Forward Guidance and Macroeconomic Outcomes Since the Financial Crisis*

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Abstract

This paper studies the effects of FOMC forward guidance. We begin by using high frequency identification and direct measures of FOMC private information to show that puzzling responses of private sector forecasts to movements in federal funds futures rates on FOMC announcement days can be attributed almost entirely to Delphic forward guidance. However a large fraction of futures rates' variability on announcement days remains unexplained leaving open the possibility that the FOMC has successfully communicated Odyssean guidance. We then examine whether the FOMC used Odyssean guidance to improve macroeconomic outcomes since the financial crisis. To this end we use an estimated medium-scale New Keynesian model to perform a counterfactual experiment for the period 2009:1–2014q4 in which we assume the FOMC did not employ any Odyssean guidance and instead followed its reaction function inherited from before the crisis as closely as possible while respecting the effective lower bound. We find that a purely rule-based policy would have delivered better outcomes in the years immediately following the crisis – forward guidance was counterproductive. However starting toward the end of 2011, after the Fed's introduction of "calendar-based" communications, Odyssean guidance appears to have boosted real activity and moved inflation closer to target. We show that our results do not reflect Del Negro, Giannoni, and Patterson (2015)'s forward guidance puzzle.

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1 Introduction

Over the last thirty years the FOMC completely revised its communications policy, eventually making guidance about the future path of the funds rate a central component of those communications. Whereas the Committee once refrained from announcing its target for the federal funds rate, in February 1994 it began issuing a press release following every meeting stating the target. In 1999 it began the practice of publishing statements containing explicit guidance about the future stance of policy. After the May meeting of that year the committee released a statement that said the committee had "adopted a directive that is tilted toward the possibility of a firming in the stance of policy." Various incarnations of forward guidance came after, for example for a period of time the post-meeting statement referenced the "balance of risks" that hinted at the likely direction of future rate changes if they were to occur. Perhaps the most prominent use of forward guidance before the financial crisis was the inclusion in the statement following its June 2004 meeting of "pace that is likely to be measured" when referring to future rate increases.

After 2008q4 even more explicit forward guidance became one of the two primary tools of monetary policy after the zero lower bound made it impossible to counteract weak economic conditions by lowering the funds rate.[1] In December 2008 the Committee began using language that rates would remain exceptionally low for "some time." In March 2008 "some time" was replaced with "extended period." So-called "calendar-based" forward guidance was introduced in August 2011 when the corresponding statement indicated that exceptionally low levels of the funds rate would remain in place "at least through mid-2013." In the December 2012 statement the calendar-based language was replaced with the so-called Evans rule whereby the maintenance of low rates was tied to specific economic conditions. While the specificity of the Evans rule was dropped in March 2014, the statement has continued to highlight that any future policy tightening will be closely tied to tangible evidence about the state of the economy.[2]

[1] Recently several foreign central banks have successfully lowered policy rates below zero. However throughout the period we are interested in the FOMC has acted as if the (near) zero lower bound has been a binding constraint.

[2] The other main tool of monetary policy since the financial crisis was "quantitative easing" (QE). While there is considerable debate over the importance of the various possible channels through which QE might affect real activity it is widely viewed to at least in part involve influencing private sector expectations of future short term interest rates. See Evans, Fisher, Gourio, and

Before the financial crisis that unwound from 2007 to 2009, academic interest in the FOMC's forward guidance primarily arose from the aforementioned changes in its communication policy. That crisis and the subsequent spell with the fed funds rate constrained near its effective lower bound gave the topic much greater policy relevance. So motivated, Campbell, Evans, Fisher, and Justiniano (2012) extended the work of the previous empirical literature on forward guidance in two directions. First, they demonstrated that data from the post-crisis period continued to conform to the patterns documented by Gürkaynak, Sack, and Swanson (2005) in which yields on securities responded significantly to changes in federal funds rate futures on days with FOMC statements. That is, the financial crisis did not permanently damage the transmission mechanism from forward guidance to asset prices. Second, they examined how private expectations of macroeconomic variables responded to forward guidance shocks in the pre-crisis period. They found strong evidence that an unexpected tightening of future rates *lowered* unemployment expectations and weaker evidence that it *raised* inflation expectations.

