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Abstract

We offer a tale of two major postwar business cycle episodes: the pre-1980s and the post-1982s prior to the Great Recession. We revisit the sources of business cycles and the reasons for the large variations in aggregate volatility from the first to the second episode. Using a medium-scale DSGE model where monetary policy potentially has cost-channel effects, we first show the Fed most likely targeted deviations of output growth from trend growth, not the output gap, for measure of economic activity. When estimating our model with a policy rule reacting to output growth with Bayesian techniques, we find the US economy was not in a state of indeterminacy in *either* of the two sub-periods. Thus, aggregate instability before 1980 did not result from self-fulfilling changes in inflation expectations. Our evidence shows the Fed reacted more strongly to inflation after 1982. Based on sub-period estimates, we find that shocks to the marginal efficiency of investment largely drove the cyclical variance of output growth prior to 1980 (61%), while they have seen their importance falls dramatically after 1982 (19%). When looking at the sources of greater macroeconomic stability during the second episode, we find no support for the "good-luck hypothesis". Change in nominal wage flexibility largely drove the decline in output growth volatility, while the change in monetary policy was a key factor lowering inflation variability.

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

We offer a tale of two major US postwar business cycle episodes: the pre-1980 and post-1982 sub-periods. We do not include the Great Recession and the years after to focus on economic episodes during which the Federal Reserve (Fed) implemented conventional monetary policy. We find that the US economy was in a state of determinacy during *both* episodes, the Fed adopted a more aggressive stance against inflation after 1982, technological shocks dominated non-technological shocks prior to 1980 but not after 1982. The second episode has seen greater output stability mainly because of increased nominal wage flexibility, and the lower inflation variability was in good part due to the Fed's more aggressive fight against inflation.

It is generally agreed that the Fed implemented conventional monetary policy between the early 1960s and the Great Recession, a period we refer to as "normal times" with respect to policy-making. Conventional monetary policy usually refers to the Fed's practice of setting nominal interest rates based on a comprehensive feedback rule (Taylor (1993); Clarida, Galí, and Gertler (2000)). The consensus holds that between the early 1960s and late 1970s, the Fed adjusted nominal interest rates less than one-for-one for each percentage change in inflation, resulting into self-fulfilling fluctuations, high and volatile inflation, and macroeconomic instability more generally. The consensus is also that between the early 1980s and the Great Recession, the Fed reacted much more than one-for-one to inflation and helped achieving determinacy and greater macroeconomic stability.

Following the influential work of Clarida, Galí, and Gertler (1999, 2000) (CGG), a rule widely accepted was one stating that the Fed smooths short-term movements in nominal interest rates and systematically reacts to short-run deviations of inflation from target and to the level of the output gap. Subsequently, Smets and Wouters (2007) have proposed a variant of the CGG-rule telling that while the Fed smooths interest rates and reacts to inflation, it also adjusts the nominal interest rate in response to the level of the output gap and the change in the output gap. We refer to this policy rule as "the mixed output gap-output growth rule" or "mixed policy rule" for short.

The mixed policy rule has been used in different contexts to address important macroeconomic questions. Justiniano, Primiceri, and Tambalotti (2010, 2011) and Khan and Tsoukalas (2011, 2012) have used the mixed rule in DSGE models to study the sources of business cycle fluctuations. Coibion and Gorodnichenko (2011) have extended it to allow for an interest smoothing effect of order two, and have explored the effect of positive trend inflation on the prospect of indeterminacy and the sources of persistent changes in target interest rate. Coibion, Gorodnichenko, and Wieland (2012) have used the mixed rule to study the optimal rate of inflation in a New Keynesian price setting model.

However, Khan, Phaneuf, and Victor (2020) have questioned whether the Fed has ever targeted the output gap. Using a medium-scale DSGE model emphasizing the interaction between positive trend inflation, sticky wages and economic growth, as opposed to standard sticky-price models without economic growth, they have shown that achieving determinacy with the mixed rule or a rule targeting only the output gap requires implausibly large departures from the Taylor Principle.

In this context, our paper makes four contributions. For this purpose, we use a DSGE wage and price setting framework that includes real adjustment frictions, positive trend inflation, real per capita output growth, an input-output production structure and working capital. In theory, monetary policy can work through a cost channel because firms have access to working capital from a financial intermediary to pay some of their input costs while they reimburse the loans at the end of the period at the nominal interest rate (Christiano and Eichenbaum (1992); Christiano, Eichenbaum, and Evans (1997, 2005); Christiano, Trabandt, and Walentin (2011); Phaneuf, Sims, and Victor (2018)). The empirical support for the cost channel is presented in Ravenna and Walsh (2006), Chowdhury, Hoffmann, and Schabert (2006), and Tillman (2008), among others.

Our first substantive finding is to show through numerical simulations that the prospect of determinacy will be less likely with a cost-channel for monetary policy if the Fed targets the output gap. Quite remarkably, a policy rule reacting to deviations of output growth from trend growth ensures determinacy for inflation responses close to the original Taylor Principle despite the existence of a cost channel and positive trend inflation.

Our second contribution comes from the estimation of our medium-scale DSGE model with a policy rule reacting to deviations of output growth from trend growth. The model is estimated with the help of a Bayesian econometric procedure for three samples of data: 1960:Q1-2007:Q3, 1960:Q1-1979:Q2 and 1982:Q4-2007:Q3. We find that contrary to conventional wisdom, the economy was in a state of determinacy during our two sub-periods. This precludes the possibility that self-fulfilling inflation expectations were the source of macroeconomic instability during the period 1960:Q1-1979:Q2.

At the same time, we find that there was an important change in conventional monetary policy after 1982:Q3. The most important one pertains to the Fed's reaction to inflation which was much stronger after 1982. Specifically, while the estimated response to inflation was 1.13 prior to 1980, it increased to 1.91 after 1982. We find that the Fed's reaction to output growth was stronger too and that the degree of interest rate smoothing was higher after 1982. Clarida, Galí, and Gertler (2000) and Coibion and Gorodnichenko (2011) also report evidence of a significant increase in the Fed's reaction to inflation after the early 1980s.

Our third contribution is to assess the sources of postwar business cycles conditioned on our estimated models. In particular, we ask what these sources were based on the cyclical forecast error variance decompositions of our observable variables. When looking at the estimates from our full-sample, we find that technology shocks in the production of installed capital (Marginal Efficiency of Investment or MEI shocks) have been the key drivers of the cyclical variance of output growth, investment growth, hours, inflation and interest rates. Our results are broadly consistent with those presented in Justiniano, Primiceri, and Tambalotti (2010, 2011), Khan and Tsoukalas (2011), and Phaneuf and Victor (2019).

