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Is Unconventional Monetary Policy Stabilizing? Evidence From the Great Recession and Recovery Years*

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Abstract

Is unconventional monetary policy stabilizing? With the Great Recession and the advent of COVID-19, this is a question macroeconomists should urgently answer. We estimate a medium-sized New Keynesian model using Bayesian techniques over a sample of data that spans from 1983:Q1 to 2019:Q4. Our focus is on the Great Recession and the recovery years. We distinguish between periods of conventional and unconventional monetary policy using the shadow rate of Wu and Xia (2016). We offer four main sets of substantive results. First, conditioned on monetary policy shocks, output and consumption constantly rise between 2008:Q1 and 2015:Q4, and quite significantly so, while hours worked modestly exceed their pre-recession level, and investment is mildly below its pre-2008 level. Second, conditioned on adverse and monetary policy shocks, the maximum declines in output, consumption, investment and hours are significantly smaller and occur sooner than conditioned on adverse shocks only. The effect of monetary policy on hours is particularly strong. Third, output, consumption and investment return to their pre-recession levels between one and two years sooner conditioned on both adverse and monetary policy shocks than on adverse shocks only. Fourth, our estimated model provides a relatively accurate description of the behavior of inflation during the Great Recession and recovery years despite its New Keynesian essence. Overall, our findings show that in light of extraordinary events like the Great Recession and COVID-19, unconventional policy tools could be a useful card in the hands of the Fed for stabilizing purposes in years to come.

JEL classification: E31, E32, E37.

Keywords: Unconventional Monetary Policy; Great Recession; Recovery Years; New Keynesian Model; Shadow Rate; Bayesian Estimation.

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1 Introduction

In the 2020 Presidential Lecture to the American Economic Association, former Federal Reserve's Chair Ben Bernanke (2020) proposes incorporating new unconventional policy tools into the standard central bank toolkit. A possible reason for this recommendation is that simulations from the Fed's main macroeconometric model suggest that policy rules like those used prior to the Great Recession should deliver short-term interest rates constrained at zero as much as one-third of the time in the future, with adverse consequences on overall economic performance (Kiley and Roberts, 2017). Bernanke concludes that "the old methods won't do" and that "if monetary policy is to remain relevant, policymakers will have to adopt new tools, tactics, and frameworks."

Since Bernanke's Presidential Lecture, the advent of COVID-19 with the dramatic toll inflicted on human lives, and the great economic distress many have to endure, have made it more than urgent to assess whether unconventional policy tools can have stabilizing powers when the economy is near or at the zero lower bound (hereafter ZLB) on the nominal interest rate. This is what this paper does, by offering empirical evidence as to whether unconventional monetary policy was effective in mitigating the severity and duration of the Great Recession and strengthening and speeding up the recovery with the Fed facing the ZLB.

Conventional monetary policy usually refers to the Fed's practice of setting nominal interest rates from comprehensible feedback-rules (Taylor, 1993; Clarida, Galí, and Gertler, 1999, 2000). There is a consensus in the literature that prior to 1980 the Fed did not react strongly enough to deviations of inflation from target, and that this presumably fueled self-fulfilling inflation expectations and generated high and volatile inflation, as well as unstable output growth. The consensus view also holds that after Paul Volcker's nomination as Chair of the Federal Reserve in 1979, monetary policy reacted much more aggressively to inflation, a policy stance described as "non accommodative" by Clarida, Galí, and Gertler (2000) and "hawkish" by Coibion and Gorodnichenko (2011). Between the early 1980s and the Great Recession, inflation remained steadily low and displayed much less variability, while output growth was also much more stable.

The Great Recession and the ZLB on the nominal interest rate signaled a sudden change in the orientation of monetary policy. Because the recession was expected to be more severe and last longer than any other one during the post-WWII era, the main concern of the Fed shifted temporarily from ensuring price stability to giving the economy a boost that would mitigate the adverse effects of the recession and speed up the recovery. This led the Fed to use unconventional monetary policy tools which included large-scale purchases of financial assets (quantitative easing), as well as increasingly explicit communication about the central bank's outlook and policy plans (forward guidance).

Given this background, our paper asks the following questions about the effectiveness of unconventional monetary policy tools. Was unconventional monetary policy expansionary? Did it help reduce the severity and length of the Great Recession? Did it help sustain and speed up the recovery? We intend to offer quantitative answers to these questions using a medium-sized New Keynesian model estimated with Bayesian techniques for a sample of data covering the period 1983:Q1 to 2019:Q4.

Our model features nominal wage and price contracts, real adjustment frictions, real per capita output growth, intermediate goods, and a cost-channel for monetary policy. Following Christiano, Trabandt, and Walentin (2010), and Phaneuf, Sims, and Victor (2018), monetary policy may have direct supply-side effects as a fraction of firms' variable input costs, including the purchase of intermediate goods, must be financed through short term loans which are reimbursed at some nominal interest rate. That monetary policy can have some cost-channel effects might be important given our focus on its effectiveness. The Great Recession and business cycles more generally, are driven by shocks to the wage and price markups, neutral and investment-specific technologies, the transformation of investment goods into installed capital , risk premium, monetary policy and government spending.

When estimating our model, we distinguish between periods of conventional and unconventional monetary policy using the shadow federal funds rate constructed by Wu and Xia (2016) (see also Wu and Zhang (2019)). The shadow rate is a measure extracted from an affine term structure model that allows inferences from the full yield curve about what would have been the short-term interest rate without the ZLB. It is intended to summarize total accommodation from conventional monetary policy and unconventional policy tools. During years of conventional monetary policy, the shadow rate equals the effective federal funds rate, whereas at the ZLB, it summarizes the use of unconventional policy tools mapped into the interest rate domain. The main advantage of the shadow rate is that it does not require the explicit modeling of a structural break at the ZLB. This alleviates computational issues, while facilitating model estimation and the conduct of counterfactual experiments.[1]

A key relation in the model is the shadow rate rule. Wu and Zhang (2019) assume a shadow rule which is broadly similar to the textbook Taylor rule (Galí, 2008), wherein the nominal interest rate systematically responds to current inflation and to the level of the output gap, the latter being measured by the deviations of current output from the equilibrium level of output assuming flexible prices. We use instead an inertial interest rate rule stating that the shadow rate reacts to deviations of inflation from target and output growth from trend growth. The reason for choosing this specification is that Khan, Phaneuf, and Victor (2020a,b) have shown that achieving determinacy in a New Keynesian model with both sticky wages and sticky prices with the Fed targeting the output gap, requires large departures from the original Taylor Principle, and this at low rates of trend inflation such as 2% and 3%.

Following the approach laid out in Ireland (2011), we use the Kalman filter to generate smoothed shocks from our estimated model. This allows the identification of shocks which have been recessionary, and those which had some expansionary effects. We compare the actual paths of key macroeconomic variables like output, consumption, investment, hours worked, and inflation during the Great Recession and the years after, with counterfactual paths conditioned on both individual shocks and a mixture of shocks.

Our main findings are summarized as follows. We first identify the adverse shocks which according to our model were responsible for the Great Recession and the slow and weak economic recovery. We identify the main recessionary shocks as being those to the production of installed capital or marginal efficiency of investment, risk premium and price markup.

[1] Wu and Xia (2016) use a formal structural break test after estimating the shadow rate and find no evidence of a structural break, which is corroborated by Wu and Zhang (2019).

The other two adverse shocks, but to a lesser degree, are those to investment-specific technology and the wage markup. The favorable or expansionary shocks were those to neutral technology, monetary policy and to a lesser extent government spending.

According to the data, there was a large drop of 4.5% in output during the Great Recession. Meanwhile, consumption dropped by 2.3%, investment by 25.6%, and hours worked by 11.5%. Furthermore, the recovery was weak and slow. For example, it is only in 2014:Q3 that output and consumption got back to their pre-recession level. Investment returned to its pre-recession level in 2018:Q1. Hours have not returned yet to their pre-recession level.

We find that conditioned on adverse shocks, the counterfactuals from our estimated model are generally consistent with the relative declines in these aggregates, the great severity of the recession, and the fact that the recovery was weak and slow.

A first set of substantive findings are answers to the main questions about the effectiveness of unconventional monetary policy. Based on counterfactual experiments from our estimated model conditioned on a shock to the shadow rate, we find that the Fed's policy was indeed expansionary. Our counterfactual implies that output increases constantly between 2008:Q1 and 2015:Q4. While actual output has increased by 1.7% by the end of 2015 relative its pre-recession level, the counterfactual says the increase is 12%. We find a similar pattern for consumption, but with a different magnitude. Also, while investment has dropped drastically during the Great Recession, our counterfactual says it decreases below its pre-recession level between 2008:Q1 and 2012:Q1, but by a much smaller percentage than the actual drop. Furthermore, investment exceeds its pre-recession level between 2012:Q1 and 2016:Q1. Hours worked according to the counterfactual do not fall between 2008:Q1 and 2015:Q4, compared to the sharp drop that was observed during the Great Recession and the recovery years.

Did unconventional monetary policy help reduce the severity and length of the Great Recession? We offer evidence that it did, and this based on the following counterfactual experiments. First, we ask how severe and lasting the recession would have been, conditioned on adverse shocks being the only shocks hitting the economy. Second, we answer this question, conditioned on adverse and monetary policy shocks.

Conditioned on adverse shocks only, the recession would have been even more severe and longer. For example, final output would have dropped by nearly 15% instead of 4.5%, with a trough in 2011:Q1 instead of 2009:Q4. With expansionary monetary policy shocks, the trough would have occurred in 2010:Q1 or one year sooner than with adverse shocks only, and the drop in output would have been 11.6%.

Did unconventional monetary policy help sustain and speed up the recovery? Our evidence suggests it did. We show that conditioned on adverse shocks only, output would have returned to its pre-recession level in 2016:Q3, whereas with both adverse and monetary policy shocks, it would have reached its pre-2008 level in 2015:Q1 or almost two years sooner. Consumption conditioned on adverse shocks would have returned to its pre-recession level in 2017:Q1, compared to 2015:Q4, or more than a year sooner, conditioned on adverse and MP shocks. Investment would have been back to its pre-recession level in 2018:Q1 driven by adverse shocks only, and in 2016:Q4 conditioned on adverse and monetary policy shocks.

