Did the Fed Remain at the ZLB Long Enough? Lessons from the 2008-2019 Period

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Abstract

We present evidence suggesting the Fed can learn useful lessons by looking at the effectiveness of its policy over the 2008-2019 time period. Using a medium-scale New Keynesian model estimated with Bayesian techniques, we find that by raising the nominal interest rate above the ZLB from 2015:4 to 2019:4 and gradually limiting recourse to quantitative easing, the Fed undid most of the stimulus it gave the economy during the 2008-2014 time segment. We estimate that during the two years prior to lift-off, the per quarter average deviation of inflation from target was negative so that potential fears of rising inflation were unwarranted. Investment growth was most adversely affected by the Fed's policy during the 2015-2019 time segment. Total hours worked had not yet returned to their pre-recession level of 2008 by the end of 2019. We conclude that faced with exceptional events such as the Great Recession and the pandemic, the monetary and fiscal authorities in the future could combine their efforts to provide stimulus over a longer period of time than they did after the Great Recession.

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1 Introduction

More than a decade after the Great Recession (GR) crisis, many countries were again facing highly depressed economic activity at the onset of the COVID-19 pandemic. While these two exceptional events are linked to very different sources, both saw central banks such as the Federal Reserve (the Fed) and the European Central Bank being limited in their actions by the Zero Lower Bound (ZLB) on the nominal interest rate, and being constrained to use unconventional policy tools to provide economic stimulus.[1]

Early in the GR, the Fed decided to use forward guidance and quantitative easing as unconventional policy tools. A recent macroeconomic literature, both theoretical and empirical, has suggested that these tools helped mitigate the length and severity of the GR, while speeding up and bolstering the recovery.

However, an open question is the following: How long should the Fed implement unconventional monetary policy to solidify a lasting economic recovery after exceptional economic events like the GR and the COVID-19 pandemic? For instance, in the contemporary context, Fed's Chairman Jerome Powell in his Jackson Hole speech (August 27, 2021) noted that while the dynamics of inflation are complex, signs of inflationary pressures appear to be building in the economy.[2] According to the June 2021 FOMC participants' assessment of what policy seems appropriate, the profile for interest rate hikes is clearly upward sloping for 2022 and 2023.[3] Thus, how long should the interest rate be kept at the ZLB remains a crucial question for policymakers.

We argue in the present paper that the Fed can learn important lessons by comparing the effectiveness of its policy over the 2008-2014 and 2015-2019 time segments prior to the pandemic. We show that by raising the nominal interest rate above the ZLB in 2015-2019 in reaction to fears of rising inflation, and by putting a stop to the increase in the size of its balance sheet in 2014 and even reducing it in 2017 until the end of 2019, the Fed basically undid most of the stimulus it gave the economy during the 2008-2014 time segment. Fears of inflation were possibly fueled by

[1] The term conventional monetary policy refers to a central bank altering a short-term interest rate according to a well specified rule to achieve its macroeconomic objectives.

[2] https://www.federalreserve.gov/newsevents/speech/powell20210827a.htm.

[3] https://www.federalreserve.gov/monetarypolicy/files/fomcprojtabl20210616.pdf.

the decline in the unemployment rate from 10% in 2009 to 5% in 2015, with the NAIRU roughly estimated at 6%. However, the decline in the unemployment rate disguised the reality that total hours worked was far from recovering to its pre-GR level.

Meanwhile, there were also concerns expressed by some FOMC members that these fears were unfounded, and that it was too early to announce that interest rate was about to be raised above the ZLB.[4] Based on a medium-scale New Keynesian (NK) model estimated with Bayesian techniques, we offer new evidence supporting the view that there were no urgent reasons to believe that inflation was about to rise. In fact, we show that in the two years preceding the lift-off of interest rates, the estimated per quarter deviations of inflation from target were often negative or near-zero. By raising the interest rate above the ZLB and restraining its unconventional policy interventions, the Fed not only put a halt to the economic recovery but, as we intend to show, undid all of the stimulus it gave the economy between 2008-2014.

A vast literature studies issues related to the GR.[5] Some identify the main sources behind the GR (Ireland (2011); Christiano et al. (2014); Del Negro et al. (2015); Christiano et al. (2015)). Others explore why deflation has not been stronger and did not last longer when faced with highly depressed economic activity (Coibion and Gorodnichenko (2015); Del Negro et al. (2015)). Some investigate whether fiscal policy and unconventional monetary policy have stabilizing power at the ZLB (Sims and Wolff (2018); Campbell et al. (2019); Sims and Wu (2019, 2020)). Others study whether a binding ZLB constraint matters for macroeconomic volatility and how the economy responds to shocks (Garín et al. (2019); Debortoli et al. (2019)).

Our work contributes to this literature by emphasizing the relative effectiveness of monetary and fiscal policies over the 2008-2014 and 2015-2019 time segments. The framework used for our purpose belongs to a class of medium-scale New Keynesian (NK) models that includes, among others, those of Christiano et al. (2005), Smets and Wouters (2007), Justiniano and Prim-

[4]Some dissent is evident in the transcripts of the December 15 2015 FOMC Meeting. For example, Lael Brainard (pg. 122-123) "*I'm also mindful of the fact that there are important risks on the other side—in particular, the risk that inflationary pressures may emerge with greater force than is expected today. As I take into account the risks on both sides, the combination of asymmetrically greater room to tighten than to ease through conventional means; core inflation stubbornly below its target, with the deterioration we've seen in inflation expectations; and downside risks arising from abroad leads me to place somewhat greater weight on the possible regret associated with tightening too early than on the possible regret associated with waiting a little longer to see some of these risks play out before moving.*"

[5]Useful surveys can be found in Kuttner (2018) and Sims and Wu (2020).

iceri (2008), Justiniano et al. (2010, 2011), Khan and Tsoukalas (2011), and more recently Del Negro et al. (2015), Christiano et al. (2015), Ascari et al. (2018), and Khan et al. (2020).[6]

The paper closest to ours is Mouabbi and Sahuc (2019) (hereafter, MS). MS use the Smets and Wouters (2007) model to gauge the consequences for inflation and output in the Euro area of implementing unconventional monetary policy during the GR. To quantify unconventional policy, they use a shadow interest rate measuring the shortest maturity rate extracted from a term structure model that would generate the observed yield curve had the ZLB not been binding.

Our approach differs from theirs in the following ways. First, our focus is on the two time segments, 2008-2014 and 2015-2019, allowing us to examine both periods of unconventional policy and normalization in their entirety. Second, our DSGE model differs from theirs by accounting for intermediate goods which firms use as inputs following Basu (1995), and an extended working capital channel as suggested by Phaneuf et al. (2018). Third, we draw the distinction in the estimation between investment-specific technology (IST) shocks and shocks to the marginal efficiency of investment (MEI) following Justiniano et al. (2011).