To better understand forward guidance Campbell et al. (2012) introduced a theoretical distinction between *Delphic* and *Odyssean* forward guidance. The former gets its name from the oracle of Delphi, who forecasted the future but promised nothing. Just so, central bankers routinely discuss macroeconomic fundamentals and outcomes objectively while forecasting their own likely responses to future developments. Moreover since the May 1999 meeting the policy statement routinely includes an assessment of current conditions as well as references to how the committee expects the economy to evolve in coming months. In contrast, Odyssean forward guidance consists of central bankers' statements that bind them to future courses of action. Just as Odysseus bound himself to his ship's mast so he could enjoy the pleasure of the Sirens' song without succumbing to the inevitable temptation to drown himself while swimming towards them, a central banker can improve welfare by publicly committing to a time-inconsistent plan that uses expectations of suboptimal future outcomes to improve current economic conditions. The forward guidance that implements the time-inconsistent Ramsey plans in Eggertsson and Woodford (2003) is Odyssean.

Krane (2015) for references to the relevant literature. Krishnamurthy and Vissing-Jorgensen (2011) argued that signalling lower rates for longer is the main channel through which QE affects borrowing rate. So QE also can be viewed through the lens of forward guidance.

If FOMC statements reveal information about near-term economic developments that would otherwise remain out of the public's hands, then the direct effects of the fundamentals so revealed (for example, lower unemployment and higher inflation from strong aggregate demand) will accompany the optimal policy response to those fundamentals (for example, an increase in expected future policy rates). That is, simple expectational regressions suffer from a simultaneity problem when FOMC statements contain Delphic forward guidance. Although this Delphic hypothesis is reasonable, it could also be wrong. Campbell et al. (2012) did not even commence with its empirical examination. Accordingly, we take up this challenge by using direct measures of FOMC private information based on now-public Greenbook forecasts. We find that the puzzling responses of private sector forecasts to FOMC announcements can be attributed almost entirely to Delphic forward guidance. However a large fraction of the variability in federal funds futures rates on days with FOMC announcements remains unexplained by private information as we measure it. We conclude that the high frequency approach to identification leaves open the possibility that the FOMC has successfully communicated Odyssean guidance.

Our ultimate goal is to assess whether the FOMC has successfully communicated Odyssean guidance to yield improved economic performance since the financial crisis. Below we review a nascent literature that examines the macroeconomic effects of forward guidance using VARs. This literature uses a variety of strategies to identify forward guidance shocks and finds that these shocks have influenced real activity as standard New Keynesian (NK) models predict Odyssean guidance can, at least qualitatively. Nevertheless VARs are inadequate for addressing our question. The literature pools pre- and post-crisis data to improve power, yet there is clear evidence that the nature of forward guidance changed substantially after the crisis. Consequently there is too little data to apply reduced form tools. Furthermore a structural framework is inherently more suited to the kind of counter-factual that would shed light on the effects of forward guidance over a particular period.

Given the generally validating findings of the reduced form empirical literature for NK models subjected to Odyssean guidance, we address our question with such a model. Our framework employs an enhanced version of the workhorse medium-scale model pioneered by Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007). The model's forward guidance takes the form of unanticipated signals from the FOMC about the future values of the interest rate rule's time-

varying intercept, building on the insights of Laséen and Svensson (2011) and Campbell et al. (2012). Since our question is empirical we estimate the forward guidance signals' stochastic structure. To do so we develop a new methodology that allows us to integrate the information obtained from high frequency identification of forward guidance on FOMC announcement days into an estimated model of quarterly macroeconomic fluctuations.

In addition to introducing forward guidance we enhance the model by including a household preference for safe and liquid assets as suggested by Fisher (2015) and Jaimovich and Rebelo (2009) (JR) preferences over consumption and work. Liquidity preferences introduce a spread between the money market interest rate controlled by the central bank and returns to physical capital, because money market securities yield benefits over and above providing for the transfer of consumption from one period to the next. Therefore these preferences bring discounting to the linearized inter-temporal consumption Euler equation. As discussed by Campbell, Fisher, Justiniano, and Melosi (2016), Carlstrom, Fuerst, and Paustian (2015), Kiley (2014), and McKay, Nakamura, and Steinsson (2015) the absence of discounting in standard models is essential to understanding why the effects of Odyssean guidance can be implausibly large in NK models. With discounting consistent with an empirically plausible spread such large effects are mitigated in our model.[3] We include JR preferences because forward guidance operates in part through wealth effects. These preferences provide flexibility in the transmission of shocks through wealth effects. Moreover including JR preferences greatly enhances the model's ability to capture business cycle co-movement among the different components of GDP thereby increasing the empirical plausibility of our framework.