Unconventional monetary policy helped working hours recover from the Great Recession. Hours actually fell by 11.5% relative to their pre-recession level during the Great Recession with a trough in 2010:Q1. Conditioned on adverse shocks only, the drop in hours would have been 15.5% with a trough in 2011:Q1. Conditioned on adverse and monetary shocks, the trough would have occurred in 2011:Q1, but this time with a decline in hours of 12% relative to their pre-recession level. In 2015:Q4, the decline in hours would have remained quite high at 8% conditioned on adverse shocks, while it would have been smaller at 5% conditioned on adverse and MP shocks. Our evidence hence suggests unconventional monetary policy helped sustain and speed up the recovery.

A final and important question addressed in the paper is that of the behavior of inflation during the Great Recession. Hall (2011) argues that inflation which was negative at the onset of the Great Recession, should have declined much more than it did according to the New Keynesian credo. Research efforts have been devoted at understanding the behavior of inflation during the Great Recession. Del Negro, Giannoni, and Schorfheide (2015) have shown that adding financial frictions and a time-varying inflation target to an otherwise standard medium-scale DSGE model helps predicting a strong contraction in economic activity and a protracted but relatively modest decline in inflation during the Great Recession and years of recovery. Using a DSGE model that assumes perfectly flexible nominal wages, sticky prices, a binding ZLB constraint and financial frictions, Christiano, Eichenbaum, and Trabandt (2015) show that a fall in TFP relative to trend and a rise in the cost of working capital might explain the behavior of inflation during the Great Recession. We find that the path of inflation conditioned on adverse and monetary policy shocks closely match the actual path observed during the Great Recession and recovery years, and this, despite the Keynesian essence of our DSGE model.

The rest of the paper is organized as follows. Section 2 describes our DSGE model, including the shadow policy rule. Section 3 lists the observables used in the estimation and broadly describes the Bayesian estimation procedure. Section 4 presents some estimation results, including model's fit and variance decomposition of observables based on our estimated model. Section 5 identifies what were the adverse shocks during the Great Recession and recovery years, and assesses their macroeconomic consequences. Section 6 focuses on whether unconventional monetary policy has been stabilizing, that is, whether it helped mitigating the recessionary effects of adverse shocks and amplifying the expansionary effects of favorable shocks. Section 7 assesses how our estimated model can cope with the behavior of inflation during the Great Recession and the recovery years. Section 8 contains concluding remarks.

2 Model

Following Erceg, Henderson, and Levin (2000), the model laid out in this section assumes imperfectly competitive labor and goods markets, sticky wages and sticky prices. It also features real adjustment frictions like consumer habit formation, investment adjustment costs and variable capital utilization following Christiano, Eichenbaum, and Evans (2005). Economic growth stems from trend growth in neutral and investment-specific technology (Justiniano and Primiceri, 2008). Firms' production and their pricing decisions are related through input-output linkages. Firms borrow working capital to finance a fraction their variable input costs. Conventional and unconventional monetary policies are described by a shadow rule wherein the Fed smooths short-term movements in nominal interest rates, while systematically reacting to deviations of inflation from an exogenously fixed target, and to deviations of output growth from trend growth.

Business cycle fluctuations are driven by eight different types of disturbances. Three are technological: shocks to neutral technology, investment-specific technology and to the production of installed capital. Two are shocks to the wage and price markups. The last three are shocks to the risk premium, monetary policy, and government spending.

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:

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

$\varepsilon_{p,t}$ 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:

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

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:

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

where A_t is an 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 the 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:

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

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 $\overline{\phi} \equiv \phi^{-\phi} (1-\phi)^{\phi-1} \left(\alpha^{-\alpha} (1-\alpha)^{\alpha-1} \right)^{1-\phi}$, $mc_t = \frac{MC_t}{P_t}$, 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 $t+s$, $\Pi^p_{t,t+s} = \Pi^s_{k=1}\pi^{\iota_p}_{t+k-1}\pi^{1-\iota_p}$ 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 optimal price:

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

where λ^r_t 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,

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

and the physical capital accumulation process,

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

b_t in the utility function is an exogenous risk premium 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, 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 $AC(.) = 0$, $AC'(.) = 0$, and $AC''(.) > 0$, δ is the rate of depreciation of physical capital, and ϑ_t is a stochastic shock to the marginal efficiency of investment (MEI).

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

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

where ε_t^b is 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, and this 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 agences 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:

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

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:

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

where ξ_w^s is the probability that a wage chosen in period t will still be 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:

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

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

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 the AR(1) process:

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

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 stationnary model around the non-stochastic steady state. The full set of equilibrium conditions can be found in Appendix A.

3 Data and Estimation Methodology

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

3.1 Data

The model of Section 2 is estimated with US quarterly data on output, consumption, investment, real wages, hours worked, inflation, the shadow rate, and the relative price of investment goods to consumption goods. A detailed description of the data can de found in Appendix B.

All nominal series are converted in real terms by dividing with the price deflator corresponding to our measure of output. Furthermore, output, consumption, investment and hours worked are expressed in per capita terms by dividing with the civilian non-institutional population between 16 and 65. The shadow rate equals the effective federal funds rate during years of conventional monetary policy, whereas for years during which the Fed used unconventional policy tools, it corresponds to the shadow rate of Wu and Xia (2016). All data except the shadow rate are in logs and seasonally adjusted.

3.2 Bayesian Methodology

We a subset of the model's structural parameters with a Bayesian procedure. This procedure is now widely used when estimating DSGE models, and recent overviews of it can be found 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:

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

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

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: $\overline{g}_{\Omega} = 100 \log g_{\Omega}$, $\overline{L} = 100 \log L$, $\overline{\pi} = 100 \log \pi$, $\overline{S} = 100 \log S$ and $\overline{g}_v = 100 \log g_v$. The symbol ˆ denotes a variable which is measured as a log-deviation from steady state.

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

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

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 two million draws and use this (after dropping the first 20% of the draws) to report *i*) the posterior mean of the structural parameters and shock processes, and the 10 and 90 percentiles of their posterior distributions, and the *ii*) parameter estimates conditioned on the posterior mode. All estimations are done using Dynare (Adjemian et al. (2011)).

3.3 Prior Distribution

Some parameters are held fixed prior to estimation. We assign them values commonly found in the literature. The quarterly rate of depreciation of physical capital δ is set at 0.025, which implies an annual rate of depreciation of 10%. The steady-state ratio of government spending to GDP is set to 0.21, which corresponds to the average value of G_t/Y_t in our sample. The elasticity of substitution between differentiated goods and that between differentiated labor skills are each set at 10.

Table 1 lists the choice of priors for the parameters we estimate. We use prior distributions which are broadly consistent with those adopted in the literature, for example by Smets and Wouters (2007) and Justiniano et al. (2011). 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 firms' input costs financed by working capital, ψ, we also use a Beta prior, with mean 0.3 and standard deviation 0.1.

4 Estimation Results

4.1 Parameter Estimates

Table 1 reports the mean and the 10 and 90 percentiles of the posterior distributions of the structural parameters and the shock processes obtained by the Metropolis-Hastings algorithm. Table 2 presents estimates conditioned on the posterior mode. Recall that these estimates are obtained from a sample of data covering the period 1983:Q1 to 2019:Q4. Broadly speaking, the estimates are generally consistent with the rest of the literature.

We find that the estimate governing the shadow rate response to deviations of inflation from target is about 1.6, while it is 0.23 for the response to deviations of output growth from trend growth. The degree of interest rate smoothing is high and slightly above 0.9.

Two parameters about which we know little based on the previous literature are ψ and ϕ. We report estimates of ψ of 0.265 conditioned on the posterior mean and 0.243 conditioned on the posterior mode. What these estimates tell us is that firms need working capital to finance a relatively modest fraction of their variable input costs, which might be viewed as more realistic than other assumptions concerning the use of working capital, for example that firms need working capital to finance all of their wage bill but none of their other factor costs each period.

Estimates of the share of intermediate goods into gross production are respectively 0.41 conditioned on posterior mean and 0.43 based on posterior mode. While these estimates support the existence of a degree of roundaboutness in the US production structure, our estimates are somewhat lower than the values typically assigned in studies that calibrate this share and which typically lies between 0.5 and 0.7. One possible reason explaining this difference is that studies where this share is calibrated rely on data from the US manufacturing sector, whereas our estimate of ϕ is one for the whole US economy.

4.2 Model's Fit

We assess the model's empirical fit by focusing on standard empirical moments. They are summarized in Table 3, which compares moments in the data and those conditioned on the posterior mean from our estimated model. The reported volatility and correlation statistics are for variables measured in growth rates.

The model accounts relatively well for the moments in the data considering that the period 2008:Q1 to 2019:4 is one of high macroeconomic instability. The model somewhat overpredicts the volatility of output growth, consumption growth and investment growth, and underestimates the volatility of hours. It does reasonably well accounting for the variability of real wages, inflation and the relative price of consumption goods to investment goods. It underpredicts the volatility of the nominal interest/shadow rate.

We also report some key contemporaneous correlations. Interestingly, the model closely matches the correlations between output growth and consumption growth, and between output growth and investment growth. Note also, that the model also generates a positive correlation between consumption growth and investment growth, although it underestimates this correlation relative to the data.

Note also that the model correctly predicts that the correlation between output growth and inflation is negative, and that between output growth and the relative price of consumption goods to investment goods is negative, that the correlation between hours worked and the real wage is weakly positive, and that the correlation between the nominal interest rate/shadow rate and inflation is moderately positive.

4.3 Variance Decomposition

To assess the sources of business cycle fluctuations, we compute the variance decomposition of our observables at the business cycle frequency of 6-32 quarters based on our estimated model. The results are reported in Table 4.

Our evidence does not speak with one voice. We find that technological shocks contribute to 52% of the cyclical variance of output growth, with shocks to the marginal efficiency of investment accounting for 33.7% of that variance. Non-technological shocks explain 82% of the cyclical variance of consumption growth, with risk premium shocks accounting for most of it. Investment-specific technology (IST) shocks and those to the marginal efficiency of investment (MEI) contribute more than 70% of the cyclical variance of investment growth. Technological and non-technological shocks contribute almost equally to the cyclial variance of hours. Price markup shocks account for more than 40% of the variance of inflation. Finally, monetary policy shocks explain nearly 40% of the variance of the nominal interest rate/shadow rate.

