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Abstract

We estimate a multi-shock DSGE model with a Bayesian method allowing for determinacy or indeterminacy (Bianchi and Nicoló, 2020). Contrary to conventional wisdom, determinacy is preferred to indeterminacy before and after 1980. The post-1984 contribution of shocks to the marginal efficiency of investment to the cyclical variance of output growth fell dramatically, from 50% to 20%. Greater nominal wage flexibility drove the large decline in output and employment fluctuations after 1984. Inflation variability declined from a hawkish policy stance against inflation and changes in preference parameters. Lower trend inflation and smaller shocks did not play a key role.

JEL classification: E31, E32, E37.

Keywords: Conventional Monetary Policy; Determinacy; Bayesian Estimation; Sources of Business Cycle; Changes in Aggregate Volatility.

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1 Introduction

From the mid-1960s through the early 1980s, the US economy experienced high and volatile inflation along with severe recessions. By contrast, between 1984 and the Great Recession, inflation remained steadily low, while output growth was relatively stable. However, from a theoretical standpoint, the exact source of changes in macroeconomic volatility is less agreed upon.

One explanation is that the US economy was in a state of indeterminacy prior to Paul Volcker's nomination as Chair of the Federal Reserve because monetary policy was passive, failing to respond sufficiently strongly to inflation. This presumably led to self-fulfilling inflation expectations and endogenous fluctuations. It is only after Volcker's nomination as Chair of the Fed that the economy returned to determinacy during the period known as the Great Moderation. In support of this, Clarida et al. (2000) report estimates of parameters governing the policy responses to inflation consistently below one during the pre-Volcker period and generally above two after 1980. Lubik and Schorfheide (2004) offer corroborating evidence using a Bayesian estimation method allowing for indeterminacy in a standard New Keynesian price-setting model with zero trend inflation.

Another view put forth by Coibion and Gorodnichenko (2011) is that passive monetary policy is not the only explanation. They show that with positive trend inflation determinacy requires policy responses to inflation which are potentially much higher than one. They conclude high trend inflation was also a key factor leading to indeterminacy.[1] It is only when trend inflation dropped to a lower level and the Fed adopted a more aggressive stance against inflation that the economy returned to determinacy.

By contrast, another line of reasoning is that neither passive monetary policy nor lower trend inflation was a key factor explaining the Great Moderation. Instead, the US economy has benefited from several shocks that were much smaller after 1984, the so-called "good luck" hypothesis put forth by Stock and Watson (2003), Sims and Zha (2006), and Smets and Wouters (2007).

[1] See also Kiley (2007), Ascari and Ropele (2009), and Wolman (2011).

Using a Bayesian method recently proposed by Bianchi and Nicoló (2020) allowing estimation under indeterminacy or determinacy, we revisit the business cycle episodes embracing the Great Inflation and Great Moderation and test these different theories. Contrary to conventional wisdom, we find that none of these theories explain the macroeconomic instability experienced before 1980 and the stability witnessed between 1984 and the Great Recession.

Following recent developments on positive trend inflation and the impact of alternative Taylor rule specifications on the prospect of indeterminacy, we estimate a DSGE model in which the central bank targets deviations of output growth from trend output growth for measure of economic activity not the output gap or both the output gap and output growth as in most previous studies on indeterminacy.

Working from a sticky-price model with positive trend inflation, Coibion and Gorodnichenko (2011) have shown that a policy rule targeting output growth improves stabilization relative to one aiming at output gap. Using a medium-scale DSGE model, Khan et al. (2020) have shown that targeting the output gap, or both the output gap and output growth, requires very strong policy response to inflation for determinacy, while a rule aiming at output growth achieves determinacy generally complying with the Taylor Principle. Using a Bayesian estimation method allowing for positive trend inflation and indeterminacy, Brault and Phaneuf (2021) offer evidence from a sticky-price model that a rule responding to output gap delivers an indeterminacy outcome before and after 1980, while one reacting to output growth generates determinacy in both periods.

We use for our purpose a model that includes standard New Keynesian (NK) features like nominal wage and price rigidities, real adjustment frictions and economic growth (Erceg et al., 2000; Christiano et al., 2005; Smets and Wouters, 2007). We add to these standard features, intermediate goods (Basu, 1995; Huang et al., 2004) and an extended working capital channel (Christiano et al., 2011; Phaneuf et al., 2018). The first ingredient realistically accounts for the fact that firms can use the outputs of others as inputs in production. The second ingredient allows firms to use working capital extensively, that is, to finance a fraction of all their input costs and not only their labour cost. Working capital introduces a cost-channel for monetary policy which usually raises the prospect of indeterminacy under positive trend inflation. It puts the stabilizing properties of a rule targeting output growth to a more demanding test.

Based on estimated models, we find that determinacy is preferred to indeterminacy for the pre-1980 sample. Interestingly, the estimated models correctly predict a sharp decline in trend inflation after 1984, from 6.6% to 3.2%.[2] Moreover, we find that the policy response to inflation prior to 1980 exceeded Taylor's prescription of 1.5, a finding which is consistent with Orphanides (2002), who claimed that monetary policymakers satisfied the Taylor principle even before the entry of Paul Volcker as Chair of the Federal Reserve. Our empirical findings thus do not support the view that macroeconomic instability experienced during the pre-Volcker years resulted from indeterminacy due to monetary policy not satisfying the Taylor principle or trend inflation being high.[3]

Unlike previous studies, we look at systematic monetary policy and policy shocks during both episodes. In the spirit of the early works on rational expectations models with nominal rigiditries by Fischer (1977), Taylor (1980) and Mishkin (1982), we distinguish between systematic policy which is summarized by the reactive part of the Taylor rule agents forming rational expectations correctly anticipate, and policy shocks agents cannot anticipate correctly.

Our estimated policy rules suggest the degree of interest rate smoothing, and the interest rate responses to inflation and output growth became stronger after 1984. While systematic monetary policy was moderately active prior to 1980, we find using Kalman smoothed shocks computed from our estimated models that while policy shocks were negative on average during both episodes, they were more frequent and much larger before 1980. This was particularly the case between OPEC I (1973:Q3) and the end of the 1970s. Our evidence

[2] Smets and Wouters (2007), using an estimation method imposing determinacy before and after the 1980s, note that the steady-state inflation rate is only marginally lower in the second subperiod versus the first period.

[3] Albonico et al. (2020) also use the estimation method suggested by Bianchi and Nicoló (2020) for a model where monetary policy targets both the level of the output gap and output growth and find the pre-1980s were characterized by indeterminacy. But as Khan et al. (2020) show, when a rule targets both the output gap and output growth, the effect of the gap on the prospect of indeterminacy is disproportionate relative to the effect of output growth.

suggests that in the wake of OPEC I, the Fed resorted to expansionary policy shocks during several quarters and this quite strongly, presumably with the objective of stabilizing unemployment that rose from 4.8% in 1973:Q4 to 9% in 1975:Q2. This might also explain why the policy response to inflation is found to be moderately greater than one instead of lower than one before 1980.

We use our estimated models to reassess the sources of postwar business cycles. We find evidence of a sharp decline in the contribution of MEI shocks to the cyclical forecast variance decomposition of output growth from the Great Inflation to the Great Moderation. Whereas these shocks contributed 50% to the cyclical variance of output growth prior to 1980, they explained only 20% during the Great Moderation. The small contribution of MEI shocks to the cyclical variance of output growth during the Great Moderation echoes the empirical findings of Christiano et al. (2014). Using a model emphasizing the role of risk shocks estimated with data spanning from 1985:Q1 to 2010:Q2, they found that MEI shocks explain only 13% of the cyclical variance of output growth.[4]

Other main findings pertain to the factors driving the Great Moderation. We offer evidence of a significant rise in nominal wage flexibility after 1984, but no sizable variation in the degree of price stickiness. Based on several counterfactual experiments, we show that the greater nominal wage flexibility was the key factor lowering the volatility of output growth and change in hours during the Great Moderation. We argue that higher nominal wage flexibility likely resulted from large-scale deunionization in the US private sector after 1980.

However, greater nominal wage flexibility does not account for lower inflation variability. We find that the key factor behind the lower volatility of inflation is a more hawkish systematic monetary policy and much smaller policy shocks after 1984. We also find that changes in some preference parameters also contributed to reducing inflation variability.

Quite importantly, despite our estimated models correctly predict trend inflation was much lower after 1984, we find no evidence that lower trend inflation played a significant role driving the Great Moderation. However, this by no means implies that trend inflation is

[4] Note that their sample does not begin prior to 1985:Q1 due to data limitations, so we lack evidence about what their model would imply for a period like the Great Inflation.

unimportant, as it can still have major long-run and welfare implications as shown by Ascari (2004), Kiley (2007), Ascari et al. (2018), and Phaneuf and Victor (2019, 2021), among others.

Finally, while the Great Moderation had witnessed smaller shocks, we find no evidence of the 'good-luck hypothesis' playing a significant role generating greater macroeconomic stability during that period.

The rest of the paper is organized as follows. Section 2 describes our medium-scale DSGE model. Section 3 describes our estimation strategy and data. Section 4 analyzes our estimation results, including our estimated model under determinacy and indeterminacy in the Great Inflation period. Section 5 studies the sources of macroeconomic fluctuations. Section 6 analyzes the factors responsible for the sharp decline in macroeconomic volatility after 1983. Section 7 contains concluding remarks.

2 The Model

As in Christiano et al. (2005) and Smets and Wouters (2007), our DSGE model embeds Calvo (1983) wage and price contracts, consumer habit formation, investment adjustment costs, and variable capital utilization. To this relatively standard medium-scale New Keynesian model, we add non-zero steady state inflation, real per capita output growth, intermediate goods, and working capital. We close the model with a Taylor rule for monetary policy.

2.1 Gross Output

Gross output, X_t, is produced by a perfectly competitive firm using a continuum of intermediate goods, X_{jt}, $j \in (0,1)$ and the following CES production technology:

$$X_t = \left(\int_0^1 X_{jt}^{\frac{1}{1+\lambda_{p,t}}} dj \right)^{1+\lambda_{p,t}}, \tag{1}$$

where $\lambda_{p,t}$ is the desired price markup over marginal cost which follows an ARMA (1,1) process:

$$\lambda_{p,t} = \left(1-\rho_p\right)\lambda_p + \rho_p \lambda_{p,t-1} + \varepsilon_{p,t} - \theta_p \varepsilon_{p,t-1}, \tag{2}$$

λ_p denoting the steady-state desired markup and $\varepsilon_{p,t}$ being an independent and identically distributed (i.i.d.) price-markup shock following a normal distribution with mean zero and variance, σ_p^2, denoted as $N(0, \sigma_p^2)$.

