The Dynamic Effects of Forward Guidance Shocks*

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January 15, 2016

Abstract

We examine the macroeconomic effects of forward guidance shocks at the zero lower bound. Empirically, we identify forward guidance shocks using a two-step procedure, which embeds high-frequency futures contracts in a structural vector autoregression. An exogenous extension of the zero lower bound duration increases economic activity and prices. We show that a standard model of nominal price rigidity largely replicates these empirical results. To calibrate our theoretical model, we generate a model-implied futures curve which allows us to closely link our model with the data. Our results suggest no disconnect between the empirical effects of forward guidance shocks and the predictions from a standard model of monetary policy.

JEL Classification: E32, E52

Keywords: Forward Guidance, Federal Funds Futures, Zero Lower Bound

*We thank Susanto Basu, Troy Davig, Christopher Otrok, and Stephen Terry for helpful discussions. Also, we appreciate the feedback from participants at various seminars and conferences. Thealexa Becker and Trenton Herriford provided excellent research assistance and we thank CADRE for computational support. The views expressed herein are solely those of the authors and do not necessarily reflect the views of the Federal Reserve Bank of Kansas City or the Federal Reserve System.
Available at: http://dx.doi.org/10.18651/RWP2016-02

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1 Introduction

In December 2008, the Federal Open Market Committee (FOMC) lowered the federal funds rate to its effective lower bound. With economic conditions continuing to deteriorate and its conventional policy tool unavailable, the Federal Reserve communicated its intent to keep future policy rates exceptionally low. Communication about the future path of policy, known as forward guidance, became a fixture of U.S. monetary policy in subsequent years.

However, recent theoretical and empirical works are divided on the macroeconomic effects of forward guidance. In standard models with nominal price rigidities, Eggertsson and Woodford (2003) show that lowering the expected path of policy rates can be highly effective in increasing economic activity and inflation. However, Del Negro, Giannoni and Patterson (2012) and Kiley (2014) argue that these theoretical models overpredict the expansionary effects of forward guidance. Empirical work by Campbell et al. (2012) and Nakamura and Steinsson (2015) argues that communicating lower expected rates may signal bad news about the macroeconomic outlook. Through this macroeconomic news effect, these papers suggest that lower expected policy rates can cause contractions in expected economic activity and employment.

We aim to address this apparent disconnect between the empirical evidence and theoretical predictions of macroeconomic models. First, we identify the empirical effects of forward guidance shocks at the zero lower bound. Our empirical approach centers on a two-step identification procedure which embeds high-frequency futures-based measures of expected policy rates in a structural vector autoregression (VAR). We identify a forward guidance shock as a change in the expected path of policy that is exogenous to current economic activity and prices. An exogenous extension of the zero lower bound duration results in a persistent economic expansion. Economic activity peaks one year after the shock and prices gradually rise over time. Our findings are robust to alternative information assumptions in the VAR, different measures of economic activity and prices, and alternative measures of expected future interest rates.

After identifying forward guidance shocks in the data, we examine their effects in a standard model of nominal price rigidity. Using a global solution method, we calibrate and solve a New-Keynesian model with a zero lower bound constraint. We model a forward guidance shock as an exogenous innovation to the central bank's desired policy rate at the zero lower bound. To closely align with the futures contracts from our empirical results, we generate a model-implied futures curve using the household's stochastic discount factor. We calibrate our nonlinear model such that a forward guidance shock in the model generates the same movements in futures rates that we observe in the data. This modeling strategy allows us to determine the appropriate calibration for several model parameters and the forward guidance shock process.

Our theoretical model is largely consistent with the macroeconomic effects of forward guidance shocks in the data. An exogenous decline in expected future policy rates in the model generates movements in economic activity and prices similar in magnitude to our empirical evidence. The key model features are a reasonable degree of nominal price rigidity, habits in household consumption, and a moderate degree of smoothing in the central bank's desired rate. These necessary ingredients are common in the models Christiano, Eichenbaum and Evans (2005) and others use to study the dynamic effects of conventional monetary policy shocks away from the zero lower bound. Thus, our findings suggest that dynamic equilibrium models, with a mix of both nominal and real rigidities, remain useful in examining the effects of forward guidance shocks at the zero lower bound.

We present two key findings. First, we show that forward guidance shocks that lower the expected path of policy stimulate economic activity and prices. Thus, unlike previous research, we find only a limited role for the macroeconomic news effect in FOMC policy rate announcements. Second, we find no disconnect between our empirical evidence and a textbook model of monetary policy if we calibrate the forward guidance shock process using futures rates.

On our first finding, regarding the role of macroeconomic news in FOMC announcements, we fully explore the source of the divergence between our results and those in Campbell et al. (2012). Using a single-equation framework, these authors specify their regression model in first differences and find a significant role for macroeconomic news in FOMC announcements. If we instead estimate their regression model in levels, however, we find that the stimulatory effects from an announcement of lower expected policy rates overwhelms any macroeconomic news effect. Thus, the dominance of the macroeconomic news effect appears to be a feature of the first-differenced regression. Given these differential findings, we then turn again to a VAR framework which nests the first-difference specification as a special case when the variables enter in levels. The VAR model suggests that forecasters revised-down their unemployment rate forecasts and revised-up their inflation forecasts in response to forward guidance about lower future policy rates.

On our second finding, regarding the theoretical predictions of macroeconomic models, our results suggest that the "Forward Guidance Puzzle" posited by Del Negro, Giannoni and Patterson (2012) may be overstated. Our conclusion relies on calibrating the appropriate-sized forward guidance shock using the model-implied futures curve. In both our empirical evidence and theoretical model, a typical expansionary forward guidance shock moves 12-month ahead futures rates by about two basis points. This shock extends the zero lower bound duration by one month in our model. Del Negro, Giannoni and Patterson (2012), however, simulate a much longer one-year extension of the zero lower bound period. Our calibrated model suggests that a one-year extension requires a very large exogenous shock, which is a highly unlikely event according to our VAR model. Our much smaller exogenous shock produces modest increases in output and inflation that are consistent with our empirical evidence.

2 Identifying Forward Guidance Shocks in the Data

We use a two-step procedure to identify exogenous forward guidance shocks in the data. In the first step, we measure the unexpected component of policy announcements around FOMC meetings using high-frequency measures of future policy rates. In the second step, we embed these policy surprises into a standard block-recursive monetary VAR. As we discuss in detail, this second step helps isolate the exogenous policy shock from possible macroeconomic news contained in the FOMC announcement.

Since we focus on the effects of forward guidance shocks at the zero lower bound, we restrict our analysis to the December 2008 - December 2014 sample period. Econometrically, this sample choice helps avoid any potential structural change caused by mixing data before and after the onset of the zero lower bound. In Section 4.2, we show that our simple theoretical model supports this sample selection: Policy shocks in our model have different macroeconomic effects at and away from the zero lower bound. Therefore, we focus solely on the zero lower bound period to avoid confounding our estimated responses with the pre-zero lower bound effects.

2.1 Identification Step 1: High-Frequency Futures Data

In our baseline model, we use federal funds futures contracts to measure the expected path of future policy rates. Using daily data, we compute the daily change in futures rates around each regularly-scheduled FOMC meeting from contracts that settle up to 12 months in the future.[1] Following Gurkaynak (2005), we then construct the change in the federal funds rate expected to prevail after the 7th-upcoming FOMC meeting, which occurs about one year in the future. As in Romer and Romer (2004) and Barakchian and Crowe (2013), we assign a value of zero to months in which there is no FOMC meeting and cumulatively sum the resulting monthly series to compute the implied level of the expected interest rate. The use of a single expected interest rate to measure the stance of policy helps us easily map our empirical framework into our theoretical model. In Section 6, however, we show that our empirical results are robust to using alternative measures of interest-rate expectations, such as multiple federal funds futures contracts, Eurodollar futures, and U.S. Dollar denominated overnight-indexed swaps. Appendix A, which is available on the Federal Reserve Bank of Kansas City's webpage, contains additional details on the data construction.

2.2 Controlling for Macroeconomic News

In the previous section, we derived the unexpected policy surprise around each FOMC meeting. However, these unexpected movements might not reflect exogenous forward guidance shocks. Romer and Romer (2004), Campbell et al. (2012), Gertler and Karadi (2015), Nakamura and Steinsson (2015) argue that the FOMC possesses private information about the state of the economy. Thus, unexpected policy announcements may reveal news about the macroeconomy, which was previously unavailable to the private sector. To cleanse the policy surprise of possible news about the state of the economy, we follow Christiano, Eichenbaum and Evans (2005) and many others and use a structural VAR model to identify monetary policy shocks that are exogenous to current economic activity and prices.

2.3 Identification Step 2: A Structural Vector Autoregression

In the second step of our identification procedure, we embed our measure of expected policy rates into a structural vector autoregression. The reduced-form of our monetary VAR is as follows:

$$X_t = \beta + \sum_{i=1}^{q} B_i X_{t-i} + u_t, \tag{1}$$

where q is the number of lags determined by the Schwartz-Bayesian Information Criteria (SBIC) and $Eu_t u_t' = \Omega$ is the covariance matrix for residuals.[2] The corresponding structural

[1] Gurkaynak, Sack and Swanson (2005) show that using an event window smaller than one day does doesn't materially change their results.

[2] Our results are robust to using the number of lags suggested by the Akaike Information Criterion (AIC).

model is written as:

$$A_0 X_t = \alpha + \sum_{i=1}^{q} A_i X_{t-i} + \varepsilon_t, \tag{2}$$

where $\mathrm{E}\varepsilon_t \varepsilon_t{}' = \Delta$ is the diagonal covariance matrix for structural shocks.[3] The variables in the model are divided into two groups:

$$X_t = \begin{pmatrix} X_{1,t} \\ X_{2,t} \end{pmatrix}. \tag{3}$$

$X_{1,t}$ contains measures of economic activity and prices and $X_{2,t}$ contains the measure of expected future policy rates discussed in the previous section.[4] Assuming A_0 is block recursive, we can recover the structural model from the reduced form VAR via:

$$A_0 = \begin{bmatrix} A_{11} & \mathbf{0}_{12} \\ A_{21} & A_{22} \end{bmatrix}, \tag{4}$$

where A_{ij} is an $n_i \times n_j$ matrix of parameters and $\mathbf{0}_{ij}$ is an $n_i \times n_j$ zero matrix for $i, j = 1, 2$. The vector of structural shocks is: $\varepsilon_t = \left(\varepsilon'_{1,t}\, , \varepsilon'_{2,t}\right)'$. We order our policy variable last, which identifies a forward guidance shock $\varepsilon_{2,t}$ as the change in expected future policy rates that is orthogonal to current activity and prices. In addition, our identifying assumptions implies that the macroeconomic conditions in $X_{1,t}$ adjust slowly to changes in the expected policy rates in $X_{2,t}$.

Our identification scheme allows the FOMC to have a larger information set than the financial market participants, which is consistent with the recent findings of Campbell et al. (2012), Nakamura and Steinsson (2015), and Gertler and Karadi (2015). By ordering our policy variable last, we assume that the central bank knows current-month indicators of activity and prices, which are unavailable in real time. However, two points regarding this assumption are worth emphasizing. First, we can change our assumptions regarding the central bank's information set by altering the ordering of our recursive VAR. In Section 2.6, we show that our empirical findings are almost unchanged if we instead order our policy variable first. Second, any macroeconomic news component that is not captured by the VAR biases our results downward.[5] Thus, our findings represent a lower bound if significant contractionary news remains in our identified shocks.