The contribution of MEI shocks to the cyclical variance of output growth implied by our model deserves a few comments. Justiniano, Primiceri, and Tambalotti (2011) estimate that MEI shocks account for 60% of the cyclical variance of output growth. Khan and Tsoukalas (2011) estimate this contribution at 72.4% if the cost of utilizing physical capital more intensively is measured as an increased depreciation rate and 59.1% if this cost is measured as foregone consumption. Justiniano et al. use a sample of data running from 1954:Q3 to 2009:Q4, while the sample of data used by Khan and Tsoukalas spans from 1954:Q3 to 2004:Q4. By contrast, Christiano, Motto, and Rostagno (2014) report that MEI shocks account for only 13% of the cyclical variance of output growth, while risk shocks contribute to 62% of that variance. Note that their sample ranges from 1985:Q1 to 2010:Q2.

Now, Khan, Phaneuf, and Victor (2020a) have shown that the statistical inference about the importance of MEI shocks in New Keynesian models can be sensitive to the choice of the sample period. When estimating a medium-sized DSGE model from 1960:Q1 to 2007:Q3, they find that MEI shocks account for about 50% of the cyclical variance of output growth. When estimating the model over the 1960:Q1-1979:Q2 subperiod, they find MEI shocks account for 60% of that variance. By contrast, when the subsample is 1982:Q4-2007:Q3, the contribution of MEI shocks shrinks to only 19%, which is broadly consistent with the evidence reported by Christiano et al. concerning the mild importance of MEI shocks after 1982. Here, we use a longer sample than either Christiano et al. or Khan et al. do, and extend it till the end of 2019. As we later discuss the higher contribution of MEI shocks to the cyclical variance of output growth when taking into account the longer sample might be explained by the fact that these shocks are among the strongest adverse shocks contributing to the Great Recession and the weak and slow economic recovery.

5 The Sources of the Great Recession

What were the main shocks responsible for the Great Recession and why was the recovery weak and slow? The next Section offers tentative answers to these questions based on our estimated DSGE model.

5.1 Adverse Shocks

Panel A of Table 5 reports estimates of individual shocks from 2008:Q1 to 2009:Q4. They are Kalman smoothed shocks conditioned on information from the full sample of data.

At the beginning of the Great Recession, the economy was hit by a combination of negative shocks to total factor productivity, government spending and marginal efficiency of investment. In the second and third quarter of 2008, it was hurt by two additional adverse shocks, that is, by negative shocks to the risk premium and positive shocks to the price markup.

As for MEI shocks, the economy was hit by a sequence of negative shocks starting in 2007:Q3, which culminated in 2008:Q4 with an unprecedented negative shock by post-1982 standards that was 2.6 times larger than its highest precedent negative value observed in 1988:Q1. The fourth quarter of 2008 also saw a large IST shock that was 2.9 times larger than its highest previous negative value observed in 1986:Q2. The risk premium shock of 2008:Q4 was also important, being surpassed only by the negative shock of 2000:Q1.

Given the key role of adverse MEI shocks in the Great Recession and the recovery years, we reflect for a moment upon the interpretation that may be given to this shock. Whereas in our model IST shocks map one-to-one into the relative price of investment goods, MEI shocks affect the accumulation of physical capital while being orthogonal to the relative price of investment. Therefore, what possible interpretation can be given to this shock?

It has been suggested that MEI shocks can be interpreted as shocks to the production of installed capital. Based on the agency cost models of Bernanke and Gertler (1989) and Carlstrom and Fuerst (1997), Justiniano, Primiceri, and Tambalotti (2011) argue that there is an equivalence between the New Keynesian model with MEI shocks and the agency cost model wherein fundamental disturbances to the intermediation ability of the financial system play a key role. Carlstrom and Fuerst (1997) argue that their agency cost framework is isomorphic to a model where there are costs to adjusting the capital stock insofar as net worth is kept constant. To support this interpretation, Justiniano et al. compare the MEI shock implied by their estimated New Keynesian model with a proxy for the external finance premium.

In this spirit, Figure 1 compares the MEI shock from our estimated model with a measure of spread between the corporate-borrowing rate and the interest rate paid by the US government, the later being the Moody's seasoned Baa corporate bond yield relative to the yield on the ten-year Treasury bond. The comparison is for the period 1986:Q1 to 2019:Q4 due to data limitations. First, note that the correlation between the two measures is quite strongly negative, being -0.72 for our sample. Second, the large negative MEI shock that occurred in 2008:Q4 coincides with the largest increase in the spread by post-1986:Q1 standards.

There exist other types of models that have investigated the sources of the Great Recession and where financial frictions are explicitly taken into account. These models include those of Christiano, Motto, and Rostagno (2014) and Christiano, Eichenbaum, and Trabandt (2015). We believe our findings obtained from our New Keynesian framework without explicit modeling of financial frictions are not necessarily inconsistent with theirs. Furthermore, our main objective differs somewhat from theirs in that, while we focus on the factors responsible for the Great Recession, our main goal is to offer a quantitative assessment of the effectiveness (or lack thereoff of effectiveness) of unconventional monetary policy.

Now, in 2008:Q4 the economy was also hit by three very favorable shocks, also by post-1983:Q1 standards: two large positive shocks to neutral technology and government spending, and one big negative price markup shock. The monetary policy shock was mildly expansionary. The positive neutral technology shock of 2008:Q4 was followed by a string of positive TFP shocks until the end of the Great Recession in 2009:Q4. The government spending shock remained significantly positive in 2009:Q1 and Q2. The MEI shock was modestly negative in 2009:Q1, but was positive in the following three quarters until the end of the recession. The IST shock was also positive during the four quarters in 2009.

The effective federal funds rate was close to zero by 2008:Q4. Since 2007:Q1, the Fed has experienced a long sequence of negative shocks to the nominal interest rate while it was bringing down the nominal interest rate from 5.26% in June of 2006 to nearly zero around 2008:Q4. Note that the expansionary policy shocks in the first two quarters of 2008 were quite large. They were followed in 2009 by a sequence of negative policy shocks, but this time to the shadow rate.

Knowing that the economic recovery was both weak and slow, Panel B of Table 5 also considers the composition of adverse and favorable shocks during the 24 quarters of the recovery years, that is, from 2010:Q1 to 2015:Q4. Five shocks were adverse more than half of the time during the recovery: shocks to neutral technology, government spending, price markup, risk premium and marginal efficiency of investment. Note that the shocks to neutral technology, government spending, risk premium and MEI were unfavorable 2/3 of the time or more during that period. Only the IST shocks, the wage markup shocks and, of course, the shocks to the shadow rate were favorable more than half of time during that period. This particular mixture of shocks, with adverse shocks being more numerous than favorable shocks between 2010:Q1 and 2015:Q4, explains why the recovery was both weak and slow in the aftermath of the Great Recession.

5.2 Macroeconomic Consequences of Adverse Shocks

From the beginning of the Great Recession in 2008:Q1 till the end in 2009:Q4, output has dropped by nearly 4.2%, consumption by 2.3%, investment by 23% and log hours by 11.8%. We identify the shocks that generated these important drops in the main macroeconomic aggregates.

Figure 2 compares the actual path for output between 2008:Q1 and 2019:Q4 (red solid line) with simulated paths conditioned on each of the three main shocks that were responsible for the adverse effects on output (blue solid lines). These shocks are the MEI, risk premium and price markup shocks.

It is worth noticing that the counterfactual path for output conditioned on the MEI shock and the actual path follow one another relatively closely, although there is a larger drop in output from 2008:Q4 until 2011:Q4 based on the conditional path. The decline in output conditioned on the risk premium shock is also stronger than the actual decline after 2008:Q4, with a trough occurring one quarter after the actual one. The path of output conditioned on the price markup shock differs quite markedly from the other two conditional paths, in that its most adverse effect on output occur after the end of the recession in 2011:Q2.

Figure 3 makes a similar comparison for consumption paths. The one shock that definitely had a recessionary impact on consumption is the risk premium shock. While consumption actually declined by about 2.25% from 2008:Q1 to 2009:Q4, the drop is 4.5% conditioned on the risk premium shock, with a trough in 2009:Q3. The risk premium shock being the only one having a significant adverse effect on consumption, this helps understand why the drop in consumption was significantly smaller during the Great Recession than for either output, investment or hours.

Figure 4 focuses on the effects of adverse shocks on investment. In this particular case, we compare the actual path of investment with the paths conditioned on each of the eight shocks since all had adverse effects on investment during the Great Recession. Unsurprisingly, the MEI shock had the most adverse effect on investment from 2008:Q1 to 2009:Q4. Conditioned on this shock, the drop in investment is 33.5% instead of 23% in 2009:Q4. The price markup shock also had a strong adverse effect on investment. The drop in investment conditioned on this shock is almost 27% by the end of the recession in 2009:Q4. Three other shocks initially had a recessionary impact on investment, but eventually had expansionary effects during the recovery: the monetary policy, neutral technology and risk premium shocks. In the case of the neutral technology shock, the expansionary effect was relatively modest and short-lived. That all shocks simultaneously had adverse effects on investment helps understand why the decline in investment was strong from the beginning till the end of the Great Recession.

Figure 5 contrasts the actual and conditional paths of (the log of) hours. In this case too, almost all shocks, with the exception of the monetary policy shock, had significant adverse effects on hours during the Great Recession and the recovery years. Since the beginning of the Great Recession, the price markup shock depressed hours worked by 6.6% in 2009:Q4, with a trough at -10.4% in 2011:Q3. The MEI and risk premium shocks also had significant a negative impact on hours during the Great Recession. Conditioned on the MEI shock, the trough in hours worked occurred in 2009:Q2 with hours dropping by 6.1% relative to their pre-recession level. Conditioned on the risk premium shock, the trough was at 6% in 2010:Q1. The neutral technology shock was also a significant factor depressing hours, with a maximum decline in hours of 3.9% in 2009:Q2. When combining these four shocks, we find that conditional hours declined by more than 14% by the end of the Great Recession.