Our model estimates from the 2008-2014 time segment suggest that unconventional monetary policy shocks contributed positively to output growth, investment growth, and hours growth in each quarter between 2008:1 and 2012:1, and again between 2013:4 and 2014:3. Policy shocks also exerted a positive impact on consumption growth in almost every quarter of the 2008-2014 time segment. Our evidence hence suggests that unconventional monetary policy helped mitigating the effects of adverse shocks during the GR and speeding up the recovery throughout the course of the 2008-2014 time segment.

Our evidence for the 2015-2019 time segment reveals that monetary policy shocks contributed negatively to output growth, consumption growth, investment growth, and hours growth in almost every quarter of that segment. The negative effects of monetary policy shocks on investment growth were particularly strong between 2015 and 2017. As a result, aggregate investment did not return to its pre-recession level until 2018:1 and total hours worked still had not returned to their pre-GR level by the end of our sample in 2019:4.

[6]Medium-scale DSGE NK models as opposed to small-scale DSGE NK models include rigidities both on nominal wages and prices, capital accumulation, and different real adjustment frictions.

Another way to gauge the relative effectiveness of monetary policy over the 2008-2019 time period is by estimating the average percentage contribution per quarter of monetary policy shocks to output growth, consumption growth, investment growth, and hours growth during both time segments. When doing so, we find that the average contribution of monetary shocks to output growth was 0.23% per quarter during the first segment and -0.26% during the second segment. This change is predominantly driven by the impact of monetary policy on investment. The average percentage contribution per quarter to investment growth was 0.63% during the first segment and -0.88% during the second segment. Therefore, our evidence suggests that after 2015 the Fed essentially undid the stimulus it gave the economy during the first segment.

Turning to fiscal policy (measured as government spending shocks), our evidence suggests that it had some positive impact on output growth and hours growth in 2008:4-2009:2, but mostly negative and weakly positive effects for the rest of the first segment. Meanwhile, these shocks had significant negative effects on consumption growth during the 2008-2014 segment and almost no effect on investment growth. Compared to unconventional monetary policy, fiscal shocks had a minimal stabilizing impact on the economy during the first time segment. While fiscal shocks did have some positive effects on the real economy during the 2015-2019 time segment, these expansionary effects were not strong enough to sustain a faster economic recovery.

When looking at how inflation behaved during the GR and following years, our evidence based on Kalman smoothed shocks identifies adverse price markup shocks and favorable monetary policy shocks as those that prevented a stronger and more lasting deflation faced with a highly depressed economic activity during the GR and ensuing years. Our evidence also suggests there were no urgent reasons in 2014-2015 to fear that inflation was about to rise significantly prior to the Fed's lift-off of nominal interest rates.

Overall, our empirical findings lend credence to the view that by reducing the stimulus provided by unconventional monetary policy in 2014-2015, and by setting the nominal interest rate above the ZLB until the end of 2019, the Fed's policy slowed the recovery, and in fact undid most of the expansionary impact it had on the economy between 2008 and 2014. We conclude that one potential lesson to learn from our empirical findings is that when confronted with exceptional events like the GR and the COVID-19 pandemic, the Fed should consider keeping the nominal interest rate at ZLB while implementing unconventional monetary policy for a longer period of time than it did to sustain a stronger and more lasting recovery. Fiscal policy could also be used more actively to help achieving this goal.

The rest of the paper is organized as follows. Section 2 describes our DSGE model. Section 3 describes the data and Bayesian estimation strategy. Section 4 discusses the estimation results. Section 5 focuses on the shocks driving the GR and their impact on economic activity and inflation. Section 6 assesses the effectiveness of monetary policy over the two time segments. Section 7 contains concluding remarks.

2 Model

Our model assumes imperfectly competitive labor and goods markets characterized by sticky wages and sticky prices. It also features real adjustment frictions such as consumer habit formation, investment adjustment costs, and variable capital utilization. Economic growth stems from trend growth in neutral and investment-specific technology (Justiniano and Primiceri, 2008). Firms make use of intermediate goods as part of their inputs. They borrow working capital to finance a fraction of their variable input costs. The shadow policy rate is set in accordance with a Taylor-type rule.

2.1 Gross Output

Given the input-output production structure, we distinguish between gross total output, X_t, and final output, Y_t. 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 CES production technology

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

with $\lambda_{p,t}$ following the exogenous stochastic process

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

$\varepsilon_{p,t}$ is *i.i.d.* $N\left(0, \sigma_p^2\right)$ and denotes a price-markup shock, $\lambda_{p,t}$ being the desired markup of price over marginal cost for intermediate firms.

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

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

where P_{jt} is the price of good j, and P_t is the aggregate price index given by

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

2.2 Intermediate Goods Producers and Price Setting

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

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

where A_t is exogenous neutral technological progress, whose 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 a TFP or neutral technology shock which is i.i.d. $N(0, \sigma_z^2)$. Γ_{jt} denotes the intermediate inputs, $\widehat{K}_{jt}$ the capital services, and L_{jt} the labor input used by the j^{th} producer. Ω_t is a growth factor which is composed of trend growth in neutral and investment-specific technologies. F is a fixed cost implying zero steady-state profits and ensuring the existence of balanced growth path.

The stochastic growth factor Ω_t is given by the 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). 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

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

where g_v is the steady-state growth rate of the IST process and ϵ_t^I is an IST shock which is i.i.d. $N\left(0, \sigma_{\epsilon^I}^2\right)$.

The cost-minimization problem of a typical j firm is

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

subject to

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

R_t^k is the nominal rental price of capital services, and W_t is the nominal wage index. The parameter ψ is the percentage of input costs financed through working capital. If $\psi = 0$, firms do not use working capital at all to finance their input costs. If instead $\psi = 1$, then firms finance all of their input costs through working capital, reimbursing their short-term loan at the shadow interest rate S_t.

If we define $\Psi_t \equiv (1-\psi+\psi S_t)$ and solve the cost-minimization problem, then real marginal cost is given by

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

and the demand functions for the intermediate and primary factor inputs are

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

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

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

where $\overline{\phi} \equiv \phi^{-\phi}\,(1-\phi)^{\phi-1} \left(\alpha^{-\alpha}\,(1-\alpha)^{\alpha-1}\right)^{1-\phi}$, and $mc_t = \frac{MC_t}{P_t}$ 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.

Intermediate firms allowed to reoptimize their price with probability $1-\xi_p$ all choose the same price P_t^*. Firms not allowed to reoptimize their price index $P_{j,t-1}$ to lagged inflation, π_{t-1}, and steady-state inflation, π. The price-setting rule is given by

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

where ι_p and $1-\iota_p$ denote the degree of price indexation to past inflation and steady-state inflation, respectively. When given the opportunity to reoptimize 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 effective 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 in period $t+s$.