We obtain quite different results when looking at sub-sample estimates. Our pre-1980 estimates suggest the contributions of MEI shocks, and technological shocks more generally, have been higher than for the full-sample. Therefore, the pre-1980s have been marked by the dominance of technological shocks over non-technological shocks.

By contrast, our post-1982 estimates suggest the contribution of MEI shocks to output fluctuations has dropped considerably from 61% in the first sub-period to 19% in the second. The overall contribution of technological disturbances also declined significantly, from 78% of the cyclical variance of output growth to 45%. Hence, non-technological shocks have predominated after 1982.

The much smaller contribution of MEI shocks to the cyclical variance of output growth after 1982 is broadly consistent with a finding reported by Christiano, Motto, and Rostagno (2014). These authors estimate that risk shocks have contributed 62% of the cyclical variance of output growth, and MEI shocks only 13%. Our findings do not necessarily contradict theirs. Christiano, Motto, and Rostagno (2014) focus on the single period 1985:Q1-2010:Q2 due to some data limitations. By contrast, we focus on two sub-periods. Data limitations preclude the use of risk shocks for our two sub-samples. More importantly, our own post-1982 estimates suggest the contribution of MEI shocks has been much smaller in the second sub-period, down to 19% and this without risk shocks.

Our fourth contribution is to offer a new look at the reasons for greater macroeconomic stability after 1982. We perform counterfactual experiments designed at identifying the sources of the sharp decline in aggregate volatility as changes originating from the estimated shock processes, monetary policy rule, and structural parameters of the model.

Our findings provide no support for the "good-luck hypothesis". Changes in the estimated shock processes contribute negligibly to the declines in the standard deviation of output growth and inflation after 1982. Change in nominal wage flexibility drives most of the decline in the volatility of output growth, while changes in monetary policy are a key factor driving the decline in inflation variability.

The rest of the paper is organized as follows. Section 2 presents our medium-scale DSGE model with trend inflation, economic growth and a cost-channel for monetary policy. Section 3 uses numerical simulations to address the prospect of determinacy for alternative policy rules. Section 4 looks at the estimation strategy and data. Section 5 analyzes our estimation results and implications for the sources of postwar business cycles. Section 6 studies the reasons for the sharp decline in macroeconomic volatility after 1982. Finally, section 7 contains concluding remarks.

2 The Model

As in Christiano, Eichenbaum, and Evans (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-size New Keynesian model, we add non-zero steady state inflation, real per capita output growth, input-output linkages between firms, and a cost channel for monetary policy. We close the model with a mixed policy rule, and a rule reacting to output growth only. To allow for model estimation using Bayesian techniques, the model includes eight shocks. Real per capita output growth stems from stochastic trend growth in neutral and investment-specific technological progress. These theoretical ingredients represent the core of some recently estimated medium-scale DSGE models in the literature.

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. 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 gets to choose 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 is given 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:

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

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, and ψ is the fraction of factor payments financed through short-term loans at the gross nominal interest rate R_t. It is through this channel that monetary policy can have a direct effect on the cost-side of firms and on the New Keynesian Price Phillips Curve, more generally.[1]

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:

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

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

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

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 the real marginal cost which is common to all firms, r_t^k is the real rental price on capital services, and w_t is the real wage.

[1] Note that with this formulation firms are not limited to use working capital only to finance the wage bill.

Intermediate firms allowed to reoptimize their price choose a price P_t^*. Those not allowed to reoptimize will 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 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:

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

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 in (23). Each period, there is a fixed probability, $(1 - \xi_w)$, that households can reoptimize their nominal wage. As in Erceg, Henderson, and Levin (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 intertemporal preference 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.

The intertemporal preference 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. $N(0, \sigma_b^2)$ preference 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

We will consider two different monetary policy rules. The first one is the mixed output gap-output growth rule:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_R} \left[\left(\frac{\pi_t}{\pi} \right)^{\alpha_\pi} \left(\frac{Y_t}{Y_t^*} \right)^{\alpha_y} \left(\frac{Y_t / Y_{t-1}}{Y_t^* / Y_{t-1}^*} \right)^{\alpha_{\Delta y}} \right]^{1-\rho_R} \varepsilon_t^r, \tag{27}$$

where R is the steady state of the gross nominal interest rate. This rule state that the interest rate responds to deviations of inflation from its steady state, as well as to the level and the growth rate of the output gap (Y_t/Y_t^*).[2] ρ_R is a smoothing parameter, α_π, α_y and $\alpha_{\Delta y}$ are control parameters, and ε_t^r is monetary policy shock which is i.i.d. $N(0, \sigma_r^2)$.

An alternative policy rule is one where the Fed smooths movements in the nominal interest and responds to deviations of inflation from steady state and to deviations of the growth rate of real GDP $(\widehat{Y}_t / \widehat{Y}_{t-1})$ from trend output growth $g_{\widehat{Y}}$:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_R} \left[\left(\frac{\pi_t}{\pi} \right)^{\alpha_\pi} \left(\frac{\widehat{Y}_t}{\widehat{Y}_{t-1}} g_{\widehat{Y}}^{-1} \right)^{\alpha_{\Delta \hat{y}}} \right]^{1-\rho_R} \varepsilon_t^r. \tag{28}$$

[2]The GDP gap is the difference between actual GDP and its efficient level (Woodford, 2003).

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:

$$G_t = \left(1 - \frac{1}{g_t}\right) Y_t, \tag{29}$$

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

$$\ln g_t = (1 - \rho_g) \ln g + \rho_g \ln g_{t-1} + \varepsilon_{g,t}. \tag{30}$$

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 can be written as:

$$X_t = A_t \Gamma_t^{\phi} \left(K_t^{\alpha} L_t^{1-\alpha}\right)^{1-\phi} - \Omega_t F. \tag{31}$$

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

$$Y_t = X_t - \Gamma_t, \tag{32}$$

where Γ_t denotes total intermediates. Real GDP is given by

$$\widehat{Y}_t = C_t + I_t + G_t. \tag{33}$$

The resource constraint of the economy is:

$$\frac{1}{g_t} Y_t = C_t + I_t + \frac{a(u_t) K_t}{V_t^I} \tag{34}$$

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 Rule-Based Monetary Policy and the Prospect of Indeterminacy

This section shows through numerical simulations that achieving determinacy in our DSGE model calls for significant departures from the original Taylor Principle when conventional monetary policy is represented by the mixed rule. That is, the inflation responses at low rates of trend inflation which are required to ensure determinacy not only are well above 1 under the mixed rule, but they are well beyond the estimates found in the broader literature. By contrast, a policy rule responding to output growth ensures determinacy for interest rate responses to inflation close to 1, and this even when a cost channel for monetary policy is accounted for.

