THE DYNAMIC EFFECTS OF FORWARD GUIDANCE SHOCKS

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Abstract—We examine the macroeconomic effects of forward guidance shocks at the zero lower bound. Empirically, we identify forward guidance shocks using unexpected changes in futures contracts around monetary policy announcements. We then embed these policy shocks in a vector autoregression to trace out their macroeconomic implications. Forward guidance shocks that lower expected future policy rates lead to moderate increases in economic activity and inflation. After examining forward guidance shocks in the data, we show that a standard model of nominal price rigidity can reproduce our empirical findings. To estimate our theoretical model, we generate a model-implied futures curve that closely links our model with the data. Our results suggest no disconnect between the empirical effects of forward guidance shocks around policy announcements and the predictions from a standard theoretical model.

I. 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 announced its intention to keep future policy rates exceptionally low “for some time.” Such communication about the future path of policy, known as forward guidance, became a fixture of U.S. monetary policy.

However, recent theoretical and empirical work is 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 effectively stimulate economic activity and increase inflation. However, Del Negro, Giannoni, and Patterson (2015), McKay et al. (2016), and others argue that these theoretical models overstate the expansionary effects of forward guidance. In contrast, empirical work by Campbell et al. (2012) and Nakamura and Steinsson (2018) argues that communication about lower expected rates may signal bad news about the state of the economy. Through this macroeconomic news effect, these papers suggest that lowering expected policy rates may cause a contraction in expected economic activity.

We examine this apparent disconnect between the empirical evidence and theoretical predictions of macroeconomic models. First, we study the empirical effects of forward guidance shocks at the zero lower bound (ZLB). We identify forward guidance shocks in the data using high-frequency changes in futures contracts around FOMC announcements. To trace out the dynamic effects of these policy changes on macroeconomic aggregates, we embed our identified forward guidance shocks in a standard vector autoregression (VAR). We find forward guidance shocks that lower expected future policy rates result in a persistent economic expansion. Following a 1 standard deviation forward guidance shock, which lowers the eight-quarter-ahead futures rate by about 6 basis points, output increases by about 15 basis points and prices are about 5 basis points higher at their peak responses. Similar to conventional policy shocks, we find that forward guidance shocks explain only a small fraction of overall business cycle fluctuations. Our findings are robust to alternative ordering schemes in the VAR, different measures of economic activity and prices, and alternative measures of expected future interest rates. We also document similar macroeconomic effects when we estimate our empirical model prior to the onset of the zero lower bound.

After identifying forward guidance shocks in the data, we examine their effects in a standard model of nominal price rigidity. Using a nonlinear solution method, we estimate a standard 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. When desired rates are less than zero, shocks that reduce the desired rate act like an exogenous extension of the zero lower bound episode. This exogenous extension of the zero lower bound lowers expected future policy rates, which we link with our identified forward guidance shock in the data. To appropriately calibrate our forward guidance shock process, we generate a model-implied counterpart to the futures contracts used in our empirical results. Using impulse response matching, we choose the parameters of 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.

Our theoretical model can reproduce the macroeconomic effects of forward guidance shocks we find in the data. In the model, an exogenous decline in expected future policy rates generates movements in economic activity and prices similar in shape and magnitude to our empirical responses. The key features of our model are a reasonable degree of nominal price rigidity, habits in household consumption, investment adjustment costs, and variable capital utilization. Our results suggest that dynamic equilibrium models along the lines of Christiano, Eichenbaum, and Evans (2005) remain useful in examining the effects of monetary policy shocks both at and away from the zero lower bound.

We find no disconnect between the empirical effects of forward guidance shocks around FOMC announcements and the predictions from a standard theoretical model. Our findings contrast with Del Negro et al. (2015), who argue that standard
models with nominal rigidities overestimate the expansionary effects of forward guidance. Our alternative conclusion emerges from the size of the forward guidance shock we estimate. A typical expansionary forward guidance shock around a monetary policy announcement lowers eight-quarter-ahead futures rates by about 6 basis points. This shock extends the zero lower-bound duration by only one month in our model. Del Negro et al. (2015), however, simulate a much longer one-year exogenous extension of the zero lower-bound period. In our high-frequency identification of policy shocks around FOMC announcements, we do not observe forward guidance shocks of that size. Thus, our results suggest that standard models work well in analyzing the size of forward guidance shocks we observe in the data around FOMC announcements. However, our findings cannot speak to the plausibility of the model’s predictions for substantially larger shocks.

II. Forward Guidance Shocks in the Data

We use a two-step procedure to examine the macroeconomic effects of forward guidance shocks in the data. First, we identify forward guidance shocks associated with regularly scheduled FOMC meetings using high-frequency changes in interest rate futures. Then we embed these policy shocks into a Bayesian VAR to trace out their dynamic effects on macroeconomic aggregates. In our baseline results, we focus on the effects of forward guidance shocks during the zero-lower bound period (December 2008–December 2015). After presenting our baseline empirical results, we examine the effects of forward guidance shocks prior to the onset of the zero lower bound in section IIF.

A. High-Frequency Futures Data

We use a combination of federal funds and eurodollar futures contracts to measure unexpected changes in forward guidance. For each regularly scheduled FOMC meeting from 1994 to 2015, we compute the daily change in the current month or three-month-ahead federal funds futures rates and the two- to eight-quarter-ahead eurodollar futures rates. Since any expected changes in policy should be reflected in futures prices ahead of the meeting, the change in futures prices on the day of the meeting provides a measure of the unexpected portion of the policy announcement. Following Gurkaynak, Sack, and Swanson (2005), we extract a target and path factor that together summarize almost all of the variation in these futures rates around policy announcements. In this paper, we focus on the path factor, which captures unexpected changes to the future path of policy rates that are unrelated to changes in the current policy rate. We scale the path factor so that it moves the eight-quarter-ahead eurodollar futures rate one-for-one around FOMC meetings.

The path factor displays significant variation both prior to and during the zero lower bound period, and these fluctuations line up with key changes in FOMC forward guidance. Figure 1 plots our forward guidance shock series from 1994 to 2015 and annotates the dates associated with the some of the largest fluctuations. During the zero lower-bound period, we observe large declines in the expected path of rates when the FOMC announced its intention to keep future policy rates exceptionally low for “some time” in December 2008, when “some time” was replaced by “an extended period” in March 2009, and after the change to date-based guidance in August 2011. Figure 1 also illustrates that the magnitude of the movements in the path factor is similar before and during the zero lower-bound period, which suggests that the FOMC used forward guidance in both periods. Moreover, several of the largest path factor observations before December 2008 coincide with the observations in table 4 of Gurkaynak et al. (2005), who carefully document the use of forward guidance by the FOMC since the early 1990s. Thus, we leverage this pre-zero lower bound sample in our empirical analysis in two ways. First, we use this earlier sample to elicit priors for our VAR parameters at the zero lower bound. Second, we estimate the macroeconomic effects of forward guidance before the onset of the zero lower bound, which, unlike the zero lower-bound sample, was not accompanied by simultaneous large-scale asset purchases.