6 Was Unconventional Monetary Policy Stabilizing?

The present Section examines whether unconventional monetary policy tools had some stabilizing effects during the Great Recession and the recovery years. We are primarily interested in assessing whether unconventional policy tools were able to reduce the severity and length of the recession and helped strengthen and speed up the recovery.

6.1 Was Unconventional Monetary Policy Expansionary?

Figure 6 compares the actual paths of output, consumption, investment and hours (red lines) with their counterfactual paths conditioned on an expansionary shock to the shadow rate (blue lines). The counterfactual path suggests that output constantly rises from 2008:Q1 to 2015:Q4. Thus, our evidence confirms that unconventional monetary policy tools played the role intended by the Fed, that is, providing the economy a stimulus faced with the ZLB. Note that by the end of 2015, actual output was 1.7% higher than its pre-recession level, while the counterfactual scenario based on monetary policy shocks only implying it is 12% higher than its 2008:Q1 level. The counterfactual path of consumption looks broadly similar to the path of output. Conditioned on monetary policy shocks only, there is no fall in the level of consumption during the Great Recession and ensuing years, and consumption almost constantly rises from 2008:Q1 to 2019:Q4.

The results of this counterfactual experiment are somewhat different for investment. We find that from 2008:Q1 to 2012:Q1 the counterfactual level of investment is lower than its pre-recession level, although it is much higher than its actual level. Meanwhile, hours conditioned on monetary polciy shocks do not fall from 2008:Q4 till 2015:Q4 contrary to actual hours that drop sharply during the Great Recession and remain below their pre-recession level during the recovery years.

Therefore, our findings suggest that the long sequence of negative shocks to the shadow rate, which merely reflects the use by the Fed of unconventional policy tools at the ZLB, helped in sustaining the economy during the Great Recession and until the end of 2019.

6.2 Mitigating the Effects of Adverse Shocks

Another way to measure the effectiveness of unconventional monetary policy is to examine how monetary policy shocks mitigated the recessionary effects of adverse shocks. Figure 7 conveys the results of two experiments. A first experiment compares the severity and duration of the Great Recession, as well as the strength of the recovery, based on actual data and counterfactuals conditioned on all adverse shocks considered jointly. More specifically, we compare the actual paths of output, consumption, investment and hours (red lines) with the counterfactual paths conditioned on all adverse shocks (black lines). The second experiment makes a similar comparison, but assuming that the counterfactual paths are jointly conditioned on adverse shocks and monetary policy shocks (blue lines).

First, consider the paths for output. Based on actual data, there was a trough in 2009:Q4 with a drop in output that was 4.5% relative to its pre-recession level. Without favorable shocks, the counterfactual path of output conditioned on adverse shocks shows a trough occurring in 2011:Q1 with a drop in output of 15%. By comparison, conditioned on adverse and monetary policy shocks, the trough occurs in 2010:Q1, that is, one year sooner, with a drop of 11.6%. Monetary policy shocks also help strengthen and speed up the recovery. Conditioned only on adverse shocks, output returns to its pre-recession level in 2016:Q3, whereas with both adverse and monetary policy shocks, output reaches its pre-2008 level in 2015:Q1, that is, almost two years sooner.

Consumption conditioned on adverse shocks hits a trough in 2012:Q3 with a drop of 9.2% relative to its pre-recession level. Conditioned on adverse and monetary policy shocks, the trough occurs in 2010:Q4, that is, almost two years more rapidly than with adverse shocks only, with a drop of 6.7% . While consumption returns its pre-recession level in 2017:Q1 conditioned on adverse shocks, with adverse shocks and monetary policy shocks it returns to its pre-recession level in 2015:Q4, that is, more than a year sooner.

Monetary policy shocks also gave investment a stimulus during the Great Recession and the years after. The actual trough in investment occured in 2009:Q3 with a drop in investment of 25.6%. The counterfactual scenario based on adverse shocks implies a trough in 2011:Q1 with a drop of 40.2% relative to its pre-recession level. The counterfactual scenario based on adverse and monetary policy shocks predicts a trough in 2010:Q1 with a drop in investment of 33.7%. While actual investment was back to its pre-recession level only in 2018:Q1, investment conditioned on adverse and monetary policy shocks would have reached its pre-2008 level in 2016:Q4, that is, five quarters later.

Unconventional monetary policy significantly helped hours worked. Actual hours worked fell drastically during the Great Recession reaching a trough in 2010:Q1 with a drop of 11.5% relative to their pre-2008 level. A counterfactual experiment conditioned on adverse shocks implies the trough occurs in 2011:Q1 with a decline of 15.5%. Conditioned on adverse and monetary policy shocks, the trough still takes place in 2011:Q1, but this time with a 12% drop close to the actual drop in hours. Note also that at some point during the recovery the path of hours conditional on adverse and monetary policy shocks exceeds the actual path. However, by 2019:Q4 actual hours have not returned to their pre-recession level.

We conclude from the empirical evidence reported in the present subsection that unconventional monetary policy helped mitigating the recessionary effects of adverse shocks on the main macroeconomic aggregates (output, consumption, investment and hours) and this quite significantly so, and that it helped sustaining and speeding up the recovery. Furthermore, it favored a faster return of output, consumption and investment to their pre-recession levels.

6.3 Amplifying the Expansionary Effects of Favorable Shocks

Some shocks had favorable effects on output, consumption, investment and hours during the Great Recession and the ensuing years of recovery. Figure 8 makes a comparison of the actual paths of output, consumption, investment and hours and the paths for these variables conditioned on both neutral technology and government spending shocks. That neutral technology shocks did not contribute to the Great Recession is in stark contrast with the findings of Ireland (2011) suggesting that TFP and preference shocks were the main disturbances driving the Great Recession. After a small decline at the onset of the Great Recession, the conditional level of output exceeds its pre-recession level during the Great Recession and the recovery. Relative to its pre-recession level, conditional output reaches a peak in 2010:Q4 with an increase of 9.2% that mainly resulting from an increase in the level of consumption of about 8.6% in 2010:Q4. Conditioned on these two types of shocks, investment declines by about 6% in 2008:Q4 relative to its pre-2008 level, and rises above its pre-recession level by 2.3% in 2010:Q4, and falls again below its pre-2008 level in 2011:Q2 for several years. Conditioned on these two shocks, hours fall relative to their pre-2008 level in 2008:Q2, but much less than they actually did both during the Great Recssion and recovery years.

Figure 9 combines neutral technology, government spending and monetary policy shocks. Conditioned on these three shocks, there is no initial drop in output and the rise in output is significantly stronger relative to its pre-recession level. The same is true for consumption. As for investment, the initial fall relative to the pre-recession level is much smaller and the increase much stronger to the point of almost completely avoiding a fall after 2011:Q2. Finally, under this counterfactual scenario hours worked almost completely avoid a fall between 2008:Q1 and 2015:Q4.

7 Inflation During the Great Recession

Del Negro, Giannoni, and Schorfheide (2015), and Christiano, Eichenbaum, and Trabandt (2015), have taken a closer look at the behavior of inflation during the Great Recession and the ensuing years of recovery following Hall (2011)'s argument that according to New Keynesian models in which inflation adjusts in response to a measure of slack in economic activity, the drop in inflation should have been much stronger and more lasting due to the severity and duration of the recession. Del Negro, Giannoni, and Schorfheide (2015) suggest that adding financial frictions and a time-varying inflation target to an otherwise standard medium-scale DSGE model helps predicting a strong contraction in economic activity and a protracted but relatively modest decline in inflation during the Great Recession and years of recovery. Using a DSGE model which imposes perfectly flexible nominal wages combined with sticky prices, a binding ZLB constraint and financial frictions, Christiano, Eichenbaum, and Trabandt (2015) show that a fall in TFP relative to trend and a rise in the cost of working capital might explain the behavior of inflation during the Great Recession.

Figure 10 assesses whether our medium-sized New Keynesian model featuring the shadow rate can account for the behavior of inflation between 2008:Q1 and 2015:Q4. This figure seeks to identify the main factors responsible for the behavior of inflation during the Great Recession and the recovery years according to our estimated model.

The left-hand side of the figure compares the actual path of inflation (red line) with the path of inflation conditioned jointly on the MEI and price markup shocks (blue line). These two shocks have triggered a sudden drop in inflation shortly after the beginning of the Great Recession. However, the decline in inflation did not last for long as inflation got back to its pre-recessionary level in 2009:Q2 although output remained below its pre-recessionary level until 2014:Q3. The right-hand side of the figure compares the actual path of inflation with the path conditioned on the adverse shocks all considered simultaneously (blue line).

Conditioned on all adverse shocks, the inflation path would have been only slightly different from the actual path during the Great Recession. It is mostly during the years of the recovery that the two inflation paths would have diverged more considerably. Then, inflation rates would have been much lower and often negative during the recovery.

8 Conclusion

The joint occurrence of the Great Recession and the zero lower bound on the nominal interest rate has posed a new dilemma to monetary policy by postwar historical standards. That is, the Federal Reserve has been deprived of its flexibility at a moment when it was needed most. It then turned to unconventional policy tools with the hope of mitigating the extreme severity of the Great Recession, as well as sustaining and speeding up the economic recovery.

While recognizing the urgency of the situation, some economists have recommended that the Fed should give up on unconventional policy tools and return to rule-based monetary policy as soon as possible. The issue is debatable.

We see two challenges posed by strictly adhering to this recommendation at the present times. First what if, as some economists and macroeconomic models seem to suggest, the zero lower bound on nominal interest rates become an element of economic reality for years to come? How would rule-based policy cope with this reality? Second, if this recommendation also means that the inflation target and the average rate of nominal interest rate should be raised in the near future so that an era of rule-based policy can be reintroduced, how important should these increases be? We raise this question, since recent developments in New Keynesian modeling seem to suggest that even a moderate increase in the long-run rate of inflation from 2% to 3% or 4% might entail significant welfare costs and might worsen the prospect of determinacy at modest rates of trend inflation such as 3% or 4%.

We see the empirical findings we have presented here as a useful indication that if unconventional policy tools are used at the right moment, for the right purpose, and in a responsible way, such as in the Great Recession and during the COVID-19 pandemic, unconventional monetary policy might be a potentially useful card in the hands of the Fed.