3.1 Calibration

Some parameters are calibrated to their conventional long-run targets in the data, while others are based on the previous literature. The calibration is summarized in Table 1, with the unit of time being a quarter. Some parameters like $\beta = 0.99$, $b = 0.8$, $\eta = 6$, $\delta = 0.025$ and $\alpha = 0.33$ are standard values in the literature and require no explanation, some others do.

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

$$a(Z_t) = \gamma_1(Z_{t-1} - 1) + \frac{\gamma_2}{a}(Z_t - 1)^2,$$
$$S\left(\frac{I_t}{I_{t-1}}\right) = \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - g_v\right)^2.$$

The investment adjustment cost parameter is $\kappa = 3$, consistent with the estimate in Christiano, Eichenbaum, and Evans (2005). The parameter γ_1 is set so that steady state utilization is 1, and that γ_2 is five times γ_1, consistent with the estimates provided in Justiniano, Primiceri, and Tambalotti (2010, 2011).

The elasticities of substitution between differentiated goods and differentiated skills are both set at 10, which are common values in the literature. The Calvo probability of price non-reoptimization ξ_p is 2/3, implying an average waiting time between price changes of 9 months. The Calvo probability of wage non-reoptimization ξ_w is also set at 2/3, meaning that nominal wages remain unchanged for 9 months on average.

The parameters of the mixed policy rule are the interest rate smoothing parameter, ρ_r, which is set at 0.8, the coefficient on the level of the output gap, α_y, set at 0.2, and the coefficient on the rate of change of the output gap, $\alpha_{\Delta y}$, also set at 0.2. The interest rate response to inflation, α_π will be the minimum value needed for determinacy at a given inflation trend level.

We set the fraction of factor payments financed by short-term loans, ψ, either to 0 (no cost-channel) or to 0.5, respectively. The parameter ϕ, measuring the share of intermediates into gross output is set to $\phi = 0.5$ following Basu (1995), Dotsey and King (2006) and Christiano, Trabandt, and Walentin (2011).

Mapping the model to the data, the trend growth rate of the IST term, g_v, equals the negative of the growth rate of the relative price of investment goods. To measure this in the data, we define investment as expenditures on new durables plus private fixed investment, and consumption as consumer expenditures of nondurables and services, as in Justiniano, Primiceri, and Tambalotti (2010). These series are from the BEA and cover the period 1960:I-2007:III, to leave out the financial crisis.[3] The relative price of investment is the ratio

[3]See Ascari, Phaneuf, and Sims (2018) for a detailed description of how these data are constructed.

of the implied price index for investment goods to the price index for consumption goods. The average growth rate of the relative price from the period 1960:I-2007:III is -0.00472, so that $g_v = 1.0047$. Real per capita GDP is computed by subtracting the log civilian non-institutionalized population 16 and over from the log-level of real GDP. The average growth rate of the resulting output per capita series over the period is 0.005712, so that $g_Y = 1.005712$ or 2.28 percent a year. Given the calibrated growth of IST from the relative price investment data ($g_v = 1.0047$), we then pick $g_z^{1-\phi}$ to generate the appropriate average growth rate of output. This implies $g_z^{1-\phi} = 1.0022$ or a measured growth rate of TFP of about 1 percent per year.

3.2 Determinacy Under Alternative Policy Rules

When searching for the minimum α_π-values consistent with determinacy, all other parameters keep their values pre-assigned by our calibration. Table 2 displays the minimum values consistent with determinacy for levels of trend inflation of 0, 2%, and 3% (annualized). When accounting for a cost channel for monetary policy, we assume that the fraction of input prices financed through working capital is 0.5.

Panel A of the table presents the minimum α_π-values consistent with determinacy for a coefficient on the output gap of 0.2. It reports these values without a cost channel for monetary policy ($\psi = 0$) and with it ($\psi = 0.5$). Panel B reports values for the cases where the coefficient response on the output gap is either 0.3 or 0.4, and this with working capital ($\psi = 0.5$).

A number of observations can be drawn from this table. First, one sees from Panel A that even if trend inflation is zero, strict compliance with the Taylor Principle no more guarantees determinacy. Without working capital, the minimum α_π consistent with determinacy is 1.3, while with a cost channel for monetary policy, it is 1.6.

Second, the minimum α_π-value required for determinacy gets higher with positive trend inflation. For example, with 2% and 3% trend inflation and no working capital, the minimum α_π-values are 1.9 and 2.5. These are quite large departures from the original Taylor Principle for such low levels of trend inflation.

Third, accounting for a cost channel for monetary policy makes it even more difficult to achieve determinacy without implementing very aggressive responses of nominal interest rates to inflation, beyond those typically found in the literature. Note that with working capital and 2% trend inflation, these values are 2.3, 3 and 3.6 for a coefficient response to the output gap of 0.2, 0.3 and 0.4, respectively. In fact, with gap coefficients of 0.3 and 0.4 and trend inflation of 3%, we are unable to identify value for α_π that will guarantee determinacy (to which refer as "empty set").

Finally, we also consider the case where monetary policy responds to deviations of output growth from trend growth with a coefficient response to output growth of 0.2 (not formally reported). The results are striking. Whether trend inflation is zero or positive at 2% or 3%, and whether there is working capital or not, we find that $\alpha_\pi \geq 1$ will ensure determinacy. This is true even when ψ equals 1.

We conclude from our findings presented in this section that the Fed did not target the output gap, as this would require implausibly strong policy reactions to inflation. By contrast, our findings establish that it is much more likely for the Fed to have implemented a policy rule responding to deviations of output growth from trend growth.

4 Estimation Methodology and Data

In this section we describe the data and the Bayesian estimation methodology used in our empirical analysis. We intend to estimate the model presented in section 2 using the policy rule wherein the Fed reacts to deviations of output growth from trend growth.

4.1 Data

We estimate the 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 the GDP 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 GDP 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 GDP deflator. The nominal interest rate series is the effective Federal Funds rate. The relative price of investment is defined as in section 3.1. All data except the interest rate are in logs and seasonally adjusted.