Profit maximization and a zero-profit condition for gross output leads to the following downward sloping demand curve for the intermediate good j

$$X_{jt} = \left(\frac{P_{jt}}{P_t}\right)^{-\frac{\left(1+\lambda_{p,t}\right)}{\lambda_{p,t}}} X_t, \tag{3}$$

where P_{jt} is the price of good j and P_t is the aggregate price index:

$$P_t = \left(\int_0^1 P_{jt}^{-\frac{1}{\lambda_{p,t}}} dj\right)^{-\lambda_{p,t}}. \tag{4}$$

2.2 Intermediate Goods Producers and Price Setting

A monopolist produces intermediate good j according to the following production function:

$$X_{jt} = \max\left\{ A_t \Gamma_{jt}^{\phi} \left(\widehat{K}_{jt}^{\alpha} L_{jt}^{1-\alpha}\right)^{1-\phi} - \Omega_t F, 0\right\}, \tag{5}$$

where A_t denotes an exogenous non-stationary level of neutral technology. Its growth rate, $z_t \equiv \ln\left(\frac{A_t}{A_{t-1}}\right)$, follows a stationary AR(1) process,

$$z_t = (1-\rho_z)\, g_z + \rho_z z_{t-1} + \varepsilon_{z,t}, \tag{6}$$

where g_z is the steady-state growth rate of neutral technology, and $\varepsilon_{z,t}$ is an i.i.d. $N(0, \sigma_z^2)$ neutral technology shock. We consider an input-output production structure such that firms use the output of others as an input (Basu, 1995). Γ_{jt} denotes intermediate inputs, $\widehat{K}_{jt}$ represents capital services (i.e. the product of utilization, u_t, and physical capital, K_t), and L_{jt} the labour input used by the j^{th} producer. Ω_t represents a growth factor. F is a fixed cost, implying zero profits in the steady state and ensuring that the existence of balanced growth path.

The stochastic growth factor Ω_t is given by the following composite technological process:

$$\Omega_t = A_t^{\frac{1}{(1-\phi)(1-\alpha)}} V_t^{I\,\frac{\alpha}{1-\alpha}}, \tag{7}$$

where V_t^I denotes investment-specific technological progress (hereafter IST). A higher value of ϕ amplifies the effects of stochastic growth in neutral productivity on output and its components. For a given level of stochastic growth in neutral productivity, the economy will grow faster the larger ϕ is. IST progress is non-stationary and its growth rate, $v_t^I \equiv \ln\left(\frac{V_t^I}{V_{t-1}^I}\right)$, follows a stationary AR(1) process:

$$v_t^I = (1-\rho_v)\, g_v + \rho_v v_{t-1}^I + \eta_t^I,$$

where g_v is the steady-state growth rate of the IST process and η_t^I is an i.i.d. $N(0, \sigma^2_{\eta^I})$ IST shock.

The firm chooses its price, P_{jt}, as well as quantities of intermediates, capital services, and labour input. It is subject to Calvo (1983) pricing, where each period a firm faces a probability $(1-\xi_p)$ of reoptimizing its price. Regardless of whether a firm receives the opportunity to adjust its price, it will choose inputs to minimize total cost, subject to the constraint of producing enough to meet demand.

The cost-minimization problem of a typical firm is:

$$\min_{\Gamma_{jt}, \widehat{K}_{jt}, L_{jt}} (1-\psi+\psi R_t)(P_t\Gamma_{jt} + R_t^k \widehat{K}_{jt} + W_t L_{jt}),$$

subject to:

$$A_t \Gamma_{jt}^{\phi} \left(\widehat{K}_{jt}^{\alpha} L_{jt}^{1-\alpha}\right)^{1-\phi} - \Omega_t F \geq \left(\frac{P_{jt}}{P_t}\right)^{-\frac{\left(1+\lambda_{p,t}\right)}{\lambda_{p,t}}} X_t, \tag{8}$$

where R_t^k is the nominal rental price of capital services, W_t is the nominal wage index, the term involving the interest rate R_t reflects the presence of extended working capital channel, and ψ is the fraction of factor payments financed by working capital. Monetary policy can have direct cost-effect through this channel. This cost-channel formulation differs from that of Christiano et al. (1997, 2005) who state that firms use working capital to finance their intra-period wage bill. Working capital can be used extendedly to finance a fraction of all factor payments, and hence better captures frictions in financial markets in a parsimonious way.

Defining $\Psi_t \equiv (1-\psi+\psi R_t)$, and then solving the cost minimization problem yields the following real marginal cost:

$$mc_t = \overline{\phi} A_t^{(1-\alpha)(\phi-1)} \Psi_t \left[\left(r_t^k \right)^{\alpha} (w_t)^{(1-\alpha)} \right]^{1-\phi}, \tag{9}$$

and demand functions for intermediate input and primary factor inputs:

$$\Gamma_{jt} = \phi \frac{mc_t}{\Psi_t} \left(X_{jt} + \Omega_t F \right), \tag{10}$$

$$K_{jt} = \alpha (1-\phi) \frac{mc_t}{\Psi_t r_t^k} \left(X_{jt} + \Omega_t F \right), \tag{11}$$

$$L_{jt} = (1-\alpha)(1-\phi) \frac{mc_t}{\Psi_t w_t} \left(X_{jt} + \Omega_t F \right), \tag{12}$$

where $\overline{\phi} \equiv \phi^{-\phi} (1-\phi)^{\phi-1} \left(\alpha^{-\alpha} (1-\alpha)^{\alpha-1} \right)^{1-\phi}$, $mc_t = \frac{MC_t}{P_t}$, is real marginal cost common to all firms due to the assumption of common factor markets, r_t^k is the real rental price on capital services, and w_t is the real wage.

At time t, intermediate firms that can reoptimize their price choose a price P_t^*, while those who cannot either set $P_{jt} = P_{j,t-1}$ or index $P_{j,t-1}$ to lagged inflation, π_{t-1}, and steady-state inflation, π. The price-setting rule is therefore given by

$$P_{jt} = \begin{cases} P_{jt}^* & \text{with probability } 1-\xi_p \\ P_{j,t-1} \quad \text{or} \quad P_{j,t-1} \pi_{t-1}^{\iota_p} \pi^{1-\iota_p} & \text{with probability } \xi_p \end{cases}, \tag{13}$$

where ι_p and $1-\iota_p$ denote the degree of price indexation to past inflation and steady state inflation, respectively. When reoptimizing its price, a firm j chooses a price that maximizes the present discounted value of future profits, subject to (3) and to cost minimization:

$$\max_{P_{jt}} \quad E_t \sum_{s=0}^{\infty} \xi_p^s \beta^s \frac{\Lambda_{t+s}}{\Lambda_t} \left[P_{jt} X_{j,t+s} \Pi_{t,t+s}^p - MC_{t+s} X_{j,t+s} \right], \tag{14}$$

where β is the discount factor, Λ_t is the marginal utility of nominal income to the representative household that owns the firm, ξ_P^s is the probability that a price chosen in period t will still be in effect in period $t+s$, $\Pi_{t,t+s}^p = \Pi_{k=1}^s \pi_{t+k-1}^{\iota_p} \pi^{1-\iota_p}$ is the cumulative price indexation between t and $t+s-1$, and MC_{t+s} is the nominal marginal cost.

Solving the problem yields the following first-order-condition that determines the optimal price:

$$E_0 \sum_{s=0}^{\infty} \xi_p^s \beta^s \lambda_{t+s}^r X_{jt+s} \frac{1}{\lambda_{p,t+s}} \left(p_t^* \frac{\Pi_{t,t+s}^p}{\pi_{t+1,t+s}} - \left(1 + \lambda_{p,t+s} \right) mc_{t+s} \right) = 0, \tag{15}$$

where λ_t^r is the marginal utility of an additional unit of real income received by the household, $p_t^* = \frac{P_{jt}}{P_t}$ is the real optimal price and $\pi_{t+1,t+s} = \frac{P_{t+s}}{P_t}$ is the cumulative inflation rate between $t+1$ and $t+s$.

2.3 Households and Wage Setting

There is a continuum of households, indexed by $i \in [0,1]$, who are monopoly suppliers of labour. They face a downward-sloping demand curve for their particular type of labour given below in (23). In each period, there is a fixed probability, $(1-\xi_w)$, that households can reoptimize their nominal wage. As in Erceg et al. (2000), utility is separable in consumption and labour. State-contingent securities insure households against idiosyncratic wage risk arising from staggered wage-setting. Households are then identical along all dimensions other than labour supply and wages.

The problem of a typical household, omitting dependence on i except for these two dimensions, is:

$$\max_{C_t, L_{it}, K_{t+1}, B_{t+1}, I_t, Z_t} \quad E_0 \sum_{t=0}^{\infty} \beta^t b_t \left(\ln\left(C_t - hC_{t-1}\right) - \eta \frac{{L_{it}}^{1+\chi}}{1+\chi} \right), \tag{16}$$

subject to the following budget constraint,

$$P_t \left(C_t + I_t + \frac{a(u_t)K_t}{V_t^I} \right) + \frac{B_{t+1}}{R_t} \leq W_{it}L_{it} + R_t^k u_t K_t + B_t + \Pi_t + T_t, \tag{17}$$

and the physical capital accumulation process,

$$K_{t+1} = V_t^I \vartheta_t \left(1 - S\left(\frac{I_t}{I_{t-1}} \right) \right) I_t + (1-\delta)K_t. \tag{18}$$

b_t is an exogenous risk premium shock. C_t is real consumption and h is a parameter determining internal habit. L_{it} denotes hours and χ is the inverse Frisch labour supply elasticity. I_t is investment, and $a(u_t)$ is a resource cost of utilization, satisfying $a(1) = 0$, $a'(1) = 0$, and $a''(1) > 0$. This resource cost is measured in units of physical capital. W_{it} is the nominal wage paid to labour of type i, B_t is the stock of nominal bonds that the household enters the period with. Π_t denotes the distributed dividends from firms. T_t is a lump sum transfer from the government. $S\left(\frac{I_t}{I_{t-1}}\right)$ is an investment adjustment cost, satisfying $S\left(.\right) = 0$, $S'(.) = 0$, and $S''(.) > 0$, δ is the depreciation rate of physical capital, and ϑ_t is a stochastic shock to the marginal efficiency of investment (MEI), and is orthogonal to the IST shock, V_t^I.

We assume the following functional forms for the resource cost of capital utilization and the investment adjustment cost:

$$a(Z_t) = \gamma_1(Z_t - 1) + \frac{\gamma_2}{2}(Z_t - 1)^2,$$

$$S\left(\frac{I_t}{I_{t-1}}\right) = \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - g_v\right)^2.$$

The risk premium shock, b_t, follows the AR(1) process:

$$\ln b_t = \rho_b \ln b_{t-1} + \varepsilon_t^b, \tag{19}$$

where ε_t^b is an i.i.d. $N(0, \sigma_b^2)$ risk premium shock with variance σ_b^2. The MEI shock, ϑ_t, follows the AR(1) process:

$$\ln \vartheta_t = \rho_I \ln \vartheta_{t-1} + \varepsilon_t^I, \quad 0 \leq \rho_I < 1, \tag{20}$$

where ε_t^I is an i.i.d. $N(0, \sigma_{\varepsilon^I}^2)$ MEI shock with variance $\sigma_{\varepsilon^I}^2$.