We estimate our model using a Bayesian approach involving 18 macroeconomic time series including federal funds futures' rates that are used to identify forward guidance. Our use of futures rates in estimation makes it possible to use linear methods while being sure that the effective lower bound on interest rates is taken into account when the model's agents make decisions. We estimate our model over the period 1993q1 through 2008q3. At the estimated parameter values shocks to technology, the demand for safe and liquid assets, investment demand, and the rate of time preference account for over 90% of business cycle volatility in output, hours,

[3]See Del Negro et al. (2015) and McKay et al. (2015) for alternative approaches to introducing discounting.

consumption and investment.

We use the estimated model to measure the effects of forward guidance from 2008q4 to 2014q4. For this second sample we set the parameters at their values estimated from the first sample except that we re-estimate the stochastic structure of forward guidance using futures rates extending 11 quarters ahead. The effects of forward guidance are then isolated by comparing actual outcomes to counter-factual outcomes derived from the re-estimated model. For the counter-factual we assume the central bank takes as given the non-monetary shocks identified by the re-estimated model and chooses interest rates to be as close as possible to the policy rule inherited from the first sample, without violating the lower bound constraint and taking into account the response of private agents to its policy choices. Our findings suggest the Fed's forward guidance was counterproductive in the years immediately following the financial crisis. In particular, had the Fed communicated it was following a rule-based policy at the time, then outcomes would have been better. However from late 2011, soon after the Fed adopted calendar-based forward guidance in August 2011, macroeconomic outcomes were significantly better than they would have been under a rule-based policy.[4]

In our model extending a zero interest rate peg for additional periods leads to initial responses of output and inflation that grow with the length of the extension and eventually begin to explode. This is endemic to all NK models. Del Negro et al. (2015) report extremely large initial responses of output and inflation to an extension of a 10 quarter zero interest rate peg by just one quarter. They call this feature the "forward guidance puzzle." Being based on an estimated medium-scale NK model, their results suggest the theoretical possibility of exploding responses to extending interest rate pegs is empirically relevant. Given that our counter-factual suggests relatively modest effects of forward guidance it would seem that our estimated model has no forward guidance puzzle. Indeed it does not. We demonstrate this by conducting the experiment Del Negro et al. (2015) use to demonstrate the forward guidance puzzle and finding extremely modest effects of extending an interest rate peg.

The remainder of the paper begins with our analysis of FOMC private

[4]Engen, Laubach, and Reifschneider (2015) use a very different methodology based on the Board of Governors' FRB/US macro-econometric model to argue that improved macroeconomic outcomes from unconventional monetary policy were late to appear.

information using high frequency identification and a brief discussion of the VAR evidence on the effects of forward guidance. After this we describe the structural model; measurement and estimation of the model; properties of the estimated model; and our counterfactual policy analysis. The final section (to be completed) outlines a research agenda suggested by our findings.

2 Measures of Forward Guidance and Its Effects

This section reviews and extends the large and growing empirical literature that identifies the effects of forward guidance using reduced form methods. We argue that there the evidence is compelling that Fed communications are associated with significant movements in financial variables that incorporate views about the future, such as long term interest rates. Furthermore, the evidence strongly suggests that private expectations about the future direction of the economy and realized macroeconomic outcomes respond to Fed communications as well. This evidence is based on data from both the pre-crisis era when forward guidance was less prominent in policy-communications and from the post-crisis period when forward guidance took center-stage.

2.1 Measurement with High-Frequency Data

FOMC policy actions occur at discrete moments, usually during the U.S. business day. Financial market participants trade on these actions, and the resulting changes in asset prices can be used to identify their unexpected components. Kuttner (2001) pioneered this approach by measuring the unexpected change in the current policy rate with changes int he price of the futures contract that settled based on the average fed funds rate in the month containing the FOMC meeting. Before 1994, the change in the fed funds rate was the *only* policy action taken on a meeting date. Indeed, the FOMC typically issued no communication at a meeting's conclusion, and market participants were left to infer any policy rate change from the trading activity of the System Open Market account desk.