[3] For our purposes, we only require that Δ take on a block-diagonal form. This condition is sufficient to make the forward guidance shock uncorrelated with the other shocks.

[4] We could extend the VAR model to include a third block of variables. Similar to the model of Christiano, Eichenbaum and Evans (1999), this block could include money market variables such as the monetary base or the M2 money stock.

[5] Using Greenbook forecasts to control for the FOMC's information set, Gertler and Karadi (2015) show

2.4 Baseline Empirical Model & Statistical Inference

We estimate our baseline empirical model at a monthly frequency using several indicators of real economic activity. We include a monthly measure of GDP, a proxy for equipment investment, capacity utilization, the GDP deflator, and the expected policy rate after the 7th-upcoming FOMC meeting. We use the Macroeconomic Advisers monthly GDP and corresponding price deflator to measure aggregate real activity and prices.[6] To proxy equipment investment at a monthly frequency, we use core capital goods shipments (which excludes defense and aircraft), which is the same data the Bureau of Economic Analysis uses to calculate the official quarterly investment data.

In addition to helping identify exogenous shocks, our vector autoregression provides a natural framework for estimating the dynamic effects of a forward guidance shock. We conduct statistical inference on the structural impulse responses using a Bayesian Monte Carlo procedure. Following Sims and Zha (1999), we use a non-informative conjugate prior such that the posterior distribution of the reduced form VAR parameters is based on the ordinary least squares point estimates. Our exact implementation follows Koop and Korobilis (2010).

2.5 Baseline Empirical Results

We now return to our key empirical question: What are the macroeconomic effects of forward guidance shocks? Figure 1 plots the estimated impulse responses for an identified forward guidance shock, as well as the 80% confidence intervals of the posterior distribution. A one standard deviation forward guidance shock lowers the expected federal funds rate after the 7th-upcoming FOMC meeting by about two basis points. Per our identifying assumptions, economic activity and prices remain unchanged at impact. In the following months, however, real activity rises sharply and remains elevated for the next three years. GDP and investment follow hump-shaped patterns and overall economic activity peaks roughly 12-18 months after the policy shock. Prices rise gradually over time, peaking about 24 months after the shock.

that failing to control for policy news component biases downward the estimated stimulus from expansionary monetary policy shocks. However, the five-year release lag of this data makes their approach infeasible for our study.

[6] Macroeconomic Advisers use much of the same source data and a similar aggregation method used by the Bureau of Economic Analysis (BEA) in the calculation of real GDP. Therefore, the aggregated monthly GDP series has a high correlation with the BEA's official quarterly figures. Our results are robust to alternatively using industrial production and the producer price index for finished goods excluding food and energy.

Our identified impulse responses shares many qualitative features with the conventional policy shock responses of Christiano, Eichenbaum and Evans (2005). Forward guidance and conventional policy shocks cause movements in investment that are significantly larger than the fluctuations in overall output. Following both shocks, capacity utilization increases with a hump-shaped pattern, which peaks within one year after the shock. Most importantly though, our results suggest that an exogenous decline in expected policy rates at the zero lower bound increases broad economic activity and prices.

2.6 Alternative Ordering and Central Bank Information Set

In the previous section, we show that an exogenous decline in expected rates leads a persistent expansion of economic activity and prices. We now show that these results are robust to ordering policy first in our recursive structural VAR. This alternative ordering has two advantages. First, it allows us to relax our assumption about the amount of private information held by the central bank. By ordering our policy indicator first, we assume that the central bank only observes lagged indicators of real activity and prices. Second, this alternative ordering allows us to estimate the impact effect on the macroeconomic block.[7] If the policy announcements are uncorrelated with current macroeconomic data included in the VAR, the ordering of the policy rate is unimportant. However, if forward guidance announcements reveal the FOMC's private information, then ordering the expected policy rate first allows for a more pronounced macroeconomic news effect.

The estimated responses are nearly unchanged when we order policy before indicators of real activity and prices. Figure 2 plots the estimated impulse responses under this alternative ordering. With the exception of core capital goods, the impact effects for each macroeconomic indicator are not statistically different than zero. Core capital goods slightly increases at impact, but the post-impact impulse response looks similar to our previous results. Overall, the lack of significant impact effects under this alternative ordering suggests that our zero-impact restrictions from the previous section are generally supported by the data. Finally, the size and persistence of the forward guidance shock remains almost identical under both orderings. The robustness of the estimated responses under this alternative central bank information set suggests a limited role for macroeconomic news in FOMC announcements.

[7] Uhlig (2005) argues that the zero-impact restrictions imposed by ordering economic activity ahead of policy variables under a Cholesky decomposition may lead to significant effects on output that vanish when output is left unrestricted on impact.

We explore this issue in detail in Section 7.

2.7 Mapping Empirical VAR to Theoretical Model

Our previous results show that an exogenous forward guidance shock that lowers expected nominal rates causes a persistent economic expansion. In Sections 3 & 4 that follow, we assess the ability of a standard model of nominal price rigidity to reproduce these empirical findings. However, mapping our baseline empirical results to a standard dynamic model posses three challenges. First, the FOMC meets every six to eight weeks to set the stance of monetary policy, while a monthly-frequency model implies the central bank meets every month. Second, our empirical proxy for investment does not exactly line up with the concept of installed capital from a standard capital accumulation framework. Finally, we want to pursue a computationally-intensive calibration strategy which involves generating a model-implied futures curve. As we discuss in Section 3.7, this strategy effectively limits the number of state variables we can include in our theoretical model. Therefore, we want a parsimonious empirical model which we can closely map to a standard model of nominal price rigidity.

We find that our previous results can be effectively summarized by a simple three-variable VAR with real personal consumption expenditures (PCE), the core PCE price index, and the 12-month ahead futures rate. Since consumption, prices, and interest rates lie at the core of the New-Keynesian framework, this simple VAR allows for a tight link between our empirical evidence and our theoretical model. PCE is the largest single component of GDP and therefore provides a strong signal of economic activity at a monthly frequency. Real PCE also aligns closely with the model's definition of output, since our theoretical model abstracts from capital accumulation. We exclude the volatile food and energy components from our measure of prices due to large swings in oil prices at the early part of our sample. Unlike the meeting-frequency funds rate in our previous baseline model, the 12-month ahead futures rates allows us to easily map our empirical results to the model-implied futures curve.[8]

Figure 3 plots the estimated impulse responses for this smaller VAR model. An exogenous decline in 12-month ahead policy rates causes a significant rise in consumption and prices. This alternative model suggests the same qualitative conclusions: An exogenous forward guidance shock leads to a persistent economic expansion with higher prices.[9] In the following

[8]We follow the same estimation procedure as our baseline model but do not apply the meeting-frequency correction of Gurkaynak (2005).

[9]Similarly to our larger baseline model, ordering our policy indicator first in our three-variable VAR

sections, we use the empirical results from this simple VAR to assess whether a standard model of nominal price rigidity can reproduce these empirical findings.

3 A Theoretical Model of Nominal Price Rigidity

This section outlines the dynamic stochastic general equilibrium model we use to analyze forward guidance shocks. The model shares many features with the models of Ireland (2003) and Ireland (2011). Our model features optimizing households and firms and a central bank that systematically adjusts the nominal interest rate to offset adverse shocks in the economy. We allow for sticky prices using the quadratic-adjustment costs specification of Rotemberg (1982). The model considers shocks to household discount factors and the central bank's desired policy rate. To link our theoretical model with the our previous empirical results, we use the household's stochastic discount factor to generate a model-implied futures curve.

3.1 Households

In the model, the representative household maximizes lifetime expected utility over streams of consumption C_t and leisure $1 - N_t$. Households derive utility from consumption relative to a habit level H_t. The household receives labor income W_t for each unit of labor N_t supplied in the representative intermediate goods-producing firm. The household also owns the intermediate goods firm, which pays lump-sum dividends D_t. Also, the household has access to zero net-supply nominal bonds B_t and real bonds B_t^R. Nominal bonds pay one nominal dollar and are purchased with a discounted price $1/R_t$, where R_t denotes the one-period gross nominal interest rate. Real bonds return one unit of consumption and have a purchase price $1/R_t^R$, where R_t^R denotes the one-period gross real interest rate. The household divides its income from labor and its financial assets between consumption C_t and the amount of the bonds B_{t+1} and B_{t+1}^R to carry into next period.

The representative household maximizes lifetime utility by choosing $C_{t+s}, N_{t+s}, B_{t+s+1}$, and B_{t+s+1}^R, for all $s = 0, 1, 2, \dots$ by solving the following problem:

$$\max \mathrm{E}_t \sum_{s=0}^{\infty} a_{t+s} \beta^s \left(\log \left(C_{t+s} - bH_{t+s} \right) - \chi \frac{N_{t+s}^{1+\eta}}{1+\eta} \right)$$

subject to the intertemporal household budget constraint each period,

$$C_t + \frac{1}{R_t} \frac{B_{t+1}}{P_t} + \frac{1}{R_t^R} B_{t+1}^R \leq \frac{W_t}{P_t} N_t + \frac{B_t}{P_t} + \frac{D_t}{P_t} + B_t^R.$$

produces very similar impulse responses.

The discount factor of the household β is subject to shocks via a_t. These shocks can be interpreted as demand shocks, since an increase in a_t induces households to consume more and work less for no technological reason. We use these shocks to simulate a zero lower bound episode. The stochastic process for these fluctuations is as follows:

$$a_t = (1 - \rho_a)\, a + \rho_a a_{t-1} + \sigma^a \varepsilon_t^a \tag{5}$$

where ε_t^a is an independent standard-normal random variable.

Using a Lagrangian approach, household optimization implies the following first-order conditions:

$$a_t\,(C_t - bH_t) = \lambda_t \tag{6}$$

$$\frac{W_t}{P_t} = \chi \left(\frac{a_t}{\lambda_t}\right) N_t^{\eta} \tag{7}$$

$$1 = \mathrm{E}_t R_t \left\{ \left(\beta \frac{\lambda_{t+1}}{\lambda_t}\right) \left(\frac{P_t}{P_{t+1}}\right) \right\} \tag{8}$$

$$1 = \mathrm{E}_t R_t^R \left\{ \beta \frac{\lambda_{t+1}}{\lambda_t} \right\} \tag{9}$$

where λ_t denotes the Lagrange multiplier on the household budget constraint. Equations (6) - (7) represent the household intratemporal optimality conditions with respect to consumption and leisure, and Equations (8) - (9) represent the Euler equations for the one-period nominal and real bonds. In equilibrium, consumption habits are formed external to the household and are linked to last period's aggregate consumption $H_t = C_{t-1}$.

3.2 Intermediate Goods Producers

Each intermediate goods-producing firm i rents labor $N_t(i)$ from the representative household in order to produce intermediate good $Y_t(i)$. Intermediate goods are produced in a monopolistically competitive market where producers face a quadratic cost of changing their nominal price $P_t(i)$ each period. Firm i chooses $N_t(i)$, and $P_t(i)$ to maximize the discounted present-value of cash flows $D_t(i)/P_t(i)$ given aggregate demand, Y_t, and the price P_t of finished goods. The intermediate goods firms all have access to the same constant returns-to-scale production function. We introduce a production subsidy $\Psi = \theta/(\theta - 1)$ to ensure that the steady state of the model is efficient, where θ is the elasticity of substitution across intermediate goods.

