active inflation targeting since the Volcker disinflation. The reduction in volatility can be attributed to the "good policy" of the monetary authority.

To provide an intuition for the approach that I adopt using the SW model, I consider the standard three-equation NK model of Lubik and Schorfheide (2004). The model is described by a dynamic IS curve

$$x_t = E_t\left(x_{t+1}\right) - \tau\left(R_t - E_t\left(\pi_{t+1}\right)\right) + g_t,$$

a NK Phillips Curve

$$\pi_t = \beta E_t\left(\pi_{t+1}\right) + \kappa\left(x_t - z_t\right),$$

and a monetary policy reaction function

$$R_t = \rho_R R_{t-1} + (1-\rho_R)\left[\psi_1 \pi_t + \psi_2 (x_t - z_t)\right] + \varepsilon_{R,t},$$

where x_t represents the deviation of output from its trend and the demand shock, g_t, and supply shock, z_t, are autoregressive processes of the form $g_t = \rho_g g_{t-1} + \varepsilon_{g,t}$ and $z_t = \rho_z z_{t-1} + \varepsilon_{z,t}$.

To test alternative theories using the SW model, I estimate different model specifications by imposing restrictions on sets of parameters and volatilities. In model 1, "Policy and Shocks", I constrain the private sector parameters, $\{\tau, \beta, \kappa\}$, to be the same across the period from 1955 to 1979 and the period from 1984 to 2007. I also allow the policy parameter, $\{\rho_R, \psi_1, \psi_2\}$, the variances of the shocks, $\{\sigma_g, \sigma_z\}$, and the autoregressive coefficients, $\{\rho_g, \rho_z\}$, to vary across the two periods. This specification considers a combination of "good luck" and "good policy" to explain the data. Relative to model 1, I then consider model 2, "Shocks only", by further restricting the policy parameter, $\{\rho_R, \psi_1, \psi_2\}$, thus considering the "good luck" view. Conversely, consistent with the "good policy" theory, model 3, "Policy only", allows for the policy parameter to vary across sub-periods, while constraining all the other structural parameters and variances to be constant. Following the intuition provided with the baseline three-equation NK model, I apply the same approach to estimate alternative model specifications of the SW model and test for the validity of the "good luck" and/or "good policy" theory in the data.

Table 5: Model comparison across model specifications

	Log data density	Posterior model prob	
Policy and shocks	-986.85	100%	100%
Shocks only	-994.51	0%	-
Policy only	-1021.08	-	0%

The table reports the marginal data densities for the three alternative specifications and the pairwise posterior model probabilities relative to model 1, Policy and Shocks.

Table 5 reports the logarithm of the marginal data densities computed using Geweke's (1999) modified harmonic mean estimator for each of the three model specifications. Unlike a standard likelihood ratio statistic, the marginal data density penalizes a model that is over-parameterized. Nevertheless, the posterior model probabilities derived as pairwise comparisons relative to model 1, Policy and Shocks, indicate that, based on the SW model, a combination of both good luck and good policy is the explanation for the observed reduction in the volatility since the mid-1980s. Also, in line with the findings of Primiceri (2005), model 2, Shocks only, has a more relevant role rather than the theory based exclusively on the change of monetary policy to an active stance, model 3 Policy only.

Table 6: Posterior distribution of common parameters

Coefficient	Description	Mean	[5 , 95]
ϕ	Adjustment cost	6.59	[4.75,8.48]
σ_c	IES	1.44	[1.25,1.63]
h	Habit Persistence	0.62	[0.51,0.73]
σ_l	Labor supply elasticity	2.14	[1.37,2.91]
ξ_w	Wage stickiness	0.84	[0.79,0.89]
ξ_p	Price Stickiness	0.77	[0.70,0.83]
ι_w	Wage Indexation	0.40	[0.24,0.56]
ι_p	Price Indexation	0.18	[0.06,0.30]
ψ	Capacity utiliz. elasticity	0.68	[0.55,0.81]
Φ	Share of fixed costs	1.63	[1.50,1.75]
α	Share of capital	0.22	[0.19,0.25]
$\bar{\pi}$	S.S. inflation rate (quart.)	0.60	[0.48,0.71]
$100(\beta^{-1}-1)$	Discount factor	0.10	[0.04,0.16]
$\bar{l}$	S.S. hours worked	0.67	[-0.29,1.55]
$\bar{\gamma}$	Trend growth rate (quart.)	0.42	[0.39,0.45]

The table reports the posterior estimates of the structural parameters constrained to be the same in the pre- and post-Volcker period.

Focusing on the estimation of model 1, Policy and Shocks, table 6 reports the posterior estimates of the constrained parameters across the two subsamples. As expected, the posterior distribution of the model parameters are in line with those estimated for the two samples separately and reported in section 6.1. The comparison of the posterior estimates of the structural parameters in table 7 indicates that the conduct of monetary policy changed toward a more aggressive stance in the post-Volcker period. Moreover, consistent with the findings of Sims and Zha (2006), among others, the magnitude of the volatility of the shocks is significantly reduced in the post-Volcker period. These results provide evidence that, according