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Table 1: Results from Metropolis-Hastings (parameters)

	Prior			Posterior			
	Distribution	Mean	Stdev.	Mean	Stdev.	HPD inf	HPD sup
α	normal	0.300	0.0500	0.148	0.0098	0.1320	0.1641
ι_p	beta	0.500	0.1500	0.125	0.0502	0.0451	0.2031
ι_w	beta	0.500	0.1500	0.407	0.0839	0.2681	0.5436
g_Y	normal	0.400	0.0250	0.374	0.0241	0.3345	0.4138
g_I	norm	0.200	0.0250	0.244	0.0248	0.2030	0.2845
h	beta	0.500	0.1000	0.854	0.0243	0.8143	0.8941
$\bar{l}$	norm	0.000	0.5000	-0.120	0.4865	-0.9286	0.6700
$\pi^\star$	norm	0.500	0.1000	0.592	0.0875	0.4492	0.7366
$100(\beta^{-1}-1)$	gamma	0.250	0.1000	0.122	0.0455	0.0486	0.1921
χ	gamma	2.000	0.7500	3.270	0.8156	1.9449	4.5388
ξ_p	beta	0.660	0.1000	0.735	0.0333	0.6803	0.7897
ξ_w	beta	0.660	0.1000	0.703	0.0386	0.6393	0.7667
σ_a	gamma	5.000	1.0000	5.544	1.0230	3.8806	7.1955
κ	gamma	4.000	1.0000	5.947	0.9842	4.3469	7.5424
ψ	beta	0.300	0.1000	0.265	0.0931	0.1126	0.4120
ϕ	beta	0.500	0.1000	0.412	0.0698	0.2976	0.5270
ϕ_π	normal	1.500	0.3000	1.586	0.2009	1.2528	1.9171
$\phi_{\Delta y}$	normal	0.125	0.0500	0.225	0.0501	0.1433	0.3082
ρ_R	beta	0.600	0.2000	0.909	0.0111	0.8904	0.9267
ρ_z	beta	0.400	0.2000	0.310	0.0672	0.1991	0.4204
ρ_g	beta	0.600	0.2000	0.991	0.0048	0.9844	0.9989
ρ_{ist}	beta	0.200	0.1000	0.324	0.0744	0.2002	0.4455
ρ_p	beta	0.600	0.2000	0.984	0.0092	0.9707	0.9980
ρ_w	beta	0.600	0.2000	0.920	0.0517	0.8627	0.9776
ρ_b	beta	0.600	0.2000	0.892	0.0374	0.8350	0.9504
ρ_{mei}	beta	0.600	0.2000	0.930	0.0299	0.8834	0.9776
θ_p	beta	0.500	0.2000	0.763	0.0801	0.6412	0.8895
θ_w	beta	0.500	0.2000	0.959	0.0308	0.9211	0.9964
η^m	invg	0.100	1.0000	0.129	0.0084	0.1153	0.1427
ϵ^z	invg	0.500	1.0000	0.413	0.0403	0.3467	0.4779

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Table 1: (continued)

	Prior			Posterior			
	Distribution	Mean	Stdev.	Mean	Stdev.	HPD inf	HPD sup
ϵ^g	invg	0.500	1.0000	0.313	0.0186	0.2825	0.3433
η^I	invg	0.500	1.0000	0.570	0.0340	0.5141	0.6250
ϵ^p	invg	0.100	1.0000	0.233	0.0246	0.1929	0.2734
ϵ^w	invg	0.100	1.0000	0.447	0.0302	0.3975	0.4958
ϵ^b	invg	0.100	1.0000	0.075	0.0105	0.0586	0.0904
ϵ^I	invg	0.500	1.0000	4.233	0.5619	3.3142	5.1138

Notes: The highest posterior density (HPD) interval is given by the range between HPD inf and HPD sup.

Table 2: Results from posterior maximization (parameters)

	Prior			Posterior	
	Distribution	Mean	Stdev	Mode	Stdev
α	normal	0.300	0.0500	0.1467	0.0096
ι_p	beta	0.500	0.1500	0.1080	0.0485
ι_w	beta	0.500	0.1500	0.4121	0.0828
g_Y	normal	0.400	0.0250	0.3754	0.0241
g_I	normal	0.200	0.0250	0.2442	0.0250
h	beta	0.500	0.1000	0.8532	0.0231
$\bar{l}$	normal	0.000	0.5000	-0.1050	0.4902
$\pi^\star$	normal	0.500	0.1000	0.6002	0.0858
$100(\beta^{-1} - 1)$	gamma	0.250	0.1000	0.1045	0.0431
χ	gamma	2.000	0.7500	2.9995	0.7747
ξ_p	beta	0.660	0.1000	0.7411	0.0324
ξ_w	beta	0.660	0.1000	0.7036	0.0365
σ_a	gamma	5.000	1.0000	5.2958	0.9967
κ	gamma	4.000	1.0000	5.6468	0.9428
ψ	beta	0.300	0.1000	0.2431	0.0963
ϕ	beta	0.500	0.1000	0.4298	0.0724
ϕ_π	normal	1.500	0.3000	1.6201	0.1957
$\phi_{\Delta y}$	normal	0.125	0.0500	0.2260	0.0499
ρ_R	beta	0.600	0.2000	0.9106	0.0108
ρ_z	beta	0.400	0.2000	0.3183	0.0674
ρ_g	beta	0.600	0.2000	0.9939	0.0046
ρ_{ist}	beta	0.200	0.1000	0.3213	0.0748
ρ_p	beta	0.600	0.2000	0.9883	0.0087
ρ_w	beta	0.600	0.2000	0.9532	0.0209
ρ_b	beta	0.600	0.2000	0.9017	0.0324
ρ_{mei}	beta	0.600	0.2000	0.9422	0.0266
θ_p	beta	0.500	0.2000	0.8002	0.0692
θ_w	beta	0.500	0.2000	0.9774	0.0153
η^m	invg	0.100	1.0000	0.1268	0.0081

(Continued on next page)

Table 2: (continued)

	Prior			Posterior	
	Distribution	Mean	Stdev	Mode	Stdev
ϵ^z	invg	0.500	1.0000	0.3988	0.0403
ϵ^g	invg	0.500	1.0000	0.3081	0.0181
η^I	invg	0.500	1.0000	0.5640	0.0330
ϵ^p	invg	0.100	1.0000	0.2353	0.0240
ϵ^w	invg	0.100	1.0000	0.4318	0.0278
ϵ^b	invg	0.100	1.0000	0.0711	0.0092
ϵ^I	invg	0.500	1.0000	3.9618	0.4986

Table 3: Theoretical moments from model evaluated at posterior mean

	Data	Model
Std (Output)	0.61	1
Std (Consumption)	0.4	0.72
Std (Investment)	2.25	4
Std (Real wage)	0.83	0.99
Std (Log hours)	5.75	5.08
Std (Inflation)	0.4	0.6
Std (IST)	0.53	0.6
Std (Nominal rate)	0.85	0.52
Corr (Output,Consumption)	0.65	0.61
Corr (Output, Investment)	0.78	0.75
Corr (Output, Hours)	0.09	0.14
Corr (Output, Inflation)	-0.13	-0.01
Corr (Output, IST)	-0.18	-0.06
Corr (Output, Nominal)	0.2	-0.14
Corr (Cons., Investment)	0.36	0.04
Corr (Hours, Wage)	0.14	0.06
Corr (Nominal, Inflation)	0.44	0.46

Notes: Std(x) is the standard deviation of variable x. Corr(x,y) is the contemporaneous correlation between variable x and y. Output, consumption, investment, real wage are in growth rates. Hours is in log levels. Inflation and the nominal interest rate are in quarterly percentage units.

Table 4: Variance decomposition at business cycle frequency

Variables ↓ / Shocks →	MP	N. Tech.	Govt.	IST	P-markup	W-markup	RP	MEI
Output	6.75	18.03	4.35	0.56	15.64	1.71	19.29	33.67
Consumption	3	17.68	0.93	0.06	5.02	1.73	70.85	0.73
Investment	4.54	5.7	0.01	1.2	12.59	0.74	3.08	72.15
Real wage	0.23	37.59	0	0.12	20.56	40.36	0.33	0.8
Log hours	7.33	12.89	2.42	0.25	17.96	4.12	18.7	36.33
Inflation	4.99	12.01	0.23	0.36	41.95	5.62	18.05	16.79
RPI	0	0	0	100	0	0	0	0
Nominal rate	39.76	3.43	0.28	0.36	14.61	2.99	16.86	21.71

Notes: Abbreviations in the top row are the following: MP = monetary policy, N. Tech. = Neutral technology, Govt. = Government spending, IST = Investment specific technology, P-markup = Price markup, W-markup = Wage markup, RP = Risk premium, and MEI = Marginal efficiency of investment.