2.4 Employment Agencies

A large number of competitive employment agencies combine differentiated labour skills into a homogeneous labour input sold to intermediate firms, according to:

$$L_t = \left(\int_0^1 L_{it}^{\frac{1}{1+\lambda_{w,t}}} di\right)^{1+\lambda_{w,t}}, \tag{21}$$

where $\lambda_{w,t}$ is the stochastic desired markup of wage over the household's marginal rate of substitution. The desired wage markup follows an ARMA(1,1) process:

$$\lambda_{w,t} = (1 - \rho_w)\,\lambda_w + \rho_w \lambda_{w,t-1} + \varepsilon_{w,t} - \theta_w \varepsilon_{w,t-1}, \tag{22}$$

where λ_w is the steady-state wage markup and $\varepsilon_{w,t}$ is an i.i.d. $N(0, \sigma_w^2)$ wage-markup shock, with variance σ_w^2.

Profit maximization by the perfectly competitive employment agencies implies the following labour demand function:

$$L_{it} = \left(\frac{W_{it}}{W_t}\right)^{-\frac{1+\lambda_{w,t}}{\lambda_{w,t}}} L_t, \tag{23}$$

where W_{it} is the wage paid to labour of type i and W_t is the aggregate wage index:

$$W_t = \left(\int_0^1 W_{it}^{-\frac{1}{\lambda_{w,t}}} di\right)^{-\lambda_{w,t}}. \tag{24}$$

2.5 Wage setting

Households set wages in a staggered fashion. Each period, a household can reoptimize its wage with probability $1 - \xi_w$. Households allowed to reoptimize their nominal wage choose a wage W_t^*. Those not allowed to reoptimize will either set $W_{it} = W_{i,t-1}$ or index $W_{i,t-1}$ to lagged inflation, π_{t-1}, and steady-state inflation, π. The wage-setting rule is then given by:

$$W_{it} = \begin{cases} W_{it}^* & \text{with probability } 1-\xi_w \\ W_{i,t-1} \text{ or } W_{i,t-1}\left(\pi_{t-1} e^{\frac{1}{(1-\alpha)(1-\phi)} z_{t-1} + \frac{\alpha}{(1-\alpha)} v_{t-1}^I}\right)^{\iota_w} \left(\pi e^{\frac{1}{(1-\alpha)(1-\phi)} g_z + \frac{\alpha}{(1-\alpha)} g_v}\right)^{1-\iota_w} & \text{with probability } \xi_w, \end{cases} \tag{25}$$

where W_{it}^* is the reset wage. When allowed to reoptimize its wage, the household chooses the nominal wage that maximizes the present discounted value of utility flow (16) subject to demand schedule (23). The optimal wage rule is determined from the following first-order condition:

$$E_t \sum_{s=0}^{\infty} (\beta\xi_w)^s \frac{\lambda_{t+s}^r L_{it+s}}{\lambda_{w,t+s}} \left[w_t^* \frac{\Pi_{t,t+s}^w}{\pi_{t+1,t+s}} - (1+\lambda_{w,t+s}) \frac{\eta \varepsilon_{t+s}^h L_{it+s}^{\chi}}{\lambda_{t+s}^r}\right] = 0, \tag{26}$$

where ξ_w^s is the probability that a wage chosen in period t will still be in effect in period $t+s$, $\Pi_{t,t+s}^w = \Pi_{k=1}^s \left(\pi e^{\frac{1}{(1-\alpha)(1-\phi)} g_z + \frac{\alpha}{(1-\alpha)} g_v}\right)^{1-\iota_w} \left(\pi_{t+k-1} e^{\frac{1}{(1-\alpha)(1-\phi)} z_{t-k+1} + \frac{\alpha}{(1-\alpha)} v_{t-k+1}^I}\right)^{\iota_w}$ is the cumulative wage indexation between t and $t+s-1$, and ι_w is the degree of wage indexing to past inflation. Given our assumption on preferences and wage-setting, all updating households will choose the same optimal reset wage, denoted in real terms by $w_t^* = \frac{W_{it}}{P_t}$.

2.6 Monetary and Fiscal Policy

The Taylor rule includes an interest rate smoothing effect governed by ρ_r, a reaction to the weighted sum of deviations of current inflation from target and deviations of expected inflation from target over the next three quarters governed by α_π, and to deviations of current output growth from trend growth governed by α_y. Coibion and Gorodnichenko (2011) propose a similar type of rule where the nominal interest rate reacts to future inflation, the current output gap and output growth. The policy rule is:

$$R_t = R_{t-1}^{\rho_r} \left[E_t \left(\pi_{t,t+3} \right)^{\frac{1}{4}\alpha_\pi} \left(\frac{\hat{Y}_t}{\hat{Y}_{t-1}} g_\Omega^{-1} \right)^{\alpha_y} \right]^{1-\rho_r} \epsilon_t^r \tag{27}$$

where $\pi_{t,t+3}$ is the sum of expected inflation over the current and future three quarters, and ϵ_t^r is a monetary policy shock which is i.i.d. $N(0, \sigma_r^2)$. The reactive part of this policy rule is what we refer to as systematic monetary policy.

Fiscal policy is fully Ricardian. The government finances its budget deficit by issuing short-term bonds. Public spending is a time-varying fraction of final output, Y_t:

$$G_t = \left(1 - \frac{1}{g_t}\right) Y_t, \tag{28}$$

where g_t is the government spending shock that follows the AR(1) process:

$$\ln g_t = (1 - \rho_g) \ln g + \rho_g \ln g_{t-1} + \varepsilon_{g,t}, \tag{29}$$

where g is the steady-state level of government spending and $\varepsilon_{g,t}$ is an i.i.d. $N(0, \sigma_v^2)$ government spending shock with variance, σ_v^2.

2.7 Market-Clearing and Equilibrium

Market-clearing for capital services, labour, and intermediate inputs requires that $\int_0^1 \widehat{K}_{jt} dj = \widehat{K}_t$, $\int_0^1 L_{jt} dj = L_t$, and $\int_0^1 \Gamma_{jt} dj = \Gamma_t$.

Gross output is written as:

$$X_t = A_t \Gamma_t^{\phi} \left(K_t^{\alpha} L_t^{1-\alpha} \right)^{1-\phi} - \Omega_t F. \tag{30}$$

Value added, Y_t, is related to gross output, X_t, as

$$Y_t = X_t - \Gamma_t, \tag{31}$$

where Γ_t denotes total intermediates. Real GDP is given by

$$\widehat{Y}_t = C_t + I_t + G_t. \tag{32}$$

The resource constraint of the economy is:

$$\frac{1}{g_t} Y_t = C_t + I_t + \frac{a(u_t)K_t}{V_t^I} \tag{33}$$

2.8 Log-Linearization

Economic growth stems from neutral and investment-specific technological progress. Therefore, output, consumption, intermediates and the real wage all inherit trend growth $g_{\Omega,t} \equiv \frac{\Omega_t}{\Omega_{t-1}}$. In turn, the capital stock and investment grow at the rate $g_I = g_K = g_{\Omega,t} g_{v,t}$. Solving the model requires detrending variables, which is done by removing the joint stochastic trend, $\Omega_t = A_t^{\frac{1}{(1-\phi)(1-\alpha)}} V_t^{I\,\frac{\alpha}{1-\alpha}}$, and taking a log-linear approximation of the stationary model around the non-stochastic steady state. The full set of equilibrium conditions can be found in the Appendix.

3 Estimation Methodology and Data

In this section we describe the data and the Bayesian estimation methodology used in our empirical analysis. We estimate the model presented in Section 2.

3.1 Data

We estimate our model with quarterly US data on output, consumption, investment, real wages, hours worked, inflation, the nominal interest rate, and the relative price of investment goods to consumption goods. All nominal series are expressed in real terms by dividing with a chain-weighted consumption price deflator. Moreover, output, consumption, investment and hours worked are expressed in per capita terms by dividing with civilian non-institutional population between 16 and 65. Nominal consumption is defined as the sum of personal consumption expenditures on nondurable goods and services. Nominal gross investment is the sum of personal consumption expenditures on durable goods and gross private domestic investment. The real wage is measured as compensation per hour in the non-farm business sector divided by the consumption deflator. Hours worked is the log of hours of all persons in the non-farm business sector, divided by the population. Inflation is measured as the quarterly log difference in the consumption deflator. The nominal interest rate series is the effective Federal Funds rate. The relative price of investment is the ratio of the implied price index for investment goods to the price index for consumption goods. All data except the interest rate are in logs and seasonally adjusted.

3.2 Bayesian Methodology

We use Bayesian methods to estimate a subset of model parameters. Recent overviews of this estimation methodology are presented in An and Schorfheide (2007) and Fernández-Villaverde (2010). Following Bianchi and Nicoló (2020), we use a method that explicitly allows the possibility of estimating the model under indeterminacy and determinacy. We use the statistical fit of the models to determine which model version is preferred by the data.

The key steps in this methodology are as follows. The model presented in the previous sections is solved using standard numerical techniques and the solution is expressed in state-space form as follows:

$$\mathbf{X}_t = \mathbf{A}\mathbf{X}_{t-1} + \mathbf{B}\varepsilon_t$$
$$\mathbf{Y}_t = \mathbf{C} + \mathbf{D}\mathbf{X}_t$$

where the observation vector, $\mathbf{Y}_t$, is given by

$$\mathbf{Y}_t = \begin{bmatrix} \overline{g}_\Omega \\ \overline{g}_\Omega \\ \overline{g}_\Omega \\ \overline{g}_\Omega \\ \overline{L} \\ \overline{\pi} \\ \overline{R} \\ \overline{g}_v \end{bmatrix} + \begin{bmatrix} \widehat{gdp}_t - \widehat{gdp}_{t-1} + \widehat{g}_{\Omega,t} \\ \widehat{c}_t - \widehat{c}_{t-1} + \widehat{g}_{\Omega,t} \\ \widehat{i}_t - \widehat{i}_{t-1} + \widehat{g}_{\Omega,t} \\ \widehat{w}_t - \widehat{w}_{t-1} + \widehat{g}_{\Omega,t} \\ \widehat{L}_t \\ \widehat{\pi}_t \\ \widehat{R}_t \\ -\widehat{v}_t^I \end{bmatrix}.$$

A and **B** denote matrices of reduced form coefficients that are non-linear functions of the structural parameters, **C** is the steady state values of the observation variables, and **D** is a matrix identifying the observation variables. $\mathbf{X}_t$ denotes the vector of model variables, ε_t the vector of exogenous disturbances, $gdp_t = \frac{GDP_t}{\Omega_t}$, $c_t = \frac{C_t}{\Omega_t}$, $i_t = \frac{I_t}{\Omega_t}$ and $w_t = \frac{W_t}{\Omega_t}$. The parameters $\overline{g}_\Omega$, $\overline{L}$, $\overline{\pi}$, $\overline{R}$ and $\overline{g}_v$ are related to the model's steady state as follows: $\overline{g}_\Omega = 100 \log g_\Omega$, $\overline{L} = 100 \log L$, $\overline{\pi} = 100 \log \pi$, $\overline{R} = 100 \log R$ and $\overline{g}_v = 100 \log g_v$. The symbol ˆ over a variable denotes that it is measured as a log-deviation from steady state.