Table 7: Posterior distribution of unrestricted parameters

		Pre-Volcker (55:4 - 79:2)		Post-Volcker (84:1 - 07:3)	
Coefficient	Description	Mean	[5 , 95]	Mean	[5 , 95]
σ_a	Technology shock	0.54	[0.47,0.60]	0.36	[0.31,0.40]
r_π	Taylor rule inflation	0.85	[0.73,0.97]	1.80	[1.37,2.18]
r_y	Taylor rule output gap	0.15	[0.09,0.21]	0.05	[0.02,0.10]
$r_{\Delta y}$	Taylor rule Δ(output gap)	0.17	[0.12,0.22]	0.17	[0.12,0.21]
ρ	Taylor rule smoothing	0.86	[0.80,0.91]	0.84	[0.80,0.88]
σ_b	Risk premium shock	0.14	[0.08,0.19]	0.15	[0.08,0.21]
σ_g	Government sp. shock	0.53	[0.46,0.60]	0.41	[0.36,0.46]
σ_I	Investment-specific shock	0.45	[0.35,0.56]	0.30	[0.23,0.37]
σ_r	Monetary policy shock	0.17	[0.15,0.20]	0.12	[0.10,0.14]
σ_p	Price mark-up shock	0.30	[0.25,0.34]	0.09	[0.07,0.11]
σ_w	Wage mark-up shock	0.26	[0.22,0.30]	0.31	[0.25,0.37]
σ_ν	Sunspot shock	0.06	[0.01,0.11]	-	-
ρ_a	Persistence technology	0.97	[0.96,0.98]	0.93	[0.89,0.96]
ρ_b	Persistence risk premium	0.75	[0.55,0.93]	0.38	[0.05,0.71]
ρ_g	Persistence government sp.	0.90	[0.86,0.95]	0.97	[0.95,0.98]
ρ_I	Persistence investment-specific	0.68	[0.55,0.81]	0.74	[0.62,0.86]
ρ_r	Persistence monetary policy	0.35	[0.20,0.51]	0.32	[0.19,0.45]
ρ_p	Persistence price mark-up	0.24	[0.04,0.42]	0.82	[0.73,0.92]
ρ_w	Persistence wage mark-up	0.34	[0.12,0.55]	0.69	[0.50,0.88]
μ_p	MA price mark-up	0.77	[0.64,0.92]	0.63	[0.44,0.83]
μ_w	MA wage mark-up	0.38	[0.21,0.57]	0.56	[0.32,0.80]
ρ_{ga}	$Cov(\sigma_a, \sigma_g)$	0.62	[0.46,0.76]	0.40	[0.22,0.57]

The table reports the posterior estimates of policy parameters and the exogenous shocks for the pre- and post-Volcker period.

to the SW model, *both* theories contribute to explain the reduction in U.S. macroeconomic volatility.

6.5 IRFs from Bayesian Vector Autoregressions

In this section, I provide additional empirical evidence in support of the findings of section 6.2 in which I show that the transmission of fundamental shocks in the SW model differs substantially across regimes. In particular, I estimate a medium-scale BVAR model and document that the propagation mechanism of productivity and monetary policy shocks depends on the conduct of monetary policy also when adopting a reduced-form approach.

The data consists of eight time series. In addition to the seven quarterly U.S. macroeconomic time series used in SW, I also include the time series for total factor productivity obtained from the estimation of the SW model. Using the eight observables, I estimate a BVAR in each of the three subsamples described in section 4: the first sample from 1955:1 until 1969:4, the second from 1970:1 until 1979:2 and the last sample from 1984:1 until 2007:3.

I estimate a BVAR model of the following form:

$$y_t = C + B_1 y_{t-1} + ... + B_p y_{t-p} + \varepsilon_t$$

where y_t is a $n \times 1$ vector of endogenous variables, $\varepsilon_t \sim N(0, \Sigma)$ is an $n \times 1$ vector of exogenous shocks, and $C, B_1, ..., B_p$ and Σ are matrices of suitable dimensions containing the model's unknown parameters. To estimate the BVAR model, I adopt the hierarchical approach of Giannone et al. (2015). Their estimation strategy ensures a good performance in terms of accuracy of the estimation of impulse response functions in identified VARs. Giannone et al. (2015) propose a hierarchical modeling approach that combines the conjugate priors most commonly used in the literature. First, they set a "Minnesota" prior assuming that each variable follows a random walk process (Litterman, 1979, 1980). Second, they include a "sum-of-coefficients" prior assuming that a no-change forecast for each variable is a good forecast at the beginning of the sample (Doan et al., 1984). Finally, they set a "dummy-initial-observation" prior such that a no-change forecast for all variables is a good forecast at the beginning of the sample, consistent with cointegration (Sims, 1993).

To identify the productivity and monetary policy shocks, I adopt a relatively standard identification scheme. First, I order (the logarithm of) total factor productivity (tfp_t) as first variable, therefore assuming that it does not react contemporaneously to any other shock. Second, I order the inflation rate as second variable, assuming that it can react on impact to unexpected changes in productivity while reacting with a lag to any other shock. Finally, the federal funds rate is ordered last, thus assuming that all the other variables of the BVAR model react with a lag to a monetary policy shock. This identification scheme results in ordering the variables of the model as $y_t \equiv \{ltfp_t, dlP_t, dlGDP_t, dlCONS_t, dlINV_t, dlWAG_t, lHours_t, FEDFUNDS_t\}$, where dl denotes the percentage change measured as log difference and l denotes the log. Finally, due to the small size of the first two samples, I estimate the model with one lag, while for the last sample period, I choose five lags in line with Giannone et al. (2015).[41]

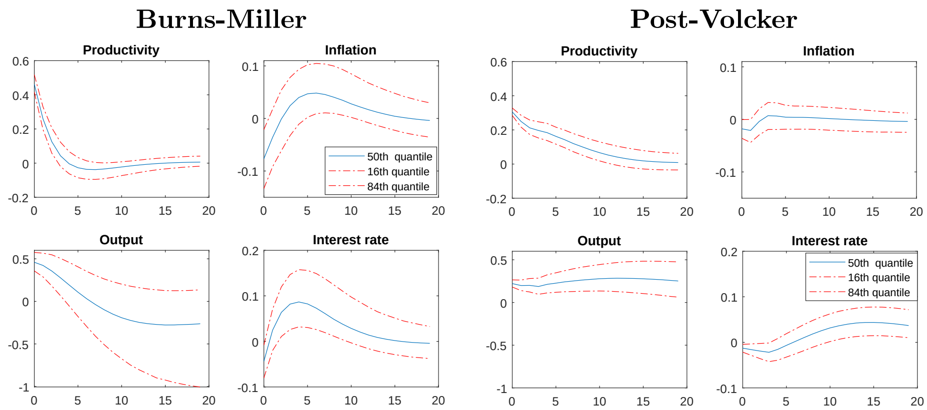

Figure 7: Productivity shock from BVAR

The figure reports the 50th (solid) as well as the 16th and 84th percentiles (dashed) of the distribution of the impulse response functions of the BVAR to a one standard deviation productivity shock.

Figure 7 reports the 50th (solid line) as well as the 16th and 84th percentiles (dashed lines) of the distribution of the IRFs to a one standard deviation exogenous shock to total factor productivity in two sample periods. The four panels on the left report the IRFs of selected variables during the Burns-Miller period identified as a period of passive monetary policy from the estimation of the SW model.[42] The four panels to the right report the IRFs of the same variables for the post-Volcker period associated with a more active stance of the Federal Reserve. The variables reported in figure 7 are total factor productivity, the inflation rate, economic activity and the federal funds rate, while appendix F reports the IRFs of all variables included in the BVAR specification.