B. Baseline Empirical Model

To trace out the macroeconomic effects of a forward guidance shock, we embed the cumulative sum of the path factor in a structural VAR. We estimate our baseline empirical model at a monthly frequency using several indicators of real economic activity, a measure of aggregate prices, and a government bond yield. Specifically, we include a monthly measure of real GDP, a proxy for real equipment investment, capacity utilization, the GDP deflator, the path factor, and the two-year Treasury yield. The choice to include the two-year Treasury yield follows Gertler and Karadi (2015) and others who argue that the FOMC’s forward guidance operates with roughly a two-year horizon. We use the Macroeconomic Advisers monthly GDP series and its corresponding price deflator to measure aggregate real activity and prices. We proxy equipment investment at a monthly frequency with deflated core capital goods shipments, a series the Bureau of Economic Analysis uses to calculate the official quarterly investment data. Appendix B contains details on the data

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Footnotes:

1. The payoffs on these contracts depend on the effective federal funds rate for federal funds futures and the three-month LIBOR on dollar-denominated deposits for eurodollar futures.

2. In the appendix, we provide additional details on the construction of our target and path factors and provide a comparison with the Gurkaynak et al. (2005) path factor for the overlapping sample.

3. This approach follows Romer and Romer (2004) and Barakchian and Crowe (2013), who point out that including the cumulative sum of unexpected interest rate changes in a VAR is most consistent with the many VAR models that include the federal funds rate in levels. Following these papers, we assign a value of 0 to months in which there is no FOMC meeting before cumulatively summing the path factor series.
construction. GDP, the GDP deflator, and investment enter the VAR in natural log form.\footnote{We could instead follow Romer and Romer (2004) and estimate the coefficients of interest from the vector moving average (VMA) more directly by regressing macroeconomic aggregates on lags of the path factor. However, this approach implies that we lose a number of initial data points. Since our sample is already limited, we use a VAR approach which is asymptotically equivalent assuming that the VMA has a VAR representation.}

Following much of the previous VAR literature studying the effects of conventional monetary policy shocks, we order our forward guidance shock measure after real activity and the price level but before the two-year Treasury yield using a recursive identification scheme. This ordering assumes that macroeconomic conditions adjust slowly to changes in expected policy rates but financial markets may respond immediately. At a monthly frequency, the assumption that a
monetary policy announcement today does not affect real activity or prices within the period seems plausible. However, our results are not sensitive to this ordering. In section IIE, we show that our results are unchanged if we order the path factor first.

We estimate and conduct statistical inference on the VAR from a Bayesian perspective. Our primary interest is to examine the effects of forward guidance shocks during the zero lower bound period. However, figure 1 illustrates that changes in FOMC forward guidance around policy announcements also occurred prior to the onset of the zero lower bound. Therefore, we use the data from the pre-zero lower-bound period as a presample to form our priors for the VAR parameters during the zero lower-bound period. We refer to this as our empirical Bayes prior. In section IIE, however, we show that we find similar results if we instead use a standard Minnesota prior or an uninformative prior that centers the VAR coefficients at the OLS estimates during the zero lower-bound period. We refer to this as our empirical Bayes prior. In section IIE, however, we show that we find similar results if we instead use a standard Minnesota prior or an uninformative prior that centers the VAR coefficients at the OLS estimates during the zero lower-bound period. Using standard information selection criteria, we include three lags in the VAR.

C. Empirical Impulse Responses

We now turn to our key empirical question: What are the macroeconomic effects of forward guidance shocks? Figure 2 plots the estimated impulse responses to an identified forward guidance shock along with 90% probability intervals. A 1 standard deviation forward guidance shock lowers the path factor by about 6 basis points. Since we normalized our path factor to move one-for-one with the eight-quarter eurodollar future, this decline in the path factor implies that two-year-ahead futures rates also decline by about 6 basis points.

A forward guidance shock induces a gradual expansion in economic activity accompanied by increases in investment and capacity utilization and some modest inflationary pressures. Per our ordering assumption, economic activity and prices remain unchanged at impact. In the following months, output rises in a hump-shaped pattern and remains elevated for the next four years. At its peak response, output increases by almost 15 basis points. Investment and capacity utilization also exhibit hump-shaped responses and remain elevated for several years. However, they rise by more than output and reach their peaks more quickly. Prices move up slowly over the horizon of the impulse response and level out after three or four years. Notably, the increase in economic activity and prices persists well beyond the time that expected future rates remain depressed. For instance, the two-year Treasury yield initially declines with expected future rates but starts to overshoot after just two years. However, output and prices remain elevated throughout the impulse response horizon. Thus, we find that forward guidance shocks share many of the same empirical features of conventional policy shocks as identified by Christiano et al. (2005) and others.

These estimated responses contrast with the work of Campbell et al. (2012) and Nakamura and Steinsson (2018), which finds that an unexpected decline in future policy rates lowers forecasts of real activity and inflation. In the appendix, we show that meaningful differences in our policy shock series relative to these two papers help to reconcile our differing conclusions. However, we prefer our path factor shock series for two reasons. First, prior to the zero lower bound, our estimated path factor shock moves closely with the path factor developed in Gurkaynak et al. (2005) and thus is consistent with the seminal work in this area. Second, changes in our path factor during the zero lower bound are consistent with the narrative of FOMC communications. Around some key policy announcements, the policy shocks series of Nakamura and Steinsson (2018) and Campbell et al. (2012) either show little variation or have signs that differ from market commentary at that time.

D. Forecast Error Variance Decompositions

Similar to conventional policy shocks, forward guidance shocks account for only a small fraction of business-cycle fluctuations. At the two-year horizon, we find that forward guidance shocks explain less than 10% of the total unexpected fluctuations in output. For comparison, we also estimate variance decompositions for conventional monetary policy shocks based on the VAR models of Romer and Romer (2004) and Christiano et al. (2005). These models find that conventional policy shocks explain 25% and 41% (respectively) of the unexpected fluctuations in output over the two-year horizon. While forward guidance shocks account for a smaller fraction of the variation in output at business-cycle frequencies compared to conventional monetary policy shocks, these differences do not appear to be statistically meaningful.

E. Robustness of Empirical Results

Our baseline results show that a decline in the expected path of the policy rate leads to a persistent expansion in economic activity, a gradual rise in prices, and lower Treasury yields. Before asking whether a standard theoretical model can match these estimated responses, we explore the robustness of our empirical findings. Figures 3 and 4 show the impulse responses to a forward guidance shock from several alternative specifications of the VAR model. To keep these figures easily readable, we omit the probability intervals in the main text. In the appendix, however, we present the probability intervals that accompany the point estimates for each alternative empirical specification. Based on the analysis in this section, we conclude that the qualitative and
quantitative features of our estimated responses to a forward guidance shock are robust across several dimensions of our VAR model.