Since its February 1994 meeting, the FOMC has typically made a post-meeting statement. Although these began as terse announcements of anticipated tightening and loosening in money markets, the soon routinely announced its policy rate

decision and justification for it within the context of the committee's macroeconomic outlook. In May 1999, the committee added forward-looking language to its statement that indicated whether the balance of risks to the achievement of its dual mandate was tilted towards undesirable inflation or output performance. As the FOMC followed the subsequent trend set by inflation-targeting central banks towards greater transparency regarding its policy goals and actions, its statement's forward-looking language expanded. Most notably, the FOMC repeatedly stated its expectation of maintaining low interest rates in the wake of the 2001 recession for a "considerable period." Once the removal of that accommodation was underway, the committee consistently forecasted that it would be removed "at a measured pace."

Both policy experience and modern macroeconomic theory emphasize the influence of the private-sector's expectations of future outcomes on current macroeconomic performance; so the FOMC's statments and other communications can be reasonably characterized as policy actions *additional* to any adjustments in the policy rate. However, the conditions under which such communications are *effective* remain unclear. Krugman (1998) and Eggertsson and Woodford (2003) implicitly assume that monetary policy makers can manipulate private sector expectations to be consistent with any rational expectations equilibrium. Unsurprisingly, this assumption makes proper communication policy very effective at improving macroeconomic outcomes. In contrast Bassetto (2016) models central bank communications as "cheap talk." When the central bank has private information about economic fundamentals, such cheap talk can (coarsely) communicate that to the public and thereby improve outcomes. However, these communications leave the equilibrium set unchanged if the public and policy maker are equally well informed. In this sense, central bank communications about future objectives and constraints are redundant policy instruments.

Although theory provides no certain identification of the efficacy of central bank communication, the high-frequency estimation strategy of Kuttner (2001) can be used to shed empirical light upon it. Kohn and Sack (2004) took an important first step in this empirical research program by measuring the variance of asset price changes on days of FOMC meetings with and without accompanying post-meeting statements. After carefully controlling for the effects of any contemporaneous public announcements of macroeconomic news, they found that issuing a statement substantially increased the variance of fed funds futures contracts dated 3 months

ahead as well as Eurodollar futures contracts dated 2 and 4 quarters ahead. (See their Table 3.) That is, central bank communications substantially change asset prices closely associated with policy rate changes in the near future. In this sense, FOMC communications demonstrably include forward guidance.[5]

Gürkaynak, Sack, and Swanson (2005) (hereafter GSS) continued this research agenda by examining the content of FOMC forward guidance in more detail and by characterizing its effects on Treasury yields. Specifically, GSS measured changes in fed funds futures and eurodollar futures contracts with one year or less to expiration over 30 minute windows centered on FOMC announcements. They then demonstrated that these changes have a simple two-factor structure in which the factors themselves account for nearly all of the sample variance. After an appropriate rotation, they label these the *target* and *path* factors. By assumption these are orthogonal; and only the target factor influences the current policy rate. Therefore, the path factor definitionally captures the effects of forward guidance on expected future policy rates.[6] GSS furthermore showed that the path factor's largest realizations coincided with historically prominent cases of forward guidance. (See their Table 4.) Finally, they demonstrated that the path factor substantially influences the yields on two, five, and ten-year Treasury notes. In modern macroeconomic models, central bank forward guidance influences current economic performance only to the extent that it changes such bond rates, so this finding is necessary for us to continue entertaining the hypothesis that it can be an effective policy tool.

Campbell et al. (2012) extended the work of GSS in two directions. First, they demonstrated that data from the post-crisis period continued to conform to the patters documented by GSS. That is, the financial crisis did not permanently damage the transmission mechanism from forward guidance to asset prices. Second, they examined how private expectations of macroeconomic variables responded to forward guidance shocks in the pre-crisis period. They found strong evidence that an unexpected tightening of future rates *lowered* unemployment expectations and

[5]One might object that such asset price changes reflect only movements in term premiums rather than changes in underlying expectations of future interest rates. Indeed, **?** document substantial variation in these expected securities' expected excess holding returns. However, this variation occurs over business-cycle frequencies and so is not obviously relevant for the high-frequency changes measured by Kohn and Sack (2004).

[6]This statement is subject to the terms and conditions in Footnote 5.

weaker evidence that it *raised* inflation expectations. (See their Table 3.)