The size of the estimated one standard deviation shock during the Burns-Miller period (approximately 50 basis points) almost halves during the post-Volcker period (approximately 30 basis points). However, these estimates are fully in line with the size of the productivity

[41] While the choice of one lag for the first two subsample ensures a precise estimate of the model parameters, the results are qualitatively unchanged to the number of lags.

[42] The results are roughly unchanged when considering the Martin subsample that is also associated with the conduct of a passive monetary policy.

shock estimated from the SW model and reported in table 2. Moreover, the comparison of the IRFs between the two subsamples shows the same differences in the propagation of the productivity shock highlighted in section 6.2. During the Burns-Miller period, productivity shocks led not only to an expansion of economic activity, but also to a persistent *inflationary* effect and a corresponding rise in the federal funds rate. On the contrary, a productivity shock under a more active monetary regime is associated with a rise in output, a temporary *deflationary* effect, and an initial drop in the federal funds rate. Strikingly similar patterns and magnitudes are reported in figure 1 that presented the Bayesian IRFs to a productivity shock in the context of the SW model.

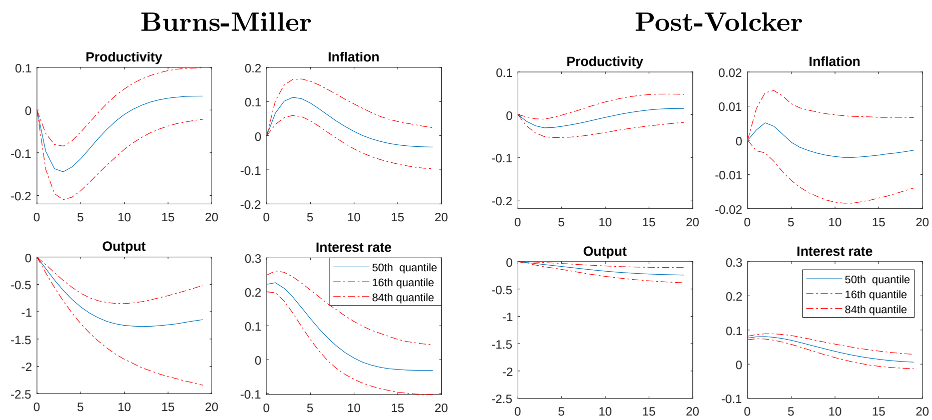

Figure 8: Monetary policy shock from BVAR

The figure reports the 50th (solid) as well as the 16th and 84th percentiles (dashed) of the distribution of the impulse response functions of the BVAR to a one standard deviation monetary policy shock.

Figure 8 reports the IRFs of the same variables to a one standard deviation shock to the federal funds rate in the two subsamples. Even in this case, the size of the monetary policy shock is in line with the estimated standard deviation of the monetary policy shock in the SW model in the two samples. As reported in table 2, the mean estimate was 22 basis points for the Burns-Miller period and 12 basis points for the post-Volcker period. Moreover, the transmission of an exogenous tightening in monetary policy differs substantially in terms of both magnitudes and direction between the two subsamples. During the post-Volcker period, the increase in federal funds leads to a lagged decline in both output and productivity. The dynamics of the inflation rate are in line with the "price puzzle" (Sims, 1992), for which an increase in the federal funds rate predicts an initial rise in inflation and a lagged decline. However, the magnitudes are small and not significant. The propagation substantially differs for the Burns-Miller sample during which the exogenous monetary policy tightening leads to a persistent drop in economic activity and productivity, while inducing a significant inflationary effect. Even in this case, the IRFs are similar to the estimated Bayesian IRFs from the SW model and plotted in figure 3.

7 Conclusions

The conventional interpretation of the post-war data through the lens of a medium-scale NK model depends on the standard assumption of active monetary policy. In this framework, the run-up in inflation from the early 1960s until the late 1970s is exclusively attributed to mark-up shocks.

I have argued that the assumption of active monetary policy over the entire post-war period cannot be easily reconciled with the data and substantially affects the identification of the sources of U.S. business cycles. To understand the behavior of the data prior to the Volcker disinflation, one must allow for the possibility that the central bank operated under passive monetary policy.

I have found that the data strongly support the evidence of passive monetary policy before 1979, even when adopting the rich structure of the SW model. I have shown that non-fundamental sunspot shocks are not quantitatively relevant to explain the U.S. macroeconomic volatility prior to 1979. On the contrary, the conduct of passive monetary policy alters the transmission of fundamental shocks that propagate via the de-anchoring of self-fulfilling inflation expectations. Under this monetary regime, a sequence of positive productivity shocks in the 1960s caused inflationary pressures that the central bank accommodated. Once the assumption of active monetary policy is relaxed, mark-up shocks only account for the sudden rise in inflation during the oil crisis of the mid-1970s.

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A Appendix A

Appendix A reports the prior distributions of the structural parameters and volatility of the shocks used for the estimation of the SW model.

Table 8: 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

The table reports the prior distribution for the structural parameters of the model.

Table 9: Prior distribution of exogenous 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}	$Cov(\sigma_a, \sigma_g)$	Normal	0.50	0.25
$\rho_{\nu p}$	$Corr(\sigma_\nu, \sigma_p)$	Uniform[-1,1]	0	0.57

The table reports the prior distribution for the exogenous processes of the model.

B Appendix B

This appendix studies the implications of the *a priori* restriction about equilibrium uniqueness imposed in SW for the model estimation and presents the results of predictive checks indicating that the indeterminate specification better fits the data. As shown in table 1, the assumption is validated by the data exclusively for the post-Volcker period. On the contrary, the restriction is rejected when considering the sample prior to 1979. Table 10 reports the posterior distribution of the structural parameters estimated for each of the two local maxima found by the Metropolis-Hastings algorithm for the first sample period (1955:4-1969:4). The table allows for a comparison with the estimation results that would be obtained by imposing the same *a priori* assumption as in SW.[43] While most of the estimates are unchanged, relaxing the restriction implies that the Taylor rule coefficient on inflation is estimated to be associated with a weak response of the monetary authority, therefore rejecting the assumption imposed in SW. As shown in section 6.2 and 6.3, this finding has crucial implications for the propagation of the shocks and to explain U.S. business cycle fluctuations.

[43]Similar differences arise when using the second subsample (1970:1-1979:2) to study how the imposition of the assumption in SW would impact the results.