4.2 Bayesian Methodology

We use the Bayesian methodology to estimate a subset of model parameters. This methodology is now extensively used in estimating DSGE models and recent overviews are presented in An and Schorfheide (2007) and Fernández-Villaverde (2010). 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:

$$v_t = A v_{t-1} + B \varepsilon_t$$

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

where A and B denote matrices of reduced form coefficients that are non-linear functions of the structural parameters. v_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 follow: $\overline{g}_\Omega = 100 \log g_\Omega$, $\overline{L} = 100 \log L$,

$\overline{\pi} = 100 \log \pi$, $\overline{R} = 100 \log R$ 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, $p(\mathbf{Y}_T \Theta, M_i)$, 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, $p(\mathbf{Y}_T, M_i) = \int p(\Theta) p(\mathbf{Y}_T \mid M_i) d\Theta$ 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. The posterior distribution of parameters is evaluated numerically using the random walk Metropolis–Hastings algorithm. We simulate the posterior using a sample of one million draws and use this (after dropping the first 20% of the draws) to *i*) report the mean, and the 10 and 90 percentiles of the posterior distribution of the estimated parameters, and *ii*) evaluate the marginal likelihood of the model. All estimations are done using Dynare (Adjemian et al. (2011)).

4.3 Prior Distribution

Table 3 lists the choice of priors for the parameters we estimate. We use prior distributions broadly in line with those adopted by Smets and Wouters (2007) and Justiniano, Primiceri, and Tambalotti (2011). Some parameters are held fixed prior to the estimation. We assign to them values commonly found in the literature. 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 equal to 0.21, the average value in the sample. The steady state wage and price markups are both set equal to 20%, which correspond to elasticities of substitution between differentiated goods and skills of 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 percentage of input prices financed by working capital, ψ, we also use a Beta prior, with mean 0.3 and standard deviation 0.1.

5 Was the US In a State of Indeterminacy During the Postwar Era?

This section first compares estimates for the full-sample 1960:Q1-2007:Q3 and the two subsamples 1960:Q1-1979:Q2 and 1982:Q4-2007:Q3 in order to assess whether the US economy was in a state of indeterminacy during the postwar period and investigate the stability of the full-sample estimates. Then, it contrasts the sources of business cycle fluctuations based on our estimated models.

5.1 Full-Sample Estimates

Table 3 gives the mean and the 10 and 90 percentiles of the posterior distribution of the structural parameters obtained by the Metropolis-Hastings algorithm for the full-sample. It also presents those of the shock processes.

We find for the period 1960:Q1-2007:Q3 that the policy response to inflation, α_{π}, was 1.59 and hence close to Taylor's (1993) original prescription. At the same time, the response to output growth, $\alpha_{\Delta\hat{y}}$, was 0.23, and the degree of interest rate smoothing, ρ_R, was 0.81.

Our estimates imply that the frequency of wage adjustment has been higher than the frequency of price adjustments. That is, $\xi_w = 0.55$ implies that nominal wages have been reoptimized once every 6.6 months on average, while $\xi_p = 0.73$ implies that prices have been reset once every 11.1 months on average. Note also that the degrees of wage and price indexation to past inflation are quite small, with an estimate of 0.11 for wage indexing and

0.21 for price indexing.

We are not the first to report evidence that nominal wages have been more flexible than prices during the postwar period. For example, Rabanal and Rubio-Ramírez (2005) report estimates of ξ_w and ξ_p which are respectively 0.63 and 0.77 without indexation for the period 1960:Q1-2001:Q4, while with indexation they are $\xi_w = 0.57$ and $\xi_p = 0.76$, respectively.

Galí (2011) also offers evidence of relatively flexible nominal wages based on a thorough empirical investigation of the Wage Phillips Curve using a postwar sample of data covering the period 1964:Q1-2009:Q3. Under the assumption of a Frisch labour supply elasticity of 1, he obtains an estimate of ξ_w of 0.52 (see Table 3).

Our estimation also confirms the existence of a cost channel for monetary policy with a posterior mean for the extent of input costs financed through working capital which is $\psi = 0.23$. We also find evidence of roundaboutness in the production structure, with a posterior mean for the share of intermediate inputs into gross output which is $\phi = 0.57$. This estimate is broadly consistent with values normally assigned to share ϕ by calibration.

5.2 Sub-Sample Estimates

Tables 4 and 5 report our sub-sample estimates. We find that in each sub-period the Fed has conducted its policy in compliance with the Taylor Principle, with responses to inflation greater than 1. Therefore, the US economy was not in a state of indeterminacy in either sub-period.

However, we find evidence of significant changes in the estimated parameters of the policy rule. The most notable pertains to the policy response to inflation. The posterior mean of α_π is 1.16 for the period 1960:Q1-1979:Q2, while it is 1.9 for the period 1982:Q4-2007:Q3. Our estimates hence suggest the Fed accommodated inflation much less after 1982. The Fed reacted also somewhat more to output growth in the second sub-period with a posterior mean for $\alpha_{\Delta\hat{y}}$ of 0.2 compared to 0.16 in the first sub-period. Finally, the Fed increased the degree of interest rate smoothing in the second sub-period to 0.87 relative to 0.79 in the first sub-period.

Our findings stand in contrast to most of the previous literature on determinacy. This literature says that indeterminacy prior to 1980 resulted mainly from self-fulfilling changes in inflation expectations. For instance, Clarida, Galí, and Gertler (1999, 2000) reported GMM estimates of policy rules suggesting the US economy was in an indeterminate state in the pre-1980s. According to them, the Fed did restore determinacy between 1979:Q3 and 1996:Q4 by adopting a policy that was much less accommodative, with estimated responses to inflation of nearly two. The baseline measure of the output gap used by CGG was constructed by the Congressional Budget Office (CBO). Unlike our approach to estimating policy rules which is model consistent, their policy rules were estimated apart from any particular structural model.

Coibion and Gorodnichenko (2011) provided more recent evidence showing that a lower level of trend inflation, not just changes in the parameters of the mixed policy rule, helped the economy moving from a state of indeterminacy prior to 1980 to one of determinacy after 1982. Their evidence was also based on policy rules estimated apart from a particular structural model.

Lubik and Schorfheide (2004) offered estimates of policy rules which are consistent internally with a structural New Keynesian model featuring sticky prices and a monetary authority adjusting nominal interest rates in response to inflation and to the level of the output gap. They find that pre-Volcker policy led to indeterminacy while post-1982 monetary policy helped achieving determinacy.

Smets and Wouters (2007) also provided model consistent estimates of mixed policy rules. Like us, their evidence suggested the US economy was in a determinate state prior to 1980 and after 1984. But unlike us, they find no evidence of a significant change in the parameters of the policy rule between the two periods.