The vector of observable variables at time t to be used in the estimation is

$$\mathbf{Y}_t = \left[\Delta \log Y_t, \Delta \log C_t, \Delta \log I_t, \Delta \log \frac{W_t}{P_t}, \log L_t, \pi_t, R_t, v_t^I \right],$$

where Δ denotes the first-difference operator.

Let Θ denote the vector that contains all the structural parameters of the model. The non-sample information is summarized with a prior distribution with density $p(\Theta)$. The sample information (conditional on version M_i of the DSGE model) is contained in the likelihood function, $p(\mathbf{Y}_T \mid \Theta, M_i)$, where $\mathbf{Y}_T = [Y_1, ..., Y_T]'$ contains the data. The likelihood function allows one to update the prior distribution of Θ, $p(\Theta)$. Then, using Bayes' theorem, we can express the posterior distribution of the parameters as

$$p(\Theta \mid \mathbf{Y}_T, M_i) = \frac{p(\mathbf{Y}_T \mid \Theta, M_i) p(\Theta)}{p(\mathbf{Y}_T, M_i)},$$

where the denominator, $p(\mathbf{Y}_T, M_i) = \int p(\Theta) p(\mathbf{Y}_T \mid \Theta, M_i) d\Theta$ is the marginal data density conditional on model M_i. In Bayesian analysis the marginal data density constitutes a measure of model fit with two dimensions: goodness of in-sample fit and a penalty for model complexity. All estimations are done using Dynare (Adjemian et al. (2011)). We report the mode of the estimated parameters and the associated log data densities of each model.

To estimate the model when it is characterized by indeterminacy we follow the procedure outlined in Bianchi and Nicoló (2020), who propose appending to the model the following auxiliary process

$$\omega_t = \left(\frac{1}{\alpha_{BN}}\right)\omega_{t-1} - \zeta_t + \eta_{f,t}, \tag{34}$$

where ω_t is an independent autoregressive process, ζ_t is a sunspot shock with standard deviation given by σ_ζ, and $\eta_{f,t}$ an expectational error.[5] This methodology requires that when there is a determinate state, the auxiliary process must be stationary. This requires that the $\frac{1}{\alpha_{BN}} < 1$ and the resulting dynamics of the model are unaffected by the auxiliary process. But when there is an indeterminate state, the auxiliary process must be non-stationary, implying that $\frac{1}{\alpha_{BN}} > 1$. In this case the expanded state space (including the auxiliary process) will satisfy the Blanchard-Kahn conditions and create a mapping from the sunspot shock, ζ_t, to the expectational error $\eta_{f,t}$. This solution method yields identical solutions for endogenous variables as one obtained with the framework suggested by Lubik and Schorfheide (2003).

While the above method characterizes determinant and indeterminant regions, we found that standard posterior approximation methods such as the Random-Walk Metropolis Hastings algorithm could not accurately characterize both regions in a single estimation. We instead proceed by imposing that the model is either in the determinacy or indeterminacy regions, computing posterior estimates, and evaluating the log data density in each region. We then compare the data densities in the determinacy versus indeterminacy regions, selecting the region which yields a higher log data density.

[5] As shown by Bianchi and Nicoló (2020), without loss of generality one can assume that this expectation error is associated with inflation, that is, $\eta_{f,t} = \pi_t - E_{t-1}(\pi_t)$.

3.3 Prior Distributions

Table 2 lists the choice of priors for the parameters to estimate and the estimates based on the posterior mode. Most prior distributions are broadly in line with the literature. Some parameters are held fixed prior to the estimation. We give them values commonly found in the literature. For instance, the rate of depreciation of physical capital is set at $\delta = 0.025$, implying an annualized rate of depreciation of 10%. The steady-state ratio of government spending to GDP is set at 0.22 in the pre-1980 sample and 0.20 in the post-1984 sample, which corresponds to the average ratio for our samples. The steady-state wage and price markups with zero trend inflation are 12.5 and 20 percent, which corresponds to an elasticity of substitution between differentiated goods equal to 9 and between differentiated skills equal to 6. For the share of intermediates into gross output, ϕ, we use a Beta prior with mean 0.5 and standard deviation 0.1. For the fraction of input costs financed by working capital, ψ, we assume a Beta prior with mean 0.3 and standard deviation 0.1.

For the estimation under indeterminacy, the parameter α_{BN} has a uniform prior in the range [0,2] and the sunspot shock an inverse gamma distribution with mean equal to 0.1 and standard deviation equal to 1.

4 Estimation Results

This section presents and discusses our estimation results. They are reported in Table 1 for the cases of indeterminacy and determinacy in the period 1966Q1 to 1979:Q2.

4.1 Indeterminacy vs Determinacy in the Pre-Volcker Years

There are two main differences when estimating our model imposing indeterminacy versus determinacy prior to 1980. They concern estimates of the policy rule and of the level of trend inflation. When imposing indeterminacy, we find a policy response to inflation α_π equal to 0.927. That is, monetary policy is passive and does not comply with the original Taylor principle (policy response to inflation smaller than 1).

Monetary policy with determinacy is found to be moderately active with an estimate

α_π of 1.564, and remains active even when taking into account uncertainty surrounding the estimate. The policy response to output growth is also higher according to the model with determinacy at 0.151 compared to 0.129 to the model with indeterminacy.

Now, the model with indeterminacy has the counterfactual implication of severely underestimating the average annualized rate of inflation. With indeterminacy, the estimated average rate of inflation is 2.8%. Since our sample covers the years of high inflation in the 1960s and 1970s when the actual average rate of inflation based on the consumption deflator was nearly 6%, this relatively low trend inflation can be seen as an anomaly of the model with indeterminacy.

By sharp contrast, the estimated average rate of inflation in the model with determinacy is 6.6%. Therefore, the model with determinacy better captures the level of trend inflation observed during the Great Inflation. But at the same time, despite the high level of trend inflation, determinacy is achieved with a moderately active policy response to inflation.

The log marginal density statistics (Laplace approximation) are respectively -479 for the model with indeterminacy and -471 for the model with determinacy. Therefore, the model with indeterminacy has an inferior fit with the data for the pre-Volcker period.[6] Our finding that determinacy is preferred for the pre-Volcker years contrasts sharply with the rest of the literature. For instance, Clarida et al. (2000) reported estimates using several rule specifications showing that the policy responses to inflation are systematically lower 1. Lubik and Schorfheide (2004) obtained a similar result using a Bayesian estimation method that explicitly accounts for the possibility of indeterminacy. Coibion and Gorodnichenko (2011) found that a more hawkish stance towards fighting inflation, combined with a lower level of trend inflation, helped the economy transitioning from a state of indeterminacy before 1980 to one of determinacy after 1982.[7]

All these studies have in common that monetary policy minimally targets the output gap

[6] We do not formally report the estimation results for the Great Moderation since it is obvious that the model version with determinacy is preferred to the model with indetermiancy.

[7] More recently, Albonico et al. (2020) estimated a medium-scale DSGE model with and without rule-of-thumb consumers and found that passive monetary policy and sunspot fluctuations characterized the pre-Volcker period.

for measure of economic activity. Some also assume that policy targets output growth in addition to output gap. However, as Khan et al. (2020) show, when monetary policy targets both the output gap and output growth in an economy with positive trend inflation, the effect of targeting the output gap on the prospect of indeterminacy is disproportionately important relative to the impact of aiming at output growth. By comparison, a policy rule targeting output growth but not the output gap achieves determinacy with policy responses to inflation complying with the Taylor principle.

4.2 Parameter Estimates for the Great Inflation and Great Moderation

Table 2 reports parameter estimates under determinacy for the periods 1966:Q1-1979:Q2 and 1984:Q1-2007:Q3. They indicate the policy response to inflation increased from 1.564 in the pre-Volcker years to 2.274 during the Great Moderation. Therefore, there was a clear shift in systematic monetary policy towards fighting inflation more aggressively after 1984:Q1. We also find that the response of the interest rate to output growth was stronger during the Great Moderation, with estimates equal to 0.151 and 0.185, respectively. Finally, the interest rate smoothing parameter increased from 0.628 to 0.823. These shifts in policy parameters consolidated the determinacy outcome during the Great Moderation. Note that estimated trend inflation drops from 6.6% during the first period to 3.2% during the second period.

We also find noticeable changes in preference parameters from the Great Inflation to the Great Moderation. The parameter governing habit formation dropped from 0.876 in the first period to 0.752 in the second. The inverse Frisch elasticity of labour supply also declined from 2.025 to 1.424.

While we do not find a noticeable change in the degree of price flexibility from the Great Inflation to the Great Moderation, our evidence suggests there was a significant increase in the degree of nominal wage flexibility between the two periods. Specifically, ξ_w declined from 0.739 during the Great Inflation to 0.492 during the Great Moderation. We return to this finding when looking at the reasons behind the Great Moderation.

The fraction of factor payments financed by working capital ψ, and the share of intermediate inputs into gross output ϕ are two new parameters in the literature on medium-scale

DSGE models estimated with Bayesian methods. Our estimate of ψ is relatively modest at 0.266 for the first period and 0.253 for the second. The estimated share of intermediate inputs is 0.499 and 0.536 for the first and second period, respectively, which is broadly consistent with calibrated values typically found in the literature (Basu, 1995; Dotsey and King, 2006).

Finally, we find noticeable changes in the AR(1) parameters of the risk-premium and MEI shocks, which are both higher during the Great Moderation. We also find a smaller MA term of the wage markup shock after 1984. The estimated wage-markup and MEI shocks are also smaller after 1984.

4.3 Monetary Policy Shocks During the Pre-Volcker Era and Great Moderation

Monetary policy shocks are generated using the Kalman smoothed shocks estimated from our model with determinacy both for the Great Inflation and Great Moderation. Table 3 conveys information about the average policy shock observed during both periods. It also compares the average shocks from 1966:Q1 to 1979:Q2, and those before and after OPEC I.

We find that the average policy shocks have been negative during the Great Inflation and Great Moderation. However, the average policy shock was 10.5 times larger during the Great Inflation. Negative policy shocks were also more frequent during the first period than during the second period.

When looking at monetary policy shocks before and after OPEC I during the pre-Volcker period, we find that the average post-OPEC I shock was negative and 13 times larger than the average pre-OPEC I shock. Furthermore, policy shocks were negative 48% of the time before OPEC I and 65% of the time after OPEC I.

Figure 1 conveys information about policy shocks during the pre-Volcker period. They were relatively small in the 1960s, indicating that the Fed did not actively resort to unsystematic policy interventions during that time. By comparison, the 1970s were a more turbulent period in terms of unsystematic policy interventions. Policy shocks were often negative and large. Our evidence hence suggests that the Fed actively resorted to unsystematic monetary policy during the 1970s, and this in a relatively strong expansionary way.

