Forward Guidance and Macroeconomic Outcomes Since the Financial Crisis*

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Abstract

This paper employs a state-of-the-art empirical DSGE model to quantify the impact of FOMC forward guidance on macroeconomic outcomes since the financial crisis. The model's forward guidance takes the form of unanticipated announcements by the FOMC about the future values of the interest rate rule's time-varying intercept. We identify these shocks' stochastic structure using changes in federal funds futures' rates induced by FOMC announcements. Our framework includes an enhanced version of the canonical medium scale New Keynesian business cycle model and many time series variables being used in its Bayesian estimation. At the estimated parameter values shocks to technology, the demand for safe and liquid assets, investment demand, and the rate of time preference account for almost all cyclicality over our estimation sample, 1993q1 through 2007q3. The estimated model is used to measure the effects of forward guidance from 2007q4 to 2014q4. We isolate the effects of forward guidance by comparing actual outcomes to counter-factual outcomes derived from the model assuming the policy-maker takes the identified shocks as given and chooses interest rates by setting forward guidance to be as close to zero as possible, subject to the lower bound constraint. Our estimates *so far* suggest forward guidance contributed to substantially improved inflation, output, consumption and labor market outcomes during 2010-2012.

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1 Introduction

This paper employs a structural model of monetary policy and business cycles to quantify the impact of monetary policy forward guidance on macroeconomic performance before, during and after the Great Recession. Over the last thirty years the FOMC completely revised its communications policy, eventually making guidance about the future path of the funds rate a central component of those communications. Whereas the Committee used to refrain from announcing its target for the federal funds rate, in February 1994 it began issuing a press release following every meeting stating the target funds rate, and in May 1999 it started publishing statements containing explicit forward guidance. Perhaps the most prominent use of forward guidance before the Great Recession was the inclusion in the statement following its June 2014 meeting of "pace that is likely to be measured" when referring to future rate increases.

After 2008q4 forward guidance became one of the primary tools of monetary policy after the zero lower bound made it impossible to counteract weak economic conditions by lowering the funds rate. In December 2008 the Committee began using language that rates would remain exceptionally low for "some time." In March 2008 "some time" was replaced with "extended period". So-called "date-based" forward guidance was introduced in August 2011 when the corresponding statement indicated that exceptionally low levels of the federal funds rate would remain in place "at least through mid-2013." In the December 2012 the date-based language was replaced with the so-called Evans rule where the maintenance of low rates was tied to specific economic conditions.

The other main tool of monetary policy since the Great Recession was "quantitative easing" (QE). While there is considerable debate over the importance of the various possible channels through which QE might affect real activity it is widely viewed to at least in part influence activity by influencing private sector expectations of future short term interest rates.[1] So QE also can be viewed through the lens of forward guidance.

Understanding the macroeconomic effects of forward guidance is clearly essential to assessing the value of its future use by the Fed and other central banks. This

[1] See Evans et al. (2015) for references to the relevant literature. Krishnamurthy and Vissing-Jorgensen (2011) have been the main proponents of the view that the signalling lower rates for longer is the main channel through which QE affects borrowing rate.

is challenging because forward guidance is not a feature of traditional monetary business cycle models. These models typically posit that the funds rate depends only on current conditions (inflation and output "gaps") and a contemporaneous shock. Since these models are ill-equipped for addressing the impact of forward guidance on macroeconomic performance it is necessary to build a new framework. This paper will provide such a framework and use it to quantify the macroeconomic impact of forward guidance.

The centerpiece of our analysis is an enhanced version of the canonical medium-scale New Keynesian model pioneered by Christiano et al. (2005) and Smets and Wouters (2007). We take this model to be the starting point of our analysis since it has become the the primary tool for understanding business cycles. Yet we view this model and the ways it has been taken to the data to be problematic for addressing our question. Therefore our analysis is based on enhancements to both the canonical model and how it is taken to the data.

Our estimation uses a full-information approach. Inference about all of the factors influencing the business cycle, including forward guidance, depends on both the structure of the model and its mapping to the data. By remedying what we view to be problematic features of conventional studies we hope to improve the credibility of our findings. While the enhancements we propose are important for the answers we get to our particular question, they should be of broader interest because they lie at the heart of business cycle analysis.

There has been a lot of empirical work...

A recent literature has investigated the so-called "forward guidance puzzle." This literature focuses on a view that the New Keynesian framework implies forward guidance has unusual features: their effects seem very large and the guidance given one quarter ahead has the same effect as guidance given arbitrarily far into the future. How does our analysis connect with this literature?

The remainder of the paper begins with a description of the methodology we employ to measure the effects of forward guidance. After this we describe the structural model; measurement and estimation of the model; properties of the estimated model; and our main results. The final section discusses some potential drawbacks to our analysis.