The comparison of the posterior estimates also highlights a higher degree of both the wage and inflation indexation, as well as more persistence of the price mark-up shock. This finding is in line with the intuition provided in section 3.1. A characteristic feature of indeterminate models lies in the richer endogenous persistence. Hence, when imposing the assumption of an active monetary policy, the model incurs a difficulty in matching the observed persistence in the data and mistakenly suggests a higher persistence than in the representation favored by the data.

Table 10: Posterior distribution of structural parameters (1955–1969)

Period: 1955:4-1969:4		Indeterminacy		Determinacy	
Coefficient	Description	Mean	[5 , 95]	Mean	[5 , 95]
ϕ	Adjustment cost	4.75	[2.90,6.63]	5.07	[3.25,6.95]
σ_c	IES	1.11	[0.86,1.37]	1.13	[0.78,1.46]
h	Habit Persistence	0.62	[0.49,0.74]	0.58	[0.43,0.74]
σ_l	Labor supply elasticity	1.98	[0.89,3.07]	1.34	[0.28,2.20]
ξ_w	Wage stickiness	0.74	[0.63,0.85]	0.78	[0.69,0.86]
ξ_p	Price Stickiness	0.60	[0.50,0.67]	0.62	[0.50,0.74]
ι_w	Wage Indexation	0.33	[0.13,0.53]	0.44	[0.21,0.67]
ι_p	Price Indexation	0.30	[0.12,0.47]	0.45	[0.17,0.72]
ψ	Capacity utiliz. elasticity	0.52	[0.31,0.74]	0.42	[0.20,0.63]
Φ	Share of fixed costs	1.59	[1.46,1.71]	1.65	[1.49,1.82]
α	Share of capital	0.24	[0.20,0.29]	0.25	[0.19,0.29]
$\bar{\pi}$	S.S. inflation rate (quart.)	0.60	[0.44,0.76]	0.63	[0.49,0.77]
$100(\beta^{-1}-1)$	Discount factor	0.17	[0.06,0.26]	0.21	[0.07,0.34]
$\bar{l}$	S.S. hours worked	1.33	[0.17,2.54]	1.83	[0.60,3.01]
$\bar{\gamma}$	Trend growth rate (quart.)	0.57	[0.38,0.76]	0.47	[0.33,0.59]
r_π	Taylor rule inflation	0.64	[0.35,0.99]	1.35	[0.98,1.69]
r_y	Taylor rule output gap	0.13	[0.05,0.20]	0.14	[0.06,0.22]
$r_{\Delta y}$	Taylor rule Δ(output gap)	0.11	[0.07,0.15]	0.12	[0.08,0.17]
ρ	Taylor rule smoothing	0.87	[0.81,0.94]	0.88	[0.83,0.93]

The table compares the posterior estimates of structural parameters for the pre-Volcker period under indeterminacy and determinacy.

To evaluate in more detail the fit of the SW model under the determinate and indeterminate specifications, I also conduct predictive checks to examine whether the model captures relevant features of the data. The role of predictive checks in Bayesian analysis has been highlighted in Lancaster (2004), Geweke (2005), Geweke (2007), Del Negro and Schorfheide (2011), and Herbst and Schorfheide (2012), among others. In particular, I run posterior predictive checks in which the distribution of the model parameters is conditioned on the observed data. I follow four steps. First, I make 500 parameter draws from the posterior predictive distribution. Second, I simulate a trajectory for each observable in the SW model

Table 11: Posterior distribution of exogenous processes (1955–1969)

Period: 1955:4-1969:4		Indeterminacy		Determinacy	
Coefficient	Description	Mean	[5 , 95]	Mean	[5 , 95]
σ_a	Technology shock	0.52	[0.44,0.61]	0.52	[0.43,0.61]
σ_b	Risk premium shock	0.19	[0.11,0.27]	0.12	[0.04,0.26]
σ_g	Government sp. shock	0.50	[0.42,0.58]	0.50	[0.42,0.58]
σ_I	Investment-specific shock	0.61	[0.42,0.79]	0.57	[0.39,0.75]
σ_r	Monetary policy shock	0.11	[0.09,0.12]	0.11	[0.09,0.14]
σ_p	Price mark-up shock	0.24	[0.20,0.28]	0.24	[0.18,0.30]
σ_w	Wage mark-up shock	0.24	[0.18,0.28]	0.26	[0.19,0.33]
σ_ν	Sunspot shock	0.14	[0.07,0.21]	-	-
ρ_a	Persistence technology	0.95	[0.92,0.99]	0.92	[0.86,0.99]
ρ_b	Persistence risk premium	0.58	[0.34,0.83]	0.79	[0.31,0.98]
ρ_g	Persistence government sp.	0.86	[0.77,0.94]	0.84	[0.73,0.95]
ρ_I	Persistence investment-specific	0.50	[0.30,0.70]	0.54	[0.33,0.74]
ρ_r	Persistence monetary policy	0.50	[0.31,0.69]	0.44	[0.27,0.60]
ρ_p	Persistence price mark-up	0.24	[0.04,0.41]	0.47	[0.12,0.93]
ρ_w	Persistence wage mark-up	0.62	[0.34,0.90]	0.47	[0.18,0.76]
μ_p	MA price mark-up	0.64	[0.43,0.85]	0.71	[0.35,0.99]
μ_w	MA wage mark-up	0.50	[0.25,0.74]	0.56	[0.26,0.91]
ρ_{ga}	$Cov(\sigma_a, \sigma_g)$	0.57	[0.38,0.76]	0.57	[0.38,0.78]
$\rho_{\nu p}$	$Corr(\sigma_\nu, \sigma_p)$	0.92	[0.82,0.99]	-	-

The table compares the posterior estimates of the parameters associated with the exogenous processes for the pre-Volcker period under indeterminacy and determinacy.

of the same length as the sample period over which the model is estimated, while I drop the first 1,000 observations. Third, I convert the simulated trajectories into sample means and standard deviations for which I then have an approximated predictive distribution. Finally, I compute the same moments from the actual data and evaluate if they are located in the tails of the predictive distributions. The rationale for such exercise is that if the moments based on the actual data lie in the tails of the distribution, then the model shows difficulties in explaining the observed features of the data.