The estimated responses to a forward guidance shock do not meaningfully change when we alter the ordering of the variables in the VAR or use different macroeconomic indicators. Figure 3 shows the impulse responses when we order our policy surprise series first in our recursive VAR. This ordering interprets the policy surprises as predetermined with respect to macroeconomic aggregates and allows economic activity and prices to respond immediately to the forward guidance shock. When the path factor is ordered first, the point estimates of the responses of all the variables are almost identical to our baseline VAR model. Figure 3 also shows the impulse responses if we measure economic activity and prices using industrial production and the consumer price index, the same variables Gertler and Karadi (2015) use in their study of monetary policy shocks. Using these alternative indicators, the peak responses of output and prices occur a bit earlier, and the response of output is a bit larger than our baseline model. However, when we account for the uncertainty surrounding the estimated responses, neither difference appears to be significant.

We find similar macroeconomic effects if we use a Minnesota prior rather than the empirical Bayes prior we employ in our baseline specification. This prior is standard in the VAR literature and balances the need to capture the rich dynamics in the data with the concern of overfitting the data by...
adding too many lags. Figure 3 illustrates that the responses of real variables, and prices are remarkably similar under a Minnesota prior with thirteen lags. The only notable difference is the response of the two-year Treasury yield, which exhibits a shallower decline and subsequently overshoots by more in later months. However, this quantitative difference with our baseline specification is not outside the range of 90% probability intervals for the two empirical models. Figure 3 also shows the estimated responses if we further restrict the VAR coefficients such that we treat the high-frequency policy surprises as exogenous. In particular, we adjust the Minnesota prior so that only own lags have non-zero coefficients in the path factor equation. The dynamics of the path factor following a forward guidance shock in this alternative specification are similar to those in figure 2; however, the path factor and two-year Treasury yield no longer overshoot. The responses of macroeconomic aggregates are also similar compared to the baseline impulse responses.\(^7\)

The estimated effects of forward guidance shocks do not depend on the use of informative priors. Figure 4 shows the impulse responses if we center the VAR parameters at the OLS estimates over the zero lower-bound period rather than using an empirical Bayes or Minnesota prior.\(^8\) Using only data beyond December 2008 to inform the VAR coefficients, we observe slightly larger responses of investment, capacity

\(^7\)In the appendix, we compare our approach to the proxy VAR approach in Gertler and Karadi (2015) and document similar effects on output following a forward guidance shock.

\(^8\)Given the short sample, we include only one lag for the VARs estimated with uninformative priors.
utilization, and prices, as well as a more persistent response of overall output to a forward guidance shock. Yet the hallmark features we previously documented remain, including the hump-shaped responses of real variables, the gradual rise in prices, and the persistence of these effects beyond the reduction in rates.

Up to this point, we have relied on the path factor to measure forward guidance surprises that are orthogonal to unexpected changes in the current federal funds rate. However, focusing only on the zero lower-bound period, we can also identify forward guidance shocks by examining fluctuations in the raw interest rate futures around policy announcements since the target range for the federal funds rate remained unchanged during this period. Figure 4 shows that we find similar macroeconomic effects to our path factor during the zero lower bound if we instead use four-, eight-, or twelve-quarter-ahead eurodollar futures to measure forward guidance shocks. This finding confirms that the path factor is able to synthesize the behavior of many futures rates around FOMC meetings. The stability of our results when we measure forward guidance shocks using the twelve-quarter-ahead eurodollar rate is particularly reassuring for two reasons. First, this horizon of rates lies beyond the range of futures we use to construct our path factor. Second, Swanson and Williams (2014) suggest that this rate was less constrained during the zero lower-bound period.

F. Quantitative Easing and Forward Guidance before 2009

The previous section provides evidence that forward guidance announcements that lower the expected path of rates at the zero lower bound lead to a modest but statistically
significant expansion of economic activity. During this period, however, the FOMC also conducted several rounds of large-scale asset purchases known as quantitative easing. Similar to forward guidance, the stated goal of these asset purchases was to ease financial conditions and promote economic activity. Announcements regarding these asset-purchase programs often appeared alongside changes in the FOMC’s forward guidance. Thus, one may be concerned that some of the macroeconomic effects we attribute to forward guidance actually emanate from large-scale asset purchases.

If asset purchases solely operate by signaling the path of future short-term interest rates, then the simultaneous quantitative easing announcements would not affect our results. For example, Krishnamurthy and Vissing-Jorgensen (2011), Woodford (2012), Bauer and Rudebusch (2014), and Bhattacharai, Eggertsson, and Gafarov (2015) argue that asset purchases acted as a commitment device to reinforce the FOMC’s guidance about future policy rates. However, if asset purchases also operate through a portfolio-rebalancing channel, then the simultaneous quantitative easing announcements could bias our estimates of the macroeconomic effects of forward guidance. To address this concern, we estimate three additional empirical specifications, which are shown in figure 5.

The first two robustness checks continue to focus on the use of forward guidance during the zero lower-bound period. First, we simply omit observations from the path factor series that coincided with the announcement of a new asset purchase. We use an uninformative prior for all three of these robustness checks.
purchase program. Figure 5 illustrates that dropping these observations results in impulse responses that are similar to our baseline estimates. Next, we include one-year-ahead blue chip forecasts for the short-term interest rates in place of the two-year Treasury yield. This specification helps determine if our forward guidance measure is capturing revisions to the expected path of interest rates versus changes in risk premiums. If our results are solely driven by a portfolio-rebalancing channel, then survey-based expectations of future short-term interest rates would likely be unchanged or even rise following the policy announcement because the portfolio-rebalancing channel would raise output and inflation independent of the FOMC’s forward guidance. However, figure 5 shows that expectations of short-term interest rates fall after a forward guidance announcement. Moreover, the decline is of similar magnitude to the movement in the path factor, which suggests that the path factor is primarily capturing revisions to the expected path of future interest rates and not portfolio-rebalancing effects from large-scale asset purchases.

Finally, we examine the macroeconomic effects of forward guidance announcements prior to the zero lower bound, a time when the FOMC made numerous announcements about the future path of policy rates but did not engage in large-scale asset purchases. Therefore, we can use this earlier sample period to trace out the macroeconomic effects of a forward guidance shock without worrying about the simultaneous use of quantitative easing. Figure 5 plots the impulse responses to a 1 standard deviation path factor shock over the 1994–2008 and 2009–2015 sample periods (estimated separately). We find that forward guidance shocks produce similar macroeconomic effects in both samples, which suggests that quantitative easing is not driving our empirical estimates during the zero lower-bound period.