The finding that private expectations' responses are the *opposite* of those we would expect from a simple New Keynesian model with forward guidance shocks that reflect exogenous changes to expected future policy actions clearly indicates that something other than such a simple story is at work. To better understand that finding (and forward guidance in general), Campbell et al. (2012) introduced the theoretical distinction between Delphic and Odyssean forward guidance described in the introduction. Campbell et al. (2012) hypothesized that the results from their expectational regressions arise from the Delphic forward guidance. If FOMC statements reveal information about near-term economic developments that would otherwise remain out of the public's hands, then the direct effects of the fundamentals so revealed (for example, lower unemployment and higher inflation from demand strength) will accompany the optimal policy response to those fundamentals (for example, an increase in expected future policy rates). That is, simple expectational regressions suffer from a simultaneity problem when FOMC statements contain Delphic forward guidance. Although this Delphic hypothesis is reasonable, it could also be wrong. Campbell et al. (2012) did not even commence with its empirical examination. Accordingly, we take up this challenge below by using direct measures of FOMC private information based on now-public Greenbook forecasts.

Additional scrutiny of asset price responses to FOMC forward guidance has also raised questions about the content and transmission of forward guidance. In the canonical log-linear New Keynesian model, the expectations theory of the term structure holds good; and changes in long-dated interest rates perfectly reflect concomitant changes in expected future spot interest rates. This applies to both real and nominal interest rates, but it is uncommon for monetary policy to influence expected real interest rates far beyond the duration of price stickiness. In contrast to this prediction Hanson and Stein (2015) found that changes in the stance of monetary policy substantially influence long-dated instantaneous forward rates. For FOMC meeting days, they regressed two-day changes in the ten-year ahead nominal instantaneous treasury yield, real TIPS yield, and implied inflation compensation (as measured by Gürkanynak, Sack, and Wright (2006, 2008) on the changes in the two-year zero-coupon nominal yield (also from Gürkanynak et al. (2006)), their preferred measure of the stance of monetary policy. They find no impact of the

two-year nominal rate on forward inflation compensation, but the same rate has substantial effects on both the real and nominal forward rates.

Hanson and Stein dismiss out of hand the possibility that these estimated responses reflect changes in expected spot interest rates ten years ahead that are driven by monetary policy actions. We find this dismissal especially justified since long-dated inflation compensation does not respond to the two-year rate. They consider two alternative explanations for their findings. Perhaps FOMC communications contain Delphic forward guidance about changes in the long-run real rate of interest (which is obviously out of the committee's control). Alternatively, investors might "reach for yield" when short rates fall by shifting their portfolios into longer dated securities. This additional demand reduces their prices but not the expectations of outcomes ten-years hence. That is, the observed price changes reflect changes in term premia. Although Hanson and Stein cannot conclusively dismiss the Delphic explanation for their finding, they prefer the premium-based alternative for a variety of empirical reasons. Our measures of the private information the FOMC might reveal in forward guidance allows us to examine their Delphic hypothesis more directly.

2.2 An Accounting Framework

To enable a more precise discussion of the measurement of forward guidance and the estimation and interpretation of its effects, we present here a simple accounting framework for asset prices. The framework characterizes the prices of two fundamental assets, a zero-duration risk-free nominal security and a corresponding inflation-protected (hereafter "real") security. In addition to these two assets, households can trade futures contracts for them with any future expiration dates. Time is continuous, but there is a central bank that makes policy decisions at discrete moments (hereafter "meetings") that are one unit of time apart from each other. The current value of the nominal security is the central bank's policy rate, so this is fixed between the central bank's meetings.

The central bank follows a policy rule like that in Laséen and Svensson (2011) and Campbell et al. (2012). At meeting-instant $t^\star$, the policy rate $i_{t^\star}$ is set to

$$i_{t^\star} = g_{t^\star} + \sum_{j=0}^{M} \xi_{t^\star - j, j} \tag{1}$$

Here, $g_{t^\star} \equiv g(\Omega^c_{t^\star-\epsilon})$ is the systematic component of the monetary policy shocks, with $\Omega^c_{t^\star-\epsilon}$ denoting the central bank's information set as of the moment $t^\star - \varepsilon$. The small time increment ε represents an implementation delay, such as the time taken to transmit the central bank's policy rule choice to its trading desk. The remaining terms are the monetary policy shocks. The shock $\xi_{t^\star,0}$ is the *current* monetary policy shock, and it is uncorrelated with its own leads and lags. The remaining terms are forward guidance shocks that the central bank revealed after past meetings. After the meeting at $t^\star - j$, the central bank revealed $\xi_{t^\star-j,j}$. At that moment, it became common knowledge that this should would be applied to the interest-rate rule j meetings hence (that is, at $t^\star$). The central bank revealed shocks that influence $i_{t^\star}$ for the last M meetings.