In table 12, I consider the period from 1955:1 to 1969:4.[44] The table compares the means and standard deviations based on the data with the corresponding moments simulated from the predictive distributions under determinacy and indeterminacy. For each model specification, I report the mean and the 90 percent probability intervals obtained from the predictive posterior distributions for both the mean and standard deviation of each observable of the SW model. The table confirms the finding in the previous section for which the conduct of

[44]The results for the period from 1970:1 to 1979:2 are generally in line with the findings provided in this appendix, while the differences between model specifications are more moderate due to the shorter sample size.

Table 12: Posterior predictive checks (1955–1969)

1955:4-1969:4		Data	Determinacy		Indeterminacy	
			Mean	[5 , 95]	Mean	[5 , 95]
Mean	$dlGDP_t$	0.57	0.46	[0.25,0.68]	0.51	[0.32,0.69]
	dlP_t	0.61	0.64	[-0.13,1.30]	0.48	[-0.13,1.17]
	FFR_t	0.93	1.41	[-0.28,2.92]	1.09	[0.53,1.74]
	$dlCONS_t$	0.55	0.47	[0.33,0.63]	0.51	[0.39,0.63]
	$dlINV_t$	0.53	0.46	[-0.10,0.99]	0.51	[0.00,0.99]
	$lHours_t$	2.29	2.60	[0.24,4.89]	1.31	[0.14,2.44]
	$dlWAG_t$	0.57	0.47	[0.40,0.54]	0.50	[0.43,0.58]
Standard dev.	$dlGDP_t$	1.02	1.51	[1.00,2.71]	1.12	[0.87,1.38]
	dlP_t	0.38	0.58	[0.33,1.18]	0.40	[0.25,0.63]
	FFR_t	0.42	0.90	[0.32,2.36]	0.34	[0.20,0.52]
	$dlCONS_t$	0.76	1.14	[0.61,2.50]	0.69	[0.51,0.93]
	$dlINV_t$	2.24	2.67	[1.74,4.18]	2.74	[1.91,3.73]
	$lHours_t$	1.72	2.45	[1.16,5.32]	1.60	[1.01,2.30]
	$dlWAG_t$	0.48	0.50	[0.40,0.62]	0.53	[0.42,0.65]

The table compares the mean and standard deviation based on the data with the corresponding moments simulated from the predictive distribution under determinacy and indeterminacy.

monetary policy was more likely to be passive over this sample period. While both model specifications generally capture the mean of the observables, the indeterminate specification substantially outperforms the determinate model in explaining the standard deviations. Under the indeterminate specification, the mean of the predictive distribution for the observables' standard deviation captures the corresponding moment obtained from the data. On the contrary, for almost all the observables, the standard deviations from the data are located on the tails of the predictive posterior distributions for the determinate specification.

Table 13 reports similar statistics for the sample period from 1984:1 to 2007:3. Over this period, the estimation of the SW model provided evidence of an active monetary policy consistent with a determinate specification. The predictive checks presented in the table confirm this finding. The mean of the observed data are generally captured by both the determinate and indeterminate specification. However, the determinate model substantially outperforms the indeterminate version in explaining the standard deviation of the observed data. The indeterminate specification predicts a significantly higher volatility in the inflation rate, as well as the growth rate of output, investment, and wages.

Table 13: Posterior predictive checks (1984–2007)

1984:1-2007:3		Data	Determinacy		Indeterminacy	
			Mean	[5 , 95]	Mean	[5 , 95]
Mean	$dlGDP_t$	0.50	0.45	[0.40,0.51]	0.43	[0.33,0.54]
	dlP_t	0.62	0.80	[0.64,0.96]	0.68	[-0.83,2.19]
	FFR_t	1.33	1.70	[1.48,1.91]	1.58	[0.17,3.04]
	$dlCONS_t$	0.57	0.46	[0.41,0.50]	0.43	[0.34,0.53]
	$dlINV_t$	0.48	0.46	[0.31,0.59]	0.43	[0.18,0.68]
	$lHours_t$	1.20	1.73	[0.89,2.51]	1.02	[-1.18,3.04]
	$dlWAG_t$	0.40	0.45	[0.39,0.52]	0.43	[0.28,0.60]
Standard dev.	$dlGDP_t$	0.54	0.63	[0.53,0.73]	0.74	[0.61,0.87]
	dlP_t	0.23	0.29	[0.22,0.37]	0.57	[0.29,1.02]
	FFR_t	0.60	0.29	[0.22,0.38]	0.60	[0.32,1.03]
	$dlCONS_t$	0.50	0.45	[0.36,0.54]	0.55	[0.41,0.69]
	$dlINV_t$	1.47	1.40	[1.07,1.82]	1.89	[1.44,2.44]
	$lHours_t$	2.00	1.11	[0.77,1.55]	2.18	[1.27,3.23]
	$dlWAG_t$	0.72	0.72	[0.58,0.89]	1.31	[0.98,1.68]

The table compares the mean and standard deviation based on the data with the corresponding moments simulated from the predictive distribution under determinacy and indeterminacy.

C Appendix C

Del Negro and Schorfheide (2004) modify the model in 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 is represented by equations (6)∼(9) and consists of a dynamic IS curve

$$x_t = E_t\left(x_{t+1}\right) - \tau\left(R_t - E_t\left(\pi_{t+1}\right)\right) + (1-\rho_g)g_t + \rho_z \tau z_t, \tag{6}$$

a NK Phillips curve

$$\pi_t = \frac{\gamma}{r^*} E_t\left(\pi_{t+1}\right) + \kappa\left(x_t - g_t\right), \tag{7}$$

and a Taylor rule,

$$R_t = \rho_R R_{t-1} + (1-\rho_R)\left[\psi_1 \pi_t + \psi_2\left(x_t - z_t\right)\right] + \varepsilon_{R,t}, \tag{8}$$

where $r^* = \gamma/\beta$ is the steady-state real interest rate and the demand shock, g_t follows a univariate AR(1) processes $g_t = \rho_g g_{t-1} + \varepsilon_{g,t}$. The standard deviations of the fundamental shocks $\varepsilon_{g,t}$, $\varepsilon_{z,t}$ and $\varepsilon_{R,t}$ are denoted by σ_g, σ_z and σ_R. The rational expectation forecast errors are defined as

$$\eta_{1,t} = x_t - E_{t-1}\left[x_t\right], \qquad \eta_{2,t} = \pi_t - E_{t-1}\left[\pi_t\right], \tag{9}$$