Table 5: Estimated structural shocks over the Great Recession and recovery period

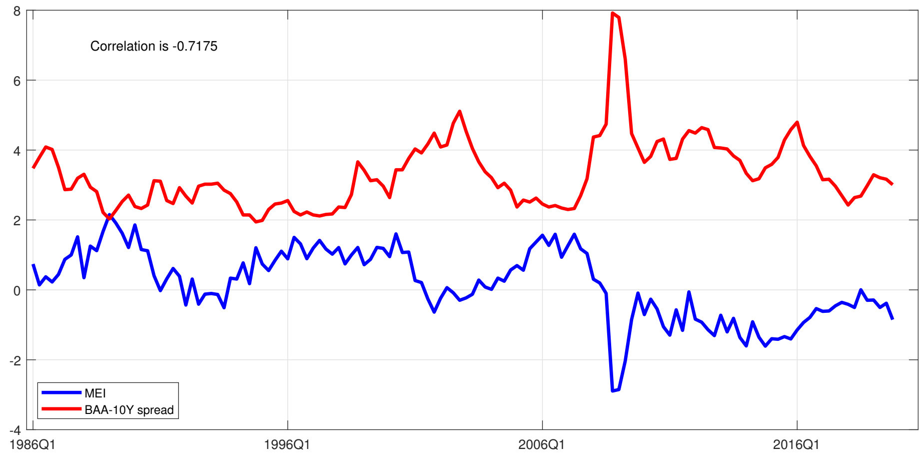
PANEL A: SHOCKS OVER THE GREAT RECESSION

	MP	Neutral Tech.	Govt.	IST	P-markup	W-markup	Risk premium	MEI
2008Q1	-0.35	-0.75	-0.58	0.65	-0.07	0.03	0.04	-5.55
2008Q2	-0.37	0.35	-0.03	0.21	0.33	-0.07	-0.08	-0.73
2008Q3	-0.14	-0.08	-0.05	0.63	0.35	0.12	-0.14	-2.38
2008Q4	-0.07	1.11	1.01	-3.42	-0.96	0.45	-0.19	-23.47
2009Q1	0.02	1.13	1.28	1.39	0.64	-1.37	-0.03	-1.34
2009Q2	-0.06	0.41	0.55	1.51	0.93	0.99	-0.09	5.18
2009Q3	-0.22	0.22	-0.54	1.01	0.56	-0.11	0.02	8.75
2009Q4	-0.17	0.17	-0.19	0.52	0.31	-0.1	-0.08	5.83

PANEL B: SHOCKS OVER THE RECOVERY

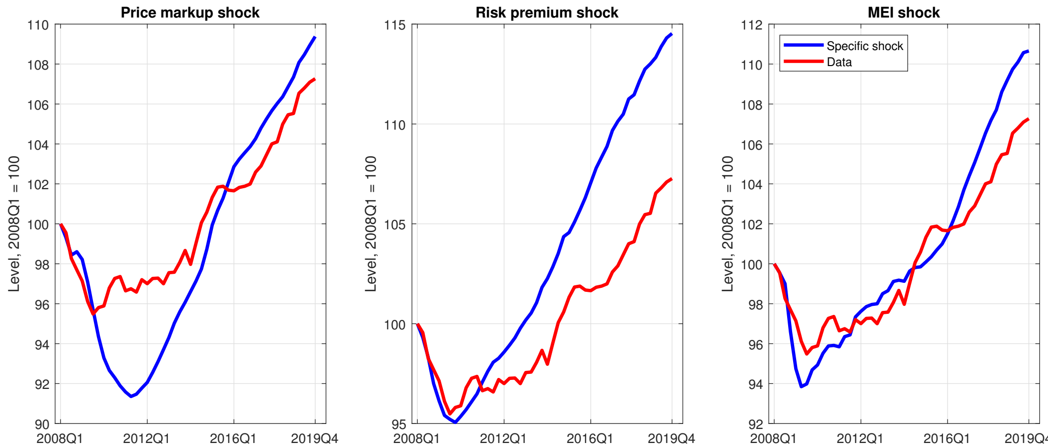
	MP	Neutral Tech.	Govt.	IST	P-markup	W-markup	Risk premium	MEI
2010Q1	-0.1	-0.02	-0.35	0.25	0.06	-0.86	0.04	-5.21
2010Q2	-0.07	-0.03	-0.05	-0.02	-0.14	0.08	-0.04	3.28
2010Q3	-0.12	-0.04	-0.26	0.48	0	-0.19	-0.04	-2.5
2010Q4	-0.19	-0.19	-0.04	0.13	0.31	-0.05	-0.05	-4.58
2011Q1	-0.17	-0.68	-0.71	0.33	0.16	0.79	0.01	-2.63
2011Q2	-0.21	-0.17	-0.27	0.59	0.15	-0.44	-0.05	5.31
2011Q3	-0.16	-0.28	-0.32	-0.4	-0.16	0.13	-0.06	-5.26
2011Q4	-0.15	0.13	-0.07	0.32	-0.04	-1.14	-0.11	8.54
2012Q1	-0.14	-0.4	-0.22	0.18	0.16	0.83	-0.03	-6.56
2012Q2	-0.04	0.16	0.08	-0.08	-0.12	0.06	-0.05	-1.22
2012Q3	-0.11	-0.31	0.2	0.44	0.02	-0.28	-0.05	-2.35
2012Q4	-0.16	-0.57	-0.24	-0.08	0.01	1.43	-0.02	-2.07
2013Q1	-0.12	0.41	0.08	0.26	0.03	-0.73	-0.07	4.12
2013Q2	-0.02	-0.38	0.06	-0.11	-0.09	0.08	-0.07	-4.42
2013Q3	-0.22	0.11	0.03	0.52	0.18	-0.29	-0.01	2.55
2013Q4	-0.22	0.1	0.08	-0.2	0.11	-0.07	0.03	-5.05
2014Q1	-0.26	-0.97	-0.62	0.12	-0.03	0.76	-0.1	-2.84
2014Q2	-0.28	0.57	-0.01	0.29	0.02	-0.25	-0.01	4.85
2014Q3	-0.13	0.11	0.11	-0.19	-0.07	-0.29	-0.01	-4.24
2014Q4	-0.03	-0.61	-0.39	-0.7	-0.43	-0.08	0.03	-2.92
2015Q1	0.14	0.5	0	-0.18	-0.3	0.65	-0.17	0.83
2015Q2	-0.01	-0.15	0.19	0.65	0.41	0.22	0.03	-0.94
2015Q3	0.03	-0.05	-0.31	-0.15	0.08	-0.11	-0.01	-0.19
2015Q4	0.2	-0.58	-0.11	0.06	-0.23	-0.29	-0.01	-1.35

Figure 1: MEI and BAA-10Y spread



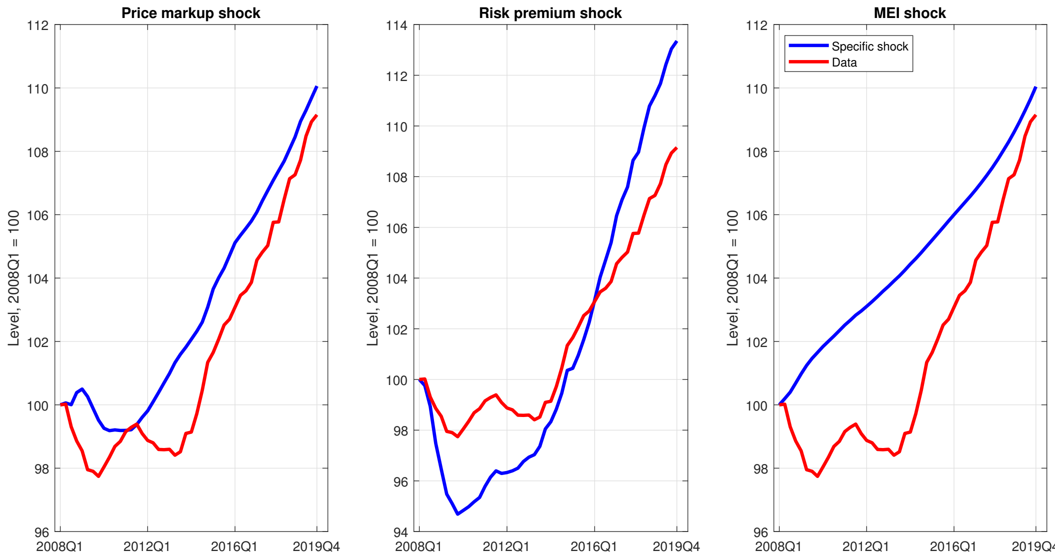
Notes: Both MEI and the BAA-10Y spreads are standardized for the figure. This does not have any implication for the correlation between the two series.

Figure 2: Output over the Great Recession and recovery in response to price markup, risk premium, and MEI shocks



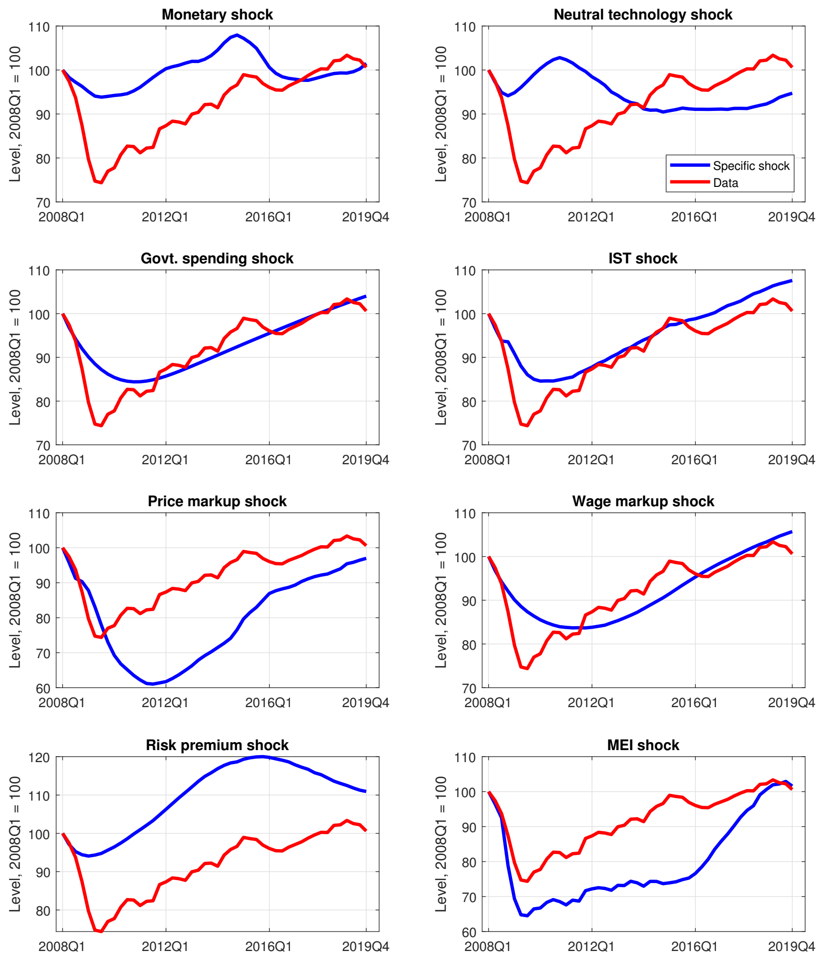
Notes: Blue lines show the evolution of output conditional only on the specific shock listed in the subtitles (price markup shocks, risk premium shocks, and MEI shocks). Red lines show the evolution of output in the data.