Just as after past meetings, the central bank reveals a vector of forward guidance shocks, $\vec{\xi}^\star_t \equiv (\xi_{t^\star,1}, \ldots, \xi_{t^\star,M})$, at the same instant that it reveals $i_{t^\star}$. Like the current policy shock, this is uncorrelated with its own leads and lags and those $\xi_{t^\star,0}$. However, it may be correlated with $\xi_{t^\star,0}$ itself. Furthermore, the elements of $\vec{\xi}^\star_t$ may be correlated with each other. We make the normalizing assumptions that $\xi_{t^\star,0} \notin \Omega^c_{t^\star-\varepsilon}$ and $\vec{\xi}_{t^\star} \notin \Omega^c_{t^\star-\varepsilon}$.[7]

At exactly $t^\star$, the central bank issues a statement $s_{t^\star} \subset \Omega^c_{t^\star-\varepsilon}$ to the public. The public incorporates this message into its information set, $\Omega^p_{t^\star}$. Within this framework, we assume that the central bank is no worse informed than the public. That is, $\Omega^p_t \subset \Omega^c_t$ for all t. At that same moment, the media also communicates news $n_{t^\star}$ ("news") to the public. The public learns nothing else between $t^\star - \varepsilon$ and $t^\star$, so we have

$$\Omega^p_{t^\star} = \Omega^p_{t^\star-\varepsilon} \cup \{i_{t^\star}\} \cup \{\vec{\xi}_{t^\star}\} \cup s_{t^\star} \cup n_{t^\star}. \tag{2}$$

Within this framework, the central bank is no worse informed than the public. That is, $\Omega^p_t \cup \Omega^c_t$ for all t.

The real value of the nominal bond is subject to erosion (or enhancement) by inflation, which equals $\pi_t \in \Omega^p_t$ at instant t. This inflation and the returns to the

[7]Since $\vec{\xi}_{t^\star}$ is revealed to the public, it obviously is in Ω^c_t for $t > t^\star - \varepsilon$. Thus, the past values of these forward-guidance shocks appear on the right-hand side of (1) redundantly. This is for expositional clarity only.

real and nominal bonds satisfy the Fisher equation

$$r_t = i_t - \pi_t$$

always. For expositional ease, we assume that the only other traded assets are futures contracts on the two bonds. When two households executing such a contract at instant t which expires in n periods, one of them agrees to exchange a zero-duration bond with a fixed yield, $f_t(n)$ (set at instant t) for the otherwise equivalent zero-duration bond with the interest rate prevailing at instant $t+n$. We use the superscripts r and i to distinguish the forward rates on real and nominal bonds from each other, and we define the n-period forward instantaneous inflation compensation with $f_t^\pi \equiv f_t^i - f_t^r$. Following Piazzesi and Swanson (2008), we define the realized excess returns to the buyers of the n-period futures contracts and the realized excess inflation premium with

$$x_t^i(n) \equiv f_t^i(n) - i_{t+n},\ x_t^r(n) \equiv f_t^r(n) - r_{t+n},\ \text{and}\ x_t^\pi(n) \equiv f_t^\pi(n) - \pi_{t+n}.$$

Continuing, we define the n-period nominal, real, and inflation-compensation term premiums as the expectations of the corresponding excess returns given Ω_t^p. That is

$$\bar{x}_t^i(n) \equiv \mathbb{E}\left[x_t^i(n) \mid \Omega_t^p\right],\ \bar{x}_t^r(n) \equiv \mathbb{E}\left[x_t^r(n) \mid \Omega_t^p\right],\ \text{and}\ \bar{x}_t^\pi(n) \equiv \mathbb{E}\left[x_t^\pi(n) \mid \Omega_t^p\right].$$

In general, we use the notation $\bar{z}_t(n)$ to denote the expectation of z_{t+n} given Ω_t^p.