and we define the vector of endogenous variables as $X_t \equiv \left(x_t, \pi_t, R_t, E_t\left(x_{t+1}\right), E_t\left(\pi_{t+1}\right), g_t, z_t\right)'$. To estimate the model, I use Bayesian techniques and consider three of the seven quarterly U.S. macroeconomic time series used in SW. Relative to the measurement equation (4) in SW, I estimate the model in (6)∼(9) using the following measurement equation,

$$\begin{bmatrix} dlGDP_t \\ dlP_t \\ FEDFUNDS_t \end{bmatrix} = \begin{bmatrix} ln\gamma \\ ln\pi^* \\ lnr^* + ln\pi^* \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix} X_t, \tag{10}$$

where *dl* denotes the percentage change measured as log difference. The series considered are: the growth rate in real GDP, the inflation rate measured by the GDP deflator, and the federal funds rate. The parameter $ln\gamma$ is the quarterly trend growth rate of real GDP, and $ln\pi^*$ and lnr^* are quarterly steady-state inflation and real interest rates expressed in percentages. I define the vectors of fundamental shocks and non-fundamental errors as,

$$\varepsilon_t = \left(\varepsilon_{R,t}, \varepsilon_{g,t}, \varepsilon_{z,t}\right)', \qquad \eta_t = \left(\eta_{1,t}, \eta_{2,t}\right)'$$

and the vector of parameters as

$$\theta = \left(ln\gamma, ln\pi^*, lnr^*, \psi_1, \psi_2, \rho_R, \kappa, \tau, \rho_g, \rho_z, \sigma_g, \sigma_z, \sigma_R\right)'.$$

Finally, while Del Negro and Schorfheide (2004) restrict the prior distributions to impose the determinate solution, table 14 reports the same prior distributions for the model parameters that are in common with Lubik and Schorfheide (2004) who tested for indeterminacy in U.S.

monetary policy.[45] However, the prior distributions for the model parameters that define the balanced growth path of the model, $\{ln\gamma, ln\pi^*, lnr^*\}$, are the same as in Del Negro and Schorfheide (2004).

Table 14: Prior distributions for Del Negro and Schorfheide (2004)

Name	*Range*	*Density*	*Mean*	*Std. Dev.*	*90% interval*
ψ_1	R^+	*Gamma*	*1.1*	*0.50*	*[0.43,2.03]*
ψ_2	R^+	*Gamma*	*0.25*	*0.15*	*[0.06,0.54]*
ρ_R	$[0,1)$	*Beta*	*0.50*	*0.20*	*[0.17,0.83]*
$ln\gamma$	R^+	*Normal*	*0.5*	*0.25*	*[0.09,0.91]*
$ln\pi^*$	R^+	*Normal*	*1.00*	*0.50*	*[0.17,1.82]*
lnr^*	R^+	*Gamma*	*0.50*	*0.25*	*[0.17,0.97]*
κ	R^+	*Gamma*	*0.50*	*0.20*	*[0.22,0.87]*
τ^{-1}	R^+	*Gamma*	*2.00*	*0.50*	*[1.25,2.88]*
ρ_g	$[0,1)$	*Beta*	*0.70*	*0.10*	*[0.52,0.85]*
ρ_z	$[0,1)$	*Beta*	*0.70*	*0.10*	*[0.52,0.85]*
σ_R	R^+	*Inverse Gamma*	*0.31*	*0.16*	*[0.14,0.60]*
σ_g	R^+	*Inverse Gamma*	*0.38*	*0.20*	*[0.17,0.74]*
σ_z	R^+	*Inverse Gamma*	*1.00*	*0.52*	*[0.47,1.95]*
σ_ν	R^+	*Uniform*	*1.00*	*0.58*	*[0.10,1.90]*
$\rho_{R\nu}$	*[-1,1]*	*Uniform*	*0.00*	*0.58*	*[-0.90,0.90]*
$\rho_{g\nu}$	*[-1,1]*	*Uniform*	*0.00*	*0.58*	*[-0.90,0.90]*
$\rho_{z\nu}$	*[-1,1]*	*Uniform*	*0.00*	*0.58*	*[-0.90,0.90]*

The table reports the distributions used as priors for the model parameters.

Finally, table 15 presents the posterior distributions for the Del Negro and Schorfheide's (2004) model.

[45] The only difference with respect to Lubik and Schorfheide (2004) is that we use a flatter prior for the parameter κ. While the authors set a gamma distribution with mean 0.5 and standard deviation 0.2, I use a prior that sets the standard deviation to 0.4, leaving the mean unchanged. Choosing a flatter prior avoids facing an issue in the convergence of the parameter.

Table 15: Posterior distributions for Del Negro and Schorfheide (2004)

Period: 1984:1-2007:3	Determinacy		Indeterminacy	
Coefficient	Mean	[5 , 95]	Mean	[5 , 95]
ψ_1	1.58	[1.01,2.12]	0.55	[0.12,1.00]
ψ_2	0.44	[0.17,0.70]	0.64	[0.37,0.93]
ρ_R	0.87	[0.84,0.91]	0.63	[0.47,0.79]
$ln\gamma$	0.55	[0.39,0.74]	0.52	[0.35,0.68]
$ln\pi^*$	1.01	[0.53,1.48]	0.87	[0.20,1.54]
lnr^*	0.58	[0.43,0.72]	0.60	[0.33,0.87]
κ	0.10	[0.04,0.16]	0.17	[0.03,0.28]
τ^{-1}	3.96	[3.02,4.90]	3.20	[2.88,4.09]
ρ_g	0.97	[0.95,0.98]	0.84	[0.77,0.91]
ρ_z	0.67	[0.53,0.82]	0.59	[0.45,0.73]
σ_R	0.16	[0.14,0.18]	0.10	[0.08,0.12]
σ_g	0.37	[0.20,0.53]	0.58	[0.40,0.77]
σ_z	0.41	[0.32,0.49]	0.39	[0.31,0.47]
σ_ν	-	-	0.23	[0.19,0.26]
$\rho_{R\nu}$	-	-	-0.433	[-0.68,-0.18]
$\rho_{g\nu}$	-	-	-0.29	[-0.60,0.01]
$\rho_{z\nu}$	-	-	-0.44	[-0.72,-0.18]

The table compares the posterior estimates of structural parameters of the Del Negro and Schorfheide (2004) model for the period between 1984:1 and 2007:3 under determinacy and indeterminacy.