2 Counterfactual Methodology

This second section describes our methodology for counterfactual policy analysis. Since this is written in terms of a general linear model, there is no need to go into the details of our specific model when describing the methodology. This section should also make any relevant connections to our earlier work in Brookings I on the measurement of forward guidance and its implications.

3 The Model

We measure the effects of forward guidance by employing an enhanced version of the canonical medium-scale New Keynesian model pioneered by Christiano et al. (2005) and Smets and Wouters (2007). Our model incorporates many of the refinements that have been introduced since the seminal papers were written. Novel to our model are Jaimovich and Rebelo (2009) preferences that are modified to include habit formation in consumption, a preference for safe and liquid assets as described in Fisher (2015), and our modeling of monetary policy. Since much of the model's specification is familiar our discussion of most of its features is brief. For more details see the online appendix.

3.1 Households

The economy consists of a large number of identical, infinitely lived households with preferences described by the lifetime utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t \varepsilon_t^b \Big[U(V_t) + \varepsilon_t^s L(\frac{B_{t+1}}{P_t R_t}) \Big]. \tag{1}$$

The period utility function U is specified as

$$U(V) = \frac{V^{1-\gamma_C} - 1}{1 - \gamma_C}$$

with $\gamma_C > 0$. The argument of U is given by

$$V_t = C_t - \varrho \bar{C}_{t-1} - X_t H_t^{1+\gamma_H}$$

where C_t denotes the household's date t consumption purchased in the final goods market at nominal price P_t, $\bar{C}_t$ denotes *aggregate* per capita consumption (which is equal to C_t in equilibrium), H_t denotes hours worked, and X_t evolves as

$$X_t = \left(C_t - \varrho \bar{C}_{t-1}\right)^{\mu} X_{t-1}^{1-\mu}.$$

These are the preferences introduced in Jaimovich and Rebelo (2009) except we have modified them to include external habit formation in consumption.[2] Jaimovich and Rebelo (2009) preferences include the parameter $\mu \in (0,1)$ which controls the wealth elasticity of labor supply while preserving compatibility with balanced growth. The parameter $\varrho > 0$ determines the degree of habit formation and γ_H controls the Frisch elasticity of labor supply in the special case in which $\varrho = \mu = 0$.

As $\mu \to 0$ and in the absence of habit formation these preferences reduce to the specification considered by Greenwood et al. (1988). In this special case labor supply depends only on the current real wage faced by households and is independent of the marginal utility of weatlth. So when μ and ϱ are both small, anticipated changes in income do not affect current labor supply. As μ gets larger the wealth elasticity gets larger and in the polar case when $\mu = 1$ preferences reduce to the kind most commonly studied in the current business cycle literature.

The flexible wealth effects on labor supply have important implications for determining the effects of technology shocks in a New Keynesian model. With small effects of wealth on labor supply it is possible for hours to respond pro-cyclically to a positive neutral technology shock. This kind of flexibility makes it possible for business cycle co-movement to arise from neutral technology shocks in a New Keynesian model where with conventionally specified preferences it does not.

The household's subjective discount factor is decomposed into the non-stochastic component $\beta \in (0,1)$ and the exogenous *discount factor shock* ε_t^b. This shock has been shown by Justiniano et al. (2010) and others to be an important driver of consumption fluctuations. In addition it is often used, for example by Egertsson and Woodford (2003), to motivate why monetary policy might become constrained by the ZLB and so it is particularly relevant for our analysis. We assume ε_t^b evolves

[2] Schmitt-Grohé and Uribe (2012) study a real business cycle model with the same preferences except their formulation involves internal habit.

according to

$$\ln \varepsilon_t^b = \rho_b \ln \varepsilon_{t-1}^b + \eta_t^b, \eta_t^b \sim N(0, \sigma_b),$$

The second novel feature of preferences is the inclusion of the increasing and concave period utility function L. The argument of L, $B_{t+1}/(P_t R_t)$, equals the real quantity of one-period safe (risk free) and liquid bonds purchased by the household from the government in date t. It consists of the nominal quantity of those assets, B_{t+1} their return from date t to date $t+1$, R_t, and the nominal price of consumption P_t. Including L introduces a demand for safe and liquid assets that is absent from existing empirical New Keynesian models. Krishnamurthy and Vissing-Jorgensen (2011) used such preferences to study the market for government securities.

Including this model feature serves two purposes. First it allows the interest rate controlled by the central bank, R_t, to deviate from the return to installed capital. New Keynesian models typically maintain the assumption that these two rates of return coincide. Since the level of the federal funds rate is typically included as an observable in estimation, the assumption of equality directly influences the values of parameters and the business cycle decompositions derived from those parameters.