Solving the maximization problem yields the following optimal price setting equation

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

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 reset price and $\pi_{t+1,t+s} = \frac{P_{t+s}}{P_t}$ is cumulative inflation 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 labor. They face a downward-sloping demand curve for their particular type of labor given in (23). Each period, households face a probability $(1-\xi_w)$ giving them the opportunity to reset their nominal wage. As in Erceg et al. (2000), utility is separable in consumption and labor. State-contingent securities insure households against idiosyncratic wage risk arising from staggered wage-setting. Under these circumstances, households are then identical along all dimensions other than labor 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

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

and the physical capital accumulation process

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

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

The 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 i.i.d. $N\left(0, \sigma_b^2\right)$.

The functional forms for the resource cost of capital utilization and the investment adjustment cost are

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

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

The MEI shock, ϑ_t, follows the AR(1) process

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

where η_t^I is i.i.d. $N\left(0, \sigma_{\eta^I}^2\right)$.

2.4 Employment Agencies

A large number of competitive employment agencies combine differentiated labor skills into a homogeneous labor 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

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

where λ_w is the steady-state wage markup and ε_w is a *i.i.d.* $N\left(0, \sigma_w^2\right)$ wage-markup shock.

Profit maximization by the perfectly competitive employment agencies implies the following labor 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 labor of type i and W_t is the aggregate wage index given by

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

2.5 Wage setting

Each period, a household reoptimizes its nominal wage with probability $1-\xi_w$. Households given the opportunity to reset their nominal wage all choose the same wage rate W_t^*. Those not allowed to reset their wage index $W_{i,t-1}$ to lagged inflation, π_{t-1}, and steady-state inflation, π. The wage-setting rule is then given by

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

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 flow utility flow (16) subject to demand schedule (23). From the first-order condition, the optimal wage rule is

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

where ξ_w^s is the probability that a wage chosen in period t will still be effective 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 and $1-\iota_w$ denote the degree of wage indexing to past and steady-state inflation, respectively. Given our assumption on preferences and wage-setting, all updating households choose the same optimal reset wage, denoted in real terms by $w_t^* = \frac{W_{it}}{P_t}$.

2.6 Monetary and Fiscal Policy

Following Wu and Xia (2016) and Wu and Zhang (2019), the shadow rate federal funds rate S_t intends to summarize both rule-based monetary policy and the use of unconventional monetary policy tools. With rule-based policy, the shadow rate equals the effective federal funds rate. With unconventional policy tools, $S_t < 0$.

The shadow rate complies with a rule stating that the Fed smooths its short-term movements and reacts to deviations of inflation from target, and to deviations of the growth rate of real GDP $(\widehat{Y}_t/\widehat{Y}_{t-1})$ from trend output growth

$$\frac{S_t}{S} = \left(\frac{S_{t-1}}{S}\right)^{\rho_R} \left[\left(\frac{\pi_t}{\overline{\pi}}\right)^{\alpha_\pi} \left(\frac{\widehat{Y}_t}{\widehat{Y}_{t-1}} g_{\widehat{Y}}^{-1}\right)^{\alpha_{\Delta y}} \right]^{1-\rho_R} \varepsilon_t^r, \tag{27}$$

where ρ_R is a smoothing parameter, α_π, and $\alpha_{\Delta y}$ are control parameters, and ε_t^r is monetary policy shock which is i.i.d. $N(0, \sigma_r^2)$.

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

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

where g_t is a government spending shock that follows an AR(1) process given by

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

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

2.7 Market-Clearing and Equilibrium

Market-clearing for capital services, labor, 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

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

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

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

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

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

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 log-linearized equilibrium conditions can be found in Appendix A.

3 Data and Estimation

This section describes the data and Bayesian estimation methodology used in our empirical analysis.

3.1 Data

We estimate the model of Section 2 using eight US quarterly data series from 1983:1 to 2019:4. Data on macroeconomic aggregates was obtained from the Federal Reserve Bank of St. Louis Economic Database (FRED). In the following we report the corresponding FRED code in brackets. Output is US nominal gross domestic production (`GDP`). Consumption is the sum of consumption expenditures on nominal non-durables and services (`PCND` and `PCESV`). Investment is the sum of expenditures on nominal durable consumption and gross private domestic investment (`PCDG` and `GPDI`). Hours worked is the total number of hours worked in the non-farm business sector (`HOANBS`). Nominal wages is the compensation per hour in the non-farm business sector (`COMPNFB`).

Our measures of the price level of consumption and investment goods are constructed chain-weighted measures intended to capture variations in composition. Our chain-weighted measure for consumption makes use of the non-durable consumption price deflator (`DNDGRD3Q086SBEA`) and the consumption services deflator (`DSERRD3Q086SBEA`). Our chain-weighted measure for investment makes use of the durable consumption price deflator (`DDURRD3Q086SBEA`) and the gross private domestic investment deflator (A006RD3Q086SBEA).

We deflate all of the above nominal variables using our consumption price deflator and define the relative price of investment as the investment deflator divided by the consumption deflator. Additionally, output, consumption, investment, and hours worked are constructed as per capita measures using the civilian noninstitutional population (CNP16OV).

Our measure of the short-term nominal interest rate is based on two sources. When monetary policy is conducted during conventional times we use the federal funds rate (FEDFUNDS). When policy is conducted during unconventional times we specify the nominal interest rate as the shadow rate series from Wu and Xia (2016).[7] We refer to periods as unconventional times when the shadow interest rate series is strictly less than zero.

3.2 Estimation

The solution to the linear rational expectations (LRE) model is given by

$$s_t = \Phi_1(\theta)s_{t-1} + \Phi_\epsilon(\theta)\epsilon_t, \tag{34}$$

where s_t is a state vector, ϵ_t is a vector of exogenous shocks, and Φ_1 and Φ_ϵ are functions of the structural parameters of the DSGE model denoted by the vector θ. Our corresponding observation equation is given by

$$y_t = \Psi_0(\theta) + \Psi_1(\theta)s_t. \tag{35}$$

Our model contains eight observables: real output growth, real consumption growth, real investment growth, real wage growth, log of hours worked, inflation, the shadow interest rate, and the relative price of investment. These observables are mapped to our model in the following way

[7] This series is available at https://sites.google.com/view/jingcynthiawu/shadow-rates.

$$
\begin{bmatrix} \Delta \log Y_t \\ \Delta \log C_t \\ \Delta \log I_t \\ \Delta \log w_t \\ \log L_t \\ \Delta \log P_t \\ \text{Shadow rate}_t \\ \text{RPI}_t \end{bmatrix} = \begin{bmatrix} \overline{g}_\Omega \\ \overline{g}_\Omega \\ \overline{g}_\Omega \\ \overline{g}_\Omega \\ \overline{L} \\ \overline{\pi} \\ \overline{S} \\ \overline{g}_v \end{bmatrix} + \begin{bmatrix} \widehat{gdp}_t - \widehat{gdp}_{t-1} + \widehat{g}_{\Omega,t} \\ \widehat{c}_t - \widehat{c}_{t-1} + \widehat{g}_{\Omega,t} \\ \widehat{i}_t - \widehat{i}_{t-1} + \widehat{g}_{\Omega,t} \\ \widehat{w}_t - \widehat{w}_{t-1} + \widehat{g}_{\Omega,t} \\ \widehat{L}_t \\ \widehat{\pi}_t \\ \widehat{S}_t \\ -\widehat{v}_t^I \end{bmatrix},
$$

where $\overline{g}_\Omega$ captures steady state economic growth from neutral and investment-specific technology. In each case the non-stationary model variables are detrended, that is, $gdp_t = \frac{GDP_t}{\Omega_t}$, $c_t = \frac{C_t}{\Omega_t}$, $i_t = \frac{I_t}{\Omega_t}$, and $w_t = \frac{W_t}{\Omega_t}$. The parameters $\overline{L}$, $\overline{\pi}$, $\overline{R}$ and $\overline{g}_v$ refer to the steady state values of hours worked, inflation, the nominal interest rate, and growth rate of the relative price of investment. The symbol ˆ denotes a variable measured as a log-deviation from steady state.