Another significant change in our parameter estimates between the two periods has to do with the Calvo probability of wage non-reoptimization. That is, while the posterior mean of ξ_w is 0.7 for the first sub-period, it falls to 0.5 for the second sub-period. By comparison the Calvo probability of non-reoptimization is significantly higher for prices at 0.78 for the first sub-period and 0.76 for the second.

Our evidence therefore suggests nominal wage flexibility increased after 1982:Q3. Rabanal and Rubio-Ramírez (2005) obtain similar evidence of a higher frequency of adjustment for wages than for prices, and this for the sample 1982:Q4-2001:Q4. Specifically, their estimate of ξ_w is about 0.57, while that of ξ_p is about 0.84.

The fraction of input prices financed through working capital ψ is quite stable in both periods, with an estimate of 0.28 for the first sub-sample and 0.27 for the second. Therefore, there is empirical support for a cost channel for monetary policy. Note also that the posterior mean for the share of intermediates into gross output ϕ is 0.41 in the first period and 0.37 in the second. These estimates are lower than the values generally pre-assigned to this share by calibration, which are often based on data covering only the manufacturing sector.

When looking at estimates of the shock processes, we find that almost all of shocks have been smaller after 1982:Q3. Note in particular the sharp decrease in the size of the MEI shock. At the same time, almost all of shocks have been more persistent in the second sub-period relative to the first.

5.3 Reinterpreting Postwar Business Cycles

We identify the key sources of postwar business cycles through the forecast error variance decompositions of variables corresponding to our observables. They are based on the means of the model's posterior distribution. Table 6 reports variance decompositions at the business cycle frequency of 6-32 quarters using the full-sample estimates (Panel A) and sub-sample estimates (Panels B and C, respectively).

What is striking about the results we obtain based on our full-sample and sub-sample estimates is that they do not speak with one voice. When looking at the variance decomposition for the full-sample period, we find that the MEI shock has been the key disturbance driving the cyclical variance of output growth, investment growth and hours with a percentage contribution of 50%, 68.4% and 53.5%, respectively. They have also contributed to 44.5% and 55.5% of the cyclical variance of inflation and interest rates. These percentages are broadly consistent with those found in Justiniano and Primiceri (2008), Justiniano, Primiceri, and Tambalotti (2010, 2011), Khan and Tsoukalas (2011) and Phaneuf and Victor (2019) for samples of data covering the postwar period. Also, when summing the percentage contributions of technological shocks (i.e. of shocks to the marginal efficiency of investment, neutral technology and IST), we find that they explain nearly 68% of output fluctuations based on posterior means, leaving only 32% to be explained by non-technological shocks. We also find that the risk premium shock is the main driver behind variations in consumption growth at 60.3%.

Now, things are quite different when looking at evidence from our sub-sample estimates. We find that for the first sub-period the MEI shock has explained 61% of the cyclical forecast error variance decomposition of output growth, 80% of the variance of investment growth, and 63.5% of the variation in hours. Technological shocks have accounted for about 78% of the variance of output fluctuations, leaving only 22% to be explained by non-technological shocks. However, the MEI has contributed only 7.7% of inflation variability, with wage and price markup shocks explaining almost 65% of the that variability.

Evidence for our second sub-sample period is very different, for now the MEI shock contributes only to 19% of the cyclical variance of output. The contributions of technological disturbances to the cyclical variance of output have summed to 44.7%, so that non-technological disturbances have explained 55.3% of that variance after 1982:Q3. The MEI shock was again the key disturbance driving the variance of investment growth at 56.1%. While the risk premium shock accounted for 46.3% of the variance of consumption growth, the neutral technology shock explained a non-negligible 23.1%. The wage markup shock drove 44.7% of hours variability. Finally, wage and price markup shocks have explained 48.4% of inflation variability and the MEI shock 17.9%.

The dramatic decline in the contribution of MEI shocks to the cyclical variance of output growth from 61% in the pre-1980s to 19% after 1982:Q3 is worth emphasizing in light of the evidence offered by Christiano, Motto, and Rostagno (2014). These authors have argued that "risk shocks" have been the most important shocks driving output fluctuations. They report that risk shocks have contributed to 62% of the cyclical variance of output growth. At the same time, they report that the MEI shock has explained only 13% of that variance.

We argue that there is no contradiction between our findings and theirs, and this for the following reasons. First, Christiano, Motto, and Rostagno (2014) focus on a sample of data covering the period 1985:Q1-2010:Q2, and this due to data limitations. By contrast, we focus on two sub-samples because of our emphasis on postwar conventional monetary policy prior to the Great Recession. Data limitations preclude the use of risk shocks for our two sub-samples. Second and perhaps most importantly, our own estimates for the post-1982:Q3 period suggest MEI shocks have lost a lot of their importance in the second part of the postwar period–19% in our model vs 13% in Christiano, Motto, and Rostagno (2014)–and this in the absence of risk shocks. Therefore, it is hard to conclude that the small influence of MEI shocks after 1982:Q3 can be attributable to risk shocks only. Whereas our evidence suggests MEI shocks have been very important in the first part of the postwar period, the evidence of Christiano, Motto, and Rostagno (2014) is silent on this point.

6 A New Look at the Post-1982 Episode

This section assesses the sources of the greater macroeconomic stability after 1982 through the lens of our estimated models. Table 7 reports the actual standard deviations of output growth and inflation for the two sub-samples, those predicted by our estimated models for the sub-periods 1960:Q1-1979:Q2 and 1982:Q4-2007:Q3, and those implied by some counterfactual experiments described below.

While our estimated models overstate the volatility of output growth and the variability of inflation, they capture their sharp declines from the first to the second sub-period. Specifically, while the actual volatility of output growth was about 43% smaller after 1982:Q3 than in the pre-1980, our estimated models imply it is 45% smaller. Inflation variability actually declined by about 54%, while our models predict it has dropped by about 46%.

This raises the following question: What are the key factors explaining these sharp decreases in output and inflation volatility? To answer this question, we conduct a number of counterfactual experiments based on the modes of the parameter posterior distributions.

A set of experiments asks what are the standard deviations of output growth and inflation under the following three counterfactual scenarios. First, the estimated shock processes of the first sub-period are embedded into the second sub-period model. This scenario labelled "Shock" in Table 7 helps assessing how much of the decline in aggregate volatility is due to "good luck". Second, the first-period policy rule is inserted into the second sub-period model. This scenario labelled "Policy" assesses whether monetary policy helped achieving greater macroeconomic stability after 1982. Third, the first-period structural parameters other than the estimated shock processes and policy rule are included into the second sub-period model. This scenario labelled "Structure" conveys information about whether greater macroeconomic stability resulted from changes in some fundamental structural features of the economy.