Completing the framework requires us to describe the evolution of inflation and the determination of futures prices. We assume that π_t evolves stochastically and that $\pi_\tau \in \Omega_t^p$ for all $\tau \leq t$. Otherwise, we leave inflation's stochastic process and the influence of monetary policy upon it unspecified. We make the weakest possible assumption regarding the futures prices: The rate of each contract consummated at t is a function of Ω_t^p only. Henceforth, we leave this dependence implicit in our expressions. While this imposes very little structure, it is sufficient for our accounting purposes.

With the framework's specification complete, we can proceed to consider the measurement of monetary policy disturbances using high-frequency asset-price data. Consider first a stylized version of the Kuttner (2001) measurement strategy.[8] Given

[8] Kuttner used futures contracts for which the floating rate was the average fed funds rate

the price of a futures' contract with floating rate $i_{t^\star} \equiv f^i_{t^\star}(0)$ written at $t^\star - \varepsilon$, this procedure proxies for $\xi_{t^\star,0}$ with

$$\Delta_\varepsilon f^i_{t^\star}(0) \equiv f^i_{t^\star}(0) - f^i_{t^\star-\varepsilon}(\varepsilon).$$

To determine the requirements for $\Delta_\varepsilon f^i_{t^\star}(0) \approx \xi_{t^\star,0}$, use the monetary policy rule and the term premium's definition to get

$$\Delta_\varepsilon f^i_{t^\star}(0) - \xi_{t^\star,0} = \bar{x}^i_{t-\varepsilon}(\varepsilon) + g(\Omega^c_{t^\star-\varepsilon}) - \mathbb{E}\left[g(\Omega^c_{t^\star-\varepsilon}) \mid \Omega^p_{t-\varepsilon}\right] \tag{3}$$

The estimation error's first component is the ε-period term premium; and we label the remaining terms' sum the contribution of central bank private information. So for this stylized version of the Kuttner procedure to yield reasonably accurate sequences of contemporaneous policy shocks, the term premium should vary little across meetings and the central bank should not base its policy rate choices on any private information in its possession. The requirement on the term premium is consistent with the results of Piazzesi and Swanson (2008), which show that this premium's variance is concentrated at business-cycle frequencies. We test the assumption on private information below.

As noted above, GSS and Campbell et al. (2012) extended the Kuttner strategy to measure the surprise component of expected future policy rates with changes in nominal futures rates. For $j \in \{1, 2, \ldots, M\}$, these changes can be written as

$$\begin{aligned}
\Delta_\varepsilon f^i_{t^\star}(j) &\equiv f^i_{t^\star}(j) - f^i_{t^\star-\varepsilon}(j+\varepsilon) \\
&= \bar{i}_{t^\star}(j) - \bar{i}_{t^\star-\varepsilon}(j+\varepsilon) + \bar{x}^i_{t^\star}(j) - \bar{x}^i_{t^\star-\varepsilon}(j+\varepsilon) \\
&= \xi_{t^\star,j} + \bar{g}_{t^\star}(j) - \bar{g}_{t^\star-\varepsilon}(j+\varepsilon) + \bar{x}^i_{t^\star}(j) - \bar{x}^i_{t^\star-\varepsilon}(j+\varepsilon) \\
&= \xi_{t^\star,j} + \Delta_\varepsilon \bar{g}_{t^\star}(j) + \Delta_\varepsilon \bar{x}^i_{t^\star}(j).
\end{aligned}$$

Analogously to the current policy rate, the futures-based surprise measure sums the forward guidance shock, a revision to the expectation of the interest-rate rule's systematic component, and a policy-induced change in the term premium.

By definition, the shock $\xi_{t^\star,j}$ is one component of Odyssean forward guidance.

realized over the contract month; and so inference of the fed funds shock from the change in this contract's price requires careful accounting of the FOMC meeting's monthly timing. This work is obviously unnecessary in our more abstract environment.