We estimate the vector of structural parameters using Bayesian estimation. All estimations are performed using Dynare (Adjemian et al. (2011)). After obtaining posterior mode estimates, we approximate the posterior distribution of the structural parameters using the random walk Metropolis-Hastings algorithm with 2,000,000 draws.[8] We drop the first 20% of draws to avoid any issues associated with initial conditions. In our subsequent analysis we report both parameter mean and mode estimates, but use the mode estimates in computing the Kalman smoothed shocks and variance decompositions.

3.3 Prior Distributions

Some parameters are fixed prior to estimation. The quarterly rate of depreciation of physical capital δ is calibrated 0.025, implying an annual rate of depreciation of 10%. The steady-state ratio of government spending to GDP is 0.19, corresponding to the average of the ratio G_t/Y_t observed in our sample. The elasticity of substitution between goods and that between skills are both set at 10, implying steady-state wage and price markups of about 11% when trend inflation is zero.

[8] The mode is computed using Chris Sims' *csminwel* optimization function.

Table 1 lists the priors for the parameters we intend to estimate. We use prior distributions broadly consistent with those in the literature (Smets and Wouters, 2007; Justiniano et al., 2011). Two parameters which are less common, for which we specify priors, are the fraction of firms input costs financed via working capital and the share of intermediate inputs in gross output. For the percentage of firms' input costs financed by working capital, ψ, we specify a Beta prior with mean equal to 0.3 and standard deviation equal to 0.1. For the share of intermediate inputs in gross output, we specify a Beta prior with a mean of 0.5 and standard deviation of 0.1. This intermediate share range is standard.[9]

4 Estimation Results

This section presents the parameter estimates and the variance decompositions.

4.1 Parameter Estimates

Table 1 contains posterior estimates of the means and modes of the structural parameters and shocks, along with their 90% HPD intervals. These estimates are obtained from a sample of data running from 1983:1 to 2019:4. Many of our estimates are inline with those found in other work, and as such, we omit their discussion here and instead focus on a few parameter estimates which are important for our analysis. Our comments are based on the estimated modes of parameters as those conditioned on means are relatively similar.

The estimated shadow rate response to deviations of inflation from target is 1.63, while the response to deviations of output growth from trend growth is 0.23. The degree of interest rate smoothing is 0.91. Estimates of the policy responses to inflation, α_{π}, using data from the mid-1980s to just before the onset of the GR, are typically higher than those we report. This suggests that when including this longer sample of data ending in 2019, and therefore years of unconventional monetary policy, the estimated policy reaction to inflation was somewhat more accomodative.

Two parameters about which little is known when estimated are ψ and ϕ. We find an estimate

[9] For example, see the discussion in section II of Basu (1995).

of ψ which is 0.24, suggesting that firms use working capital to finance a modest fraction of their input costs. Our estimate of the share of intermediate goods is 0.43, implying that the US production structure is characterized by some degree of roundaboutness. This estimate is somewhat smaller than the value typically assigned through calibration which is around 0.5. A possible explanation for the difference is that studies calibrating ϕ typically rely on evidence from the US manufacturing industry, while our estimate is for the share of intermediates for the whole US economy.

4.2 Variance Decomposition

Table 2 reports the variance decomposition of observables at the business cycle frequency of 6-32 quarters implied by our estimated model. The two primary shocks driving the cyclical variance of output growth are the MEI shock at 33% and the TFP shock at 20%. Justiniano et al. (2011) report that the MEI shock contributes to 60% of the cyclical variance of output growth for a sample of data ranging from 1954:1 to 2009:1. However, Brault et al. (2021) report there was a significant drop in the contribution of the MEI shock to only 21% during the Great Moderation for a sample period of 1984:1-2007:3, which overlaps with a large part of our sample.

The price markup shock also contributes to 16% of the cyclical variance of output growth, 18% of the cyclical variance of hours, and 39% of the cyclical variability of inflation. The preference shock contributes to 70% of the cyclical variance of consumption growth, to 19% of the cyclical variance of output growth and inflation, and to 18% of the cyclical variance of hours growth.

5 Shocks, Economic Activity and Inflation

In the following section we use the estimated Kalman smoothed shocks from our model to examine which shocks have been contractionary and which have been expansionary over the 2008-2019 period. We also provide a quantitative assessment about how much each type of shock contributed to output growth over the 2008-2014 and 2015-2019 time segments. Finally, we examine which factors shaped the behavior of inflation during the GR.

5.1 Shocks

Figure 1 plots the shocks estimated by our model for the period 2008-2019. The first quarter of 2008 witnessed a combination of negative shocks to TFP, government spending, and the MEI. During the second and third quarter of 2008 the main contractionary shocks were the MEI, preference, price markup, and TFP shocks.

By far, the largest contractionary shock during the GR was the MEI shock in 2008:4; this shock was 2.6 times larger than its previous highest negative value in 1988:1. The preference shock was often negative between 2008 and 2014, its highest negative value was recorded in 2008:4. The price markup shock was generally positive during the GR, except in 2008:4 when it was strongly negative. Therefore, according to our model, the fourth quarter of 2008 witnessed three major adverse shocks that mainly contributed to the GR. Meanwhile, the TFP shock was significantly positive during the GR, except in the early stage.

Shocks to the nominal interest rate were systematically negative during the 2008-2014 time segment, except in 2009:1. Then, from 2015 to 2019, monetary policy shocks were quite positive during some quarters. Furthermore, negative shocks to the shadow rule were generally smaller during the second segment than the negative shocks that were observed during the first segment. This is suggestive that the Fed tightened its policy between 2015 and 2019.

MEI shocks were much smaller and nearly zero during the second time segment. The government spending shock was negative at the start of the GR, but positive in 2008:4. Its highest positive value was in 2009:1.

5.2 Economic Activity

Figure 2 assesses the percentage contribution of shocks to output growth in each quarter of the 2008-2019 period. MEI shocks were the main drivers of the GR. By comparison, the IST shocks had a small impact on output growth. Our evidence hence confirms the relevance of drawing a distinction between MEI and IST shocks. Price markup shocks had adverse effects on output growth early in the GR, strong contractionary effects during the second year of the GR, and contributed to slow down the recovery between 2010:1 and 2011:3. Preference shocks were also contractionary during the GR.