Each intermediate goods-producing firm maximizes discount cash flows using the household stochastic discount factor:

$$\max \mathrm{E}_t \sum_{s=0}^{\infty} \left(\beta^s \frac{\lambda_{t+s}}{\lambda_t}\right) \left[\frac{D_{t+s}(i)}{P_{t+s}}\right]$$

subject to the production function:

$$\left[\frac{P_t(i)}{P_t}\right]^{-\theta} Y_t \leq N_t(i),$$

where

$$\frac{D_t(i)}{P_t} = \Psi \left[\frac{P_t(i)}{P_t}\right]^{1-\theta} Y_t - \frac{W_t}{P_t} N_t(i) - \frac{\phi_P}{2} \left[\frac{P_t(i)}{\Pi P_{t-1}(i)} - 1\right]^2 Y_t.$$

The first-order conditions for the firm i are as follows:

$$\frac{W_t}{P_t} N_t(i) = \Xi_t N_t(i) \tag{10}$$

$$\begin{aligned} \phi_P \left[\frac{P_t(i)}{\Pi P_{t-1}(i)} - 1\right] \left[\frac{P_t}{\Pi P_{t-1}(i)}\right] &= \Psi(1-\theta) \left[\frac{P_t(i)}{P_t}\right]^{-\theta} + \theta \Xi_t \left[\frac{P_t(i)}{P_t}\right]^{-\theta-1} \\ &+ \phi_P \mathrm{E}_t \left\{ \left(\beta \frac{\lambda_{t+1}}{\lambda_t}\right) \frac{Y_{t+1}}{Y_t} \left[\frac{P_{t+1}(i)}{\Pi P_t(i)} - 1\right] \left[\frac{P_{t+1}(i)}{\Pi P_t(i)} \frac{P_t}{P_t(i)}\right] \right\}, \end{aligned} \tag{11}$$

where Ξ_t is the multiplier on the production function, which denotes the real marginal cost of producing an additional unit of intermediate good i.

3.3 Final Goods Producers

The representative final goods producer uses $Y_t(i)$ units of each intermediate good produced by the intermediate goods-producing firm $i \in [0, 1]$. The intermediate output is transformed into final output Y_t using the following constant returns to scale technology:

$$\left[\int_0^1 Y_t(i)^{\frac{\theta-1}{\theta}} di\right]^{\frac{\theta}{\theta-1}} \geq Y_t.$$

Each intermediate good $Y_t(i)$ sells at nominal price $P_t(i)$ and the final good sells at nominal price P_t. The finished goods producer chooses Y_t and $Y_t(i)$ for all $i \in [0, 1]$ to maximize the following expression of firm profits:

$$P_t Y_t - \int_0^1 P_t(i) Y_t(i) di$$

subject to the constant returns to scale production function. Finished goods-producer optimization results in the following first-order condition:

$$Y_t(i) = \left[\frac{P_t(i)}{P_t}\right]^{-\theta} Y_t.$$

The market for final goods is perfectly competitive, and thus the final goods-producing firm earns zero profits in equilibrium. Using the zero-profit condition, the first-order condition for profit maximization, and the firm objective function, the aggregate price index P_t can be written as follows:

$$P_t = \left[\int_0^1 P_t(i)^{1-\theta} di\right]^{\frac{1}{1-\theta}}.$$

3.4 Equilibrium

In the symmetric equilibrium, all intermediate goods firms choose the same price $P_t(i) = P_t$ and employ the same amount of labor $N_t(i) = N_t$. Thus, all firms have the same cash flows and we define gross inflation as $\Pi_t = P_t/P_{t-1}$. Therefore, we can model our intermediate-goods firms with a single representative intermediate goods-producing firm. To be consistent with national income accounting, we define a data-consistent measure of output $Y_t^d = C_t$. This assumption treats the quadratic adjustment costs as intermediate inputs. Shocks to household discount factors or the central bank's policy rule do not affect the equivalent flexible-price version of our baseline model. Therefore, we define the output gap as data-consistent output in deviation from its deterministic steady state $x_t = \ln(Y_t^d/Y^d)$.

3.5 Monetary Policy

We assume a cashless economy where the monetary authority sets the one-period net nominal interest rate $r_t = \log(R_t)$. Due to the zero lower bound on nominal interest rates, the central bank cannot lower its nominal policy rate below zero. We assume the monetary authority sets its policy rate according to the following policy rule subject to the zero lower bound:

$$r_t^d = \Big(1 - \phi_r\Big) r + \phi_r r_{t-1}^d + \phi_\pi \Big(\pi_t - \pi\Big) + \phi_x x_t + \nu_t \tag{12}$$

$$\nu_t = \rho_\nu \nu_{t-1} + \sigma^\nu \varepsilon_t^\nu \tag{13}$$

$$r_t = \max\Big(0, r_t^d\Big) \tag{14}$$

where r_t^d is the desired policy rate of the monetary authority and r_t is the actual policy rate subject to the zero lower bound. π_t denotes the log of the gross inflation rate and x_t is the gap between current output and output in the equivalent flexible-price economy. Finally, ν_t is an autocorrelated monetary policy shock.

Away from the zero lower bound, this policy rule acts like a Taylor (1993)-type policy rule with interest-rate smoothing. When the economy encounters the zero lower bound, however, this history-dependent rule lowers the future path of policy to help offset the previous higher-than-desired nominal rates caused by the nominal constraint. Households fully internalize this future conduct of policy. A negative exogenous ε_t^{ν} shock away from the zero lower bound acts like a conventional monetary policy shock, in which current desired and actual policy rates fall. When desired rates are less than zero, an negative exogenous ε_t^{ν} shock lowers current desired rates and future actual policy rates, which acts like an exogenous extension of the zero lower bound. This exogenous extension of the zero lower bound lowers future expected policy rates, which we link with our identified forward guidance shock in the data. Thus, our specification of monetary policy allows us to analyze both conventional policy shocks away from the zero lower bound and forward guidance shocks at the zero lower bound.

Our forward guidance shock specification differs from the work of Del Negro, Giannoni and Patterson (2012) and Keen, Richter and Throckmorton (2015), which use a combination of current and anticipated monetary policy shocks to model forward guidance shocks. However, we prefer our specification for two reasons. First, our specification is parsimonious and only adds a single state variable (the central bank's desired rate) to the model. In contrast, anticipated news shocks add an additional state variable for each horizon of central bank forward guidance. As we discuss in Section 3.7, we want to keep the number of state variable to a minimum so we can pursue a computationally-intensive calibration strategy.

Second, we find simulating forward guidance using news shocks somewhat cumbersome. As nicely discussed by Keen, Richter and Throckmorton (2015), an anticipated policy shock which lowers future expected policy rates causes output and inflation to rise today. Through the endogenous component in the central bank's policy rule, higher output and inflation implies higher policy rates today. Thus, to keep rates unchanged today, the economic modeler must simulate an additional *expansionary* contemporaneous policy shock to keep rates unchanged today. By contrast, our single forward guidance shock acts like an exogenous extension of the zero lower bound episode that leaves current policy rates unchanged. We believe this analysis closely aligns with the type of experiments envisioned by policymakers.

3.6 Generating Model-Implied Futures Contracts

A key issue in determining the effects of forward guidance is choosing the appropriate calibration for the exogenous shock process. We want to ensure our simulated forward guidance shock in the model is consistent with the forward guidance shock we identify in the data. Therefore, we generate a model counterpart to the federal funds futures contracts in the data. We denote the price of a n-month ahead future at time t by f_t^n. The payoff on this contract is one minus the average effective federal funds rate over the contract expiration month. For the 1-month ahead contract in our model, this payoff concept equals $1 - 12r_{t+1}$, where r_{t+1} is the monthly policy rate of the central bank next period. Using the household stochastic discount factor, we calculate the price of the one-month ahead zero net-supply futures contract by including the following equilibrium condition:

$$1 = \mathrm{E}_t \left\{ \left(\beta \frac{\lambda_{t+1}}{\lambda_t} \right) \frac{R_t}{\Pi_{t+1}} \frac{1 - 12r_{t+1}}{f_t^1} \right\}. \tag{15}$$

The structure of the futures contracts implies that an n-month contract at time t becomes an $n-1$ contract at time $t+1$. Thus, we price out the entire futures curve using the additional equilibrium condition:

$$1 = \mathrm{E}_t \left\{ \left(\beta \frac{\lambda_{t+1}}{\lambda_t} \right) \frac{R_t}{\Pi_{t+1}} \frac{f_{t+1}^{n-1}}{f_t^n} \right\}, \tag{16}$$

for each monthly contract from $n = 2, \ldots, 12$.

These model counterparts allow us to chose the appropriate-sized forward guidance shock to simulate in the model. For a given horizon, we can determine the futures-implied interest rate by computing one minus the contract price. Note: We have included an additional term R_t/Π_{t+1} in each equilibrium condition. In reality, investors in federal funds futures contracts must post collateral when entering futures positions. Since the collateral also earns a return, there is no opportunity-cost of funds associated with futures positions. For tractability, our equilibrium conditions assume that the household enters these contracts using one-period nominal bonds each period.

3.7 Solution Method & Calibration

We solve the full nonlinear model using the policy function iteration method of Coleman (1990) and Davig (2004). This global approximation method allows us to model the occasionally-binding zero lower bound and solve for the model-implied futures prices without invoking the expectations hypothesis. This method discretizes the state variables on a grid and solves for the policy functions which satisfy all the model equations at each point in the state space. Appendix B contains the details of the policy function iteration algorithm. In summary, the algorithm solves for 15 policy functions for N_t, Π_t, R_t^R, f_t^1, f_t^2, f_t^3, f_t^4, f_t^5, f_t^6, f_t^7, f_t^8, f_t^9, f_t^{10}, f_t^{11}, f_t^{12} as a function of the four state variables R_{t-1}^D, C_{t-1}, a_t, ν_t. We implement the algorithm in `FORTRAN` and parallelize the solution method using `OPENMP`.

Ideally, we would like to formally estimate our model using impulse response matching. However, despite the use of a compiled language and parallel programming, our model takes about two hours to solve for a reasonable grid size. Therefore, the repeated solutions required in formal estimation would be very time consuming. Instead, we use a guess and check calibration strategy by hand to bring the model impulse responses as close as possible to the empirical evidence from Section 2. Despite our lack of a formal estimation procedure, our calibrated model is able to largely reproduce the empirical impulse responses.

Table 1 lists the calibrated parameters of the model. To match our empirical evidence, we calibrate the model to monthly frequency. We find that the household habit parameter (b), adjustment cost in prices (ϕ_P), interest-rate smoothing parameter (ϕ_r), and the forward guidance shock parameters (ρ_ν, σ^ν) are important in fitting the model to the data. In Section 4.3, we discuss our calibration of these key parameters in detail. For the remaining parameters, we calibrate them using values from previous studies. Since the model shares features with the models of Ireland (2003) and Ireland (2011), we calibrate many of our parameters to match his values or estimates. We calibrate χ to normalize output Y to equal one at the deterministic steady state.

Our calibration strategy examines movements in futures rates both in the data and model. We pick the size and persistence of the forward guidance shock such that the model generates the same movement in 12-month ahead futures rates we observe in the data. Without disciplining movements in the model-implied expected future interest rates, it is unclear what size forward guidance shock to simulate in the model. Our strategy is broadly consistent with previous monetary policy shock literature, which chooses the conventional monetary policy shock such that the movements in the model-implied policy indicator are consistent with the identified responses of the vector autoregression Christiano, Eichenbaum and Evans (2005). However, since we focus on forward guidance shocks during the zero lower bound period, we discipline the model using expectations of future policy rates.