A second reason for introducing a demand for safe and liquid assets is that it provides a simple micro-foundation for the shock to the household's intertemporal consumption Euler equation first studied by Smets and Wouters (2007). This shock plays a crucial role in empirical New Keynesian models because it is one of the few sources of business cycle co-movement and therefore typically appears as a major source of fluctuations. Here that shock is denoted by ε_t^s and it evolves according to

$$\ln \varepsilon_t^s = \rho_s \ln \varepsilon_{t-1}^s + \eta_t^s, \eta_t^s \sim N(0, \sigma_s).$$

Since it directly impacts the utility of safe and liquid assets we refer to ε_t^s as the *liquidity preference shock*.

Fisher (2015) shows that when the spread between the return to safe and liquid assets coincides with that for installed capital then the formulation studied by Smets and Wouters (2007) is recovered. To see this consider the log-linearized intertemporal Euler equation for the detrended version of this economy:

$$\hat{\lambda}_t = \theta_s(\hat{R}_t + E_t[(\hat{\lambda}_{t+1} - \hat{\pi}_{t+1} - \sigma_c \hat{z}_{t+1}]) + \hat{\varepsilon}_t^s + (1-\theta_s)\,\hat{\varepsilon}_t^b \tag{2}$$

where $\theta_s \equiv R_*/R_*^P$ is the exogenous ratio of the government and private gross interest rates, R_* and R_*^P, "hats" denote log deviations from steady state, λ_t is the shadow value of consumption (the detrended Lagrange multiplier on the household's budget constraint), π_t is the gross rate of inflation in the consumption price, z_t is the growth rate of consumption's stochastic trend in equilibrium, and R_* and R_*^P are returns to government bonds and privately owned installed capital, respectively, along the non-stochastic growth path. When the steady state spread is zero, $R_* = R_*^P$ and $\theta_s = 1$, then (2) corresponds to equation (2) in Smets and Wouters (2007).

When $\theta_s < 1$ the equations differ in a way that has direct implications for the effects of forward guidance in the model. To see this solve (2) forward and abstract from the shocks. In this case

$$\hat{\lambda}_t = \sum_{j=0}^{\infty} (\theta_s)^{j+1} \left(\hat{R}_{t+j} - \hat{\pi}_{t+j}\right) \tag{3}$$

The direct effect of forward guidance comes through summing for all time any changes in the real return on risk free assets. Several papers have noted that this equation is an important channel through which large effects of forward guidance have been found in previous New Keynesian models. (We can elaborate substantially on this.) When there is a spread and $\theta_s < 1$ the direct effects of expected future real rates decline with the horizon of the rate increase, with the rate of decline increasing in the size of the spread. Therefore, other things equal, the effects of forward guidance are lower the larger is the spread.

In addition to owning the stock of safe and liquid assets, households own the installed capital stock K_t. This is assumed to evolve over time according to

$$K_t = \left[1 - \delta(U_t)\right] K_{t-1} + \eta_t^i \left[1 - S\left(\frac{I_t}{q_t I_{t-1}}\right)\right] I_t.$$

where I_t denotes gross investment and S and its argument correspond to the kind of investment adjustment costs introduced by Christiano et al. (2005). We assume that S evaluated along the non-stochastic growth path satisfies $S = S' = 0$ and $S'' > 0$. The term q_t, defined below, corresponds to the growth rate of investment's stochastic trend in equilibrium. The technology for transforming investment goods into installed capital is subject to the shock ε_t^i. We assume this *investment-demand* *shock* evolves according to

$$\ln \varepsilon_t^i = \rho_i \ln \varepsilon_{t-1}^i + \eta_t^i, \eta_t^i \sim N(0, \sigma_i).$$

The owners of installed capital can control the intensity with which it is utilized. Let U_t measure capacity utilization in period t. Then the effective amount of capital services supplied to firms in period t is $U_t K_t$. We assume that increasing the intensity of capacity utilization entails a cost in the form of faster depreciation, given by $\delta(U_t)$. We assume the functional form

$$\delta(U_t) = \delta_0 + \delta_1(U_t - 1) + \frac{\delta_2}{2}(U_t - 1)^2,$$

with $\delta_0, \delta_1, \delta_2 > 0$. The parameter δ_2 determines the sensitivity of capacity utilization to variation in the rental rate of capital; the parameter δ_1 governs the steady state utilization rate, which we normalize to unity; and the parameter δ_0 corresponds to the rate of depreciation along the non-stochastic growth path or steady state.