Taken together, these results provide further evidence that forward guidance shocks that lower expected future policy rates lead to hump-shaped increases in real variables, a gradual rise in prices, and that these effects persist beyond the reduction in expected rates. Moreover, the presence of quantitative easing does not appear to be biasing these findings. We now take these VAR results as stylized evidence on the effects of forward guidance in the data and ask whether a standard model of nominal price rigidity can reproduce these dynamics. Overall, our findings suggest no disconnect between the empirical effects of forward guidance shocks around FOMC announcements and the predictions from a standard theoretical model.

III. 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 features with the models of Ireland (2011) and Christiano et al. (2005). Our model features optimizing households and firms and a central bank that systematically adjusts the nominal interest rate to offset shocks to the economy but is constrained by the zero lower bound. We allow for sticky prices using the staggered price-adjustment specification of Calvo (1983). The model considers shocks to household preferences and the central bank’s desired policy rate. To appropriately calibrate our forward guidance shock process, we generate a model-implied counterpart to the futures contracts from our empirical results. Following Rotemberg and Woodford (1997) and Christiano et al. (2005), we assume that consumption, investment, and pricing decisions are made prior to the realization of both shocks. This timing assumption ensures that the impact responses of macroeconomic aggregates in the model following a forward guidance shock are consistent with the recursive identification scheme from our baseline VAR model. Appendix C provides details regarding the model’s equilibrium conditions.

A. Households

The representative household maximizes lifetime expected utility over streams of consumption $C_t$ and leisure $1 - N_t$. The household derives utility from consumption relative to a habit level $H_t$. The household receives income from the intermediate-goods-producing firm in the form of wages $W_t$ for each unit of labor $N_t$ supplied and through lump-sum dividends $D_t$. The household has access to zero net-supply, one-period nominal $B_t^R$ and real $B_t^R$ bonds. Nominal bonds pay $1.00$ and are purchased at a discounted price $1/R_t$, where $R_t$ is 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 representative household maximizes lifetime utility by choosing $C_{t+s}, N_{t+s}, B_{t+s-1}$, and $B_{t+s}^R$, for all $s = 0, 1, 2, \ldots$ by solving the following problem:

$$\text{max } E_{t-1} \sum_{s=0}^{\infty} a_{t+s} \beta^s \left( \log (C_{t+s} - bH_{t+s}) - \xi \frac{N_{t+s}^{1+\eta}}{1+\eta} \right)$$

subject to the intertemporal household budget constraint each period,

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

$\lambda_t$ denotes the Lagrange multiplier on the household budget constraint. Consumption habits are external to the household and linked to last period’s aggregate consumption $H_{t-1} = C_{t-1}$.

The discount factor of the household $\beta$ is subject to shocks via the stochastic process $\lambda_t$. We interpret these fluctuations as demand shocks since an increase in $a_t$ induces households to consume more and work less today for no technological reason. We use these shocks to simulate a large decline.
in household demand, which generates a zero lower-bound episode. The stochastic process for these fluctuations is

\[ a_t = (1 - \rho_a) a + \rho_a a_{t-1} + \sigma^\varepsilon \varepsilon_t, \tag{1} \]

where \( \varepsilon_t \) is an independent and standard normal random variable.

B. 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 market for final-goods is perfectly competitive, and thus the final-goods-producing firm earns zero profits in equilibrium. Following Ireland (2011), the aggregate price index \( P_t \) can be written as

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

C. Intermediate-Goods Producers

Each intermediate-goods-producing firm \( i \) rents labor \( N_{it} \) from the household to produce intermediate-good \( Y_{it} \), which is sold in a monopolistically competitive market. Each period, producers can reoptimize their nominal price \( P_{it} \) with a constant probability \( 1 - \omega \). Firms that cannot reset their price index it to a weighted combination of past and steady-state inflation. Intermediate-goods firms own their capital stock \( K_{it} \) and face a convex cost governed by \( \kappa \) when changing their level of investment \( I_{it} \). Firms also choose the rate of utilization of their installed physical capital \( U_{it} \), which affects its depreciation rate. The intermediate-goods firms all have access to the same constant returns-to-scale production function. A production subsidy \( \Psi = \theta / (\theta - 1) \) ensures that the steady state of the model is efficient.

We determine the optimal decisions of the intermediate-goods-producing firm in two steps. First, firms determine the minimal cost method to meet the current level of demand for their product. Thus, each firm solves the following cost minimization problem:

\[ \min E_{t-1} \sum_{s=0}^{\infty} \alpha^s \beta^s \frac{\lambda^{s+1}}{\lambda_t} \left( \frac{W_{it+s}}{P_{it+s}} N_{it+s} + I_{it+s} \right) \]

subject to the production function,

\[ Y_{it} \leq (K_{it} U_{it})^{\alpha} (N_{it})^{1-\alpha} \]

and its capital accumulation equation,

\[ K_{it+1} = (1 - \delta (U_{it})) K_{it} + \left( 1 - \frac{\kappa}{2} \frac{I_{it}}{I_{it-1}} - 1 \right) I_{it}. \]

We assume depreciation depends on utilization via the following functional form:

\[ \delta \left( U_{it} \right) = \delta + \delta_1 \left( U_{it} - U \right) + \left( \frac{\delta_2}{2} \right) \left( U_{it} - U \right)^2. \]

\( \Sigma_t \) denotes the marginal cost of producing one additional unit of intermediate good \( i \), and \( q_t \) is the price of a marginal unit of installed capital. After solving its cost minimization problem, firms that can reoptimize choose their optimal price to maximize their lifetime discounted real profits. Their profit maximization problem is

\[ \max E_{t-1} \sum_{s=0}^{\infty} \alpha^s \beta^s \frac{\lambda^{s+1}}{\lambda_t} \left( \Psi \Pi^{\alpha(1-\gamma)} \Pi^{\alpha(1-\gamma)} P_{it+s} \frac{P_{it}}{P_{it+s}} Y_{it+s} \right) \]

subject to the following demand curve,

\[ Y_{it+s} = \left[ \Pi^{\alpha(1-\gamma)} \Pi^{\alpha(1-\gamma)} \frac{P_{it+s}}{P_{it+1}} \right]^{-\theta} Y_{it+s}. \]

The inflation rate between periods \( t \) and \( t + s \) is defined as

\[ \Pi_{t+s} = \begin{cases} 1 & s = 0 \\ \frac{P_{t+1}}{P_t} \times \frac{P_{t+2}}{P_{t+1}} \times \cdots \times \frac{P_{t+s}}{P_{t+s-1}} & s = 1, 2, \ldots \end{cases} \]

The parameter \( \chi \) controls the degree of indexation to lagged inflation.