4 Theoretical Predictions to a Forward Guidance Shock

4.1 Impulse Response Analysis

We now analyze the macroeconomic effects of a forward guidance shock in the model. We want to simulate an exogenous extension of the zero lower bound episode. To compute the impulse response, we generate two time paths for the economy. In the first time path, we simulate a large negative demand shock, which causes the zero lower bound to bind for about eight months. In the second time path, we simulate the same large negative first moment demand shock, but also simulate a negative shock to the desired policy rule in Equations (12) and (13). We choose the size of the forward guidance shock such that the 12-month ahead model-implied futures contract declines by two basis points. This size shock is consistent with the empirical findings in Figure 3. In the calibrated model, this forward guidance shock extends the zero lower bound duration by one month. We assume that the economy is hit by no further shocks and compute the percent difference between the two time paths as the impulse response to a forward guidance shock at the zero lower bound.

Figure 3 shows that the model largely replicates our empirical evidence. Consumption hardly moves at impact, but rises in a hump-shaped pattern in line with the empirical response. The peak response of consumption occurs about nine months after the shock, which is only slightly smaller than the response in the data. The positive effects on consumption are slightly less persistent in the model than in the data. However, the impulse response for prices closely tracks its empirical counterpart throughout the life of the shock. With the exception of the impact and terminal values for the consumption response, all other model responses fall within the 80% confidence interval generated by our empirical model.[10] These key results suggest that the predictions from a standard model of monetary policy are in line with the empirical effects of forward guidance shocks.

Figure 4 shows the impulse responses for additional futures contracts and real interest rates. Since households expect the zero lower bound to persist for several months, the 1-month ahead futures rates don't move immediately after the forward guidance shock. However, the longer 6- and 12-month ahead contracts fall by several basis points as expected nominal policy rates decline. The combination of the forward guidance shock, nominal

[10]We could further improve the model fit by introducing other features, such as lagged expectations, that ensure consumption and prices do not respond at impact. However, these additional features would introduce further state and decision variables, which would further add to the computational time needed to solve the model.

rigidity, and the zero lower bound produces a significantly delayed reaction of real interest rates. At impact, current nominal policy rates are fixed at zero and expected inflation rises very slightly due to the nominal rigidity in price-setting. Thus, real interest rates only fall by a small amount when the economy remains at the zero lower bound. However, real rates fall sharply once the economy exists the zero lower bound and the monetary authority can lower its current nominal policy rate. This time path for real interest rates causes a very gradual increase in consumption, where the peak response occurs after households expect the economy to exit the zero lower bound.

4.2 Current Economic Conditions Matter

We find that the current macroeconomic conditions when the forward guidance shock occurs matter for determining the equilibrium outcomes. For a given-sized forward guidance shock, household and firm expectations about the overall duration of the zero lower bound affect their consumption and pricing decisions. In our baseline results, we find that a zero lower bound episode of about eight months allows the model to match the data. In this section, we simulate a larger initial shock to the economy such that the zero lower bound persists for significantly longer.

Disciplining the model using futures contracts helps us determine the appropriate zero lower bound episode to simulate in the model. Figure 4 plots the responses under an 18-month zero lower bound duration and our baseline 8-month scenario. The decline in the 1-month ahead futures now occurs much later than the baseline and the 6-month ahead futures fails to move at impact. Under the longer zero lower bound episode, the peak decline in real interest rates is smaller and occurs much later, which implies a more modest but delayed response of consumption.[11] Thus, if we simulate too long of an initial zero lower bound episode, Figure 4 shows that consumption fails to rise significantly and the 12-month ahead futures rates display a hump-shaped pattern. Both of these responses are inconsistent with the empirical evidence. However, if we simulate a very short zero lower bound episode, the decline in real rates and peak in consumption occurs much sooner than the empirical evidence.[12]

For comparison, Figure 4 also plots the responses to a conventional monetary policy shock

[11] Using a similar model, Keen, Richter and Throckmorton (2015) examine the effects of anticipated monetary policy shocks at the zero lower bound. They also find that the expansionary effects of forward guidance decrease under a longer expected zero lower bound episode.

[12] To save space, we do not plot the responses under a very short zero lower bound episode.

away from the zero lower bound. Contrary to the forward guidance shock, the largest decline in real rates occurs shortly after the conventional policy shock. Thus, consumption increases more at impact, its peak response is larger, and its maximum response occurs several months earlier. The 1- and 6-month ahead futures rates move much more at impact following the conventional policy shock. Overall, these exercises suggest conventional policy and forward guidance shocks have similar qualitative implications for the macroeconomy. However, the exact quantitative conclusions and the timing of their effects differ between both types of policy shocks.

4.3 Key Calibrated Parameters

We now discuss the calibration of several of the key model parameters. To a first-order approximation, both Rotemberg (1982) and Calvo (1983) nominal frictions generate identical New-Keynesian Phillips Curves. Therefore, we can provide an interpretation for our ϕ_P calibration using this approximate mapping. Our calibration of ϕ_P implies a linearized Phillips Curve slope on marginal cost of $\theta/\phi_P = 0.0024$. Given our calibration of β, this slope implies that prices remain unchanged for about 21 months on average. This frequency of price adjustment is higher than the macro estimates of Smets and Wouters (2007), but is lower than micro estimates from Nakamura and Steinsson (2008). However, since we are using a nonlinear solution method, Calvo and Rotemberg pricing frictions are no longer equivalent.

We find that the model generates impulse responses consistent with the data with a moderate degree of interest-rate smoothing ($\phi_r = 0.5$) and persistent forward guidance shock ($\rho_\nu = 0.9$). These estimated values are similar to the findings of Carrillo, Fève and Matheron (2007). These authors argue that persistent shocks, rather than large amounts of interest-rate smoothing, help standard models better explain the effects of a conventional monetary policy shock. We find the same mechanism is useful for capturing the dynamics of forward guidance shocks at the zero lower bound. While we cannot exactly translate our monthly habit persistence to a quarterly frequency, our calibrated monthly value ($b = 0.85$) seems highly consistent with the quarterly values commonly estimated in the previous literature.

5 Discussion of Related Literature

Our results suggest that a textbook framework of monetary policy can largely replicate the dynamic responses to a forward guidance shock at the zero lower bound. This finding contrasts with recent work by Del Negro, Giannoni and Patterson (2012), which argue that models with nominal rigidities overestimate the expansionary effects of forward guidance. Our differential conclusion emerges, in part, from size of the forward guidance shock we simulate in the model. In both our empirical evidence and model, a typical expansionary forward guidance shock lowers 12-month ahead futures rates by about 2 basis points. This shock extends the zero lower bound duration by one month in our model. Del Negro, Giannoni and Patterson (2012), however, simulate a much longer one-year extension of the zero lower bound period, which results in a very large expansion in economic activity. These authors argue this increase in activity is implausibly large, and denote their finding the "Forward Guidance Puzzle." However, our empirical evidence suggests that a one-year exogenous extension requires 10+ standard deviation shock, which is a highly unlikely event according to our VAR model.[13] Our much smaller exogenous shock produces only modest increases in output and inflation that are consistent with our empirical evidence.

A recent paper by McKay, Nakamura and Steinsson (2014) also argues that standard representative-agent macroeconomic models overstate the effects of central bank forward guidance. These authors focus on the implications of the linearized consumption Euler equation for a given path of real interest rates. Holding all other real interest rates fixed, they simulate an exogenous decline in real interest rates for a single period in the future. They show that the effects on household consumption and prices increase as the real rate shock moves farther into the future. They argue that these effects are unrealistic, so they introduce idiosyncratic household risk and borrowing constraints to temper the responses of consumption and prices.

While we find uninsurable risk or borrowing constraints are not necessary to model the dynamics of a forward guidance shock, we do not want to suggest that these factors don't matter in reality. Households and firms consider risk and borrowing constraints when making their forward-looking decisions. However, our results suggest that the standard representative-agent model with nominal price rigidities may still serve as a good approximation to the actual economy when examining the effects of forward guidance shocks. Our findings suggest the same models Christiano, Eichenbaum and Evans (2005) and many others use to study the effects of conventional monetary policy shocks remain useful in studying forward guidance shocks at the zero lower bound.

[13] Prior to conducting their forward guidance experiment, Del Negro, Giannoni and Patterson (2012) use overnight-indexed swaps rates to estimate the state of the economy and the expected path of interest rates. However, they do not use these rates to inform the size of the exogenous forward guidance shock they simulate in their model.

Our paper is also related to Nakamura and Steinsson (2015), which uses high-frequency responses of interest rates to estimate monetary non-neutrality. The authors estimate the effects of FOMC announcements on various nominal and real interest rates. Then, they estimate a medium-scale macroeconomic model using a simulated method of moments approach. They estimate the model parameters such that the impact effects on the model-implied nominal and real yield curves following a conventional monetary policy shock are consistent with their high-frequency evidence. They measure the degree of monetary non-neutrality as the ratio of the cumulative response of output to the cumulative response of inflation. In short, a model of monetary neutrality implies this measure is zero. In their baseline model, they estimate this ratio to be 3.8, which implies output moves almost four times as much as inflation after a monetary shock.

Using their measure, our baseline forward guidance shock produces a ratio of 2.1, which implies slightly less monetary non-neutrality. However, Figure 4 illustrates that the degree of non-neutrality depends on the current state of the economy. Under the longer zero lower bound scenario, the more modest increase in output implies a ratio of only 1.7. Away from the zero lower bound, a conventional monetary policy shock implies a non-neutrality ratio of 2.5. This differential response of shocks reinforces our focus on the zero lower bound period in our empirical work. In identifying forward guidance shocks in the data, we focus solely on the zero lower bound period to avoid confounding the responses with the pre-zero lower bound period.

6 Additional Empirical Evidence

We now show that our baseline empirical results are robust to alternative measures of expected future policy rates. Using several different measures of policy expectations, we show that an exogenous decline in the expected path of policy produces a sustained economic expansion.

6.1 Longer-Horizon Futures Contracts

In our baseline empirical results from Section 2, we measured policy expectations using one-year ahead federal funds futures rates. During the zero lower bound period, however, the FOMC made several announcements concerning expected policy rates further than one year in the future. For example, the August 2011 FOMC announcement indicated "exceptionally low levels of the federal funds rate at least through mid-2013." In January 2012, the FOMC used similar language to communicate that rates would be exceptionally low through "late 2014." Finally, the September 2012 statement indicated "low levels for the federal funds rate ... through mid-2015." Because these longer-horizon statements pushed one-year ahead interest rates towards their effective lower bound, the one-year ahead federal funds futures rate could be insufficient to capture the full effects of FOMC's forward guidance. Therefore, we now explore the robustness of our empirical results using longer-dated futures contracts.