According to the 'Shock' counterfactual experiment, the volatility of output growth predicted for the post-1982 period would have been mildly higher at 1.11 with the pre-1980 shock processes compared to 0.99 with the post-1982 estimates. The variability of inflation would also have been slightly higher at 0.51 compared to 0.5 with the post-1982 estimates. Hence, our estimates provide some evidence that changes in the estimated shock processes have somewhat contributed to the lower volatility of output after 1982. However, they have not contributed much to the decline in inflation variability. Therefore, we conclude that our evidence provides relatively weak empirical support to the "good-luck hypothesis".

Turning our attention to the role of monetary policy, we see that the 'Policy' counterfactual experiment implies that the volatility of output growth would have been only slightly higher at 1.01 in the second sub-period under the pre-1980 policy rule parameters. Therefore, despite the fact monetary policy was much more accommodative to inflation prior to 1980, output volatility after 1982 would have been almost the same. Interestingly, our results are quite different when looking at the variability of inflation. For then we find that the standard deviation of inflation would have reached 0.88 under the pre-1980 rule estimates. Therefore, with the post-1982 shock processes and structural parameters, the variability of inflation would have been significantly higher under the accommodative policy of the pre-1980s. Therefore, while changes in the monetary policy rule do not seem to be a factor contributing much to the reduction of output growth volatility after 1982, it has contributed significantly to the decline in inflation variability.

The 'Structure' counterfactual experiment suggests the standard deviation of output growth 2.6 would have been much higher after 1982 with the pre-1980 structural parameters. The variability of inflation would have been higher too at 0.88. These findings therefore suggest there were some significant structural changes between the first and second sub-period, a point to which we return below.

Therefore, a question that arises naturally is the following: What are the structural factors driving the sharp decrease in output volatility after 1982? Recall that according to our sub-sample estimations, the Calvo probability of nominal wage non-reoptimization dropped from the first to the second sub-period. This leads us to assess the effect of assuming that all structural parameters, except ξ_w, take their pre-1980 values. Now, we find that the standard deviation of output growth falls to 1.19, and the standard deviation of inflation drops to 0.66. In other words, increased nominal wage flexibility has been the key factor driving down output volatility after 1982.

A final counterfactual experiment assumes that all structural parameters, except ξ_w and the habit formation coefficient h, are at their pre-1980 values. Therefore, estimated shock processes and policy rule parameters take their post-1982 values as well. We find that the standard deviation of output growth is 1.26 and that for inflation is 0.54.

There are three main conclusions emerging from these counterfactual experiments. First, increased nominal wage flexibility has been a key factor driving more stable output fluctuations during the second episode. Second, monetary policy had a significant impact on inflation variability. Third, we do not find evidence suggesting the US economy was more stable after 1982 because it luckily received smaller shocks.

7 Conclusion

We have revisited two major postwar business cycle episodes: the pre-1980s and the post-1982 period prior to the Great Recession. First, we have shown that it is not very likely that the Fed implemented a rule targeting the level of the output gap or its level and rate of change. The Fed most likely followed a policy rule targeting deviations of output growth from trend growth. This rule ensures the prospect of determinacy for a much wider range of interest rate responses to inflation. Even in the presence of a cost-channel for monetary policy does this type of rule guarantee determinacy for policy responses close to the original Taylor Principle.

Model estimation suggests that considering sub-sample estimates provides quite a different understanding of the key sources of postwar business cycles. While our evidence says that shocks to the marginal efficiency of investment have been most important in driving the cyclical variance of output growth during the full-sample period and the pre-1980s, this shock has seen its importance falls quite dramatically after 1982:Q3. Furthermore, while technological shocks were more important than non-technological shocks in the pre-1980s, the reverse was true in the post-1982 period.

Our sub-period estimates also tell a new tale of the sources of greater macroeconomic stability after 1982. We find no support for the "good luck" hypothesis, or the conjecture that the economy has largely benefited from smaller shocks. Instead, we have found that a key structural change driving the sharp fall in output volatility after 1982 was increased nominal wage flexibility, while the Fed's adoption of a "hawkish" stand against inflation helped reduce inflation variability.

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Table 1: Calibrated parameters

	Description	Parameter	Value
1.	Discount factor	β	0.99
2.	Habit formation	b	0.8
3.	Labour disutility	η	6
4.	Depreciation rate	δ	0.025
5.	Capital share	α	0.33
6.	Investment adjustment costs	κ	3
7.	Utilization elasticity	γ_2	0.05
8.	Elasticity of substitution (goods)	λ_p	10
9.	Elasticity of substitution (labour)	λ_w	10
10.	Calvo price non-adjustment probability	ξ_p	0.66
11.	Calvo wage non-adjustment probability	ξ_w	0.66
12.	Financial friction (costly working capital)	ψ	$\{0, 0.5\}$
13.	Intermediate goods share	ϕ	0.5
14.	Monetary policy rule interest rate smoothing	ρ_r	0.8
15.	Monetary policy rule output gap	α_y	0.2
16.	Monetary policy rule output growth	$\alpha_{\Delta y}$	0.2
17.	Average IST growth rate	g_v	1.0047
18.	Average output growth	g_Y	1.00571
19.	Average TFP growth rate	$g_z^{1-\phi}$	1.0022

Table 2: Minimum monetary policy response, α_π, consistent with determinacy

A.	$\alpha_y = 0.2$ (output gap)	
	$\psi = 0$	$\psi = 0.5$
$\bar{\pi}$	α_π	α_π
0%	1.3	1.6
2%	1.9	2.3
3%	2.5	empty set

B.	$\alpha_y = 0.3$ (output gap)	$\alpha_y = 0.4$ (output gap)
	$\psi = 0.5$	$\psi = 0.5$
0%	1.9	2.1
2%	3.0	3.6
3%	empty set	empty set

C.	$\alpha_{\Delta y} = 0.2$ (output growth)	
	$\psi = 0$	$\psi = 0.5$
0%	$\alpha_\pi \geq 1$	$\alpha_\pi \geq 1$
2%	$\alpha_\pi \geq 1$	$\alpha_\pi \geq 1$
3%	$\alpha_\pi \geq 1$	$\alpha_\pi \geq 1$