3.2 Goods Markets

Perfectly competitive firms produce the composite final good Y_t that sells for price P_t. They produce the final good Y_t using differentiated intermediate inputs purchased from a unit mass of household owned monopolistically competitive firms, where technology

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{1}{1+\lambda_t^p}} di \right)^{1+\lambda_t^p}$$

and $Y_t(i)$ denotes the quantity of inputs purchased from intermediate good producer i. Each intermediate good producer sells its product at a mark-up over marginal cost shocked by λ_t^p, which evolves according to

$$\ln \lambda_t^p = (1 - \rho_p) \ln \lambda_*^p + \rho_p \ln \lambda_{t-1}^p - \theta_p \eta_{t-1}^p + \eta_t^p, \eta_t^p \sim N(0, \sigma_p).$$

The parameter λ_*^p denotes the mark-up in the steady state. We refer to λ_t^p as the *price mark-up shock*.

Monopolistically competitive intermediate goods producer i produces $Y_t(i)$ using the technology:

$$Y_t(i) = K_t^e(i)^\alpha [A_t^Y H_t^d(i)]^{1-\alpha} - A_t \Phi, \tag{4}$$

where $H_t^d(i)$ is composite labor input bought at wage W_t from the labor compositors described below, $K_t^e(i) = U_t(i) K_t(i)$ is effective capital rented from households and Φ is the fixed costs of production, paid in final goods (the value of Φ is chosen so that aggregate monopoly profits of intermediate goods producers are zero in steady state.) Households own the intermediate good producers so profits and losses in a stochastic equilibrium accrue to them. The term A_t^Y is the level of the neutral technology. This is a non-stationary process which evolves as

$$\nu_t = (1 - \rho_\nu) \nu_* + \rho_v \nu_{t-1} + \eta_t^\nu, \eta_t^\nu \sim N(0, \sigma_\nu),$$

where $\nu_t \equiv \ln(A_t^Y / A_{t-1}^Y)$. We refer to ν_t as the *neutral technology shock*. The term A_t is the stochastic trend of equilibrium consumption and output measured in consumption units given by $A_t = A_t^Y (A_t^I)^{\frac{\alpha}{1-\alpha}}$, where A_t^I is the level of the investment-specific technology described below.

The intermediate goods producers maximize profits according to a Calvo pricing scheme. Each firm is subject to an exogenous probability of having the opportunity to adjust its price, $\zeta_p \in (0, 1)$. Absent this opportunity firms index the previously set price using the exogenous formula $\pi_{t-1}^{\iota_p} \pi_*^{1-\iota_p}$, where $\pi_t = P_t / P_{t-1}$ is the gross rate of inflation, π_* is the the central bank's inflation target (corresponding to steady state inflation), and $\iota_p \in [0, 1]$.

Perfectly competitive firms supply investment goods to households at price P_t^I in consumption units. They produce investment goods I_t by transforming Y_t^I final goods with the linear technology $I_t = A_t^I Y_t^I$. The investment-specific technology A_t^I is a non-stationary process which evolves as

$$\omega_t = (1 - \rho_\omega) \omega_* + \rho_\omega \omega_{t-1} + \eta_t^\omega, \eta_t^\omega \sim N(0, \sigma_\omega)$$

where $\omega_t \equiv \log(A_t^I / A_{t-1}^I)$. The parameter ω_* is the mean growth rate of the investment-specific technology. We refer to ω_t as the *investment-specific technology shock*. In equilibrium investment has a stochastic trend with log growth rate $q_t = \nu_t + \omega_t / (1 - \alpha)$.

3.3 Labor Markets

We adopt Smets and Wouters (2007)'s strategy for introducing sticky wages into an environment that includes preferences that are non-separable in consumption and labor. Households' rent their homogenous labor in the perfectly competitive household labor market to a unit mass of household owned labor guilds at wage W_t^h. Each labor guild is endowed with a technology that allows it to differentiate the households' labor. They rent this differentiated labor to the labor compositors as monopolistic competitors. The labor compositors re-package the differentiated labor into the homogenous factor input H_t^s supplied in a competitive market to the intermediate good firms in the composite labor market. The labor re-packaging technology is given by

$$H_t^s = \left(\int_0^1 H_t(i)^{\frac{1}{1+\lambda_t^w}} di \right)^{1+\lambda_t^w},$$

where $H_t(i)$ is the differentiated labor of guild i and λ_t^w drives the guilds' mark-up over their marginal cost, W_t^h. We assume λ_t^w follows an exogenous process similar to λ_t^p:

$$\ln \lambda_t^w = (1 - \rho_w) \ln \lambda_*^w + \rho_w \ln \lambda_{t-1}^w - \theta_w \epsilon_{t-1}^w + \eta_t^w, \eta_t^w \sim N(0, \sigma_w).$$

The labor guilds maximize profits according to a Calvo wage-setting scheme. Each guild is subject to an exogenous probability of having the opportunity to adjust its wage, $\zeta_w \in (0,1)$. Absent this opportunity a guild indexes their previously set wage using the exogenous formula $(\pi_{t-1} z_{t-1})^{\iota_w} (\pi_* z_*)^{1-\iota_w}$, where $\iota_w \in [0,1]$ and $z_t = \nu_t + \alpha\omega_t / (1 - \alpha)$ is the log growth rate of the stochastic trend A_t.