In this section, we use 24-month U.S. Dollar denominated overnight-indexed swaps (USD-OIS) and the 21-month Eurodollar futures (USD-LIBOR) to measure investors' expectations about the path of short-term interest rates. Our choice of contract horizons follows from Swanson and Williams (2014), Gertler and Karadi (2015), and Hanson and Stein (2015), who argue the FOMC's forward guidance focused on managing interest-rate expectations over the next two years. USD OIS contracts settle on the average effective federal funds rate over the life of the contract. Thus, a single OIS contract contains information about the path of short rates over the next two years, whereas a federal funds futures contract only contains information about rates in a particular month. Eurodollar deposit futures instead settle based on the three-month London interbank offered rate at expiration.[14] Similar to the federal funds futures data, we use daily data on these futures prices to extract the change in investors' interest-rate expectations around FOMC meetings.[15]

Figure 5 shows that the macroeconomic effects of a forward guidance shock identified with longer-horizon OIS or Eurodollar futures rates.[16] Overall, the empirical effects are very similar to our baseline results from Figure 3. Under either longer-horizon futures rates, consumption rises following the shock, peaks within the first year, and remains significantly positive throughout the three-year horizon. Prices peak more quickly under the longer-horizon futures rates than our previous results in Figure 3, but the sustained increase in prices is almost identical to the baseline estimates. Importantly, the baseline model's point estimates are not statistically different than either of the models using longer-term rates.

[14] Since Eurodollar futures settle based on a three month deposit rate upon expiration, we use the 7-quarter, or 21-month, Eurodollar future which should summarize investor's expectations of interest rates 21 + 3 = 24 months in the future.

[15] Due to the structure of these contracts, there is no analogous adjustment for translating these expected rates into an FOMC meeting frequency as we did for the federal funds futures contracts.

[16] We conduct all of our robustness exercises in Section 6 with our smaller, three-variable VAR since these are the responses of interest in the theoretical model. We find similar results when using our larger VAR from Section 2.5.

These results suggest that the one-year ahead federal funds future rates largely captures the effect of the FOMC's use of forward guidance over this sample.

6.2 Path Factors

In our previous empirical results, we use the interest rate implied by a single futures contract to measure investors' expectations about the future path of monetary policy. However, this single interest rate may be an incomplete description of the expected course of monetary policy at the zero lower bound. We now show that our empirical results are robust to using information from multiple futures contracts of various horizons.

Following the work of Gurkaynak, Sack and Swanson (2005), we use principle component analysis to compress the information from a vector of interest rate futures around FOMC meetings. To capture the information content of the entire futures curve at the zero lower bound, we use federal funds futures contracts settling 5-12 months in the future. Using the same method outlined in Gurkaynak (2005), we construct the changes in interest rates expected to prevail after the 3rd-7th upcoming FOMC meetings. We then normalize these five vectors of expected rate changes and extract their first principle component, which explains about 94% of the variation in these contracts around FOMC announcements. We denote this component our federal funds futures path factor, as it closely aligns with the spirit of the Gurkaynak, Sack and Swanson (2005) path factor.[17]

Embedding our federal funds futures path factor into our VAR model produces similar results to the baseline model. The first column of Figure 6 shows that a one standard deviation forward guidance shock identified using our estimated path factor leads to a significant hump-shaped increase in consumption. Prices rise for the first year following the shock and remained elevated throughout the impulse response horizon. The robustness of our results suggests that the single futures contract in our baseline results provides a good description of the expected path of monetary policy at the zero lower bound.

[17] Using measures of both current and expected future stance of monetary policy, Gurkaynak, Sack and Swanson (2005) extract the first two principal components of the interest rate changes around FOMC announcements. After a rotation, they denote the first component the target factor, which reflects the current stance of policy. They denote the second component as a path factor, which captures the expected path of policy. Since our analysis focuses on the zero lower bound period, when current policy rates are constrained, we only include measures of expected future policy in our federal funds futures path factor. Therefore, our estimated factor closely aligns with their path factor. In Section 7, we replicate the Gurkaynak, Sack and Swanson (2005) path factor to compare our results with the previous literature.

As an additional robustness check, we also construct two alternative path factors using either overnight-index swap rates or Eurodollar futures. Following a similar procedure as our federal funds futures path factor, we use either OIS contracts settling from 12 - 36 months in the future or Eurodollar contracts with 6- to 27-month ahead settlements. Both the OIS and Eurodollar path factors explain about 95% of the variation in the interest rate changes around FOMC meetings.[18] The second and third columns of Figure 6 show the effects of an identified forward guidance shock using either the OIS or Eurodollar path factors. All three of our estimated path factors suggests very similar macroeconomic effects.

While previous work by Gurkaynak, Sack and Swanson (2005), Campbell et al. (2012), and Nakamura and Steinsson (2015) find this principal component analysis helpful in identifying monetary policy shocks, we find no obvious way to calibrate a theoretical model to match a given movement in an empirical path factor. Therefore, we instead directly include interest-rate futures in our baseline monetary VAR. This approach allows us to determinate the typical-sized movement in futures rates in the data that we can match using the model-implied futures curve. However, the results in this section illustrate that the responses of consumption and prices to a forward guidance shock are largely unchanged when we use this alternative approach.

7 Policy Announcements & Macroeconomic News

Our empirical evidence suggests that FOMC announcements that lower expected future policy rates have expansionary effects on a variety of economic indicators. However, these results contrast with an early and influential paper by Campbell et al. (2012). These authors find that lower expected policy rates are largely contractionary, implying higher expected unemployment rates. They argue their findings support the macroeconomic news hypothesis of forward guidance shocks:

> "the public believes that the FOMC has information about macroeconomic fundamentals that the public does not, and that monetary policy surprises arise from this informational advantage. In that case the forecast revision following a positive policy rate innovation encompasses the revelation of unexpectedly strong macroeconomic fundamentals as well as the contractionary effects of the innovation itself." -Campbell et al. (2012)

[18]Appendix A.3 contains additional details on the construction of the various path factors.

Why do we reach different conclusions? In this section, we provide evidence which suggests the differing results stem from the econometric specification of their regression model. Campbell et al. (2012) regress Blue Chip forecast revisions of the unemployment rate or inflation on the Gurkaynak, Sack and Swanson (2005) principal component factors. Over the December 2008 - December 2014 sample period of our paper, we reproduce their qualitative results by estimating the following regression model:

$$\Delta E_t^{BC}(y^T) = \alpha + \beta \Delta MP_{t-1} + \varepsilon_t, \tag{17}$$

where y^T is the T-quarter ahead value for either the unemployment rate or the GDP deflator inflation rate (where $T = 1, 2, 3, 4$), E_t^{BC} is the time t expectation from Blue Chip Economic Indicators, and ΔMP_{t-1} is the change in the Gurkaynak, Sack and Swanson (2005) path factor.[19] We denote this model the "difference specification" since both the left- and right-hand side variables appear in first differences.

We estimate Equation (17) separately for each macroeconomic indicator and forecast horizon using ordinary least squares. The second column of Table 2 displays the estimated policy coefficients. We confirm Campbell et al. (2012)'s findings: Unexpected declines in the future path of policy are associated with higher expected unemployment. Moreover, we find that forward guidance shocks fail to have any significant effects on expected inflation in the difference specification.

However, we reach very different conclusions on the effects of forward guidance shocks if we instead estimate the model in levels. For each indicator and horizon, we now estimate a "levels specification" using the following regression model:

$$E_t^{BC}(y^T) = \alpha + \rho(L) E_t^{BC}(y^T) + \beta \sum_{\tau=0}^{t} \Delta MP_{\tau-1} + \epsilon_t, \tag{18}$$

where $p(L)$ is a fourth-order lag polynomial and $\sum_{\tau=0}^{t} \Delta MP_{\tau-1}$ is the cumulative sum of the Gurkaynak, Sack and Swanson (2005) path factor. To prevent a spurious correlation, we include lags of the dependent variable in the levels specification, as suggested by Granger and

[19] The regression models in Campbell et al. (2012) also include the Gurkaynak, Sack and Swanson (2005) target factor. However, since the two factors are orthogonal by construction, leaving out the target factor does not affect our coefficient estimates on the path factor.

Newbold (1974).[20] The third column of Table 2 shows the estimated policy coefficients for the model estimated in levels. For each horizon, the policy coefficient in the unemployment regression now has the "expected" sign: A forward guidance shock that lowers the future path of policy is expansionary and implies statistically significant declines in expected unemployment. In addition, a lower path of policy implies a statistically significant increase in expected inflation for most forecast horizons.

We also estimate the difference and level specifications with our baseline policy measure, the expected federal funds rate after the 7th-upcoming FOMC meeting. The last two columns of Table 2 show that when we use our preferred policy indicator, the results from the difference and level specifications are even more at odds. The difference specification suggests that the macroeconomics news effect dominates and lower expected policy rates lead to higher expected unemployment rates. Meanwhile, the model estimated in levels suggests that the stimulatory effect of communicating a lower than expected rate path leads to lower expected unemployment rates.

Should we estimate the model in levels or first differences? While first differencing the model eliminates concerns of a spurious regression, the regression model may still be misspecified if the series are highly persistent but stationary. Consequently, whether the first differences model is "over-differenced" depends on whether one views the time-series as I(1) or persistent I(0) processes. The low-power of unit-root tests on finite samples suggests that distinguishing between these two hypotheses is likely to be difficult.[21] For this reason, we prefer the VAR representation of the time series over univariate regression models. Sims, Stock and Watson (1990) illustrate, from a frequentist perspective, that this approach doesn't require the researcher to take an a-priori stand on the unit root behavior so long as the variables enter the VAR in levels. Also, the univariate regression approach focuses on the significance of the point estimate, while we are more interested in the dynamic responses to the forward guidance announcements. From a Bayesian perspective, the posterior

[20] We find that transforming the Campbell et al. (2012) model into levels without including lagged dependent variables delivers every hallmark of a spurious relationship: the R^2 exceeds the Durbin-Watson statistic, the p-value of the path factor coefficient estimate is zero, and the null hypothesis of a unit-root on the regression residuals cannot be rejected according to the Phillips and Perron (1988) unit-root test. However, including lags of the dependent variables results in well-behaved error terms.

[21] Our differential conclusions for the difference versus level specifications echoes a previous literature which asks whether money granger causes output. This literature found that the answer to this question depends on whether the variables enter the VAR in differences or levels. See, for example, Sims (1972), Bernanke (1986), Eichenbaum and Singleton (1986), Christiano and Ljungqvist (1988), and Stock and Watson (1989).

distributions of the impulse response functions from our VAR can be interpreted the same regardless of the order of integration of the variables (Sims and Zha, 1999).

To trace out these dynamic effects, we estimate a three-variable VAR with the Blue Chip 4-quarter ahead forecasts for the unemployment rate and GDP deflator inflation rate and the cumulative sum of the change in the federal funds rate expected after the 7th-upcoming FOMC meeting. We order the policy variable last in our recursive identification scheme, which is consistent with the timing of the survey releases: Blue Chip forecasts are released in the first part of the month while FOMC meetings typically take place later in the month. Figure 7 shows the estimated impulse response functions for the survey expectations to an identified forward guidance shock. The Blue Chip forecasts for the unemployment rate fall significantly the month after the FOMC announcement, but more importantly, continue to fall throughout the following year. Similarly, Blue Chip forecasts for the GDP deflator increase after the FOMC announcement and the expected price level continues to rise thereafter.

In a VAR framework, which nests both the levels and first difference specifications, we find that the expansionary effects of forward guidance about lower future policy rates overwhelms any contractionary news effect. These results, together with the regression evidence from Table 2, lead us to conclude that the dominance of the macroeconomic news effect in FOMC forward guidance may not a robust feature of the data during the zero lower bound period.