Figure 2 describes how inflation and the unemployment rate behaved during the pre-Volcker period. From 1966:Q1 to 1969:Q4 the unemployment rate never exceeded 4%. Meanwhile, the rate of inflation gradually rose from 3.8% in 1966:Q1 to 4.9% in 1969:Q4. The joint behavior of inflation and unemployment rates observed during these years gave rise to the "accelerationnist hypothesis" of Friedman (1968) and Phelps (1967, 1968), whereby fueled by revisions in inflation expectations, inflation accelerated as the actual rate of unemployment was kept below the natural rate. OPEC I was immediately followed by a surge in the unemployment rate from 4.8% in 1973:Q4 to 9% in 1975:Q2. Inflation began to rise in 1972 and 1973, and culminated to a high of 13% in 1974:Q1.

Overall, our evidence suggests that systematic monetary policy was weakly active during the 1960s and 1970s, while it became significantly less accommodative to inflation during the Great Moderation. The 1960s did not witness sizable unsystematic policy interventions as evidenced by the small policy shocks observed during these years. By contrast, the 1970s witnessed frequent and sizable unsystematic policy interventions providing stimulus to the economy. The Great Moderation was also characterized by much smaller and less expansionary policy shocks on average.

5 The Sources of Postwar Business Cycles

This section identifies the key sources of postwar business cycle fluctuations based on our estimated model with determinacy. We compute the forecast error variance decomposition of variables corresponding to our observables for models estimated over our pre-1980 and post-1984 subsamples. They are based on posterior modes. Tables 4 and 5 report variance decompositions at the business cycle frequency of 6-32 quarters using the first and second subsample estimates, respectively.

The key sources of business cycle fluctuations are very different for the two episodes. When looking at the pre-1980 estimated model, we find that MEI shocks explain close to 50% of the cyclical variance of output growth. MEI shocks also explain nearly 80% of the cyclical variance of investment growth, 50% of the variance of hours, and close to 15% of the variance of interest rates. Taken together, technology shocks (the sum of TFP and MEI shocks) explain nearly 80% of the cyclical variance of output growth. Neutral technology and price-markup shocks contribute close to 90% to the cyclical variance of inflation.

When analyzing the forecast error variance decomposition for the post-1984 sample, we find that the contribution of MEI shocks to the cyclical variance of output growth falls dramatically by almost 30%, down to only 20.25%. We also find that the contribution of MEI shocks to investment growth decreased by 14%, while their contribution to change in hours declined by nearly 24%. Moreover, the overall contribution of technology shocks declined by nearly to 30%.

Our evidence of a large decline in the contribution of MEI shocks to business cycle fluctuations during the post-1984 episode is broadly consistent with the findings presented in Christiano et al. (2014). They report that MEI shocks explain only 13% of that cyclical variance of output growth when accounting for risk shocks. The sample of data used by Christiano et al. to estimate their model is 1985:Q1-2010:Q2, and thus overlaps with ours.

While wage markup shocks were relatively insignificant during the first episode, their importance increased during the second episode. In the post-1984 episode, wage markup shocks contributed to 22% of the cyclical variance of output growth, 15% of consumption growth, 32% of real wage growth, and 31% of the change in hours.

Therefore, our findings suggest that it might be misleading to assess the sources of postwar business cycles through the lens of DSGE models estimated with only one set of data for the entire postwar period.

6 Factors Explaining The Great Moderation

We identify the key factors explaining the Great Moderation. Table 6 first presents the actual standard deviations of output growth, change in hours worked and inflation for the two episodes 1966:Q1 to 1979:Q2 and 1984:Q1 to 2007:Q3. They are reported in columns $79D$ and $84D$, respectively. They are accompanied by their actual percentage variations from the first to the second episode in column $\%\Delta D$. Columns $P79 - B$ and $P84 - B$ report the standard deviations implied by our estimated models with determinacy, and the percentage variations in column $\%\Delta B$.

6.1 Identifying the Sources of the Great Moderation

The volatility of output growth actually fell by 45.7% during the Great Moderation, the volatility of change in hours worked by 35.3%, and volatility of inflation by 48.5%. Our model broadly captures these declines, predicting that the volatility of output growth declined by 31%, the volatility of change in hours by 37%, and the variability of inflation by 26%.

We assess the key factors that contributed to lowering macroeconomic volatility during the Great Moderation through counterfactual experiments. A first experiment assesses the contribution of changes in monetary policy to the Great Moderation. A second looks at changes in the shock processes. A third aims at evaluating the effect of a change in the degree of nominal wage rigidity. A fourth focuses on changes in preference parameters. Finally, a fifth experiment explores whether the lower level of trend inflation was a factor driving increased macroeconomic stability.

Table 6 compares the standard deviations of output growth, change in hours and inflation conditioned on our estimated models and those implied by the first four counterfactuals. This table shows that the main factors contributing to the declines in output and employment fluctuations are: 1) the degree of nominal wage rigidity, and 2) shock processes. The volatility of output growth in the second period with the pre-Volcker Calvo wage probability is nearly 144% higher. Importing the pre-Volcker estimated shock processes into the second period model delivers a volatility of output growth which is 29% higher.

When considering the main factors explaining the decline in inflation variability, we find they are: 1) monetary policy, 2) preference parameters, and 3) the degree of nominal wage rigidity. Importing the estimated policy rule of the pre-1980s into the second period model results into a volatility of inflation which is nearly 64% higher. The volatility of inflation when importing the pre-1980s preference parameters governing habit formation and labour supply elasticity into the second period model is nearly 50% higher. Finally, inflation is about

19% more volatile with the pre-1980s degree of nominal wage rigidity.

The next step is to combine changes in monetary policy, structural factors or shock processes. We assess their joint contribution to the Great Moderation. The results are presented in Table 7. A first experiment combines changes in the degree of nominal wage rigidity and shock processes. Importing the pre-1980 estimate ξ_w and shock processes into the post-1984 model reduces the contribution to the volatility of output growth and change in hours of wage rigidity alone, and this by a significant margin which is 47% instead of 144% for output growth, and 36.5% instead of 162% for change in hours. When combining changes in nominal wage rigidity and monetary policy, we find that the standard deviations of output growth and changes in hours are only marginally lower than those predicted when changing only nominal wage rigidity.

The results are quite different when we look at the factors explaining the lower inflation variability recorded after 1984. For then, we find that higher nominal wage flexibility played a relatively minor role in lowering inflation variability. That is, importing the pre-1980 degree of nominal wage rigidity into the post-1984 estimated model implies that inflation volatility is only 18.7% higher than predicted by the post-1984 model. By contrast, by inserting the pre-1980 monetary policy into the post-1984 model, inflation variability is 64% higher than the baseline model. Preference parameters also play a significant role lowering inflation volatility during the Great Moderation. Importing the pre-1980 preference parameters into the post-1984 model makes inflation variability 50% higher than the baseline.

When combining the pre-1980 monetary policy with either the pre-1980 nominal wage rigidity or preference parameters, we find that joining monetary policy and preference parameters is more important in lowering inflation variability. We also find that shocks play no role bringing inflation volatility down.

Another interesting question addressed by our counterfactual experiments is whether lower trend inflation played a role increasing macroeconomic stability. Recall that trend inflation declined from 6.6% before 1980 to 3.2% after 1984. So far, our estimation results have established that high trend inflation was not a factor causing indeterminacy during the pre-Volcker era under a policy rule targeting output growth for measure of economic activity, and this contrary to what has been established in most of the previous literature.[8]

However, Ascari (2004) and Ascari and Sbordone (2014) provide evidence that trend inflation can also have cyclical implications by making the impulse-responses of key macroeconomic variables to monetary policy and TFP shocks dependent on the level of trend inflation. Ascari et al. (2018) show that this dependence can be particularly strong when allowing an interaction between positive trend inflation, the MEI shock and its persistence.

The counterfactual experiments conditioned on the different levels of trend inflation before 1980 and after 1984 are summarized in Table 8. We find that the lower level of trend inflation did not have a significant impact on aggregate volatility either on its own or combined with other factors.

Thus, our results suggest that the smaller volatilities of output growth and change in hours are driven mostly by greater nominal wage flexibility, while the main factors behind the lower variability of inflation are changes in monetary policy and preference parameters. Our evidence also suggests that changes in the shock processes which is at the core of the "good-luck hypothesis" have not played a significant role in driving the Great Moderation.

6.2 Deunionization and Greater Nominal Wage Flexibility

Our findings concerning the key role of greater nominal wage flexibility in lowering output and hours volatility during the Great Moderation seem to be broadly consistent with a body of literature pointing to the rapid deunionization in the US private sector after 1980. US union density in the private sector–the number of trade union members who are employees expressed in percentage of the total number of employees in the private sector–fell from 20% in 1980 to about 7.5% in 2015 (Bryson et al., 2017). Meanwhile, the share of private sector employment into total employment increased from about 82% in 1980 to 84.5% in 2015. By comparison, union density in the public sector experienced little variation between 1980 and 2015, remaining at around 35%. The share of public sector employment into total employment dropped from 18% in 1980 to 15.5% in 2015. The consensus in the literature is that deunionization in the private sector has been a main factor leading to increased US labor

[8]See for example Coibion and Gorodnichenko (2011) and Hirose et al. (2020).

market flexibility during years corresponding to our post-1983 subsample.

There have been a number studies exploring the sources of deunionization and its effects on the US labor market and aggregate fluctuations more generally. For instance, Acemoglu et al. (2001) argued that deunionization and increased wage inequality mainly resulted from skill-biased technology.

Champagne and Kurmann (2013) proposed a model where deunionization and a doubling of the fraction of union and non-union workers receiving performance-pay for fixed lengths of nominal wage rigidity of 36 months for union workers and 18 months for non-union workers, led to a decline in real wage rigidity after 1984 and an increase in the real average hourly wages relative to output.

Mitra (2020) studied the sources of the vanishing procyclicality of average labor productivity and total factor productivity in the post-1984 period. He developed a model wherein rising deunionization after the mid-1980s in the US prompted a decline in union power as well as falling costs of hiring and firing workers that led firms to rely more on employment adjustment than on changing workers' effort through labor-hoarding. Assuming that the average waiting time between nominal wage and price adjustments is held fixed at 12 months throughout numerical simulations, he concluded that weaker reliance on labor-hoarding due to greater labor market flexibility explains the "productivity puzzle".

Unlike these contributions, our estimation results identify weaker nominal wage rigidity as the key factor explaining the significant decreases in output growth and change in hours volatility observed during the Great Moderation. Although our model does not explicitly account for the distinction between union and non-union sectors (or workers), we believe that our evidence of greater nominal wage flexibility after 1983 is consistent with the strand of literature concluding that rapid deunionization after the early 1980s has contributed to greater labor market flexibility.