Table 3: Parameter Estimates: Full Sample

parameters	prior mean	post. mean	90% HPD interval	prior	pstdev
α	0.300	0.1662	[0.1562 , 0.1769]	norm	0.0500
ι_p	0.500	0.2120	[0.1021 , 0.3189]	beta	0.1500
ι_w	0.500	0.1082	[0.0543 , 0.1613]	beta	0.1500
g_Y	0.400	0.3864	[0.3474 , 0.4249]	norm	0.0250
g_I	0.200	0.2292	[0.1902 , 0.2688]	norm	0.0250
h	0.500	0.9200	[0.8962 , 0.9442]	beta	0.1000
$\bar{l}$	0.000	0.0745	[-0.7047 , 0.8655]	norm	0.5000
$\bar{\pi}$	0.500	0.7356	[0.6135 , 0.8615]	norm	0.1000
$100(\beta^{-1}-1)$	0.250	0.1209	[0.0519 , 0.1885]	gamm	0.1000
χ	2.000	2.8534	[1.7218 , 3.9174]	gamm	0.7500
ξ_p	0.660	0.7340	[0.6948 , 0.7748]	beta	0.1000
ξ_w	0.660	0.5513	[0.4640 , 0.6350]	beta	0.1000
σ_a	5.000	5.4168	[3.7138 , 7.0358]	gamm	1.0000
κ	4.000	2.8045	[1.7983 , 3.8128]	gamm	1.0000
ψ	0.300	0.2349	[0.0937 , 0.3663]	beta	0.1000
ϕ	0.500	0.5738	[0.4707 , 0.6755]	beta	0.1000
α_π	1.500	1.5942	[1.3847 , 1.7852]	norm	0.3000
$\alpha_{\Delta\hat{y}}$	0.125	0.2263	[0.1513 , 0.2998]	norm	0.0500
ρ_R	0.600	0.8067	[0.7757 , 0.8373]	beta	0.2000
ρ_z	0.400	0.3294	[0.2177 , 0.4339]	beta	0.2000
ρ_g	0.600	0.9959	[0.9924 , 0.9995]	beta	0.2000
ρ_ν	0.200	0.2779	[0.1714 , 0.3859]	beta	0.1000
ρ_p	0.600	0.9746	[0.9528 , 0.9980]	beta	0.2000
ρ_w	0.600	0.9690	[0.9559 , 0.9819]	beta	0.2000
ρ_b	0.600	0.3253	[0.1797 , 0.4673]	beta	0.2000
ρ_ν	0.600	0.8778	[0.8268 , 0.9264]	beta	0.2000
θ_p	0.500	0.7630	[0.6740 , 0.8570]	beta	0.2000
θ_w	0.500	0.8226	[0.7498 , 0.8969]	beta	0.2000
σ_r	0.100	0.2280	[0.2072 , 0.2486]	invg	1.0000
σ_z	0.500	0.3937	[0.3270 , 0.4575]	invg	1.0000
σ_g	0.500	0.3355	[0.3077 , 0.3637]	invg	1.0000
σ_{ϵ^I}	0.500	0.5739	[0.5221 , 0.6218]	invg	1.0000
σ_p	0.100	0.1832	[0.1575 , 0.2085]	invg	1.0000
σ_w	0.100	0.2593	[0.2237 , 0.2932]	invg	1.0000
σ_b	0.100	0.1611	[0.1343 , 0.1883]	invg	1.0000
σ_{η^I}	0.500	4.3938	[3.2500 , 5.5586]	invg	1.0000

Log data density is -1351.097.

Table 4: Parameter Estimates: Pre-1979

parameters	prior mean	post. mean	90% HPD interval	prior	pstdev
α	0.300	0.1683	[0.1511 , 0.1849]	norm	0.0500
ι_p	0.500	0.3434	[0.1462 , 0.5376]	beta	0.1500
ι_w	0.500	0.0950	[0.0355 , 0.1532]	beta	0.1500
g_Y	0.400	0.3868	[0.3446 , 0.4256]	norm	0.0250
g_I	0.200	0.1948	[0.1541 , 0.2323]	norm	0.0250
h	0.500	0.8949	[0.8556 , 0.9331]	beta	0.1000
$\bar{l}$	0.000	0.0705	[-0.6981 , 0.8427]	norm	0.5000
$\bar{\pi}$	0.500	0.5912	[0.4263 , 0.7636]	norm	0.1000
$100(\beta^{-1}-1)$	0.250	0.1294	[0.0519 , 0.2067]	gamm	0.1000
χ	2.000	2.4188	[1.1948 , 3.5501]	gamm	0.7500
ξ_p	0.660	0.7831	[0.7099 , 0.8738]	beta	0.1000
ξ_w	0.660	0.6987	[0.5259 , 0.8775]	beta	0.1000
σ_a	5.000	5.0248	[3.3360 , 6.6637]	gamm	1.0000
κ	4.000	3.3941	[1.9348 , 4.7727]	gamm	1.0000
ψ	0.300	0.2841	[0.1227 , 0.4347]	beta	0.1000
ϕ	0.500	0.4148	[0.2981 , 0.5350]	beta	0.1000
α_π	1.500	1.1623	[1.0000 , 1.3262]	norm	0.3000
$\alpha_{\Delta\hat{y}}$	0.125	0.1628	[0.0902 , 0.2383]	norm	0.0500
ρ_R	0.600	0.7909	[0.7349 , 0.8447]	beta	0.2000
ρ_z	0.400	0.2838	[0.1479 , 0.4245]	beta	0.2000
ρ_g	0.600	0.9494	[0.9086 , 0.9926]	beta	0.2000
ρ_v	0.200	0.1300	[0.0322 , 0.2228]	beta	0.1000
ρ_p	0.600	0.9103	[0.8082 , 0.9950]	beta	0.2000
ρ_w	0.600	0.9313	[0.8670 , 0.9881]	beta	0.2000
ρ_b	0.600	0.3416	[0.1455 , 0.5184]	beta	0.2000
ρ_v	0.600	0.7197	[0.5014 , 0.9285]	beta	0.2000
θ_p	0.500	0.6349	[0.3620 , 0.8853]	beta	0.2000
θ_w	0.500	0.8564	[0.6487 , 0.9974]	beta	0.2000
σ_r	0.100	0.2102	[0.1795 , 0.2379]	invg	1.0000
σ_z	0.500	0.6576	[0.5490 , 0.7594]	invg	1.0000
σ_g	0.500	0.3767	[0.3265 , 0.4258]	invg	1.0000
σ_{ϵ^I}	0.500	0.6540	[0.5712 , 0.7410]	invg	1.0000
σ_p	0.100	0.1593	[0.1161 , 0.2071]	invg	1.0000
σ_w	0.100	0.2570	[0.1765 , 0.3506]	invg	1.0000
σ_b	0.100	0.1894	[0.1449 , 0.2340]	invg	1.0000
σ_{η^I}	0.500	7.1392	[3.2727 , 11.0368]	invg	1.0000

Log data density is -641.646.