8 Conclusions and Caveats

We draw several conclusions from our results. First, an unexpected decline in the path of policy rates at the zero lower bound produces a sustained economic expansion. Unlike the previous literature, we find a much more limited role for the "macroeconomic news" component in FOMC announcements during the zero lower bound period. Second, we show that these estimated effects of forward guidance in the data are fully consistent with a standard macroeconomic model with nominal rigidities. Thus, we find no disconnect between the empirical effects of forward guidance shocks and the predictions from a textbook model of monetary policy. Our conclusion rests on appropriately calibrating the size of the forward guidance shock to simulate in the model. Finally, we argue that same models economists use to study the effects of conventional monetary policy shocks remain useful in studying forward guidance shocks at the zero lower bound.

However, our results should be interpreted with one caveat. Our econometric approach to identifying the effects of forward guidance may be contaminated by the simultaneous large-scale asset purchase programs, also known as quantitative easing (QE). Announcements regarding the future path of policy rates were often accompanied by changes to the size, scope, and duration of asset purchases. If the FOMC used QE as a signaling device to convey its commitment to its forward guidance, then it is unnecessary to try and disentangle the effects of QE from forward guidance. However, if QE also operates through a portfolio-rebalancing channel, then our empirical estimates may overstate the effectiveness of forward guidance.

However, the existing evidence on the effects of QE suggest this caveat is not much of a concern. First, Krishnamurthy and Vissing-Jorgensen (2011), Woodford (2012), and Bauer and Rudebusch (2014) all find evidence in favor of the signaling channel of QE. Therefore, there may be little motivation to disentangle the effects of QE from forward guidance. Second, if QE does operate through a portfolio-rebalancing channel, it likely affects longer-term assets, whereas we measure forward guidance surprises using short-term assets. In a recent paper, Swanson (2015) confirms this conjecture in which he decomposes expected future rates into a forward guidance and a QE factor. The forward guidance factor has a large effect on short-rates while the QE factor has essentially no effect on short rates. This finding supports our assumption that high-frequency monetary policy surprises in near-term futures rates can be attributed to forward guidance.

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Table 1: Calibration of Baseline Model Parameters

Parameter	Description	Calibrated Value
β	Household Discount Factor	0.9983
b	Household Habit Persistence	0.85
ϕ_P	Adjustment Cost to Changing Prices	2500
Π	Steady State Inflation Rate	1.0
η	Inverse Frisch Labor Supply Elasticity	0.5
χ	Utility Function Constant	6.67
θ	Elasticity of Substitution Intermediate Goods	6.0
ϕ_r	Central Bank Smoothing Coefficient	0.5
ϕ_π	Central Bank Response to Inflation	0.7
ϕ_x	Central Bank Response to Output Gap	0.1
ρ_a	Preference Shock Persistence	0.95
σ^a	Preference Shock Volatility	0.005
ρ_ν	Forward Guidance Shock Persistence	0.90
σ^ν	Forward Guidance Shock Volatility	0.0001

Table 2: Univariate Regression Estimates of Private Forecasts to Forward Guidance Shocks[a]

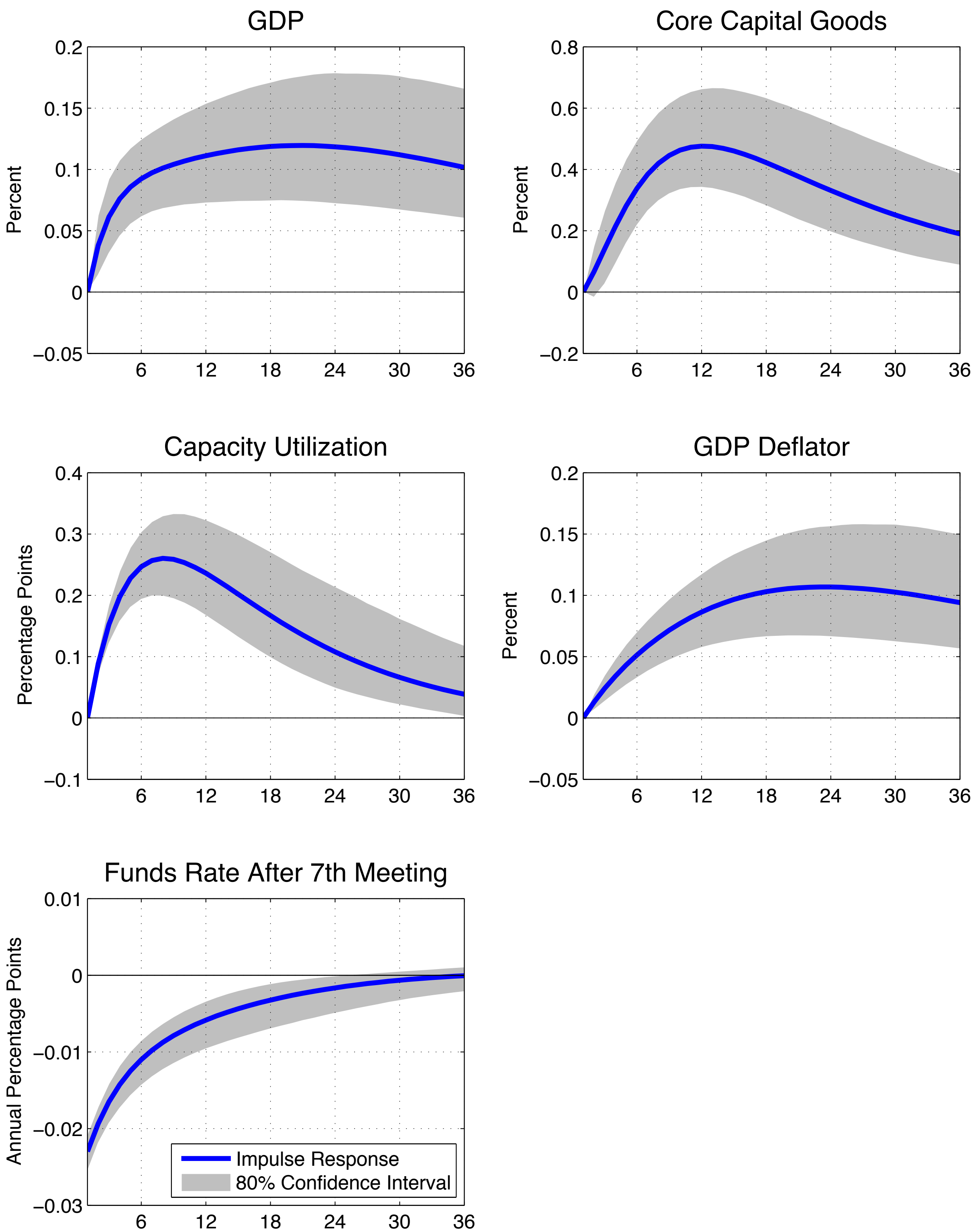
	Gurkaynak et al. 2005 Path Factor		EFFR After the 7th Next Meeting	
Forecast	Differences	Levels	Differences	Levels
Unemployment Rate				
Next Quarter	-0.31*	0.13*	-2.48*	0.86***
	(0.18)	(0.07)	(1.44)	(0.22)
2 quarters ahead	-0.24	0.11	-2.22*	0.67***
	(0.15)	(0.07)	(1.34)	(0.23)
3 quarters ahead	-0.21**	0.11*	-1.67*	0.56***
	(0.10)	(0.06)	(0.95)	(0.21)
4 quarters ahead	-0.14*	0.14**	-1.02	0.58***
	(0.08)	(0.06)	(0.92)	(0.22)
GDP Deflator				
Next Quarter	-0.09	-0.21***	-0.26	-0.76***
	(0.12)	(0.07)	(0.78)	(0.17)
2 quarters ahead	-0.01	-0.11**	-0.31	-0.47***
	(0.06)	(0.05)	(0.34)	(0.15)
3 quarters ahead	-0.06	-0.12***	-0.44	-0.45***
	(0.08)	(0.05)	(0.46)	(0.10)
4 quarters ahead	0.04	-0.09*	-0.37	-0.42***
	(0.05)	(0.05)	(0.34)	(0.12)

[a] Each row in each panel reports coefficients from a regression of monthly Blue Chip forecasts of either the unemployment rate or the GDP deflator inflation rate on a measure of forward guidance shocks. Newey and West (1987) HAC standard errors are in parentheses for the differences regressions and White (1980) HC standard errors are in parenthesis for the levels regressions. Asterisks indicate statistical significance at the *10 percent, **5 percent, and ***1 percent level. All regression models are estimated from December of 2008 to December of 2014.

[b] For the difference specification, the regression model is: $\Delta E_t^{BC}(y^T) = \alpha + \beta \Delta MP_{t-1} + \varepsilon_t$ where y^T is the T-quarter ahead value for y equal to either the unemployment rate or the GDP deflator inflation rate (where $T = 1, 2, 3, 4$), E_t^{BC} is the time t expectation from Blue Chip Economic Indicators, and ΔMP_{t-1} is the expected change in the federal funds rate after the 7th upcoming FOMC meeting or the Gurkaynak, Sack and Swanson (2005) path factor.

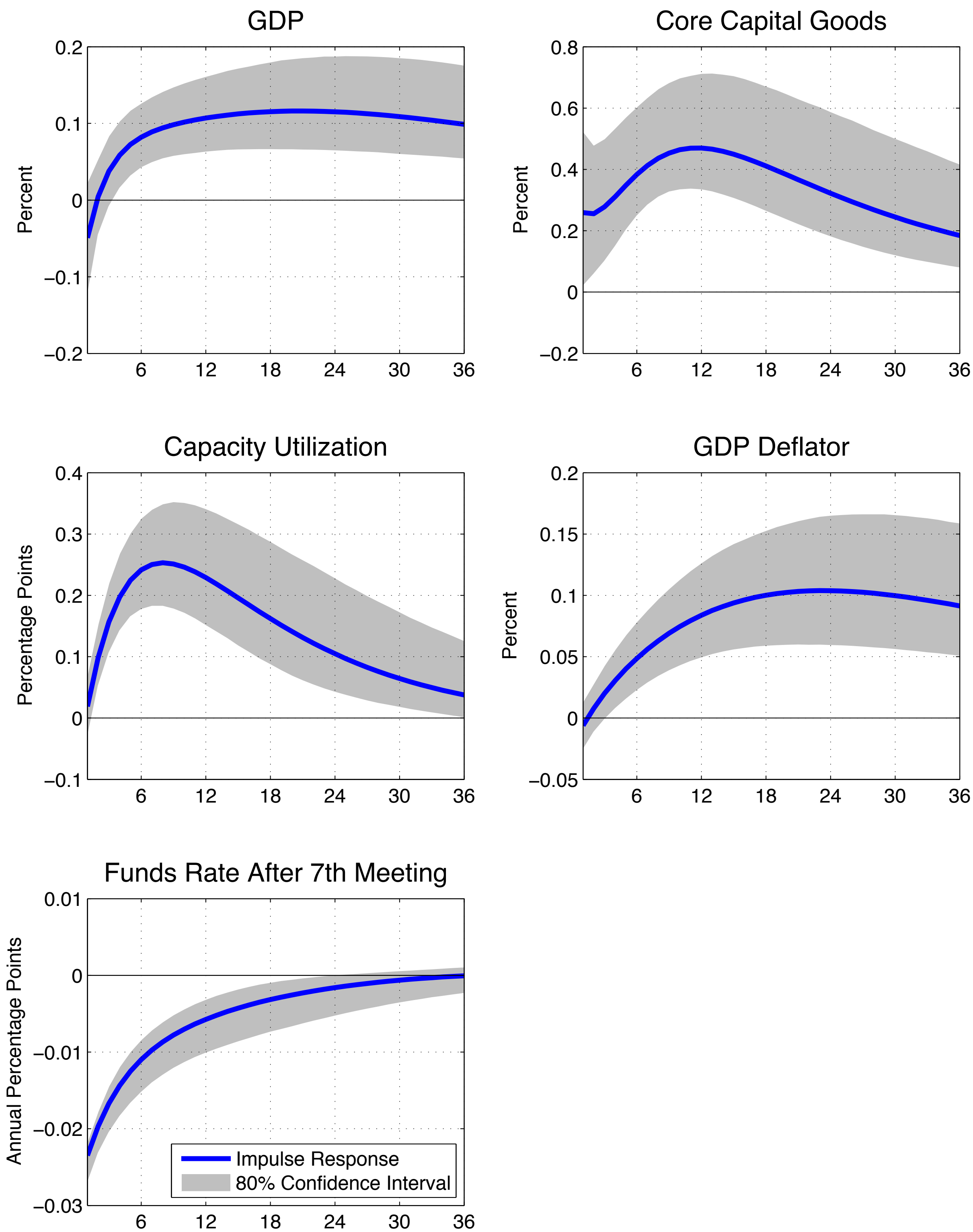
[c] For the levels specification, the regression model is: $E_t^{BC}(y^T) = \alpha + \rho(L) E_t^{BC}(y^T) + \beta \sum_{\tau=0}^{t} \Delta MP_{\tau-1} + \varepsilon_t$ where y^T is the T-quarter ahead value for y equal to either the unemployment rate or the GDP deflator inflation rate (where $T = 1, 2, 3, 4$), E_t^{BC} is the time t expectation from Blue Chip Economic Indicators, $p(L)$ is a fourth order lag-polynomial, and $\sum_{\tau=0}^{t} \Delta MP_{\tau-1}$ is the cumulative sum of the expected change in the federal funds rate after the 7th upcoming FOMC meeting or the Gurkaynak, Sack and Swanson (2005) path factor.