3.4 Central Bank and Government

In accordance with our discussion of counterfactual monetary policy in Section 2 the central bank sets the nominal interest rate on safe and liquid one-period government bonds, R_t, using the monetary policy rule

$$\ln R_t = \rho_R \ln R_{t-1} + (1 - \rho_R) \ln R_t^n + \sum_{j=0}^{M} \xi_{t-j,j}. \tag{5}$$

The parameter $\rho_R \in [0,1]$ governs the degree of interest rate smoothing. The exogenous random variables $\xi_{t-j,j}$ were introduced in Section 2. They are exogenous signals about the time-varying constant in (5), that is forward guidance shocks. Recall that the signals are assumed to be independent across time. However signals released at a point in time about constants in the policy rule in future periods may be correlated.[3] The parameter $M \geq 0$ denotes the duration of the forward guidance.

The variable R^n is the *notional* target interest rate, that is the rate the central bank would choose in the absence of interest rate smoothing. This interest rate is set according to

$$\ln R_t^n = \ln r_* + \ln \pi_t^* + \frac{\psi_1}{4} E_t \sum_{j=-2}^{1} (\ln \pi_{t+j} - \ln \pi_t^*) + \frac{\psi_2}{4} E_t \sum_{j=-2}^{1} (\ln Y_{t+j} - \ln y^* - \ln A_{t+j}) \quad (6)$$

The constant r_* corresponds to the "natural" real interest rate and π_t^* is an exogenous inflation drift that could be interpreted as the central bank's intermediate target for inflation. The drift term is included to address inflation's low-frequency movements during our sample.[4]. We call it the *inflation drift shock* and it evolves as

$$\ln \pi_t^* = (1 - \rho_\pi)\pi_* + \rho_\pi \ln \pi_{t-1}^* + +\eta_t^\pi, \eta_t^\pi \sim N(0, \sigma_\pi),$$

where π_* is steady state inflation. The last two terms correspond to the inflation and output gaps which drive the central bank's response to the economy's shocks with the parameters $\psi_1, \psi_2 \geq 0$ determining the elasticity of the response to these gaps. The inflation gap is a four-quarter moving average of the expected difference between twice and once lagged, current, and one-period-ahead log inflation and the contemporaneous value of the drift term. The output gap is a four-quarter moving average of the expected difference between twice and once lagged, current, and one-period-ahead log aggregate output and its stochastic trend. The constant y_* denotes steady state output in the model. Its inclusion in (6) guarantees that the gaps are closed and the steady state nominal interest rate on government bonds is $R_* = r_* \pi_*$.

The government issues bonds B_{t+1} and collects lump sum taxes T_t to pay for government spending $G_t = A_t g_t$ in the final goods market. Therefore its one-period

[3]Note that the calculation of the model's solution does not depend on this correlation structure.

[4]See xxx for an earlier example of a New Keynesian model with an inflation drift term in the monetary policy rule

budget constraint is

$$G_t + B_t = T_t + \frac{B_{t+1}}{R_t}.$$

We assume the government balances its budget every period, so government bonds are in zero net supply, $B_t = 0$, in equilibrium.[5] The *government spending shock* g_t evolves as

$$\ln g_t = (1 - \rho_g) \ln s_*^g + \rho_g \ln g_{t-1} + \eta_t^g, \eta_t^g \sim N(0, \sigma_g),$$

where s_*^g is a parameter equal to government's share of output in steady state.

3.5 Equilibrium

Equilibrium is defined in the usual way. All agents optimize as described above and prices adjust so markets clears. The constancy of the capital-labor ratio across intermediate good producers, Calvo pricing and wage setting, and our functional form assumptions imply there is a simple aggregation, eliminating any heterogeneity from the calculation of the equilibrium. At its core this is a real business cycle model and the first order conditions and resource constraints of the real side of the economy are the same. In addition to these equations the equilibrium is characterized by the wage and price Phillips curves derived from the Calvo price and wage setting schemes.

In equilibrium households are always on their labor supply schedules and so they are willing to work at the going wage W_t^h. Consequently wealth effects on labor supply determined by the Jaimovich and Rebelo (2009) preferences have a direct effect on equilibrium hours work. Guilds charge a mark-up over W_t^h but must deliver the differentiated labor demanded by the intermediate goods firms no matter the wage they have set. This demand is derived from the fact that intermediate good firms are contracted to deliver their goods to the final good firms no matter the price they have set. The wedges between revenues and costs for guilds and intermediate good firms are made up with positive or negative dividends to the

[5] With the introduction of liquidity preferences it is natural to extend the model to include a positive supply of safe and liquid assets. Doing so would be a step toward an environment where QE could be studied alongside forward guidance. We leave this avenue of inquiry for future work.

household. Otherwise profits are zero.

