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US Postwar Macroeconomic Fluctuations Without Indeterminacy *

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Abstract

We estimate a multi-shock DSGE model with a Bayesian method that differentiates between states of determinacy and indeterminacy. Determinacy is statistically preferred to indeterminacy before and after 1980. Key to this finding is a Taylor rule wherein the Fed targets output growth relative to trend instead of the level of the output gap or a mix of output gap and output growth. This allows us to revisit postwar macroeconomic fluctuations without indeterminacy. Relative to the pre-1980s, we find that the post-1983 contribution of shocks to the marginal efficiency of investment to the cyclical variance of output growth fell from 50% in the pre-1980s to 20% during the Great Moderation. Greater nominal wage flexibility was a main source of decline in the volatility of output and working hours during the Great Moderation, a finding which appears consistent with the post-1980 large deunionization in the private sector. Lower inflation variability resulted mostly from the Fed's hawkish stance against inflation and changes in preference parameters. Lower trend inflation and smaller shocks were not major factors driving the Great Moderation.

JEL classification: E31, E32, E37.

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

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1 Introduction

Large variations in busines cycle fluctuations like those observed from the pre-1980s to the Great Moderation offer macroeconomists a unique opportunity to confront their theories with the data. A possible explanation, as put forth by Clarida et al. (2000), is that the US economy was in a state of indeterminacy during the pre-1980s because the Fed did not adjust the nominal interest rate strongly enough in response to inflation, while a more aggressive stance against inflation helped restore determinacy after 1983.[1] Another view held by Coibion and Gorodnichenko (2011) is that a lower rate of trend inflation was a key factor moving the economy from a state of indeterminacy to one of determinacy.[2] Still, another popular explanation is that the US economy benefited from much smaller shocks after 1983 (Stock and Watson (2003), Sims and Zha (2006), and Smets and Wouters (2007)).

Our paper offers a new perspective on this timely question by providing evidence which tends to refute these leading explanations. To this end, we estimate a multi-shock New Keynesian (NK) model using a Bayesian method that explicitly allows differentiating between states of determinacy and indeterminacy, leaving the data to determine which outcome is statistically preferred.

A main finding relative to the existing literature is that determinacy is preferred to indeterminacy for both the pre-Volcker period and Great Moderation. A key factor behind this finding is that the Fed in adjusting the nominal interest rate is taken to target deviations of output growth from trend growth rather than the output gap or a mix of output gap and output growth. We adopt this approach to the Taylor rule following recent contributions on indeterminacy in economies with positive trend inflation.

Coibion and Gorodnichenko (2011) first suggested that with positive trend inflation, a policy rule aiming at the output gap widens the parameter space of policy response to inflation generating indeterminacy relative to one targeting output growth. Their conclusion is based on a sticky-price model without interest rate smoothing. By contrast, Khan et al. (2020)

[1] 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.

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

showed that if the Fed smooths interest rates under sticky prices and positive trend inflation, there is almost no difference in the ability of alternative policy rules to achieve determinacy. Instead, the key factor determining whether the economy will be in a state of determinacy or indeterminacy is sticky nominal wages, not sticky prices which play a negligible role if trend inflation is in the range of 0% to 4%. With sticky wages, the policy responses to inflation consistent with determinacy under a rule aiming at the output gap, or a mix of output gap and output growth, are implausibly high compared to those under a rule targeting output growth.

These studies either rely on calibrated small-scale NK models or medium-scale NK models with a parsimonious choice of shocks. For the first time, we base the evidence on a multi-shock, medium-scale NK model estimated using a Bayesian estimation and solution method proposed by Bianchi and Nicoló (2020) that formally differentiates between the determinacy and indeterminacy outcomes. This method consists of appending additional auxiliary equations equal to the degrees of indeterminacy. Specifically, we allow for indeterminacy of degree one. The auxiliary equation features an innovation which is a linear combination of the sunspot shock and the forecast error of inflation. Under indeterminacy, the auxiliary process is explosive, providing the appropriate number of explosive roots and yielding a solution to the model which is identical to the one obtained using the method of Lubik and Schorfheide (2003). When imposing determinacy, this auxiliary process has a root inside the unit circle, and therefore, plays no role in the model dynamics.[3]

Besides the Taylor rule targeting output growth, our model includes the standard elements of medium-scale NK models like nominal wage and price contracting and real adjustment frictions (e.g. see Christiano et al. (2005)). We add to this standard model positive trend inflation, economic growth, intermediate goods and an extended working capital channel.