D Appendix D

Figure 9 plots the historical decomposition of the output gap for two alternative specifications. The left panel decomposes the output gap for the case of a failure to stabilize the economy, as shown in section 6.1. The right panel reports the decomposition that results from the assumption of equilibrium uniqueness as conducted in SW. The two plots indicate minor differences and attribute the recessions of the late 1950s to demand shocks and the contractions of the early 1970s to a combination of mark-up and demand shocks. Also, non-fundamental disturbances had almost no effect on the observed fluctuations in the output gap. The similarity of the decomposition should not come as a surprise. Indeed, the analysis conducted in section 6.2 shows that the transmission of the structural shocks on the output gap is roughly invariant to the of monetary policy stance, given that the differences in the magnitudes are due to the larger size of the estimated standard deviations of the shocks for the pre-Volcker period.

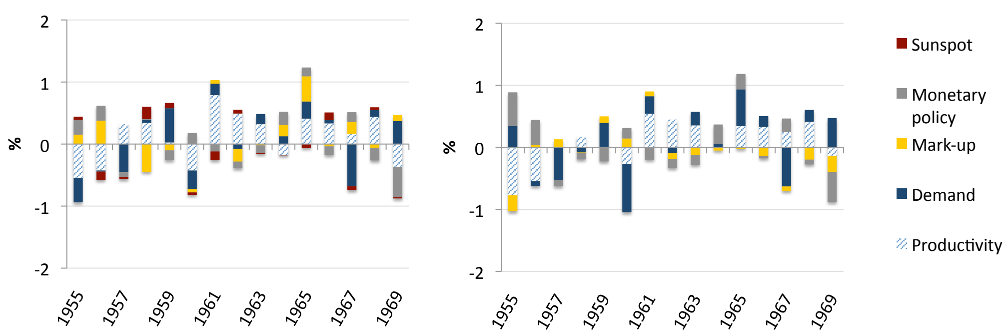

Figure 9: Historical decomposition of the output gap (1955-1969)

Historical decomposition of the output gap under indeterminacy (left) and determinacy (right).

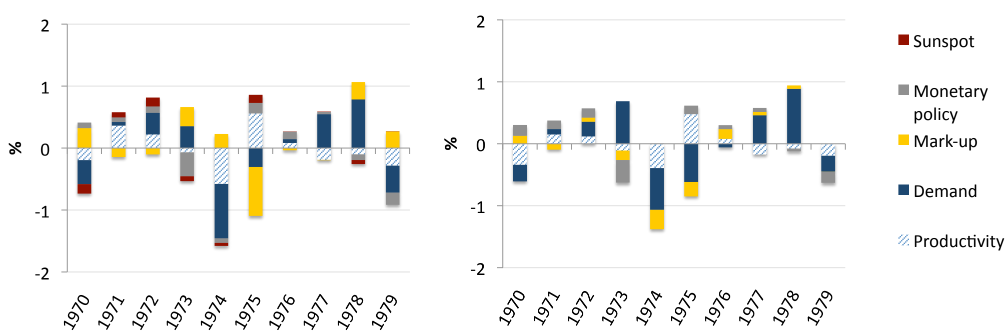

Figure 10: Historical decomposition of the output gap (1970-1979)

Historical decomposition of the output gap under indeterminacy (left) and determinacy (right).

E Appendix E

I focus on the post-Volcker period and figure 11 reports the historical decomposition for the output gap (left panel) and the inflation rate (right panel). The decomposition is conducted under an active monetary policy, as found in section 6.1 for this sample period. The results are in line with those in SW. The recessionary episodes in the early 1990s and the burst of dot com bubble are mostly explained by negative demand shocks, and mark-up shocks kept the inflation rate subdued relative to its target level during the 1990s.

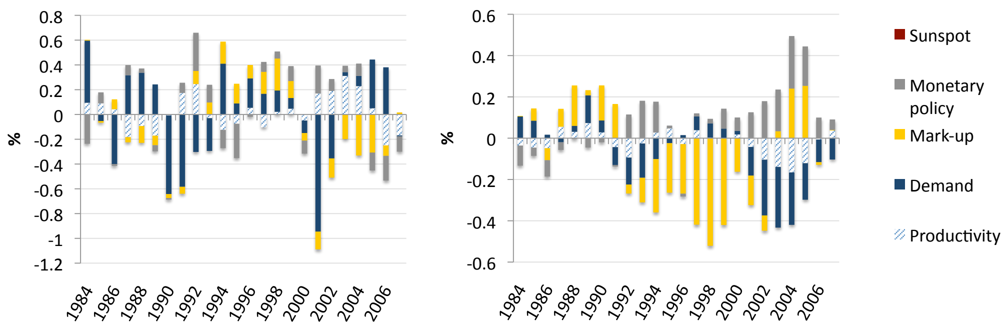

Figure 11: Historical decomposition of output gap and inflation rate (1984–2007)

F Appendix F

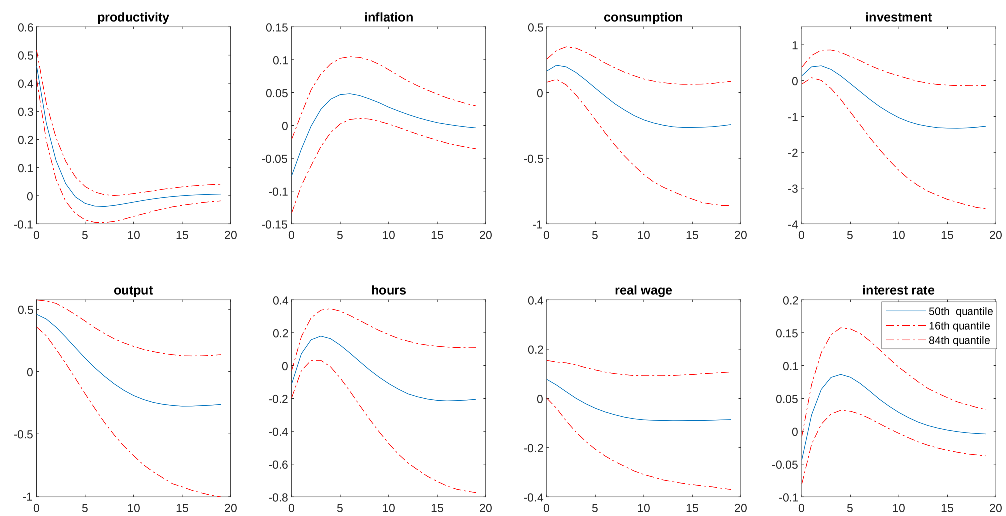

Figure 12: Productivity shock from BVAR (1970–1979)

The figure reports the 50th (solid line) as well as the 16th and 84th percentiles (dashed lines) of the distribution of the impulse response functions of the BVAR to a one standard deviation productivity shock.