Meanwhile, other types of shocks had expansionary effects on output growth during the GR and recovery years. Monetary policy shocks had an expansionary impact on output growth early in the recession, and their effects were mainly expansionary until 2012:1, especially during the first year of the GR. Their effects were weakly contractionary from 2012:2 to 2013:2, and moderately expansionary between 2013:3 and 2014:3. By contrast, the effects of monetary policy shocks were contractionary throughout the 2015-2019 time segment, weakening and slowing down the recovery, especially between 2015:1 and 2017:4.

TFP shocks contributed negatively to output growth during the first three quarters of the GR, but had significant expansionary effects between 2008:4 and 2010:4. However, from 2011:1 until the end of 2019, they had contractionary effects on output growth.

Government spending shocks had their strongest expansionary impact on output growth from 2008:4 to 2009:2. For the remaining of the first segment, however, their contractionary effects were stronger than their expansionary effects. During the second time segment, the contractionary effects of government spending shocks more or less offset their expansionary effects. Thus, unlike monetary policy shocks, government spending shocks did not provide much stimulus over the entire 2008-2019 period.

Finally, the second time segment saw MEI shocks, price markup shocks, and to a lesser extent preference shocks, contributing positively to output growth.

5.3 Inflation During the GR

We now look at the behavior of inflation during the GR. Figure 3 Panel A reports the actual rates of inflation during the GR.[10] The inflation rate declined sharply from 1.24% in 2008:2 to -1.6% in 2008:4. This was followed by a rise in the inflation rate to 0.82% in 2009:4, despite the fact economic activity was still highly depressed.

Hall (2011) has argued that faced with a strong recession and an unemployment rate significantly above the NAIRU, NK models normally predict a stronger deflation and one that lasts

[10] This is based on our constructed consumption price deflator. However, inflation measures using the GDP deflator or core CPI yield very similar inflation movements.

longer than it did during the GR. Del Negro et al. (2015) offer a tentative explanation based on a NK model with financial frictions and a time-varying inflation target. They show their model implies a strong economic contraction and a protracted but relatively modest decline in inflation during the GR. Using a DSGE model with sticky prices, perfectly flexible nominal wages, a binding ZLB constraint and financial frictions, Christiano et al. (2015) suggest that a decline in TFP relative to trend and a rising cost of working capital could explain the behavior of inflation during the GR.

While our NK model does not explicitly account for financial frictions, it nonetheless predicts a strong contraction in economic activity and a relatively modest decline in inflation. In fact, our model implies that shocks which were deflationary during the GR saw their effects counteracted by inflationary shocks, implying that on balance deflation was not strong and was only short-lived.

Panel B of Figure 3 identifies how shocks contributed to inflation during the GR. The shocks impacting inflation negatively were those to preferences, MEI, TFP and price markup (in 2008:Q4). Those that affected inflation positively, and hence prevented stronger deflation, were the monetary policy and price markup shocks (in 2008-2009, except 2008:4).

The key role of price markup shocks in explaining why deflation was not stronger and did not last longer during the GR could raise some questions. For example, Del Negro et al. (2015) argue that price markup shocks are difficult to interpret, while their effects on variables other than inflation are generally small.

Steinsson (2003) tests two alternative interpretations of cost-push shocks derived from an optimizing agent behavior model. One relies on time varying income tax, while the other is based on a stochastic elasticity of substitution between goods. Steinsson reports evidence supporting the interpretation of variations in the monopoly power of producers as assumed in our model.

Furthermore, in our model price markup shocks explain more than just the cyclical variability of inflation, contributing quite significantly to the cyclical variance of output growth (16%), investment growth (12%), real wage growth (18%) and hours growth (14%).

6 Monetary Policy and Fears of Rising Inflation

The main objective of this Section is to compare the relative effectiveness of monetary policy over the 2008-2014 and 2015-2019 time segments. Next, we question whether the fears of rising inflation that led to the lift-off of the nominal interest rate at the early stage of the second time segment were justified.

6.1 Monetary Policy

Figure 4 presents the percentage contribution per quarter of monetary policy shocks to output growth, consumption growth, investment growth, and hours growth for the period 2008-2019.

From 2008 to 2014, the nominal interest rate was at the ZLB. This led the Fed to use unconventional monetary policy tools to provide stimulus. The top left panel shows that monetary policy shocks had significant positive effects on output growth between 2008:1 and 2012:1, weak negative effects between 2012:2 and 2013:3, and again positive effects between 2013:4 and 2014:3.

By contrast, between 2015:1 and 2019:4 the effects of monetary policy shocks on output growth were mostly contractionary. The shadow rate became less negative by 2014:2. The nominal interest rate was eventually raised above the ZLB in 2016:I.[11] The effects of monetary policy shocks in subsequent years were either contractionary or weakly expansionary.

Therefore, our evidence suggests that the Fed during the second time segment undid most of the stimulus it gave the economy during the first segment. To substantiate this claim, we also compute the average percentage contribution per quarter of monetary policy shocks to output growth, consumption growth, investment growth, and hours growth in both time segments. They are presented in Table 3.

The average contribution per quarter of monetary policy shocks to output growth is 0.23 percent during the first time segment and -0.26 percent during the second. Corresponding numbers for consumption growth are 0.14 percent and -0.13 percent, respectively. The effects of monetary policy shocks on investment growth, whether positive or negative, are substantially

[11] This is according to our quarterly shadow rate series (based on averaging). In the monthly data the policy rate lifted off from the ZLB in December of 2015.

larger. Their average percentage contribution per quarter is 0.63 percent for the first time segment and −0.88 for the second. Finally, monetary policy shocks contributed 0.18 percent and −0.22 percent hours growth, respectively.

Table 3 also presents the average percentage contribution per quarter of fiscal policy or government spending shocks to output growth, consumption growth, investment growth, and hours growth in both time segments. Clearly, fiscal policy shocks did not help stimulating the economy.

Our evidence thus suggests that raising the policy rate above the ZLB after 2015 slowed the recovery and essentially undid the stimulus provided to the economy during the first time segment.

6.2 Fears of Rising Inflation

Based on our estimated model, we ask if there were serious reasons to believe inflation was on the verge of acceleration. To answer this question, we report the percentage contribution of shocks to the per quarter deviations of inflation from target from 2013:1 to 2015:4 based on our estimated model. They are presented in Figure 5.

According to our model, the effects of inflationary shocks during the two years prior to lift-off were not stronger than those of deflationary shocks. The per quarter average percentage deviations of inflation from target between 2013:1 and 2014:2, so just before the shadow rate started to be less negative, is −0.12 percent. Furthermore, for the two years preceding the lift-off, it is −0.28 percent. Therefore, our evidence suggests that fears of rising inflation were unwarranted by the time the Fed decided to raise the nominal interest rate above the ZLB.