Figure 1: Empirical Impulse Responses to Forward Guidance Shock



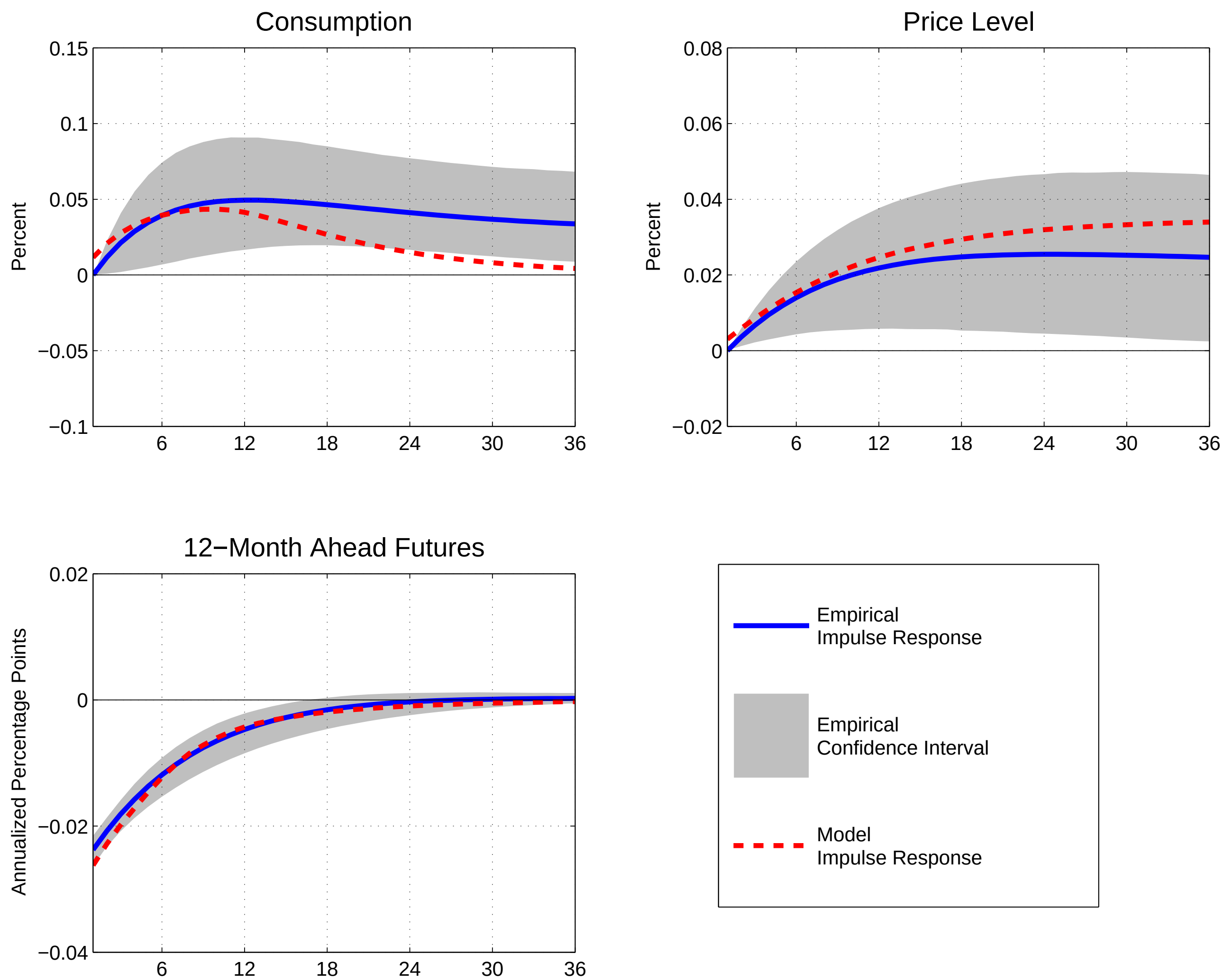
Note: The solid blue line denotes the point estimate of a one standard deviation shock and the shaded region denotes the 80% interval of the posterior distribution.

Figure 2: Empirical Impulse Responses With Policy Ordered First



Note: The solid blue line denotes the point estimate of a one standard deviation shock and the shaded region denotes the 80% interval of the posterior distribution.

Figure 3: Empirical and Model-Implied Responses to Forward Guidance Shock



Note: The solid blue line denotes the point estimate of a one standard deviation shock and the shaded region denotes the 80% interval of the posterior distribution from the VAR. The dashed red line denotes the impulse response from the model.