4 Measurement and Estimation

Since the model shares many features of a real business cycle model we adhere to practice in that literature and calibrate parameters on the real side of the economy to several first moments of the aggregate data. The remainder of the estimation uses a standard Bayesian methodology. This section briefly discuss the data we use for the models estimation and then presents our hybrid calibration-Bayesian estimation.

4.1 Data

We use 18 time series running from 1993q1 to 2007q3 in our estimation. These include data measuring output, consumption, investment, hours worked relative prices of investment, the real price of government consumption plus net exports, wage and consumer price inflation, average inflation expected over the next ten years, the federal funds rate and federal funds rate futures. In addition our calibration uses data measuring the capital stock and capital's share of aggregate income.

The bulk of our measurement derives from two simple principles. First we want our measurement to be consistent with the measure of labor input we think best addresses demographic and other low frequency developments in the supply of labor. This measure of hours is for economy-wide labor and so our measures of output, consumption, investment, capital and capital income must be consistent with this. Second we want our measurement of real quantities and prices to be consistent with the chain-weighting used in NIPA.

4.1.1 Hours

Empirical studies based on the canonical model typically measure hours with hours per capita directly from estimates of hours worked and the civilian population over the age of 16 obtained from the BLS. Such measures do not correspond well with the models because of underlying low frequency variation which they abstract from. As a consequence the results obtained are difficult to interpret. In our context, measures of the output gap are directly affected which in turn affects the coefficient on the output gap in the policy rule thereby directly impacting the identification of forward guidance. Clearly the measurement of hours is crucial to our analysis.

We use a simple procedure for overcoming this discrepancy between model and data.[6] Assume that hours per worker outside and inside the private business sector are the same. Then it is straightforward to show that hours per capita can be written

$$\begin{aligned} \frac{H}{P} &= \frac{H^{pb}}{E^{pb}} \frac{E^{cps}}{LF^{cps}} \frac{LF^{cps}}{P} \\ &= \text{Hours per worker} \times \text{Employment rate} \times \text{Labor force participation rate.} \end{aligned} \tag{7}$$

where H denotes economy-wide civilian hours worked; P denotes the civilian population over the age of 16; H^{pb} and E^{pb} denote hours and employment in the private business sector; and E^{cps} and LF^{cps} denote total civilian employment and the labor force from the CPS. Applying the log operator we obtain a simple additive decomposition of log per capita hours.

Figure 1: Total Economy-wide Hours Worked Per Capita

Figures/per-capita-hours

Figure 1 displays log per capita hours calculated using the right hand side of equation (7) over the period 1968q1 to 2015q1. One indication that this measure is problematic is that as of 2015q1 it is near the trough of the 1982 recession. While the labor market in 2015q1 arguably has some way to go to reach full employment, it seems unlikely that conditions are representative of the trough of a major recession.

Figure 2: The three components of per capita hours worked

Figures/hours-decomposition

A clearer picture of the labor market is obtained by considering the three constituent parts of log hours per capita, as displayed in Figure 2. Figure 2 demonstrates that per capita hours confounds low frequency movements in all three of its components. These movements can be attributed to a variety of demographic and social developments as well as changes in the underlying structure of the economy related to technological change and the growing role of international trade.

[6] See **?**, **?** and **?** for related discussions of non-stationarity in per capita hours worked.

Figure 2 strongly suggests that conventional measures of per capita hours are problematic; it is hard to argue that all variation in them is due to factors driving the business cycle. We are presented with two main alternatives to consider. Either we incorporate the underlying trends into our models or we remove the trends prior to analysis. Developing structural models of the trends is an extremely challenging task and goes far beyond the scope of a business cycle study. Therefore we take the latter approach.

To do so we take advantage of work done at the Federal Reserve Board described in **?** and **?**. The Board estimates variables that can be used to de-trend all three components of per capita hours.[7] We do not incorporate the estimation of these trends into our analysis. Instead we take them as given to construct an observable for per capita hours which is then used in the estimation of our model. Figure 3 displays the three components of per capita hours along with their trends and de-trended per capita hours which is derived as the sum of the differences between each component and its trend.

Figure 3: Detrending per capita hours

Figures/detrending-hours

4.2 Mapping output, consumption and investment to data quantities

NIPA chain-weighting formulas are used to match real model and data quantities. These formulas incorporate time-varying relative prices which we use in our estimation. As such the model has predictions for real GDP, consumption and investment, which are among the mostly commonly studied variables in macroeconomics. This is a step forward because while many studies use real GDP to identify output they also measure consumption and investment in GDP units which are difficult to interpret in the presence of variation in relative prices. Aside from being more realistic and therefore making our analysis more credible this approach has the advantage of bringing in new data to the model's estimation in the form of relative prices.