We conclude from the evidence presented in this section that unconventional monetary policy did provide stimulus during the GR and the 2008-2014 segment more generally. But because of fears of inflation, the Fed decided to raise the nominal interest rate above the ZLB between 2015 and 2019. However, whether these fears were justified is debatable. However, we found that this sudden change in policy undid the economic stimulus the Fed gave the economy between 2008 and 2014.

7 Conclusion

In 2020, former Chair of the Federal Reserve Ben S. Bernanke, recommended including unconventional monetary policy tools into the standard central bank toolkit. While he persuasively argues that these tools indeed have stabilizing power, something the recent literature has confirmed, we have shown in this paper that the Fed should also be concerned by the length of time unconventional monetary policy should be implemented in the face of exceptional events like the Great Recession and COVID-19 pandemic.

We have offered evidence that while unconventional monetary policy was effective between 2008-2014, the Fed between 2015 and 2019 essentially undid the stimulus it gave to the economy during the Great Recession and early recovery years. Our evidence also suggests there was no serious threat of significantly higher inflation at the time the Fed began raising the nominal interest rate above the ZLB. We conclude that the Fed should be ready in the future to rely on unconventional policy tools for a longer period of time in order to have a stronger and more lasting effect on the economy. Fiscal policy could also come to the rescue with a stronger effort than the one it provided between 2008 and 2019.

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Table 1: Estimation results 1983Q1:2019Q4

	Prior			Posterior			
	Dist.	Mean	Stdev	Mode	Stdev	Mean	90% HPDI
α	norm	0.300	0.0500	0.1524	0.0099	0.1534	[0.1366,0.1702]
ι_p	beta	0.500	0.1500	0.1076	0.0484	0.1287	[0.0470,0.2083]
ι_w	beta	0.500	0.1500	0.4120	0.0825	0.3950	[0.2573,0.5376]
g_Y	norm	0.400	0.0250	0.3752	0.0241	0.3747	[0.3355,0.4145]
g_I	norm	0.200	0.0250	0.2442	0.0250	0.2447	[0.2033,0.2854]
h	beta	0.500	0.1000	0.8526	0.0232	0.8513	[0.8114,0.8911]
$\bar{l}$	norm	0.000	0.5000	-0.1050	0.4903	-0.1164	[-0.9211,0.6989]
$\pi^\star$	norm	0.500	0.1000	0.6009	0.0857	0.6106	[0.4640,0.7579]
$100(\beta^{-1}-1)$	gamm	0.250	0.1000	0.1044	0.0431	0.1210	[0.0475,0.1916]
χ	gamm	2.000	0.7500	2.9976	0.7740	3.0162	[1.5887,4.3821]
ξ_p	beta	0.660	0.1000	0.7398	0.0323	0.7476	[0.6852,0.8106]
ξ_w	beta	0.660	0.1000	0.7027	0.0364	0.6461	[0.4820,0.7651]
σ_a	gamm	5.000	1.0000	5.2776	0.9963	5.5219	[3.8188,7.1719]
κ	gamm	4.000	1.0000	5.6117	0.9371	5.5219	[4.2462,7.4212]
ψ	beta	0.300	0.1000	0.2433	0.0964	0.2661	[0.1156, 0.4154]
ϕ	beta	0.500	0.1000	0.4290	0.0722	0.4116	[0.2964,0.5259]
α_π	norm	1.500	0.3000	1.6259	0.1957	1.6658	[1.2926,2.0268]
$\alpha_{\Delta y}$	norm	0.125	0.0500	0.2255	0.0499	0.2192	[0.1366,0.3029]
ρ_R	beta	0.600	0.2000	0.9105	0.0108	0.9100	[0.8923,0.9282]
ρ_z	beta	0.400	0.2000	0.3169	0.0674	0.3140	[0.2001,0.4262]
ρ_g	beta	0.600	0.2000	0.9939	0.0046	0.9915	[0.9844,0.9989]
ρ_v	beta	0.200	0.1000	0.3218	0.0748	0.3191	[0.1968,0.4406]
ρ_p	beta	0.600	0.2000	0.9883	0.0087	0.9810	[0.9647,0.9980]
ρ_w	beta	0.600	0.2000	0.9531	0.0210	0.9379	[0.8862,0.9925]
ρ_b	beta	0.600	0.2000	0.9017	0.0325	0.8943	[0.8382,0.9533]
ρ_I	beta	0.600	0.2000	0.9422	0.0264	0.9300	[0.8851,0.9769]
θ_p	beta	0.500	0.2000	0.7983	0.0693	0.7807	[0.6624,0.9054]
θ_w	beta	0.500	0.2000	0.9775	0.0152	0.9405	[0.8777,0.9951]
σ_r	invg	0.100	1.0000	0.1268	0.0081	0.1285	[0.1149,0.1422]
σ_z	invg	0.500	1.0000	0.3989	0.0401	0.4128	[0.3471,0.4786]
σ_g	invg	0.500	1.0000	0.3080	0.0180	0.3127	[0.2817,0.3427]
σ_{ϵ^I}	invg	0.500	1.0000	0.5640	0.0330	0.5699	[0.5142,0.6250]
σ_p	invg	0.100	1.0000	0.2355	0.0240	0.2389	[0.1963,0.2804]
σ_w	invg	0.100	1.0000	0.4320	0.0279	0.4321	[0.3695,0.4904]
σ_b	invg	0.100	1.0000	0.0715	0.0092	0.0767	[0.0593,0.0936]
σ_{η^I}	invg	0.500	1.0000	3.9460	0.4962	4.1961	[3.3079,5.0745]
Log data density				-929.278		-926.504	

Notes: Posterior mean estimates are estimated using the random walk Metropolis-Hastings (RWMH) algorithm using 2 million draws, dropping the first 20%. The average acceptance rate of the algorithm is 32.51%. HPDI (in the eighth column) refers to highest-posterior density intervals.

Table 2: Variance decomposition

Moment ↓ / Shock →	MP	Neut. Tech.	Govt.	IST	P-markup	W-markup	Pref.	MEI
Output growth	7.63	19.78	4.49	0.59	15.54	0.69	18.52	32.76
Cons. growth	3.25	19.30	1.04	0.06	4.92	0.99	69.56	0.88
Invest. growth	5.22	6.20	0.00	1.25	12.47	0.46	3.54	70.85
Wage growth	0.28	39.18	0.00	0.14	18.17	40.96	0.41	0.86
Log hours	8.45	14.02	2.53	0.27	18.00	2.27	18.22	36.24
Inflation	5.53	11.70	0.19	0.38	38.83	7.18	18.67	17.52
RPI	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00
Nominal rate	41.20	3.14	0.25	0.37	12.85	3.63	16.81	21.75
Hours growth	7.79	21.97	4.64	0.38	14.13	1.25	17.82	32.02

Notes: Variance decomposition is computed at the business cycle frequency of 6-32 quarters using a bandpass filter.