D. Equilibrium

In the symmetric equilibrium, all intermediate-goods firms face the same marginal costs and hence choose to employ the same amount of labor, capital, and utilization rate. All firms that can change their nominal price choose the same optimal price \( P_t^* \). We denote the gross one-period inflation rate as \( \Pi_t = P_t / P_{t-1} \). Under the assumption of Calvo (1983) pricing frictions, the aggregate price index \( P_t \) evolves as

\[ P_t^{1-\theta} = \theta \left( \Pi^{1-\gamma} \Pi_{t-1}^{-\theta} \right) (P_{t-1}^{1-\theta} + (1 - \theta) (P_t^{1-\theta}). \]

E. Monetary Policy

We assume 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 0. In spirit of Reifschneider and Williams (2000), we assume the monetary authority sets its policy rate according to the following history-dependent
rule subject to the zero lower bound:

\[ r_t^d = \phi_t r_{t-1}^d + \left( 1 - \phi_t \right) \left( r + \phi_n (\pi_t - \pi) + \phi_y y_t \right) + \nu_t, \]

(2)

\[ v_t = \rho v_{t-1} + \sigma^\nu \nu_t, \]

(3)

\[ r_t = \max \left( 0, r_t^d \right), \]

(4)

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. \( \pi_t \) denotes the log of the one-period gross inflation rate \( \Pi_t \), and \( y_t \) is the gap between the log of current and log of steady-state output. Finally, \( v_t \) is an autocorrelated monetary policy shock. Away from the zero lower bound, this policy rule acts like a Taylor-type policy rule with interest rate smoothing. Also, an exogenous \( \nu_t \) shock away from the zero lower bound acts like a conventional monetary policy shock.

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 lower-bound constraint. Households fully internalize this future conduct of policy. When desired rates are less than 0, an exogenous shock to the desired rate \( \nu_t \) acts like an exogenous extension of the zero lower-bound episode. This exogenous extension of the zero lower bound lowers future expected policy rates but leaves current policy rates unchanged, which we link with our identified forward guidance shock in the data. We believe this modeling framework closely aligns with our empirical measure of forward guidance as the path factor is constructed to be orthogonal to changes in the current policy rate.\(^{11}\)

F. Generating Model-Implied Futures Contracts

We want to ensure our simulated forward guidance shock in the model is consistent with the typical forward guidance shock we identify in the data. Since we measure forward guidance shocks empirically using fluctuations in futures rates, we generate a model counterpart to the eurodollar futures contracts we examine in the data.

We denote the price of an \( n \)-month-ahead eurodollar futures contract at time \( t \) by \( f_t^n \). The payoff on this futures contract equals 1 minus the current annualized three-month LIBOR rate in the contract expiration month. For the one-month-ahead contract in our model, this payoff concept equals \( 1 - 12 \times \frac{1}{3} \times \left( r_{t+1} + r_{t+2} + r_{t+3} \right) \), where \( r_{t+n} \) is the policy rate of the central bank in month \( t+n \). Therefore, we calculate the price of the one-month-ahead zero net-supply futures contract by including the following equilibrium condition in our model:

\[ f_t^1 = E_t \left\{ 1 - 12 \times \frac{1}{3} \times \left( r_{t+1} + r_{t+2} + r_{t+3} \right) \right\}. \]

(5)

For contracts of maturity longer than one month, we can determine the equilibrium futures prices as follows:

\[ f_t^n = E_t \left\{ 1 - 12 \times \frac{1}{3} \times \left( r_{t+n} + r_{t+n+1} + r_{t+n+2} \right) \right\}. \]

(6)

Note that the structure of the futures contracts implies that an \( n \)-month contract at time \( t \) becomes an \( n-1 \) contract at time \( t+1 \). Therefore, we can also conveniently write the futures prices for maturities longer than one month recursively:

\[ f_t^n = E_t \left\{ f_{t+1}^{n-1} \right\}. \]

(7)

For a given horizon, we can determine the futures-implied interest rate by computing \( 1 \) minus the contract price.\(^{12}\) These model counterparts allow us to determine the appropriately sized forward guidance shock to simulate in the model.

Since we also examine the effects of forward guidance shock on two-year Treasury yields in the data, we evaluate the model’s predictions for bond yields. Therefore, following Rudebusch and Swanson (2012), we compute the price of an \( n \)-month default-free zero-coupon bond that pays $1.00 at maturity using the following equilibrium condition:

\[ p_t^n = E_t \left\{ \left( \frac{\beta}{\lambda_t} \frac{1}{\lambda_{t+1}} \right) p_{t+1}^{n-1} \right\}, \]

(8)

where the term in parentheses is the household’s nominal stochastic discount factor and \( p_0^0 = 1.00 \). The continuously compounded yield to maturity on the \( n \)-period bond is

\[ y_t^n = -\frac{1}{n} \log p_t^n. \]

(9)

To be consistent with the timing assumptions in our structural VAR, we assume that futures rates and bond yields can change in the same period as the forward guidance shock, but output and prices are fixed at impact.

G. Solution Method

We solve our model using the OccBin toolkit developed by Guerrieri and Iacoviello (2015). This piecewise linear approximation solution method allows us to model the occasionally binding zero lower bound and solve for the

\(^{11}\)Our forward guidance shock specification differs from Del Negro et al. (2015) and others, which use anticipated “news” shocks about future monetary policy to model forward guidance shocks. In the appendix, we show that we can achieve identical macroeconomic effects from either our specification or a news shock approach. We prefer our specification because it is parsimonious and allows us to estimate our model.

\(^{12}\)Payoffs on futures contracts are not discounted using the household’s stochastic discount factor since, in reality, investors in futures contracts post collateral (which also earns a return). Thus, there is no opportunity cost of funds associated with futures positions, and it is not necessary to discount the payoffs until maturity.
model-implied futures prices in only a few seconds, which permits us to estimate several key model parameters.\footnote{13}

\section*{H. Estimation Strategy}

Our primary interest is evaluating the model’s ability to reproduce the empirical impulse responses of a forward guidance shock from section II. Therefore, we estimate our model using impulse response matching. To compute the impulse responses in our model, 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 an extended period. In the second time path, we simulate the same large, negative demand shock but also simulate a negative shock to the desired policy rate via equation (3). 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 an expansionary forward guidance shock at the zero lower bound. Since the economy is at the zero lower bound, this reduction to the desired rate acts like an exogenous extension of the zero lower-bound period.

Our estimation strategy chooses model parameters such that the model’s impulse responses come as close as possible to the empirical VAR responses. To implement this strategy, we follow Rotemberg and Woodford (1997) and Christiano et al. (2005), who choose the size of a conventional monetary policy shock such that the movements in their model-implied policy indicator are consistent with the impulse responses from an identified vector autoregression. Since the focus of this paper is on forward guidance shocks during the zero lower-bound period, however, we discipline the model using expectations of future policy rates. In particular, our estimation procedure picks the size and persistence of the forward guidance shock process, which enables the model to generate the same movement in eight-quarter-ahead futures rates that we observe in the VAR. We find that linking the model and data counterparts is crucial in order to evaluate the model’s fit. In particular, if we were to leave the movements in model-implied expected future interest rates unconstrained, then it is unclear what size forward guidance shock to simulate in the model.