6.3 Comparison with the Smets and Wouters (2007) Results

A notable study on the sources of macroeconomic volatility during the postwar period is Smets and Wouters (2007) (SW). Our estimation results differ from theirs in many ways.

First, while they report evidence of an active monetary policy during the Great Inflation and Great Moderation as we do, they find only slight differences in the control parameters of the policy rule over the two periods. So unsurprisingly, monetary policy in their model is not a significant source of lower volatility of output growth and inflation during the Great Moderation. Note, however, that they do not test whether determinacy or indeterminacy is statistically preferred based on the empirical fit of the models while we do.

Second, SW report evidence of significant increases in the average waiting time between wage and price adjustments after 1984. They find that the average frequency of price adjustment increased from once every 6.7 months in the pre-1979:Q3 period to once every 11.1 months in the post-1984 period, whereas the average frequency of wage adjustment rose from once every 8.6 months before 1979:Q3 to 11.5 months after 1984. While some may argue that lower trend inflation may have contributed to increasing the degrees of nominal wage and price rigidities after 1984, their estimation results only point to a small variation in the average rate of inflation between both subperiods. By contrast, our evidence suggests little variation in the degree of price rigidity, but a significant increase in nominal wage flexibility after 1984, consistent with greater labor market flexibility resulting from private sector deunionization.

Furthermore, in contrast to SW, our model with determinacy tracks relatively well the variations in the level of trend inflation. We find an estimated level of trend inflation of 6.6% in the Great Inflation period, which falls to an estimated level of roughly 3.2% during the Great Moderation. SW find an estimated level of trend inflation of roughly 2.9% in the pre-1979 period and 2.7% in the post-1984 period.

One final difference with SW concerns their findings about the role of shocks in generating the declines in the volatility of output growth and inflation during the Great Moderation. Their counterfactual experiments about the shock processes omit the estimated MA terms of the ARMA(1,1) generating processes for the wage and price markup shocks. This can be seen from Table 9 which compares the standard deviations of output growth and inflation using the original SW estimates and estimates from our model.

The column SW-(no MA change) shows the standard deviations of output growth and inflation in the post-1984 period conditioned on the structural shock estimates from the first subperiod, where the MA terms of the wage and price markup shock processes remain at their post-1984 estimated values. These counterfactual standard deviations match those reported by SW. By contrast, the column SW-(MA change) shows that if changes in the MA terms of the wage and price markup shock generating processes are included in the counterfactual experiment (that is, if the MA terms are also changed to the pre-1979 estimates), then the contribution of shocks to the lower volatility of output growth is marginally smaller, while their contribution to the decline in inflation variability is considerably smaller, with a standard deviation which is 1.3 when the MA terms of the wage and price markup shock processes are not changed, compared to only 0.58 when these changes are accounted for.

The third and fourth columns report the same counterfactual experiments conditioned on our estimated models. We find that omitting or accounting for changes in the MA terms of the wage and price markup shock processes does not affect our results pointing to the relative insignificance of smaller shocks in generating lower volatility of output growth and inflation.

7 Conclusion

We have revisited two major postwar business cycle episodes: the Great Inflation and the Great Moderation using an estimation method allowing formally to compare indeterminacy with determinacy. We found that determinacy is preferred to indeterminacy for the pre-Volcker period. This undermines the idea that macroeconomic fluctuations were fueled by self-fulfilling inflation expectations and driven by sunspot shocks.

We have offered evidence suggesting that systematic monetary policy was weakly active, as opposed to passive, during the pre-Volcker years. At the same time, monetary policy shocks were very expansionary during the pre-Volcker years relative to the Great Moderation period, especially between OPEC I and 1979:Q2. Systematic monetary policy became significantly less accommodating to inflation and policy shocks much smaller during the Great Moderation.

The forecast error variance decomposition based on our estimated models suggested that it may be misleading to take the postwar era as a single period. When decomposed in two subperiods, one before 1980 and another after 1984, we obtain a very different picture of the sources of postwar business cycle fluctuations. In particular, we found that the contribution of investment shocks to output fluctuations dropped by nearly 30% during the Great Moderation.

We have identified greater nominal wage flexibility, likely due to the large-scale deunionization in the US private sector, as the main factor accounting for the significant decreases in the volatility of output growth and change in hours during the Great Moderation. But increased wage flexibility played little role bringing down inflation variability after 1984. The key element driving lower inflation volatility was shown to be a hawkish policy stance against inflation and less expansionary and smaller policy shocks.

We also found that lower trend inflation did not play a role in the Great Moderation. We found little support for the 'good-luck hypothesis' in lowering either output growth or inflation volatility.

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Table 1: 1966Q1:1979Q2 ESTIMATES UNDER INDETERMINACY AND DETERMINACY

	Prior			Posterior Mode			
				Indeterminacy		**Determinacy**	
	Dist.	Mean	SD	Mode	SD	Mode	SD
α	normal	0.300	0.0500	0.1703	0.0127	0.1757	0.0121
ι_p	beta	0.500	0.1500	0.3343	0.0996	0.5737	0.0898
ι_w	beta	0.500	0.1500	0.0827	0.0398	0.0854	0.0510
g_Y	normal	0.400	0.0250	0.3910	0.0267	0.3807	0.0239
g_I	normal	0.200	0.0250	0.1987	0.0218	0.1987	0.0244
h	beta	0.500	0.1000	0.8738	0.0270	0.8763	0.0329
$\bar{l}$	normal	0.000	0.5000	-0.2066	0.4523	-0.1959	0.4131
$\pi^\star$	normal	0.985	0.7500	0.6982	0.4739	1.6657	0.1475
$100(\beta^{-1}-1)$	gamma	0.250	0.1000	0.1194	0.0478	0.0901	0.0456
χ	gamma	2.000	0.7500	1.9273	0.6569	2.0251	0.7577
ξ_p	beta	0.660	0.1000	0.8536	0.0396	0.7676	0.0327
ξ_w	beta	0.660	0.1000	0.7340	0.0465	0.7392	0.0425
σ_a	gamma	5.000	1.0000	4.8517	1.0174	4.8904	1.2049
κ	gamma	4.000	1.0000	2.8775	0.5943	2.8764	0.7490
ψ	beta	0.300	0.1000	0.2643	0.0918	0.2658	0.0832
ϕ	beta	0.500	0.1000	0.5432	0.0762	0.4992	0.0765
ϕ_π	normal	1.500	0.3000	0.9271	0.0744	1.5639	0.1723
$\phi_{\Delta y}$	normal	0.125	0.0500	0.1285	0.0499	0.1507	0.0371
ρ_r	beta	0.600	0.2000	0.7613	0.0421	0.6275	0.0451
ρ_z	beta	0.400	0.2000	0.2526	0.0887	0.3156	0.0985
ρ_g	beta	0.600	0.2000	0.9639	0.0294	0.9645	0.0308
ρ_v	beta	0.200	0.1000	0.1164	0.0656	0.1230	0.0600
ρ_p	beta	0.600	0.2000	0.2927	0.1434	0.6310	0.1276
ρ_w	beta	0.600	0.2000	0.5770	0.1567	0.8331	0.0607
ρ_b	beta	0.600	0.2000	0.8441	0.0865	0.5606	0.1337
ρ_I	beta	0.600	0.2000	0.5353	0.1174	0.4629	0.1327
θ_p	beta	0.500	0.2000	0.6943	0.1236	0.5815	0.1477
θ_w	beta	0.500	0.2000	0.5994	0.1822	0.9379	0.0291
σ_r	invg	0.100	1.0000	0.2288	0.0234	0.1899	0.0224
σ_z	invg	0.500	1.0000	0.4792	0.0742	0.5162	0.0776
σ_v	invg	0.500	1.0000	0.4073	0.0440	0.4093	0.0452
σ_{η^I}	invg	0.500	1.0000	0.6540	0.0674	0.6602	0.0630
σ_p	invg	0.100	1.0000	0.2732	0.0362	0.2424	0.0340
σ_w	invg	0.100	1.0000	0.2840	0.0410	0.3093	0.0440
σ_b	invg	0.100	1.0000	0.0851	0.0179	0.1372	0.0280
σ_{ϵ^I}	invg	0.500	1.0000	6.3084	1.4130	6.7513	2.0723
σ_ζ	invg	0.100	1.0000	0.0456	0.0349	0.0462	0.0432
α_{BN}	uniform			1.7847	0.2930	0.3386	0.2919
Log data density				-479.69		-471.92	

Notes: α_{BN} is the parameter governing the auxiliary process and σ_ζ is the standard deviation of the sunspot shock.

Table 2: ESTIMATES IN THE GREAT INFLATION AND GREAT MODERATION

		Prior		**Posterior Mode**			
				1966Q1:1979Q2		**1984Q1:2007Q3**	
	Dist.	Mean	SD	Mode	SD	Mode	SD
α	normal	0.300	0.0500	0.1757	0.0121	0.1740	0.0146
ι_p	beta	0.500	0.1500	0.5737	0.0898	0.2374	0.0695
ι_w	beta	0.500	0.1500	0.0854	0.0510	0.2237	0.0702
g_Y	normal	0.400	0.0250	0.3807	0.0239	0.3913	0.0195
g_I	normal	0.200	0.0250	0.1987	0.0244	0.2369	0.0246
h	beta	0.500	0.1000	0.8763	0.0329	0.7518	0.0382
$\bar{l}$	normal	0.000	0.5000	-0.1959	0.4131	-0.0420	0.6388
$\pi^\star$	normal	0.985	0.7500	1.6657	0.1475	0.8068	0.1069
$100(\beta^{-1}-1)$	gamma	0.250	0.1000	0.0901	0.0456	0.1706	0.0691
χ	gamma	2.000	0.7500	2.0251	0.7577	1.4237	0.5836
ξ_p	beta	0.660	0.1000	0.7676	0.0327	0.7623	0.0263
ξ_w	beta	0.660	0.1000	0.7392	0.0425	0.4918	0.0547
σ_a	gamma	5.000	1.0000	4.8904	1.2049	4.9723	1.0852
κ	gamma	4.000	1.0000	2.8764	0.7490	3.2507	1.2552
ψ	beta	0.300	0.1000	0.2658	0.0832	0.2525	0.0806
ϕ	beta	0.500	0.1000	0.4992	0.0765	0.5357	0.0578
ϕ_π	normal	1.500	0.3000	1.5639	0.1723	2.2743	0.1514
$\phi_{\Delta y}$	normal	0.125	0.0500	0.1507	0.0371	0.1854	0.0419
ρ_r	beta	0.600	0.2000	0.6275	0.0451	0.8230	0.0187
ρ_z	beta	0.400	0.2000	0.3156	0.0985	0.3062	0.0696
ρ_g	beta	0.600	0.2000	0.9645	0.0308	0.9926	0.0058
ρ_v	beta	0.200	0.1000	0.1230	0.0600	0.4551	0.0617
ρ_p	beta	0.600	0.2000	0.6310	0.1276	0.9638	0.0222
ρ_w	beta	0.600	0.2000	0.8331	0.0607	0.9645	0.0185
ρ_b	beta	0.600	0.2000	0.5606	0.1337	0.8882	0.0490
ρ_I	beta	0.600	0.2000	0.4629	0.1327	0.9158	0.0344
θ_p	beta	0.500	0.2000	0.5815	0.1477	0.8503	0.0391
θ_w	beta	0.500	0.2000	0.9379	0.0291	0.7753	0.0372
σ_r	invg	0.100	1.0000	0.1899	0.0224	0.1102	0.0088
σ_z	invg	0.500	1.0000	0.5162	0.0776	0.3444	0.0390
σ_v	invg	0.500	1.0000	0.4093	0.0452	0.2792	0.0234
σ_{η^I}	invg	0.500	1.0000	0.6602	0.0630	0.4455	0.0347
σ_p	invg	0.100	1.0000	0.2424	0.0340	0.1992	0.0231
σ_w	invg	0.100	1.0000	0.3093	0.0440	0.3125	0.0334
σ_b	invg	0.100	1.0000	0.1372	0.0280	0.1100	0.0315
σ_{ϵ^I}	invg	0.500	1.0000	6.7513	2.0723	2.6678	0.6191
Log data density				-471.92		-521.91	

Notes: Since the auxiliary process has no impact on the Great Inflation model dynamics, we have omitted those estimates in this table.