Table 3: Average contribution of monetary and fiscal policy shocks

Monetary policy shocks		
	2008Q1:2014Q4	2015Q1:2019Q4
Output growth	0.23	-0.26
Consumption growth	0.14	-0.13
Investment growth	0.63	-0.88
Hours growth	0.18	-0.22
Fiscal policy shocks		
	2008Q1:2014Q4	2015Q1:2019Q4
Output growth	-0.02	0.02
Consumption growth	-0.01	0.04
Investment growth	0.003	-0.002
Hours growth	-0.02	0.02

Notes: Average contributions are computed based on the shock decompositions of output growth, consumption growth, investment growth, and hours growth.

Figure 1: Kalman smoothed shocks 2008-2019

Figure 2: Output growth shock decomposition, 2008-2019

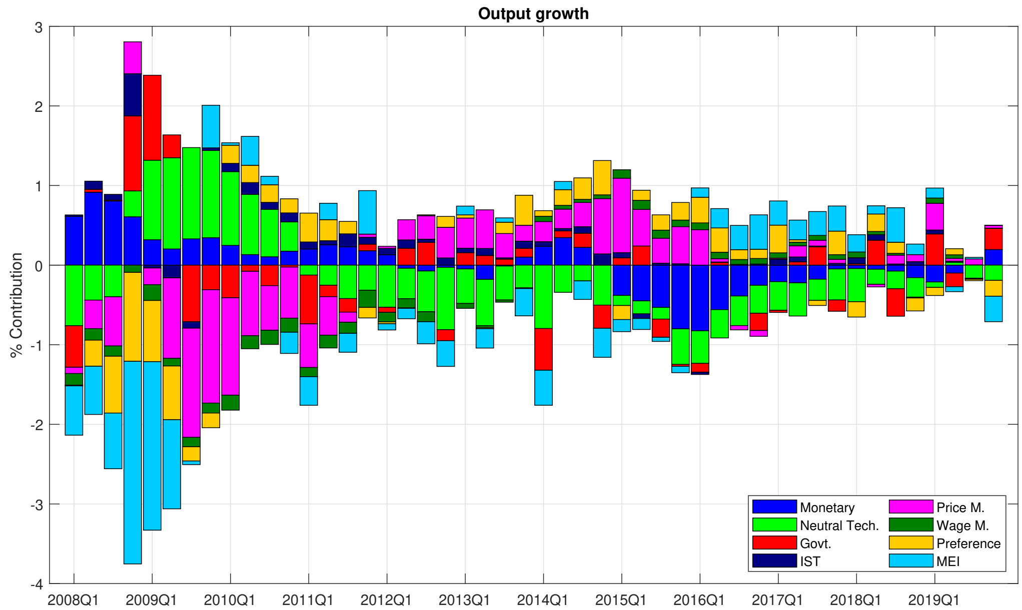
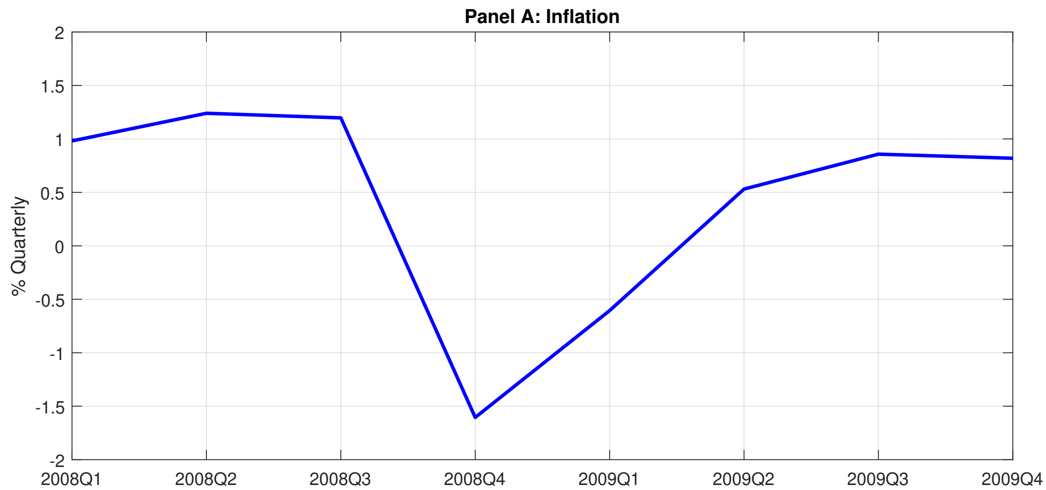


Figure 3: Inflation and inflation shock decomposition, 2008-2009



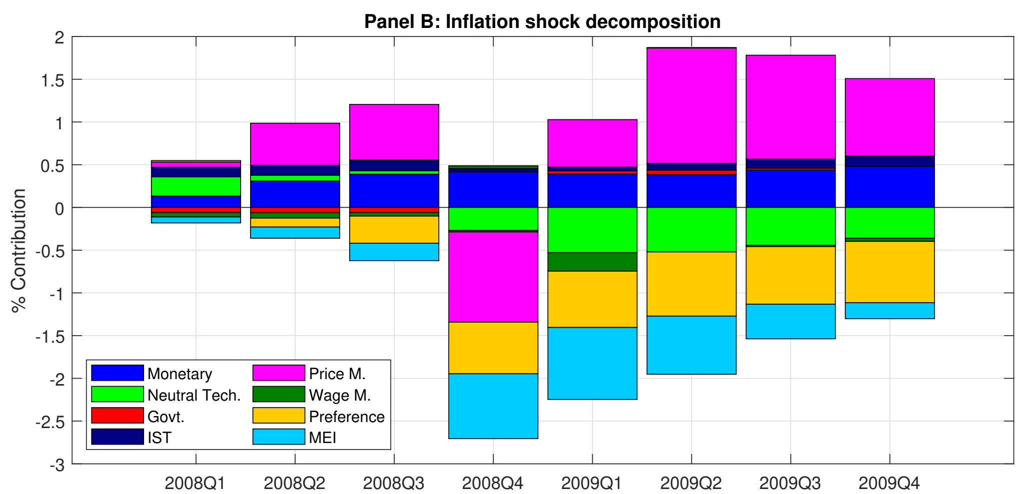


Figure 4: Monetary and fiscal policy shock contributions to output, consumption, investment, and hours growth, 2008-2019