Figure 3: Consumption over the Great Recession and recovery in response to price markup, risk premium, and MEI shocks



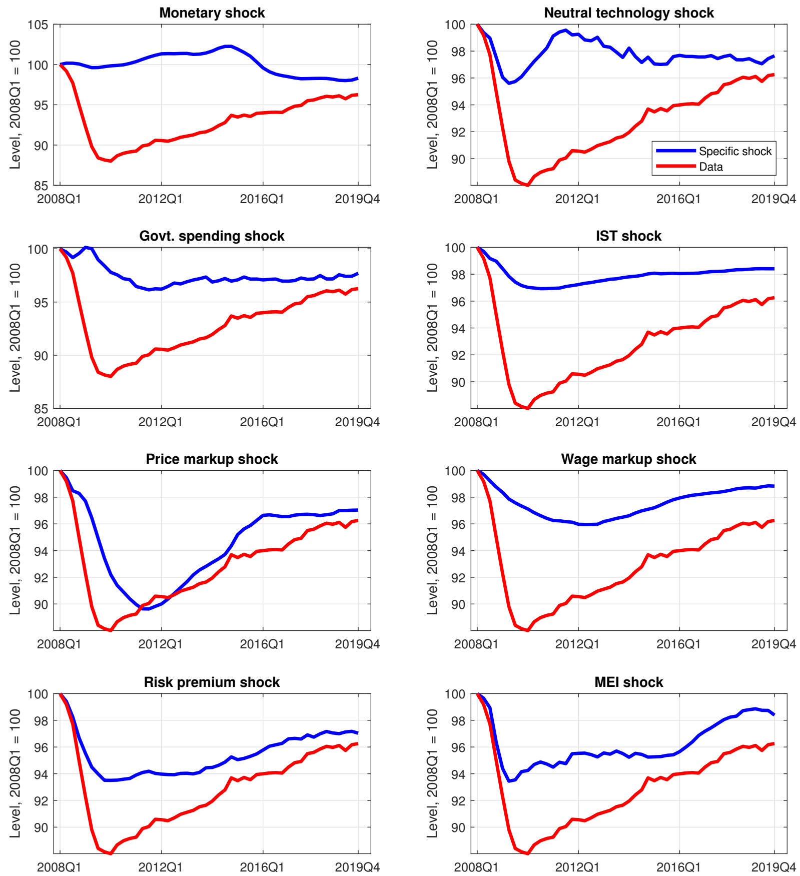
Notes: Blue lines show the evolution of consumption conditional only on the specific shock listed in the subtitles (price markup shocks, risk premium shocks, and MEI shocks). Red lines show the evolution of consumption in the data.

Figure 4: Investment over the Great Recession and recovery in response to shocks



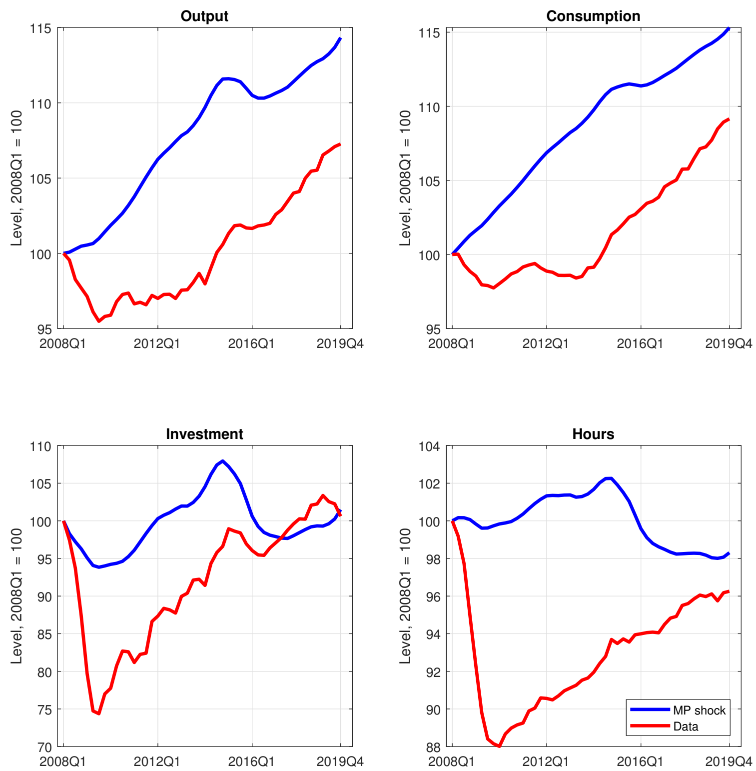
Notes: Blue lines show the evolution of investment conditional only on each type of structural shock in the model (shocks listed in subtitle). Red lines show the evolution of investment in the data.

Figure 5: Hours over the Great Recession and recovery in response to shocks



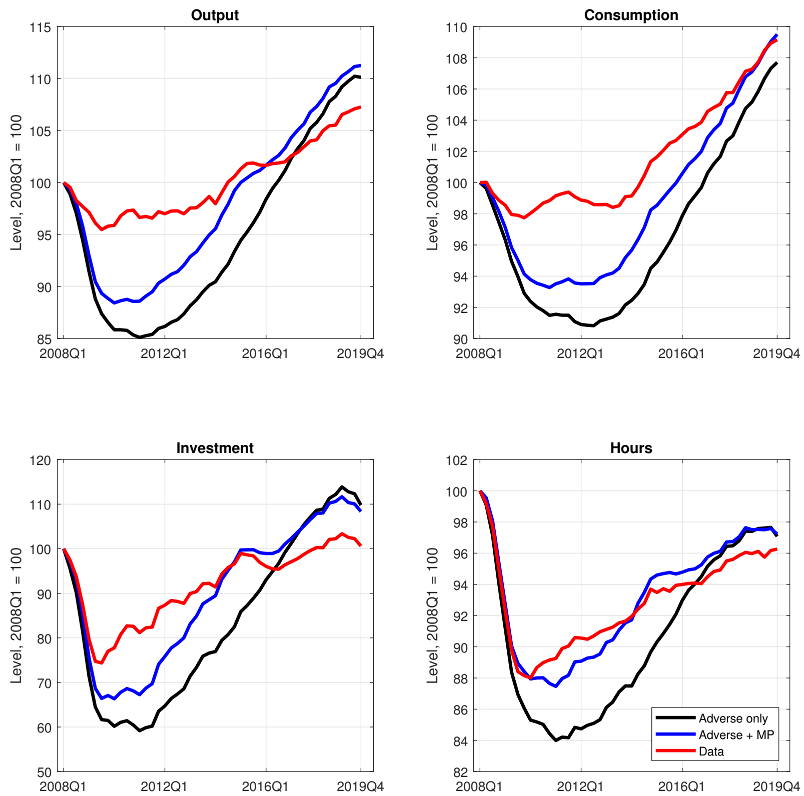
Notes: Blue lines show the evolution of hours worked conditional only on each type of structural shock in the model (shocks listed in subtitle). Red lines show the evolution of hours worked in the data.

Figure 6: Output, consumption, investment and hours conditional on monetary policy shocks



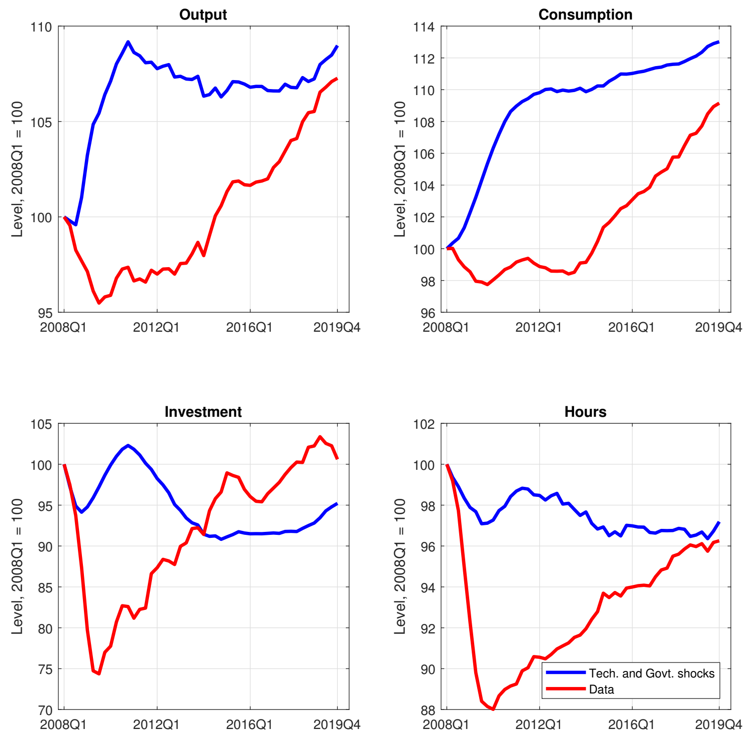
Notes: Blue lines show the evolution of output, consumption, investment, and hours worked in response to only monetary policy shocks. Red lines show the evolution of each of these variables in the data.