Figure 4: Model Responses to an Alternative Scenario & Conventional Policy Shock

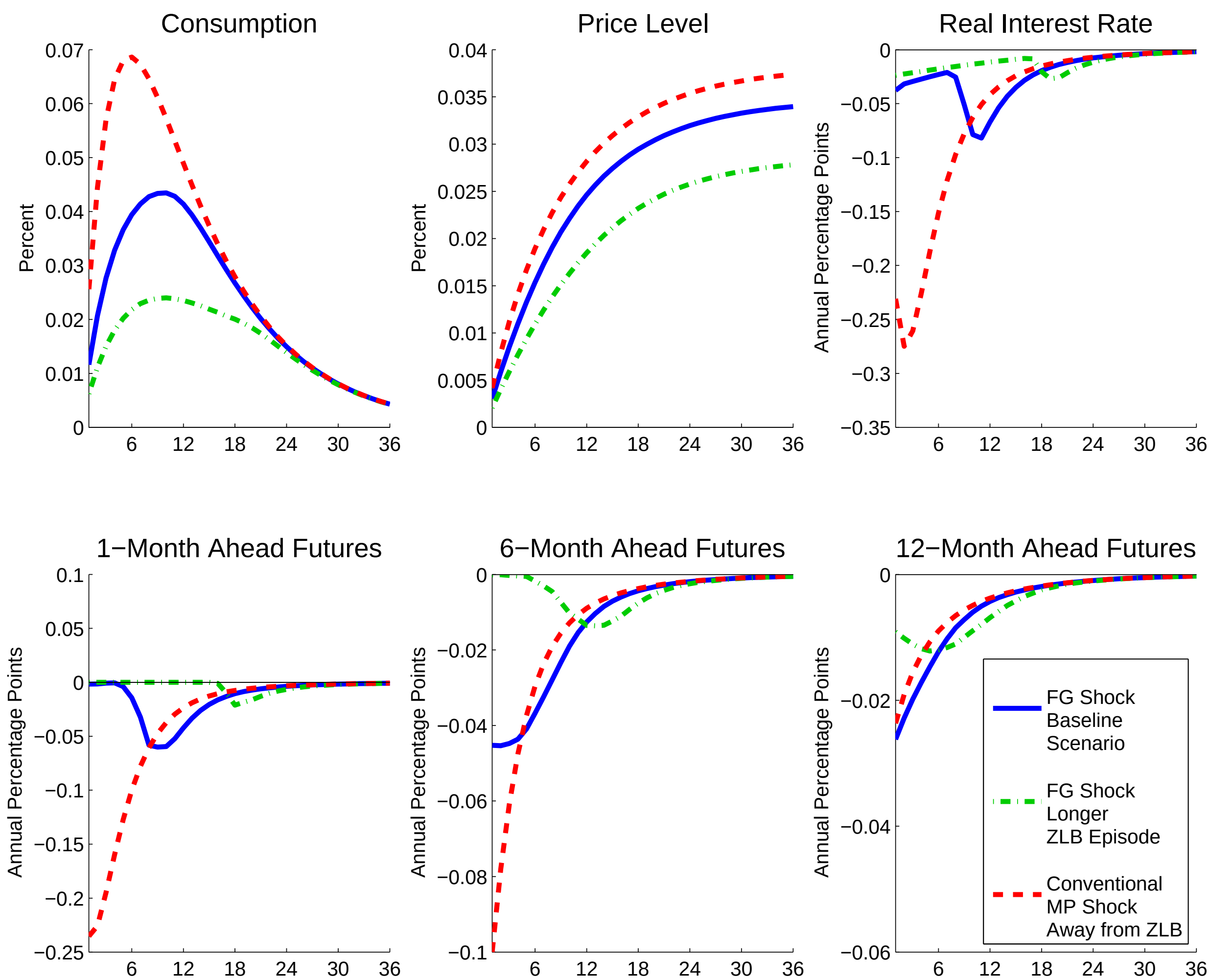
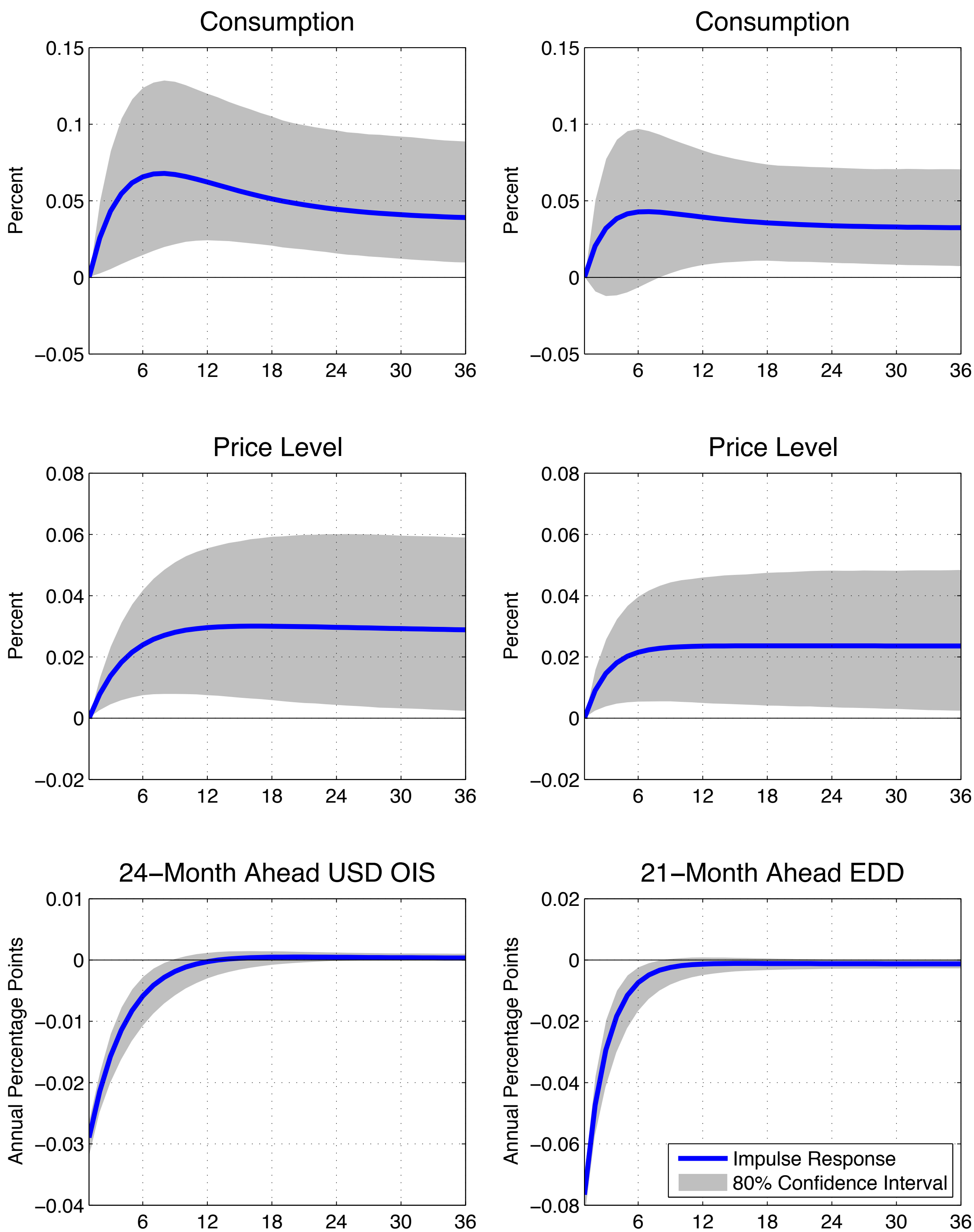
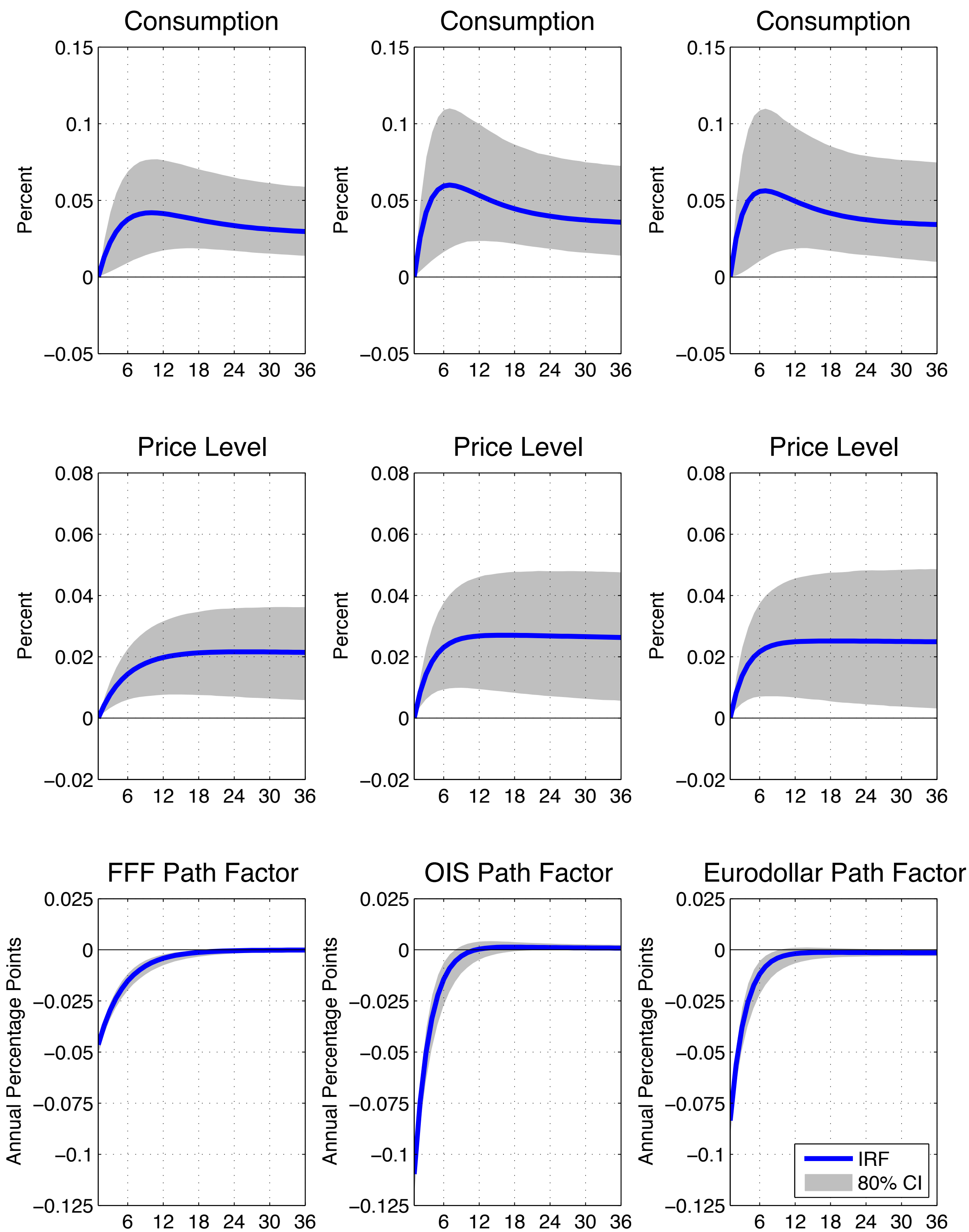


Figure 5: Empirical Impulse Responses Identified with Longer-Horizon Contracts



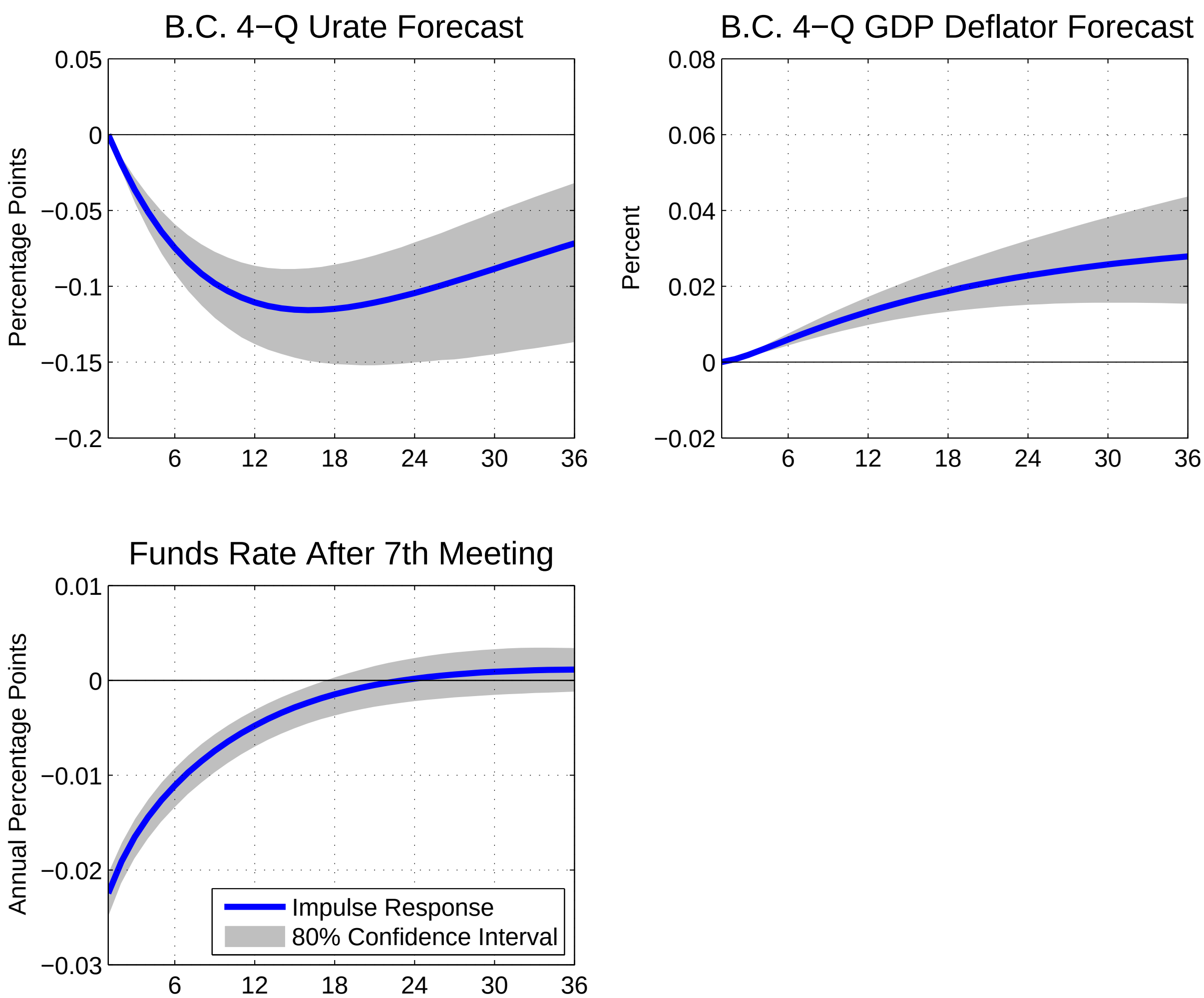
Note: The shaded areas denote the 80% interval of the posterior distribution and the solid blue line denotes the point estimate to a one standard deviation shock. Each column shows IRFs from a different VAR model.

Figure 6: Empirical Impulse Responses Identified with Various Path Factors



Note: The shaded areas denote the 80% interval of the posterior distribution and the solid blue line denotes the point estimate to a one standard deviation shock. Each column shows IRFs from a different VAR model.

Figure 7: Empirical Impulse Responses of Blue Chip Forecasts to Forward Guidance Shock



Note: The shaded areas denote the 80% interval of the posterior distribution and the solid blue line denotes the point estimate to a one standard deviation shock. The GDP deflator response is cumulatively summed and divided by twelve to convert the forecast for the annualized inflation rate to a monthly price level.