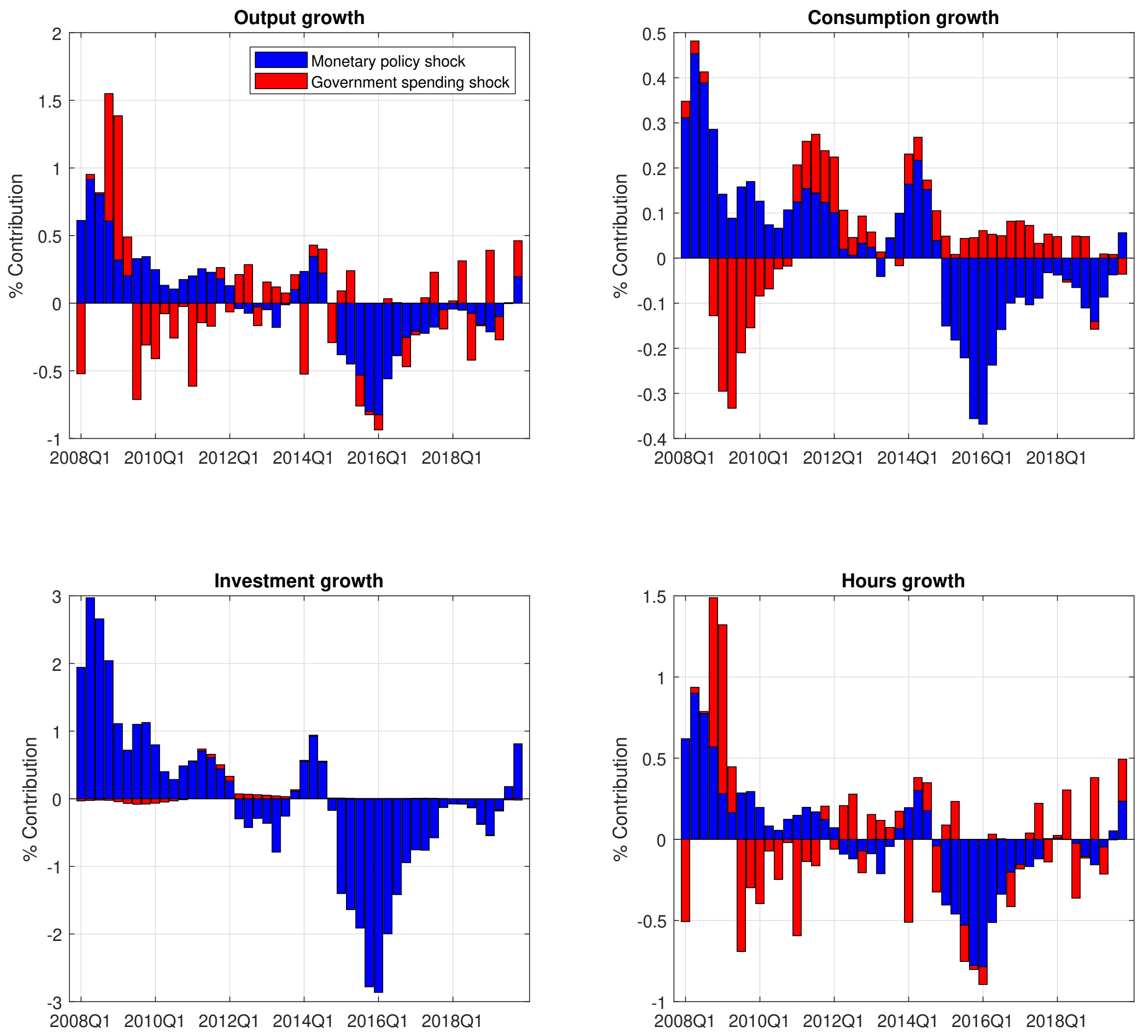


Figure 5: Inflation shock decomposition around liftoff

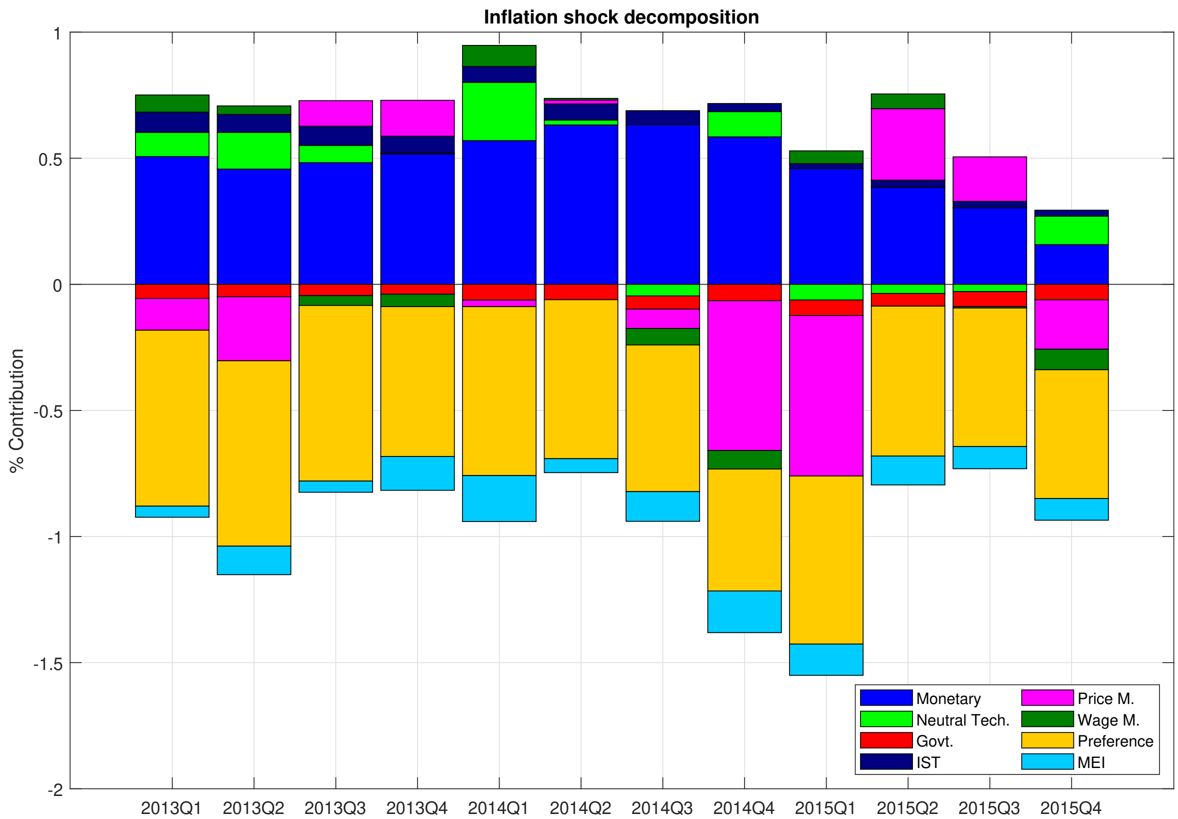


Figure 6: Unemployment, 2008-2019

A Log-linearized model

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.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$\widehat{S}_t=\rho_R\widehat{S}_{t-1}+(1-\rho_R)\left[\alpha_\pi\widehat{\pi}_t+\alpha_{\Delta y}\left(\widehat{gdp}_t-\widehat{gdp}_{t-1}\right)\right]+\widehat{\varepsilon}_t^r \tag{A15}$$

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

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

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

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

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

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

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

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

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

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

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