Following much of the previous literature, we partition the model parameters into two groups. The first group is composed of $\beta$, $\Pi$, $\eta$, $\gamma$, $\phi_0$, $\phi_1$, $\omega$, and $\delta^a$. We calibrate these parameters using steady-state relationships or results from previous studies. Table 1 contains the calibrated values for these parameters. Since the model shares features with the model of Ireland (2011), we calibrate some of our parameters to match his values or estimates. To match our VAR evidence, we calibrate the model to a monthly frequency. We set $\xi$ to normalize output $Y$ to equal 1 at the deterministic steady state.

We choose standard values for the monetary policy reaction to inflation and output ($\phi_\sigma = 1.5$, $\phi_\pi = 0.1$). Our monthly calibrations of $\beta$ and $\Pi$ imply a steady-state annualized real interest rate of 2% and a 2% annualized inflation target.

We estimate the second set of model parameters, which consists of the household habit parameter $b$, the probability that a firm can not reoptimize its price $\omega$, the degree of lagged inflation indexation $\delta$, the degree of smoothing in the monetary policy rule $\phi_\eta$, and the degree of investment adjustment costs $\kappa$, the elasticity of the return on capital with respect to capacity utilization $\sigma_\delta = \delta_2/\delta_1$, and the forward guidance shock parameters $\rho_\omega$ and $\sigma^\omega$. In addition, we estimate the size of the initial negative demand shock $e^\alpha_0$ which takes the economy to the zero lower-bound prior to the forward guidance shock. We collect these parameters into a vector $\gamma = (b, \omega, \delta, \phi_\eta, \kappa, \sigma_\delta, \rho_\omega, \sigma^\omega, e^\alpha_0)$.

Using a Bayesian impulse response matching estimator, we estimate these key model parameters by finding the values that maximize the posterior distribution. Let $\hat{\psi}$ denote the impulse response functions for the six variables in our empirical VAR stacked into a single vector with $(6 \times 48 = 288)$ rows and let the diagonal matrix $V^{-1}$ denote a measure of the precision of the empirical impulse responses.\footnote{14} Then, let $\psi(\gamma)$ denote the theoretical model’s corresponding counterpart to $\hat{\psi}$. Following Christiano, Trabandt, and Walentin (2010), we can write the approximate likelihood function as follows:

\begin{equation}
L(\hat{\psi} \mid \gamma, V) = (2\pi)^{-\frac{N}{2}} |V|^{-\frac{1}{2}} \exp\left\{-0.5(\hat{\psi} - \psi(\gamma))V^{-1}(\hat{\psi} - \psi(\gamma))\right\}.
\end{equation}

Let $p(\gamma)$ denote the joint prior density over $\gamma$. According to Bayes rule,

\begin{equation}
f(\gamma \mid \hat{\psi}, V) \propto L(\hat{\psi} \mid \gamma, V)p(\gamma),
\end{equation}

\begin{table}
\centering
\caption{Calibrated Parameters in Baseline Model.}
\begin{tabular}{|l|l|l|}
\hline
Parameter & Description & Calibrated Value \\
\hline
$\beta$ & Household Discount Factor & 0.9983 \\
$\Pi$ & Steady State Inflation Rate & 1.02 \footnote{12} \\
$\delta_0$ & Steady State Depreciation & 0.1 / 12 \\
$\delta_1$ & First-Order Utilization Parameter & $1/\beta - 1 + \delta_0$ \\
$\eta$ & Inverse Frisch Labor Supply Elasticity & 0.5 \\
$\xi$ & Utility Function Constant & 58.43 \\
$\theta$ & Elasticity of Substitution Intermediate Goods & 6.0 \\
$\alpha$ & Capital Share in Production Function & 0.33 \\
$\phi_\alpha$ & Central Bank Response to Inflation & 1.5 \\
$\phi_\eta$ & Central Bank Response to Output & 0.1 \\
$\rho_\omega$ & Preference Shock Persistence & 0.95 \\
$\sigma^\omega$ & Standard Deviation of Preference Shock & 0.005 \\
\hline
\end{tabular}
\end{table}

\footnote{14} The diagonal of $V^{-1}$ contains 1 over the squared difference between the 95th and 5th percentiles of the empirical probability interval. Omitting off-diagonal terms from $V$ helps make our estimator more transparent as it attempts to place the model’s impulse responses inside the empirical probability intervals.
where \( f(\gamma | \hat{\psi}, V) \) is the posterior density over \( \gamma \). Our estimator solves the following problem:

\[
\max_{\gamma} f(\gamma | \hat{\psi}, V).
\]

### I. Priors over Parameters

For our priors, we use a beta distribution for parameters that lie between 0 and 1 and a gamma distribution for parameters that are positive but unbounded. For the household habit parameter \( b \), degree of indexation \( \chi \), and the persistence of the forward guidance shock \( \rho \), we center the prior mode at 0.5 with a standard deviation of 0.25. For the Calvo parameter \( \sigma \), we tightly center our prior mode at 0.93, which is consistent with Nakamura and Steinsson’s (2008) evidence that prices remain fixed for about one year on average. We center our prior mode over \( \phi \) at 0.95, which is consistent with a large literature arguing that historical Federal Reserve policy features a high degree of inertia. However, we set a loose prior on this parameter since, as we discussed in section IIIIE, its interpretation changes when the economy encounters the zero lower bound.

For the investment adjustment cost parameter \( \kappa \) and elasticity of capital utilization \( \sigma_t \), we center our prior at the quarterly estimates of Christiano et al. (2005). However, since our model is calibrated to a monthly frequency, we set loose priors over these parameters to reflect our uncertainty over the exact time-aggregation function. Our prior for the size of the forward guidance shock \( \sigma_t \) is similarly uninformative. We restrict the initial aggregate demand shock \( \epsilon_0 \) to be negative in order to simulate a decline in aggregate demand that takes the economy to the zero lower bound prior to the forward guidance shock.

### IV. Estimated Responses to a Forward Guidance Shock

We now analyze the effects of a forward guidance shock in our estimated model and show that the model can reproduce our empirical evidence. Figure 2 plots both the empirical and model-implied impulse responses to a forward guidance shock. At impact, the forward guidance shock causes the model-implied eight-quarter eurodollar rate to decline by about 6 basis points, which is consistent with our empirical findings. Output, investment, and capacity utilization in the model all rise after the shock in hump-shaped patterns similar to their VAR counterparts. The model also replicates the gradual increase in prices we observe in the data. The peak response of output in the model is quantitatively similar to our empirical results, although the model-implied peak occurs slightly earlier than in the data. As in the data, the two-year bond yield falls as the forward guidance shock lowers the expected path of short-term interest rates in the economy. Importantly, all of the model’s impulse responses fall within the VAR’s probability intervals, which suggests the predictions from a standard model of monetary policy are generally in line with the empirical effects of a forward guidance shock.