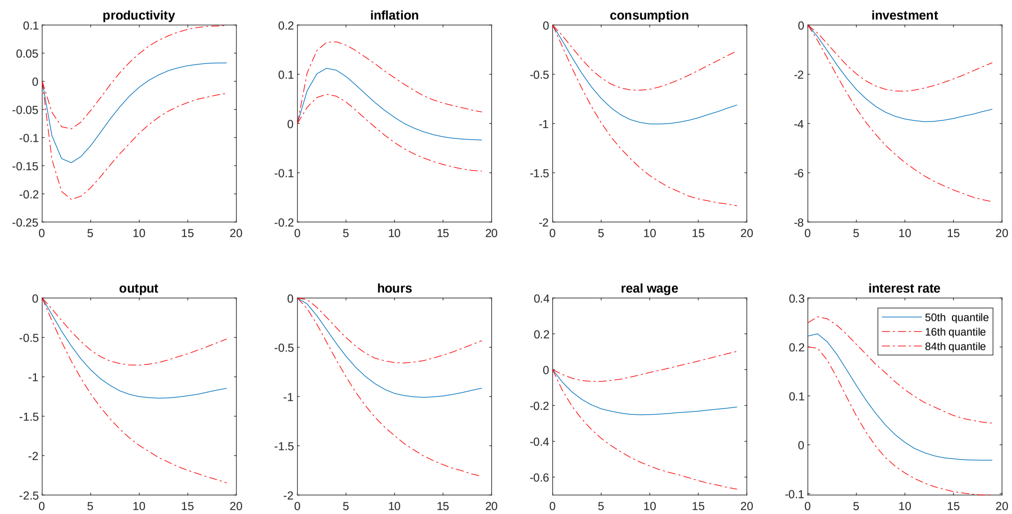

Figure 13: Monetary policy shock from BVAR (1970–1979)

The figure reports the 50th (solid line) as well as the 16th and 84th percentiles (dashed lines) of the distribution of the impulse response functions of the BVAR to a one standard deviation monetary policy shock.

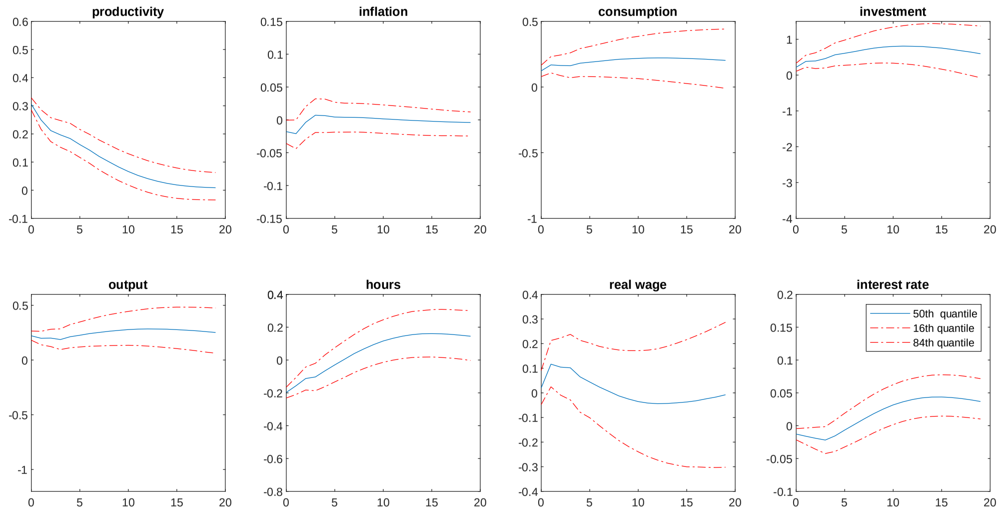

Figure 14: Productivity shock from BVAR (1984–2007)

The figure reports the 50th (solid line) as well as the 16th and 84th percentiles (dashed lines) of the distribution of the impulse response functions of the BVAR to a one standard deviation productivity shock.

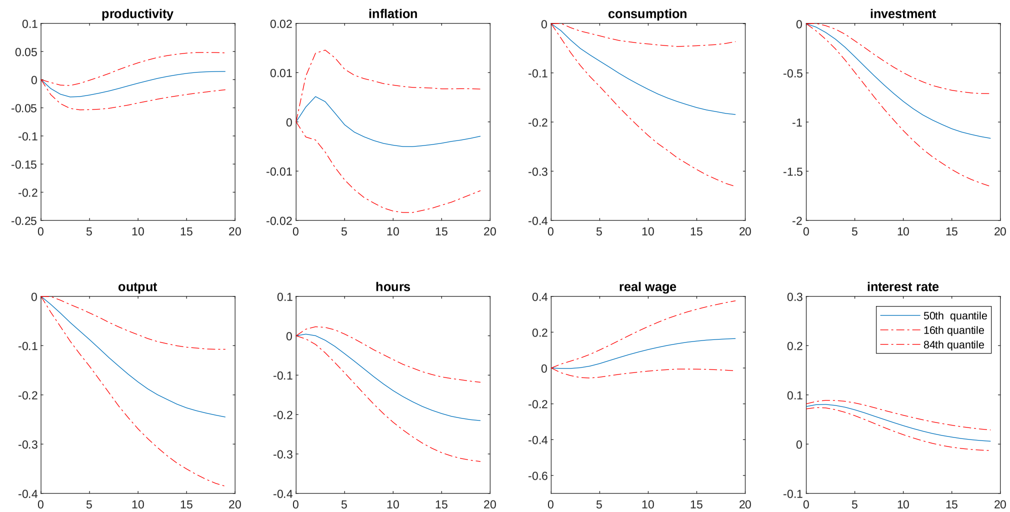

Figure 15: Monetary policy shock from BVAR (1984–2007)

The figure reports the 50th (solid line) as well as the 16th and 84th percentiles (dashed lines) of the distribution of the impulse response functions of the BVAR to a one standard deviation monetary policy shock.