[7]These variables can be obtained from http://www.federalreserve.gov/econresdata/frbus/data_only_package.zip.

Concepts of consumption, investment, capital and output

4.3 Wage and Price Inflation

In most empirical studies based on the canonical model, variables are measured with a single empirical counterpart. In our model inflation and wages are measured using multiple empirical analogues, subject to measurement error.[8] This enhancement has several advantages. First it reduces the role of markup shocks in explaining fluctuations. In most models these shocks play an outsized role in explaining labor market dynamics and inflation, yet they are difficult to interpret. Second, inflation that enters the monetary policy rule is identified using the three inflation series core CPI, core PCE inflation and market-based PCE inflation. These series are crucial inputs into actual monetary policy formation. As such the policy rule is less subject to specification error compared to the many studies that measure inflation using the GDP deflator which is not a key factor in policy formation. Third, it tends to reduce the trade-off between inflation and output stabilization which is a key factor driving whether or not the ZLB is binding in New Keynesian models.[9]

Studies often identify model consumption, which does not include consumer durables, with NIPA PCE consumption (in GDP units) which does. In our framework model consumption is nondurable and so we use real nondurable and services consumption PCE to measure it. Therefore the price of consumption goods in the model is conceptually different from the CPI and PCE measures we use in estimation because these price indices include prices of durable consumption goods. We address this incongruity by making each empirical measure of inflation a weighted average of model inflation and exogenous durables inflation. Unlike the real price of investment goods, durables inflation does not change the model's aggregate resource constraint and is used only in measurement. However, it does impact the identified shocks.

Other data series: wages and prices, expected inflation, ffr, ffr futures

4.4 Calibration

We calibrate α, s^g_*, s^i_*, π^g_*, ω_*, ν_*, θ_s

[8] **?** is an early example of using multiple indicators to measure model counterparts.
[9] See **?** and **?**.

We observe the long-run average of the following aggregates

1. The labor share: 0.40
2. The government share: 0.1532
3. The investment share: 0.2585
4. The capital output ratio: 10.48 (quarterly)
5. The real per-capita GDP growth: 1.0054 (quarterly)
6. Government deflator: 1.0025 (quarterly)
7. Growth rate of the investment-specific technology: 0.0037 (quarterly)

Calibration Strategy

- The labor share can be used to calibrate the parameter α

$$\alpha = 0.40 \tag{8}$$

- The government spending share determines $\frac{g_*}{y_*}$ as follows:

$$\frac{g_*}{y_*} = g_y = 0.1532 \tag{9}$$

- The government price growth rate pins down

$$\pi_*^g = 1.0025 \tag{10}$$

- Use the growth rate of the investment-specific technology to calibrate

$$\omega_* = 0.0037 \tag{11}$$

- The investment share pins down $\frac{i_*}{y_*}$:

$$\frac{i_*}{y_*} = 0.2585 \tag{12}$$

- The capital output ratio pins down $\frac{k_*}{y_*}$

$$\frac{k_*}{y_*} = 10$$

- Obtain the investment-capital ratio by combining the investment share and the capital output ratio measured in the data:

$$\frac{i_*}{k_*} = \frac{i_*/y_*}{k_*/y_*} = \frac{0.2585}{10} = 0.02585 \tag{13}$$

- Calculate the consumption-output share

$$\frac{c_*}{y_*} = \left(1 - \frac{i_*}{y_*} - \frac{g_*}{y_*}\right) = (1 - 0.2585 - 0.1532) = 0.5883 \tag{14}$$

- The growth rate of real chain-weighted GDP is used to pin down the growth rate of output and consumption z_* as follows:

$$1.0054 = e^{z_*}\sqrt{\frac{\frac{c_*}{y_*} + e^{\omega}\frac{i_*}{y_*} + \left(\pi_*^g\right)^{-1}\frac{g_*}{y_*}}{\frac{c_*}{y_*} + e^{-\omega}\frac{i_*}{y_*} + \pi_*^g\frac{g_*}{y_*}}}$$