To provide additional intuition for our results, figure 6 shows the impulse responses for consumption, additional futures contracts, and real interest rates. Prior to the forward guidance shock, the estimated negative aggregate demand shock implies that the economy is expected to be at the zero lower bound for 20 months. The estimated forward guidance shock then extends the zero lower-bound duration by one month. Since households expect the zero lower bound to persist for 21 months, 12-month-ahead futures rates do not move immediately after the forward guidance shock. However, the 24-month-ahead contract falls by several basis points as expected future nominal policy rates decline. The combination of the forward guidance shock, nominal price and investment rigidities, and the zero lower bound produces a hump-shaped response of real interest rates. At impact, current nominal policy rates are fixed at 0, and expected inflation rises very slightly due to the nominal rigidity in price setting. Thus, real interest rates fall only modestly while the economy remains at the zero lower bound. However, real rates fall sharply once the economy exits the zero lower bound and the monetary authority can lower its current nominal policy rate. This time path for real interest rates, in addition to habits in consumption, causes a very gradual increase in consumption, which peaks about one year after the forward guidance shock.

#### A. Role of the Initial Demand Shock

While many features of our model are standard, simulating a forward guidance shock at the zero lower bound requires us to estimate the initial conditions in the economy prior to the forward guidance shock. In figure 6, we illustrate how our estimate of the initial aggregate demand shock affects our main results.

Disciplining the model using futures contracts helps the estimation procedure determine the appropriate zero lower-bound episode to simulate in the model. In our baseline results, we find that a total zero lower-bound episode of 21 months allows the model to match the data. For comparison, we simulate a larger initial shock to the economy such that the zero lower bound persists for significantly longer. Figure 6 plots the responses under the longer 36-month zero lower-bound duration and our baseline 21-month scenario. If we simulate too large of an initial demand shock, the 24-month-ahead futures rate fails to move at impact and displays a somewhat hump-shaped pattern. This time path is clearly inconsistent with the empirical evidence from figure 2, where futures rates fall at impact and rise monotonically. Thus, appropriately choosing the initial demand shock ensures that the model can generate movements in futures rates similar to what we observe in the data.

15Our estimated zero lower-bound duration of a little less than two years is consistent with the ex ante views of professional forecasters as detailed in figure 4 of Swanson and Williams (2014).
B. Parameter Estimates

The model requires a mix of nominal and real rigidities to match the VAR impulse responses. The top panel of table 2 shows that our estimated degree of nominal rigidity $\omega$ implies that prices remain fixed for about seven quarters, on average. While prices in our model are more persistent than the microlevel estimates of Nakamura and Steinsson (2008), our results are consistent with the findings of Gali and Gertler (1999) and Del Negro et al. (2015). We find essentially no role for lagged indexation of prices with $\chi = 0.04$, which likely reflects a decline in the persistence of inflation over time.

In addition to a moderate degree of nominal rigidity, three real rigidities help the model reproduce the empirical evidence. Our estimate of consumption habits $b$ is higher than the estimate of Christiano et al. (2005), as one might expect when moving from a quarterly to a monthly frequency. As in Christiano et al. (2005), our estimate of the capacity utilization adjustment cost parameter is very small and not significantly different from 0. Since $1/\sigma_b$ governs the elasticity of capacity utilization with respect to the return on capital, our estimate of $\sigma_b$ implies a large response of utilization to a given movement in capital returns, which is consistent with our VAR evidence. Turning to investment, we find a much larger monthly investment adjustment cost parameter $\kappa$ than the quarterly estimates of Christiano et al. (2005), which suggests that at a monthly frequency, firms make more incremental adjustments in their capital stock.
We estimate a significant degree of desired-rate smoothing in the central bank’s policy rule. However, our estimate of \( \phi_r = 0.94 \) doesn’t significantly differ from its prior mode, which suggests that \( \phi_r \) may not be well identified by our impulse response matching procedure. In appendix G, we explore alternative priors for \( \phi_r \) and consistently find point estimates of \( \phi_r \) that are very near to the prior mode but imply no significant change in the model’s fit of the data. This result is not too surprising since we are only informing our estimation procedure with information on monetary policy shocks. Coibion and Gorodnichenko (2012) show that the degree of endogenous interest-rate smoothing is likely better informed by the policy response to nonmonetary shocks. However, these additional results show that the overall fit of our model does not rely on a particular assumption about the amount of history dependence in the central bank’s policy rule.\(^{16}\)

### C. Quarterly Model Estimates

Parameter estimates from our monthly-frequency model are difficult to compare with the previous literature estimating the effects of conventional monetary policy shocks at a quarterly frequency. Thus, to facilitate a quantitative comparison of our estimated parameters with those in Christiano et al. (2005), we take the parameter estimates from their table 2, row 5 (unconditional indexation) and the associated standard errors they estimate to form priors for the parameters in a quarterly version of our model.\(^{17}\) Then we estimate the posterior distribution of the parameters by minimizing the distance between the impulse responses in the data and the model. Figure 7 shows the resulting impulse responses, which are well within the posterior intervals of the VAR impulse responses for all variables and all horizons. In addition, the model’s responses are very close to the point estimates from the VAR for most variables.

What parameters deliver this close fit? The bottom panel of table 2 shows the posterior modes and standard deviations of the parameters. All of the estimated parameters are near the Christiano et al. (2005) estimates except for the Calvo pricing friction parameter, for which we estimate \( \rho_\pi = 0.88 \) compared to the Christiano et al. (2005) estimate of \( \rho_\pi = 0.72 \). However, our estimate of \( \omega \) is within a 1 standard error range of the Christiano et al. (2005) estimate.

Other than a change in the frequency of price adjustment, the same model and parameters that can account well for the dynamics of conventional monetary policy shocks prior to the zero lower bound can also account for the dynamic effects of forward guidance shocks at the zero lower bound. The increase in the Calvo parameter that we find necessary to explain these dynamics relative to the estimated value in Christiano et al. (2005) could represent either the absence of wage rigidity or the absence of a working-capital friction in our model. Christiano et al. (2005) show that removing either of these frictions increases the average duration of prices in their model. Specifically, they find \( \omega = 1 \) when they allow

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\(^{16}\)In the appendix, we also discuss the role of the persistence of the forward guidance shock process.

\(^{17}\)We choose to work with this set of estimates since we find little need for indexation in our sample.
for flexible wages and $\omega = 0.89$ when they assume that firms do not need to borrow their wage bill in advance. Moreover, our estimate of $\omega = 0.88$ is well within the range reported in the literature, including recent work of Del Negro et al. (2015).