Positive long-run or trend inflation is a fact. Real output growth stems from trend growth

[3]One can also argue that it is much easier to observe output growth relative to some long-run trend rather than the output gap. Furthermore, the concept of "output gap" defined as short-run deviations of output from the level of output at flexible nominal wages and prices and no mark up shocks (i.e. the efficient level of output) was not even known during the pre-Volcker era and a good part of the Great Moderation. For example, Clarida et al. (2000) used measures of the output gap from the Congressional Budget Office (CBO) and the deviation of (log) GDP from a fitted quadratic time trend.

in neutral and investment-specific technologies (Justiniano et al., 2011). Intermediate goods follow from firms using the output of others as a productive input (Basu (1995); Huang et al. (2004)). This also implies strategic complementarities in the firms' pricing decisions. Extended working capital implies that firms borrow financial capital to pay a fraction of all their input costs, allowing for a cost-channel by which monetary policy can also have supply-side effects.

While the consensus is that the pre-Volcker period was characterized by indeterminacy, there are nonetheless a few exceptions to this in the literature. A notable exception is Bilbiie and Straub (2013), who add the assumption of limited asset market participation to an otherwise standard NK model with sticky prices without capital accumulation. Their policy rule is one wherein the nominal interest rate reacts to expected inflation and to the contemporaneous level of output. Their evidence suggests the pre-Volcker years were characterized by determinacy. While our determinacy result for the pre-Volcker years seems consistent with theirs, the central mechanism leading to determinacy in the two models is quite different. In their model, low asset market participation results into increases in interest rate being expansionary, so that passive monetary policy ensures equilibrium determinacy.[4] In our model, the policy rule targets both expected inflation and the contemporaneous deviation of output growth from trend growth, so that a moderately active monetary policy ensures determinacy.

Still, another exception is Haque et al. (2021), who estimate a NK model with sticky prices, trend inflation, commodity price shocks, real wage rigidity, and no capital accumulation. Their policy rule includes both the level of the output gap and output growth as in Smets and Wouters (2007). They find that when combining these ingredients, the reaction to the output gap is nearly zero, so that determinacy can be achieved. Our work departs from theirs in that we account for sticky wages and sticky prices and other theoretical refinements. As shown in Khan et al. (2020), and Phaneuf and Victor (2019, 2021), the most important channel whereby trend inflation affects the determinacy outcome is through sticky wages and steady-state

[4] When extending their framework to include both sticky wages and sticky prices, two features of the present model, Ascari et al. (2017) show that a moderate amount of nominal wage stickiness prevents inversion of the slope of the IS curve.

wage dispersion, not through sticky prices and steady-state price dispersion.[5]

Our results can be summarized as follows. Our estimated model implies a sharp decline in trend inflation after 1984, from 6.6% to 3.2%.[6] Moreover, we find that the policy response to inflation prior to the 1980s exceeds Taylor's prescription of 1.5, a finding which is consistent with (Orphanides (2002)) who argued that monetary policymakers did satisfy the Taylor principle even before the entry of Paul Volcker as Chair of the Federal Reserve. Hence, our empirical findings do not support the view that the macroeconomic instability observed during the pre-Volcker period resulted from indeterminacy and passive monetary policy.[7]

While we are interested in how systematic monetary policy evolved from the pre-Volcker period to the Great Modration, we also take a close look at shocks to the Taylor rule. Our evidence suggests that interest rate smoothing and policy responses to inflation and output growth all became stronger after 1984. Using Kalman smoothed shocks extracted from our estimated model, we find that shocks to the Taylor rule were negative on average in both periods, but that they were more frequent and much stronger before 1980, thus providing expansionary stimulus to the economy despite systematic monetary policy was active during the pre-1980s. This was especially true between OPEC I and the end of the 1970s, where our evidence suggests that in the wake of OPEC I the Fed launched a series of highly expansionary policy shocks (presumably in response to the sharp increase in unemployment that followed OPEC I).

We also use our estimated model to reassess the sources of postwar business cycles. We find that there was a sharp decline in the contribution of shocks to the marginal efficiency of investment (MEI shocks) to the cyclical forecast variance decomposition of output growth–

[5]Using US disaggregated price data, Nakamura et al. (2018) find no evidence of higher dispersion with higher trend inflation. Phaneuf and Victor (2019) identify plausible conditions giving rise to a weak relation between trend inflation and price dispersion in NK models. They show that the relation that really matters in NK models is that between trend inflation and wage dispersion, not between trend inflation and price dispersion.