Table 3: MONETARY POLICY SHOCKS

	1966Q1:1979Q2	**1984Q1:2007Q3**
Average shock	-0.0494	-0.0047
Average shock (cond. on +)	0.1128	0.0776
Average shock (cond. on -)	-0.1792	-0.0962
# of negative shocks	30/54	45/95
# of positive shocks	24/54	50/95

	1966Q1:1973Q3	**1973Q4:1979Q2**
Average shock	0.0095	-0.1289
Average shock (cond. on +)	0.1248	0.0888
Average shock (cond. on -)	-0.1134	-0.2450
# of negative shocks	15/31	15/23
# of positive shocks	16/31	8/23

Notes: Monetary policy shocks are based on Kalman smoothed shocks from the mixed-forward rule model.

Table 4: PRE-1979 VARIANCE DECOMPOSITION

Moment ↓ / Shock →	MP	Neut. Tech.	Govt.	IST	P-markup	W-markup	RP	MEI
Output growth	0.74	28.11	5.57	0.65	0.30	4.64	10.61	49.38
Cons. growth	0.13	28.58	0.52	0.14	0.06	2.01	67.11	1.45
Invest. growth	0.84	14.90	0.08	1.14	0.34	4.00	0.44	78.25
Wage growth	0.09	57.64	0.03	0.03	23.14	17.76	0.70	0.61
Log hours	0.88	21.00	4.69	0.40	0.53	11.46	10.96	50.08
Inflation	0.16	42.64	0.58	0.26	45.58	2.63	3.76	4.39
RPI	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
Nominal rate	18.56	39.16	1.40	0.89	12.49	3.73	8.60	15.17
Hours growth	0.78	25.83	5.96	0.41	0.21	5.85	10.96	50.00

Notes: Variance decomposition is at the business cycle frequency of 6-32 quarters.

Table 5: POST-1984 VARIANCE DECOMPOSITION

Moment ↓ / Shock →	MP	Neut. Tech.	Govt.	IST	P-markup	W-markup	RP	MEI
Output growth	2.77	32.45	3.90	1.17	9.88	22.08	7.50	20.25
Cons. growth	1.14	30.60	1.34	0.27	2.59	15.74	40.05	8.28
Invest. growth	1.51	7.21	0.00	1.85	6.98	7.51	10.74	64.20
Wage growth	1.28	38.74	0.01	0.05	20.98	31.92	6.43	0.60
Log hours	2.52	13.08	2.58	0.76	10.44	39.19	5.27	26.17
Inflation	2.86	11.68	0.07	0.07	40.56	11.10	16.55	17.10
RPI	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
Nominal rate	16.16	3.92	0.25	0.40	6.71	4.87	24.15	43.55
Hours growth	2.93	22.22	4.73	0.85	8.69	30.91	6.38	23.29

Notes: Variance decomposition is at the business cycle frequency of 6-32 quarters.

Table 6: COUNTERFACTUAL: 1960-1979 INTO 1984-2007

Moment ↓	P79-D	P84-D	% ΔD	P79-B	P84-B	% ΔB	MP	Shocks	Wage rigidity	Util.
Std (Output gr.)	1.05	0.57	-45.68	1.23	0.85	-31.45	0.79 (-6.55)	1.09 (28.79)	2.07 (143.97)	0.83 (-3.06)
Std (Hours gr.)	0.96	0.62	-35.29	1.17	0.74	-36.73	0.71 (-3.95)	0.93 (25.62)	1.93 (161.65)	0.76 (2.92)
Std (Inflation)	0.63	0.32	-48.51	0.61	0.45	-26.02	0.74 (63.75)	0.39 (-14.22)	0.54 (18.69)	0.68 (50.14)

Notes: Counterfactuals involve calibrating the column header variables to the estimates from the 1966-1979 sample. The remaining variables are equal to the estimates in the 1984-2007 sample. Numbers in round brackets indicate the percentage decrease/increase in the standard deviation of output growth/ hours growth / inflation relative to the post-1984 baseline.

Table 7: COUNTERFACTUAL: 1960-1979 INTO 1984-2007

Moment ↓	Wage rig. + Util.	MP + Wage rig.	MP + Util.	Shocks + MP	Shocks + Wage rig.	Shocks + Util.
Std (Output gr.)	2.03 (138.59)	2.02 (138.31)	0.77 (-9.78)	1.07 (26.09)	1.25 (47.03)	1.06 (24.42)
Std (Hours gr.)	1.87 (154.31)	1.90 (156.82)	0.73 (-0.49)	0.95 (28.78)	1.01 (36.50)	0.99 (34.92)
Std (Inflation)	0.72 (58.92)	0.91 (100.73)	1.234 (172.95)	0.47 (4.91)	0.39 (-14.78)	0.44 (-3.30)

Notes: Counterfactuals involve calibrating the column header variables to the estimates from the 1966-1979 sample. The remaining variables are equal to the estimates in the 1984-2007 sample. Numbers in round brackets indicate the percentage decrease/increase in the standard deviation of output growth/ hours growth / inflation relative to the post-1984 baseline.

Table 8: COUNTERFACTUAL: 1960-1979 INTO 1984-2007

Moment ↓	Trend inf.	Trend inf. + MP	Trend inf. + Shocks	Trend inf. + Wage rig.	Trend inf. + Util.
Std (Output gr.)	0.85 (-0.09)	0.79 (-6.62)	1.09 (28.59)	2.07 (143.85)	0.82 (-3.17)
Std (Hours gr.)	0.74 (-0.16)	0.71 (-4.08)	0.92 (25.25)	1.93 (161.62)	0.76 (2.73)
Std (Inflation)	0.45 (-0.02)	0.74 (63.66)	0.39 (-14.25)	0.54 (18.71)	0.68 (50.25)

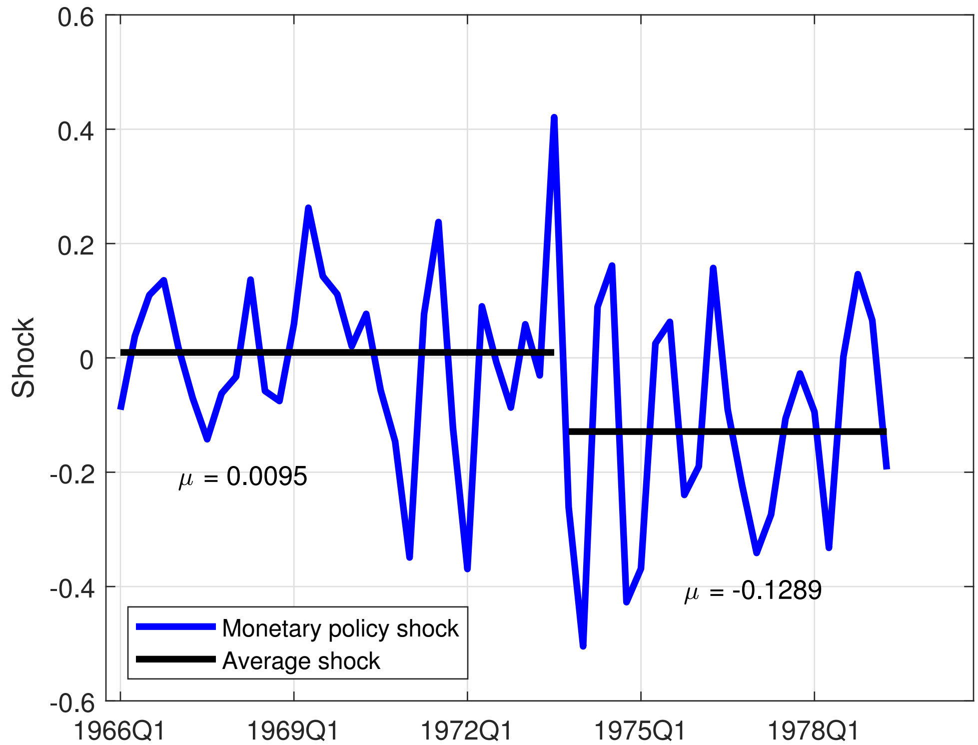
Notes: Counterfactuals involve calibrating the column header variables to the estimates from the 1966-1979 sample. The remaining variables are equal to the estimates in the 1984-2007 sample. Numbers in round brackets indicate the percentage decrease/increase in the standard deviation of output growth/ hours growth / inflation relative to the post-1984 baseline.