D. Model-Implied Responses to Specific Forward Guidance Shocks

Our results suggest that a standard model with nominal price rigidities can account for the effects of an average forward guidance shock as estimated from a VAR. However, our linear VAR only allows us to trace out the effects from a typical forward guidance shock in the data that moves futures rates by about 6 basis points. Figure 1 shows that some policy announcements generated significantly larger movements in the path factor. For example, on August 9, 2011, eight-quarter-ahead eurodollar futures rates declined by 28 basis points when the FOMC announced that rates were likely to remain low until “mid-2013.” This size of movement in futures rates equates to a 4.8 standard deviation forward guidance shock in our model. In order to further evaluate the predictions of our theoretical model, we now examine whether the model generates reasonable quantitative responses following this significantly larger forward guidance shock.

In response to the August 2011 announcement, we find that the model predicts a much larger expansion of economic activity than a typical forward guidance shock. Figure 8 illustrates the model-implied responses to the forward guidance shock on August 9, 2011. To generate these responses, we...
We choose the size of the forward guidance shock in the model such that the model-implied two-year eurodollar rates is by the same amount as we observe in the data around the August 9, 2011, FOMC announcement.

increase the size of the forward guidance shock such that the two-year-ahead futures rates in the model decline by 28 basis points, the same movement in futures rates we observe in the data. As expected, this substantially larger forward guidance shock generates a much larger increase in economic activity and prices. At its peak response, output rises by about 0.5%, which occurs a little over one year after the shock.

Are the model’s predicted effects from the August 2011 announcement reasonable? Unlike the responses to a typical forward guidance shock we identify from our VAR, we have no clear data counterpart to compare with the model’s responses for this specific shock. Alternatively, to gain some sense of reasonable magnitudes, we can compare the model-implied movement in output with the estimated effects of other unexpected monetary policy interventions. In the VAR model of Christiano et al. (2005), a typical expansionary monetary policy shock raises output by just over 0.5% after about one year. In addition, the Romer and Romer (2004) estimates imply that a 1 standard deviation expansionary policy shock increases output by around 0.6% at its peak. Therefore, the model’s response to one of the largest forward guidance shocks we observe around FOMC meetings seems reasonable in the context of other work measuring the potency of monetary policy.

We estimate this output response by simulating a 1 standard deviation shock in Romer and Romer’s (2004) three-variable VAR using their shock series and their monthly measures of output and prices.
E. Additional Model Results

In the appendix, we provide further robustness checks on the model estimation. Our baseline model assumes that monetary policy responses to deviations of output from its steady-state level. However, Coibion and Gorodnichenko (2011) provide evidence that policymakers respond more to output growth. We find that the model can fit the VAR evidence similarly well if we replace output in the policy rule with output growth. Also, a simplified model with a fixed capital stock, a common benchmark in the literature, can reproduce the empirical impulse responses to a forward guidance shock from a smaller VAR. In addition, we illustrate how our estimated degree of investment adjustment costs facilitates the model’s ability to fit the empirical responses of investment and futures rates. We also use simulated data from our structural model to show that our empirical strategy generally works well in recovering the true forward guidance shocks and the associated impulse responses.

V. Discussion

Our empirical results and our conclusions regarding the ability of standard theoretical models to match these results are both at odds with a growing literature on the effects of forward guidance. One strand of this literature emerges from the work of Del Negro et al. (2015), which argues that the output response to a forward guidance shock is implausibly large, resulting in a “forward guidance puzzle.” A second strand of this literature suggests that forward guidance announcements may contain two pieces of news: news about the future state of the economy and news about future interest rates. Work by Campbell et al. (2012) and Nakamura and Steinsson (2018) argues that the macroeconomic news effect dominates resulting in an “event-study activity puzzle.” In this section, we relate our findings to this literature and provide some explanations as to why we reach different conclusions.

A. The Forward Guidance Puzzle

Our findings contrast with the work by Del Negro et al. (2015), which argues that standard models with nominal rigidities overestimate the expansionary effects of forward guidance. Our alternative conclusion emerges from the size of the forward guidance shock we estimate. In both our empirical evidence and theoretical model, a typical expansionary forward guidance shock in a one-day window around a policy announcement lowers eight-quarter-ahead futures rates by about 6 basis points. This shock extends the zero lower-bound duration by one month in our model, which produces modest increases in output and inflation that are consistent with our empirical evidence.

Del Negro et al. (2015) simulate a much larger forward guidance shock. Motivated by the FOMC’s extension of its date-based guidance from “late 2014” to “mid-2015” in September 2012, they simulate an exogenous 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, in our estimated model, a one-year exogenous extension requires a highly unlikely 25+ standard deviation shock. Thus, our findings suggest that standard models work well in analyzing the typical forward guidance shocks we observe around FOMC announcements. However, our work cannot speak to the plausibility of the model’s predictions for substantially larger shocks that may occur between FOMC meetings or all possible experiments that might be of interest to macroeconomic modelers or policymakers.

B. Macroeconomic News in Forward Guidance Announcements

Nakamura and Steinsson (2018), building on the work of Campbell et al. (2012), argue that in addition to providing news about future interest rates (an Odyssean component), monetary policy announcements contain a significant amount of macroeconomic news (a Delphic component). If the Delphic component dominates, then an unexpected decline in policy rates could lower forecasts of economic activity. Our estimates of the effects of forward guidance should be interpreted as an on-average, net effect of FOMC communications. The VAR evidence we find seems to suggest that between these two channels, the Odyssean effect dominates on average. While there may be Delphic components to some FOMC announcements, we find that those influences are typically more than offset by expansionary Odyssean effects. To illustrate this idea, figure B.16 in the appendix shows the impulse responses if we include the five-year inflation-protected Treasury yield in our VAR model, a key variable of interest.
The plot of the nominal interest rate reflects its level after the forward guidance shock. The forward guidance shock in the top panel is chosen to match the 6 basis point decline in the eight-quarter-ahead futures rates that occurred after the September 13, 2012, FOMC meeting. The shock in the bottom panel is chosen to generate a one-year extension of the zero lower bound.

in Nakamura and Steinsson (2018). These authors argue that a lower path of the policy rate signals a lower natural real rate of interest, which causes long-term real interest rates to fall and lowers expectations for output growth. In contrast, we find that forward guidance shocks lower financial market measures of long-term real interest rates and raise actual output, which is consistent with the predictions of a standard model of monetary policy without a macroeconomic news channel.

VI. Conclusion

This paper reconciles empirical evidence on the effects of forward guidance shocks with the predictions from a standard model of nominal rigidity. Our analysis suggests no disconnect between the empirical effects of forward guidance shocks around policy announcements and the predictions from a standard model of monetary policy. Moreover, we find that the estimated parameters that govern the model’s key frictions lead us to a model economy that does not appear all that different from the model of conventional policy shocks of Christiano et al. (2005). These findings suggest that the same models economists use to study the effects of conventional monetary policy shocks remain useful in studying the effects of forward guidance shocks at the zero lower bound.

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