[6]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. Their estimate of annualized average inflation is 2.88% prior to 1979:2 and 2.68% after 1984:1

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

from 50% to 20%–from the pre-Volcker period to the Great Moderation. The smaller contribution of MEI shocks to the cyclical variance of output growth during the Great Moderation echoes the empirical findings reported by Christiano et al. (2014). Using a model that emphasizes the role of risk shocks estimated from 1985:Q1 to 2010:Q2, they find that MEI shocks explain only 13% of the cyclical variance of output growth.[8]

Our evidence concerning the factors driving the Great Moderation suggests there was a significant increase in nominal wage flexibility after 1983 relative to the pre-Volcker period. Based on counterfactual experiments, we show that greater nominal wage flexibility was the key factor lowering the volatility of output growth and change in hours. We argue that higher nominal wage flexibility appears consistent with the large-scale deunionization that took place in the US private sector after 1980.

Higher nominal wage flexibility did not account for lower inflation variability. The key factor driving lower inflation variability after 1983 was a more aggressive policy stance against inflation. Preference parameters, namely changes in the parameters governing habit formation and labour supply elasticity, also contributed to lowering inflation variability. A lower trend inflation was not a critical factor contributing to the decline in output and inflation volatility.

Finally, while the Great Moderation has witnessed smaller shocks, we do not find evidence that the 'good-luck hypothesis' played 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.

[8]Note that their sample starts only in 1985:Q1 due to data limitations, so we lack evidence about what their model would imply for the pre-Volcker period.

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 describing 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:

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

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

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

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. $N(0, \sigma_{\eta^I}^2)$ 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:

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

subject to:

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

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:

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

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

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

where $\overline{\phi} \equiv \phi^{-\phi}\left(1-\phi\right)^{\phi-1}\left(\alpha^{-\alpha}\left(1-\alpha\right)^{\alpha-1}\right)^{1-\phi}$, $mc_t = \frac{MC_t}{P_t}$, 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 $S''\left(.\right) > 0$, 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 $\alpha_{\Delta y}$. 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:

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

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 using 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 hat 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.[9] 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

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

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.

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 1966:Q1 to 1979:Q2.

4.1 Indeterminacy vs Determinacy in the Pre-Volcker Years

There are two main differences when estimating our model under indeterminacy or 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.[10] Our finding

[10] We do not formally report the estimation results for the Great Moderation since it is obvious that the model

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.[11]

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

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version with determinacy is preferred to the model with indetermiancy.

[11]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.

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 MEI shock is 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 before and after OPEC I during the pre-Volcker period.

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. Therefore, our evidence suggests monetary policy shocks 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.

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 to output growth 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 the 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 in the data for 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.

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.[12]

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 be-

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

fore 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 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 an increase in the volatility of real average hourly wages relative to output after 1984.

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 Smets and Wouters (2007)

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 pre-Volcker period and the Great Moderation using an estimation method that allows us to discriminate between indeterminacy and determinacy. We found that determinacy is preferred to indeterminacy for the pre-Volcker period. This result 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 during the Great Moderation.

The forecast error variance decomposition based on our estimated models suggests that it may be misleading to take the postwar era as a single period for the estimation. When divided in two subperiods, the pre-Volcker period and the Great Moderation, we obtain very different findings about the sources of postwar business cycle fluctuations. In particular, we find that the contribution of investment shocks to output fluctuations dropped by nearly 30% during the Great Moderation.

Our evidence points to greater nominal wage flexibility, likely due to the large-scale de-unionization 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.

Increased wage flexibility played a little role in bringing down inflation variability after 1984. The key elements driving lower inflation volatility were shown to be a hawkish policy stance against inflation and variations in preference parameters. We also found that lower trend inflation and the ‘good-luck hypothesis’ did not play a significant role driving the Great Moderation.

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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
α_π	normal	1.500	0.3000	0.9271	0.0744	1.5639	0.1723
$\alpha_{\Delta y}$	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	

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
α_π	normal	1.500	0.3000	1.5639	0.1723	2.2743	0.1514
$\alpha_{\Delta y}$	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 under determinacy, 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 parameters to the estimates from the 1966-1979 sample. The remaining parameters 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 parameters to the estimates from the 1966-1979 sample. The remaining parameters 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 parameters to the estimates from the 1966-1979 sample. The remaining parameters 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.

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.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$\widehat{R}_t = (1-\rho_r)\left[\frac{1}{4}\alpha_\pi E_t\widehat{\pi}_{t,t+3} + \alpha_{\Delta y}\left(\widehat{gdp}_t - \widehat{gdp}_{t-1}\right)\right] + \rho_r\widehat{R}_{t-1} + \widehat{\varepsilon}_t^r \tag{A15}$$

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

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

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

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

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

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

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

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

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

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

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