Table 5: Parameter Estimates: Post-1982

parameters	prior mean	post. mean	90% HPD interval	prior	pstdev
α	0.300	0.1589	[0.1416 , 0.1757]	norm	0.0500
ι_p	0.500	0.1909	[0.0712 , 0.3051]	beta	0.1500
ι_w	0.500	0.2182	[0.1094 , 0.3228]	beta	0.1500
g_Y	0.400	0.3867	[0.3454 , 0.4266]	norm	0.0250
g_I	0.200	0.2338	[0.1885 , 0.2753]	norm	0.0250
h	0.500	0.8096	[0.7565 , 0.8627]	beta	0.1000
$\bar{l}$	0.000	-0.1059	[-0.9149 , 0.6872]	norm	0.5000
$\bar{\pi}$	0.500	0.6515	[0.5347 , 0.7638]	norm	0.1000
$100(\beta^{-1}-1)$	0.250	0.1521	[0.0716 , 0.2365]	gamm	0.1000
χ	2.000	2.2895	[1.1146 , 3.4066]	gamm	0.7500
ξ_p	0.660	0.7562	[0.6992 , 0.8133]	beta	0.1000
ξ_w	0.660	0.5030	[0.3957 , 0.6061]	beta	0.1000
σ_a	5.000	5.2119	[3.5160 , 6.8843]	gamm	1.0000
κ	4.000	3.8019	[2.5993 , 4.9675]	gamm	1.0000
ψ	0.300	0.2746	[0.1165 , 0.4328]	beta	0.1000
ϕ	0.500	0.3675	[0.2638 , 0.4728]	beta	0.1000
α_π	1.500	1.9039	[1.6008 , 2.2207]	norm	0.3000
$\alpha_{\Delta\hat{y}}$	0.125	0.1974	[0.1167 , 0.2779]	norm	0.0500
ρ_R	0.600	0.8668	[0.8395 , 0.8944]	beta	0.2000
ρ_z	0.400	0.2856	[0.1636 , 0.4059]	beta	0.2000
ρ_g	0.600	0.9909	[0.9829 , 0.9990]	beta	0.2000
ρ_ν	0.200	0.4838	[0.3691 , 0.6079]	beta	0.1000
ρ_p	0.600	0.9508	[0.9103 , 0.9947]	beta	0.2000
ρ_w	0.600	0.9683	[0.9458 , 0.9925]	beta	0.2000
ρ_b	0.600	0.8243	[0.7148 , 0.9286]	beta	0.2000
ρ_ν	0.600	0.8775	[0.7994 , 0.9557]	beta	0.2000
θ_p	0.500	0.7071	[0.5780 , 0.8541]	beta	0.2000
θ_w	0.500	0.7236	[0.5825 , 0.8742]	beta	0.2000
σ_r	0.100	0.1255	[0.1101 , 0.1412]	invg	1.0000
σ_z	0.500	0.4916	[0.4236 , 0.5576]	invg	1.0000
σ_g	0.500	0.2893	[0.2552 , 0.3229]	invg	1.0000
σ_{ϵ^I}	0.500	0.4639	[0.4083 , 0.5180]	invg	1.0000
σ_p	0.100	0.1931	[0.1593 , 0.2264]	invg	1.0000
σ_w	0.100	0.2957	[0.2409 , 0.3527]	invg	1.0000
σ_b	0.100	0.0978	[0.0727 , 0.1195]	invg	1.0000
σ_{η^I}	0.500	3.0810	[2.3186 , 3.8709]	invg	1.0000

Log data density is -556.518.

Table 6: Variance Decompositions at the Business Cycle Frequency (6-32 quarters)

Variables ↓/ Shocks (→)	MP	Tech.	Gov.	IST	P-Markup	W-Markup	Pref.	MEI
					A. Full Sample			
Output growth	3.24	17.93	2.80	0.36	8.78	12.56	4.72	49.61
Consumption growth	0.38	22.57	1.02	0.07	1.58	13.40	60.28	0.70
Investment growth	3.43	10.57	0.03	0.54	8.74	7.87	0.37	68.44
Hours	3.08	9.40	1.74	0.20	8.07	21.21	2.81	53.48
Wage growth	1.10	41.16	0.01	0.01	30.65	22.61	0.96	3.49
Inflation	2.57	18.37	0.27	0.26	20.67	11.80	1.56	44.49
RPI growth	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
Interest rate	24.34	6.33	0.35	0.35	7.75	3.94	1.48	55.45
					B. Pre-1979			
Output growth	2.13	16.36	2.96	0.27	8.05	3.69	5.37	61.17
Consumption growth	0.73	31.50	0.20	0.02	2.73	4.46	58.98	1.38
Investment growth	1.96	7.58	0.02	0.42	7.31	2.26	0.05	80.40
Wage growth	0.46	42.98	0.03	0.04	33.58	19.49	0.49	2.92
Hours	2.40	11.54	2.11	0.24	9.10	7.24	3.93	63.45
Inflation	1.21	22.52	0.91	0.86	48.36	16.59	1.89	7.65
RPI growth	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
Interest rate	35.14	8.57	0.90	1.01	22.56	8.98	2.00	20.84
					C. Post-1982			
Output growth	2.53	24.79	3.18	0.67	13.76	27.04	8.75	19.28
Consumption growth	0.98	23.09	1.04	0.17	3.95	21.74	46.13	2.89
Investment growth	1.95	8.84	0.02	1.45	12.34	11.79	7.51	56.10
Wage growth	1.27	33.66	0.02	0.03	33.17	25.14	5.34	1.38
Hours	2.30	9.83	1.91	0.38	13.44	44.70	6.03	21.41
Inflation	5.01	11.98	0.15	0.14	32.39	15.97	16.48	17.87
RPI growth	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
Interest rate	21.21	5.69	0.28	0.35	17.36	7.80	18.95	28.36

MP = Monetary policy, Tech. = Technology, Gov. = Government spending, P-Markup = Price Markup, W-Markup=Wage Markup, Pref. = Preference

Table 7: Counterfactual Scenarios

	Output growth	Inflation
Pre-1979		
Data	1.06	0.72
Model	1.81	0.93
Post-1982		
Data	0.6	0.32
Model	0.99	0.5
Counterfactuals (with post-82 estimated model)		
Pre-1979 shocks	1.11	0.51
Pre-1979 monetary policy	1.01	0.88
Pre-1979 structure	2.60	0.88
Pre-1979 structure (except wage rigidity is post-82)	1.19	0.66
Pre-1979 structure (except wage rigidity and habits are post-82)	1.26	0.54

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.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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