Figure 7: Output, consumption, investment and hours conditional on adverse shocks and monetary policy shocks



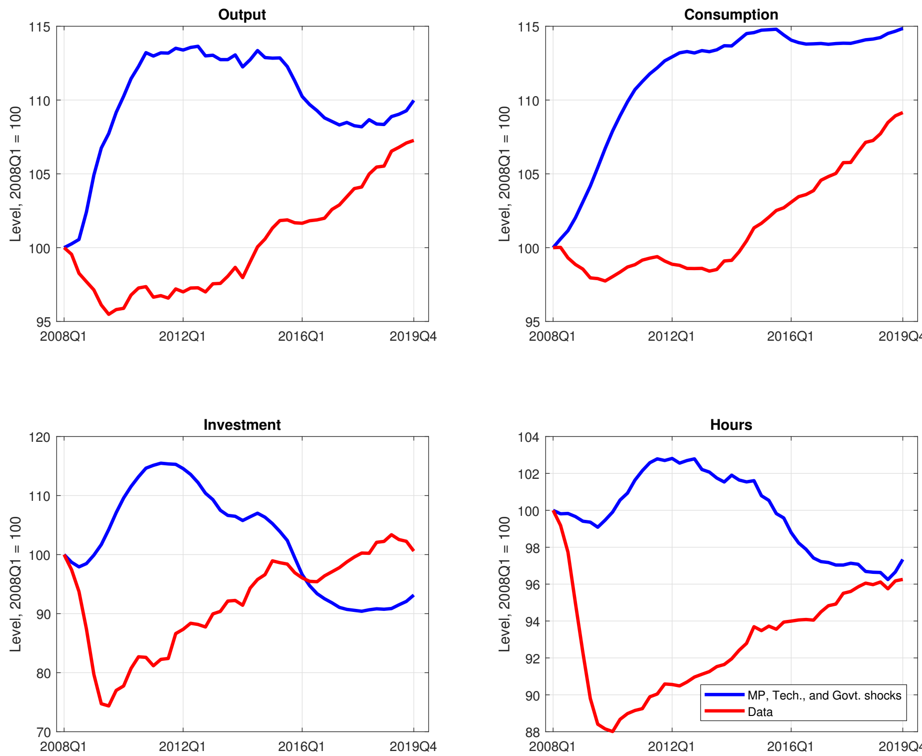
Notes: Black lines show the evolution of output, consumption, investment, and hours worked conditioned on only adverse shocks (shocks to IST, wage and price markups, risk premium, and marginal efficiency of investment). Blue lines show the evolution of these same variables conditioned on adverse shocks and monetary policy shocks. Red lines depict the evolution of these variables in the data.

Figure 8: Output, consumption, investment and hours conditional on neutral technology and government spending shocks



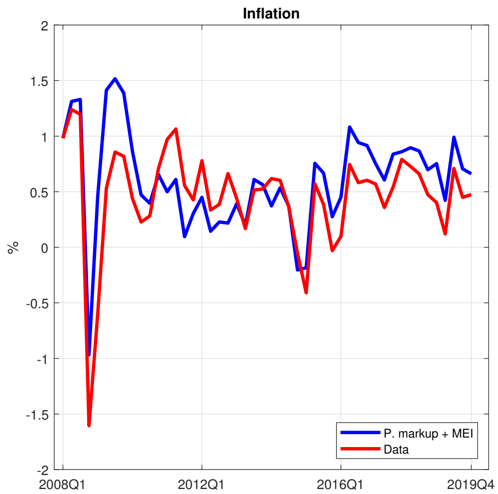
Notes: Blue lines show the evolution of output, consumption, investment, and hours worked conditioned only on neutral technology and government spending shocks. Red lines show the evolution of these same variables in the data.

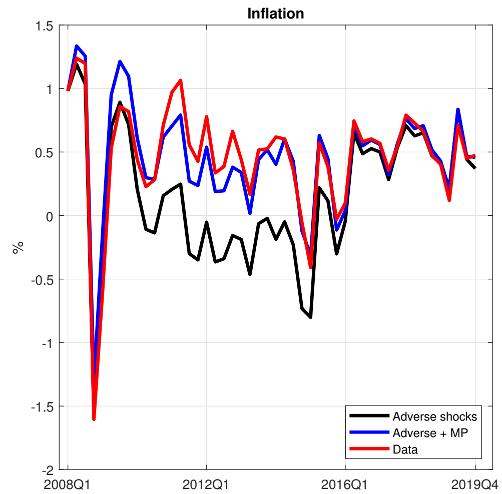
Figure 9: Output, consumption, investment and hours conditional on monetary policy, neutral technology, and government spending shocks



Notes: Blue lines show the evolution of output, consumption, investment, and hours worked conditioned only on neutral technology, government spending, and monetary policy shocks. Red lines show the evolution of these same variables in the data.

Figure 10: Inflation in response to price markup, MEI, adverse, and monetary policy shocks





Notes: In the left figure, the blue line depict the evolution of inflation conditioned on price markup and MEI shocks. In the right figure, the black line depict the evolution of inflation conditioned on adverse shocks (shocks to IST, wage and price markups, risk premium, and marginal efficiency of investment), while the blue line depict the evolution of inflation conditioned on adverse and monetary policy shocks. In both figures the red lines show the evolution of inflation in the data.

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.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

B Data Construction

In this appendix we describe the construction of the data used as observables in the Bayesian estimation of the model. We closely follow the data construction used in Görtz and Tsoukalas (2017), but restate the construction here for simplicity. Most of the data were obtained from the St. Louis Federal Reserve Economic Database (FRED). We report FRED reference codes where applicable. Table 6 reports the raw data series used in the construction of the observables. The data were retrieved on June 10th, 2020.

Table 6: Data used in construction of observables

Variable name	Source	Notes
Nonfarm business compensation per hour	FRED	FRED code (COMPNFB)
Gross domestic product	FRED	FRED code (GDP)
Real gross private domestic investment	FRED	FRED code (GPDIC1)
Nonfarm business hours of all persons	FRED	FRED code (HOANBS)
Durable goods consumption expenditures	FRED	FRED code (PCDG)
Services consumption expenditures	FRED	FRED code (PCESV)
Nondurable goods consumption expenditures	FRED	FRED code (PCND)
Population level	FRED	FRED code (CNP16OV)
Effective federal funds rate	FRED	FRED code (FEDFUNDS)
Nondurable consumption deflator	FRED	FRED code (DNDGRD3Q086SBEA)
Services consumption deflator	FRED	FRED code (DSERRD3Q086SBEA)
Durable consumption deflator	FRED	FRED code (DDURRD3Q086SBEA)
Shadow rate	Wu and Xia (2016)	See table notes

Notes: The shadow interest rate series from Wu and Xia (2016) is available from Jing Cynthia Wu's website at https://sites.google.com/view/jingcynthiawu/shadow-rates.

For variables which are reported in a frequency different than quarterly, we convert these series to quarterly by taking the average (such as interest rates). We obtain data for the period 1983I:2019IV.

Let C_t^{nd}, C_t^d, C_t^s and I_t^f denote nominal non-durable consumption, durable consumption, consumption of services, and fixed investment. Additionally let P_t^{nd}, P_t^d, P_t^s denote price deflators associated with non-durable consumption, durable consumption, and consumption of services. We define aggregate nominal consumption as the sum consumption of non-durable goods and services,

$$C_t^{nominal} = C_t^{nd} + C_t^{s}, \tag{A27}$$

and aggregate nominal investment as the sum of durable consumption and gross private domestic investment,

$$I_t^{nominal} = C_t^{d} + I_t^{f}. \tag{A28}$$

Next we define real growth rates of non-durable consumption, consumption of services, durable consumption, and gross private domestic investment. Each series is deflated by its own associated price deflator,

$$g_t^{nd} = \Delta\ln C_t^{nd} - \Delta\ln P_t^{nd}, \tag{A29}$$

$$g_t^{s} = \Delta\ln C_t^{s} - \Delta\ln P_t^{s}, \tag{A30}$$

$$g_t^{d} = \Delta\ln C_t^{d} - \Delta\ln P_t^{d}, \tag{A31}$$

$$g_t^{I_f} = \Delta\ln I_t^{f} - \Delta\ln P_t^{I_f}. \tag{A32}$$

After obtaining real growth rates of each individual series, we compute real aggregate consumption growth and investment growth as the share-weighted growth rates of each component series as follows,

$$g_t^{c} = \left(\frac{C_{t-1}^{nd}}{C_{t-1}^{nominal}}\right) g_t^{nd} + \left(\frac{C_{t-1}^{s}}{C_{t-1}^{nominal}}\right) g_t^{s}, \tag{A33}$$

$$g_t^{i} = \left(\frac{C_{t-1}^{d}}{I_{t-1}^{nominal}}\right) g_t^{d} + \left(\frac{I_{t-1}^{f}}{I_{t-1}^{nominal}}\right) g_t^{I_f}. \tag{A34}$$

We set 2005 as our base year (where nominal quantities are equal to real quantities) and use the above associated growth rates to compute real consumption and investment paths (denoted C_t^{real} and I_t^{real}). After computing the level of real consumption and real investment, we define our measures of price level for consumption and investment which are given by,

$$P_t = \frac{C_t^{nominal}}{C_t^{real}} \tag{A35}$$

$$P_t^I = \frac{I_t^{nominal}}{I_t^{real}} \tag{A36}$$

Lastly we convert our aggregates to per capita measures by dividing with our population measure (POP_t). Our observables used in the estimation of the model are given by the following equations,

$$\Delta \ln Y = \Delta \ln \left(\frac{GDP}{POP_t * P_t} \right) \tag{A37}$$

$$\Delta \ln C = \Delta \ln \left(\frac{C_t^{nominal}}{POP_t * P_t} \right) \tag{A38}$$

$$\Delta \ln I = \Delta \ln \left(\frac{I_t^{nominal}}{POP_t * P_t} \right) \tag{A39}$$

$$\Delta \ln \frac{W_t}{P_t} = \Delta \ln \left(\frac{\text{COMPNFB}}{P_t} \right) \tag{A40}$$

$$\ln L_t = \ln \left(\frac{\text{HOANBS}}{POP} \right) \tag{A41}$$

$$\pi_t = \Delta \ln P_t \tag{A42}$$

$$v_t^I = \Delta \ln \left(\frac{1}{(P_t^I / P_t)} \right) \tag{A43}$$

The last observable used in the estimation is the shadow rate. To construct the shadow rate we use the effective federal funds rate when the rate are above 0 and the shadow rate constructed by Wu and Xia (2016) when the rate is below 0.[2] That is,

$$S_t = \begin{cases} \ln(1 + \frac{\text{Fed funds}_t}{100}) * 100 & \text{Wu-Xia}_t > 0 \\ \ln(1 + \frac{\text{Wu-Xia}_t}{100}) * 100 & \text{Wu-Xia}_t \leq 0 \end{cases} \tag{A44}$$

The Wu-Xia measure of the short term interest rate is negative for the period 2009III:2015III. Equations (11)-(18) are the 8 observables used in the estimation of the model.

[2] Wu and Xia (2016) report the shadow rate at a monthly frequency. We convert this to quarterly by taking 3 month averages.