Table 9: SHOCKS COUNTERFACTUALS IN SMETS AND WOUTERS VERSUS OUR MODEL

Moment ↓	SW (no MA change)	SW (MA change)	Our model (no MA change)	Our model (MA change)
Std (Output gr.)	1.20	1.08	1.11	1.10
Std (Inflation)	1.30	0.58	0.34	0.39

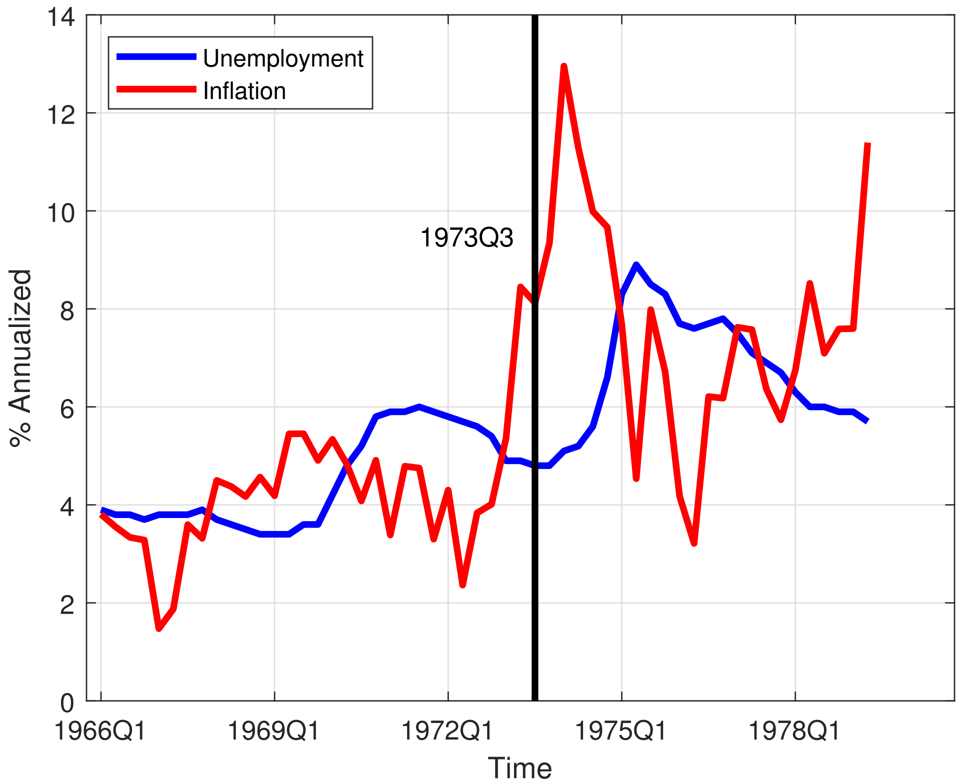
Notes: In each case the counterfactual is *what would have been the standard deviation of output growth and inflation in the Great Moderation if the shock processes were what they equaled in the pre-1979 period*. In both models we treat the monetary policy shock as part of the rule and **not** part of the shocks.

Figure 1: MONETARY POLICY SHOCKS IN THE GREAT INFLATION



Notes: The average monetary policy shock is depicted in the figure by μ. The average shock is computed for the sample 1960Q1:1973Q3 and 1973Q4:1979Q2. Monetary policy shocks are those obtained from the Kalman smoothed shocks for the mixed-forward rule.

Figure 2: UNEMPLOYMENT AND INFLATION DURING THE GREAT INFLATION



Notes: The black line indicates OPEC I which occurs at 1973Q3. Inflation is computed as the log difference in the consumption deflator. Unemployment is computed as the quarterly average of the number of unemployed as a percentage of the labour force (FRED code: `UNRATE`).

A Full Set of Log-linearized Equilibrium Conditions

For each trending variable M_t, we define $\widehat{m}_t = \log \widetilde{M}_t - \log \widetilde{M}$, where $\widetilde{M}_t$ represents the corresponding stationary variable and $\widetilde{M}$ its steady state.

$$\widehat{x}_t = \frac{\widetilde{X}+F}{\widetilde{X}}\left[\phi\widehat{\gamma}_t + \alpha\left(1-\phi\right)\left(k_t - \widehat{g}_{\Omega,t} - \widehat{g}_{I,t}\right) + (1-\alpha)(1-\phi)\widehat{L}_t\right] \tag{A1}$$

$$k_t = \widehat{g}_{\Omega,t} + \widehat{g}_{I,t} + \widehat{mc}_t - \frac{R\psi_K}{\Psi_K}\widehat{R}_t - \widehat{r}_t^k + \frac{\widetilde{X}}{\widetilde{X}+F}\widehat{x}_t \tag{A2}$$

$$\widehat{L}_t = \widehat{mc}_t - \frac{R\psi_L}{\Psi_L}\widehat{R}_t - \widehat{w}_t + \frac{\widetilde{X}}{\widetilde{X}+F}\widehat{x}_t \tag{A3}$$

$$\widehat{\gamma}_t = \widehat{mc}_t - \frac{R\psi_\Gamma}{\Psi_\Gamma}\widehat{R}_t + \frac{\widetilde{X}}{\widetilde{X}+F}\widehat{x}_t \tag{A4}$$

$$\widehat{y}_t = \frac{\widetilde{X}}{\widetilde{X}-\widetilde{\Gamma}}\widehat{x}_t - \frac{\widetilde{\Gamma}}{\widetilde{X}-\widetilde{\Gamma}}\widehat{\gamma}_t \tag{A5}$$

$$\widehat{\pi}_t = \frac{1}{1+\iota_p\beta}\iota_p\widehat{\pi}_{t-1} + \frac{\beta}{1+\iota_p\beta}E_t\widehat{\pi}_{t+1} + \kappa_p\widehat{mc}_t + \kappa_p\frac{\lambda_p}{1+\lambda_p}\widehat{\lambda}_{p,t} \tag{A6}$$

$$\widehat{\lambda}_t^r = \left\{\begin{array}{c} \frac{h\beta g_\Omega}{(g_\Omega-h\beta)(g_\Omega-h)}E_t\widehat{c}_{t+1} - \frac{g_\Omega^2+h^2\beta}{(g_\Omega-h\beta)(g_\Omega-h)}\widehat{c}_t + \frac{hg_\Omega}{(g_\Omega-h\beta)(g_\Omega-h)}\widehat{c}_{t-1}+ \\ +\frac{\beta hg_\Omega}{(g_\Omega-h\beta)(g_\Omega-h)}E_t\widehat{g}_{\Omega,t+1} - \frac{hg_\Omega}{(g_\Omega-h\beta)(g_\Omega-h)}\widehat{g}_{\Omega,t} + \frac{(g_\Omega-h\beta\rho_b)}{(g_\Omega-h\beta)}\widehat{b}_t \end{array}\right\} \tag{A7}$$

$$\widehat{\lambda}_t^r = \widehat{R}_t - E_t\widehat{\pi}_{t+1} + E_t\widehat{\lambda}_{t+1}^r - E_t\widehat{g}_{\Omega,t+1} \tag{A8}$$

$$\widehat{r}_t^k = \sigma_a\widehat{u}_t \tag{A9}$$

$$\widehat{\mu}_t = \left\{\begin{array}{c} \left[1-\beta(1-\delta)g_\Omega^{-1}g_I^{-1}E_t\left(\widehat{\lambda}_{t+1}^r + \widehat{r}_{t+1}^k - \widehat{g}_{\Omega,t+1} - \widehat{g}_{I,t+1}\right)\right] \\ +\beta g_\Omega^{-1}g_I^{-1}\left(1-\delta\right)E_t\left(\widehat{\mu}_{t+1} - \widehat{g}_{\Omega,t+1} - \widehat{g}_{I,t+1}\right) \end{array}\right\} \tag{A10}$$

$$\widehat{\lambda}_t^r = \left\{\begin{array}{c} \left(\widehat{\mu}_t + \widehat{\vartheta}_t\right) - \kappa\left(g_\Omega g_I\right)^2\left(\widehat{i}_t - \widehat{i}_{t-1} + \widehat{g}_{\Omega,t} + \widehat{g}_{I,t}\right) \\ +\kappa\beta\left(g_\Omega g_I\right)^2 E_t\left(\widehat{i}_{t+1} - \widehat{i}_t + \widehat{g}_{\Omega,t+1} + \widehat{g}_{I,t+1}\right) \end{array}\right\} \tag{A11}$$

$$\widehat{k}_t = \widehat{u}_t + \widehat{\bar{k}}_t \tag{A12}$$

$$E_t\widehat{\widehat{k}}_{t+1} = \left(1-(1-\delta)g_\Omega^{-1}g_I^{-1}\right)\left(\widehat{\vartheta}+\widehat{i}_t\right)+(1-\delta)g_\Omega^{-1}g_I^{-1}\left(\widehat{\widehat{k}}_t-\widehat{g}_{\Omega,t}-\widehat{g}_{I,t}\right) \tag{A13}$$

$$\left\{\begin{array}{c} \widehat{w}_t = \frac{1}{1+\beta}\widehat{w}_{t-1}+\frac{\beta}{(1+\beta)}E_t\widehat{w}_{t+1}-\kappa_w\left(\widehat{w}_t-\chi\widehat{L}_t-\widehat{b}_t+\widehat{\lambda}_t^r\right)+\frac{1}{1+\beta}\iota_w\widehat{\pi}_{t-1} \\ -\frac{1+\beta\gamma_w\iota_w}{1+\beta}\widehat{\pi}_t+\frac{\beta}{1+\beta}E_t\widehat{\pi}_{t+1}+\frac{\iota_w}{1+\beta}\widehat{g}_{\Omega,t-1}-\frac{1+\beta\iota_w}{1+\beta}\widehat{g}_{\Omega,t}+\frac{\beta}{1+\beta}E_t\widehat{g}_{\Omega,t+1}+\kappa_w\widehat{\lambda}_{w,t} \end{array}\right\} \tag{A14}$$

$$\widehat{R}_t = (1-\rho_r)\left[\alpha_\pi\widehat{\pi}_t+\alpha_y\left(\widehat{gdp}_t-\widehat{gdp}_{t-1}\right)\right]+\rho_r\widehat{R}_{t-1}+\widehat{\varepsilon}_t^r \tag{A15}$$

$$\widehat{gdp}_t = \widehat{y}_t-\frac{r^k\widetilde{K}}{\widetilde{Y}}g_\Omega^{-1}g_I^{-1}\widehat{u}_t \tag{A16}$$

$$\frac{1}{g}\widehat{y}_t = \frac{1}{g}\widehat{g}_t+\frac{\widetilde{C}}{\widetilde{Y}}\widehat{c}_t+\frac{\widetilde{I}}{\widetilde{Y}}\widehat{I}_t+\frac{r^kK}{\widetilde{Y}}g_\Omega^{-1}g_I^{-1}\widehat{u}_t \tag{A17}$$

$$\widehat{g}_{\Omega,t} = \frac{1}{(1-\phi)(1-\alpha)}\widehat{z}_t+\frac{\alpha}{1-\alpha}\widehat{\nu}_t \tag{A18}$$

$$\widehat{g}_{I,t} = \widehat{\nu}_t \tag{A19}$$

$$\widehat{b}_t = \rho_b\widehat{b}_{t-1}+\varepsilon_{t,b} \tag{A20}$$

$$\widehat{\vartheta}_t = \rho_\vartheta\widehat{\vartheta}_{t-1}+\varepsilon_{\vartheta,t} \tag{A21}$$

$$\widehat{\lambda}_{p,t} = \rho_p\widehat{\lambda}_{p,t-1}+\varepsilon_{p,t}-\theta_p\varepsilon_{p,t-1} \tag{A22}$$

$$\widehat{\lambda}_{w,t} = \rho_w\widehat{\lambda}_{w,t-1}+\varepsilon_{w,t}-\theta_w\varepsilon_{w,t-1} \tag{A23}$$

$$\widehat{g}_t = \rho_g\widehat{g}_{t-1}+\varepsilon_{g,t} \tag{A24}$$

$$\widehat{z}_t = \rho_z \widehat{z}_{t-1} + \varepsilon_{z,t} \tag{A25}$$

$$\widehat{\nu}_t = \rho_\nu \widehat{\nu}_{t-1} + \varepsilon_{\nu,t} \tag{A26}$$