All the variables in this equation are unknown except for z_*. So we can solve for the the growth rate of output and consumption z_*:

$$z_* = \ln 1.0054 - \frac{1}{2}\ln\left(\frac{\frac{c_*}{y_*} + e^{\omega}\frac{i_*}{y_*} + \left(\pi_*^g\right)^{-1}\frac{g_*}{y_*}}{\frac{c_*}{y_*} + e^{-\omega}\frac{i_*}{y_*} + \pi_*^g\frac{g_*}{y_*}}\right) \tag{15}$$

$$= 0.0048 \tag{16}$$

- The growth rate of the labor-augmenting technology ν_* can be easily obtained by exploiting the following equation:

$$z_* = \upsilon_* + \frac{\alpha}{1-\alpha}\omega_* \tag{17}$$

- We are now in a position to identify the depreciation rate δ_0 using the steady-state equation pinning down the investment capital ratio by using the steady-state equilibrium equation; that is,

$$\begin{aligned} \frac{i_*}{k_*} &= 1-(1-\delta_0)e^{-z_*-\omega_*} \\ &\Rightarrow \delta_0 = 1+\left(\frac{i_*}{k_*}-1\right)e^{z_*+\omega_*} \\ &= 0.017 \end{aligned}$$

where the investment capital ratio is given by equation (13) and the growth rates ω_* and z_* are given by equations (11) and (15).

- From the steady-state equilibrium (note that $r_*^k = \delta_1$) we have that

$$\frac{y_*}{k_*} = e^{-z_*-\omega_*}\frac{\delta_1}{\alpha} \tag{18}$$

where r_*^k denotes the rental rate of capital. These two steady-state equations allow us to pin down the parameter $\delta_1 \equiv \delta'(1)$ through the following equation:

$$\delta_1 = \alpha\left(\frac{k_*}{y_*}\right)^{-1}e^{z_*+\omega_*} \tag{19}$$

$$= 0.0403 \tag{20}$$

where the capital output ratio is a target.

- In steady state, the real rate of return on private bonds can be derived by equation (**??**)

$$r_*^p \equiv \frac{R_*^P}{\pi_*} = \frac{e^{\sigma_c z_*}}{\beta} \tag{21}$$

In steady state the real rental rate of capital is given by equation (**??**), which can be expressed as follows:

$$r_*^k = \left[\frac{e^{\sigma_c z_*}}{\beta}\right]e^{\omega_*} - (1-\delta_0) \tag{22}$$

Combining equation (21) with the one above yields

$$r_*^k = r_*^p e^{\omega_*} - (1-\delta_0)$$

and hence

$$r_*^p = \left[r_*^k + 1 - \delta_0\right] e^{-\omega_*}$$

Recall that $r_*^k = \delta_1$, then

$$\begin{aligned} r_*^p &= (1 - \delta_0 + \delta_1)\, e^{-\omega_*} \\ &= 1.0195 \end{aligned}$$

- The liquidity premium in steady state (i.e., $\frac{R_*^G/\pi_*}{r_*^p}$) can now be computed by assuming a *nominal* average federal funds rate of 4.4% annualized (i.e., $R_*^G = 1.011$ gross quarterly rate) and an annualized average inflation rate of 2% ($\pi_* = 1.005$ gross quarterly rate). Hence. the liquidity premium in steady state is equal to 0.9867.

- Using equation (22) and the fact that $r_*^k = \delta_1$ (from the FOCN on the utilization rate), we can calibrate the discount factor β :

  $$\beta = \left(1 - \delta_0 + \delta_1\right)^{-1} e^{\omega_*} e^{\sigma_c z_*}$$

  where σ_c is a parameter of the utility function to be estimated.

4.5 Bayesian Estimation

5 Estimated Model

We are currently unsure about this sections title, but we know its goal: Give the estimated model credibility by running it through its paces. This will include

- The variance (spectral) decomposition of major aggregate variables fluctuations into contributions by the models structural shocks.

- Presentation of impulse-response functions for the four most important shocks (as measured by their contribution to output fluctuations). These are the neutral technology shock, the risk-premium shock, the investment cost shock, and the time preference shock.

- Presentation of impulse-response functions for monetary-policy shocks, both target and path style shocks.
- An evaluation of how (or whether) the Forward Guidance Puzzle manifests itself in our estimated model.
- A forecast error decomposition for output (and perhaps other series) for 2001, which encompasses the Bush II recession.
- The decomposition of inflation (Obs Dec by Series)

6 Results

Again, we are unsure about this sections title. Perhaps something like Forward Guidance During and After the Financial Crisis ? Regardless of its title, it will include

- Forecast error decompositions for the key series for each year in 2009-2013. This provides a structurally-informed history of the great recession and the following less-than-great recovery.
- Plots of the monetary policy shocks over this period. Hopefully, we could identify specific events /meetings that are associated with large shocks.
- The counterfactual/TMFP results. This will include what we are currently calling the money shot, which shows the very large contraction that would have been induced had interest rates risen as soon as possible.
- Assess the robustness of our results to reasonable changes in our procedure. We are not sure exactly what will go here, but we will get What if you did x? style questions. This is where the answers go.

7 Conclusion

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