The revision to the expectations of $g_{t^\star+j}$ embodies other Odyssean forward guidance (the revelation of $\vec{\xi}_{t^\star}$), the current policy shock ($\xi_{t^\star,0}$), Delphic forward guidance (the revelation of $s_{t^\star}$), and public news (the receipt of $n_{t^\star}$). Although the public receives these three pieces of information simultaneously, it is helpful to imagine them being received sequentially in the order $n_{t^\star}$, $s_{t^\star}$, $\xi_{t^\star,0}$, $\vec{\xi}_{t^\star}$. This allows us to write $\Delta_\varepsilon \bar{g}_{t^\star}(j)$ as the sum of four orthogonal components, each of which reflects one of these messages.

$$
\begin{aligned}
\Delta_\varepsilon \bar{g}_{t^\star}(j) &= \iota^{\vec{\xi}}_{t^\star}(j) + \iota^{\xi_0}_{t^\star}(j) + \iota^{s}_{t^\star}(j) + \iota^{n}_{t^\star}(j); \text{ with} \\
\iota^{n}_{t^\star}(j) &\equiv \mathbb{E}\left[g_{t^\star+j} \mid \Omega^p_{t^\star-\varepsilon} \cup \{n_{t^\star}\}\right] - \mathbb{E}\left[g_{t^\star+j} \mid \Omega^p_{t^\star-\varepsilon}\right] \\
\iota^{s}_{t^\star}(j) &\equiv \mathbb{E}\left[g_{t^\star+j} \mid \Omega^p_{t^\star-\varepsilon} \cup \{n_{t^\star}\} \cup \{s_{t^\star}\}\right] - \mathbb{E}\left[g_{t^\star+j} \mid \Omega^p_{t^\star-\varepsilon} \cup \{n_{t^\star}\}\right] \\
\iota^{\xi_0}_{t^\star}(j) &\equiv \mathbb{E}\left[g_{t^\star+j} \mid \Omega^p_{t^\star-\varepsilon} \cup \{n_{t^\star}\} \cup \{s_{t^\star}\} \cup \{\xi_{t^\star,0}\}\right] - \mathbb{E}\left[g_{t^\star+j} \mid \Omega^p_{t^\star-\varepsilon} \cup \{n_{t^\star}\} \cup \{s_{t^\star}\}\right], \text{ and} \\
\iota^{\vec{\xi}}_{t^\star}(j) &\equiv \mathbb{E}\left[g_{t^\star+j} \mid \Omega^p_{t^\star-\varepsilon} \cup \{n_{t^\star}\} \cup \{s_{t^\star}\} \cup \{\xi_{t^\star,0}\} \cup \{\vec{\xi}_{t^\star}\}\right] - \mathbb{E}\left[g_{t^\star+j} \mid \Omega^p_{t^\star-\varepsilon} \cup \{n_{t^\star}\} \cup \{s_{t^\star}\} \cup \{\xi_{t^\star,0}\}\right] \\
&= \mathbb{E}\left[g_{t^\star+j} \mid \Omega^p_{t^\star}\right] - \mathbb{E}\left[g_{t^\star+j} \mid \Omega^p_{t^\star-\varepsilon} \cup \{n_{t^\star}\} \cup \{s_{t^\star}\} \cup \{\xi_{t^\star,0}\}\right].
\end{aligned}
$$

If we again appeal to Piazzesi and Swanson (2008) to justify ignoring the term premium's change, we can write the surprise change in the j-period ahead forward rate as

$$
\Delta_\varepsilon f^i_{t^\star}(j) \approx \xi_{t^\star,j} + \iota^{\vec{\xi}}_{t^\star}(j) + \iota^{\xi_0}_{t^\star}(j) + \iota^{s}_{t^\star}(j) + \iota^{n}_{t^\star}(j). \tag{4}
$$

If the public and central bank were always equally well-informed and there were no Odyssean forward guidance; then the first, second, and fourth terms would identically equal zero. The change in the futures rate would equal a contribution from the propagation of the current policy shock through the economy and into the policy rule's value in $t^\star + j$ ($\iota^{\xi_0}_{t^\star}(j)$) and a term from the arrival of news from sources other than the central bank ($\iota^{n}_{t^\star}(j)$). The inclusion of Delphic forward guidance in s_t introduces $\iota^{s}_{t^\star}(j)$. Finally, Odyssean forward guidance makes the first two terms non-zero. In this sense, () decomposes the surprise in the j-period ahead futures contract rate into four components: Odyssean forward guidance (the first two terms summed), Delphic forward guidance, the current policy shock's propagation, and the effects of coincident news.

The characterization of the standard monetary shock measurement scheme is now in place, so we can proceed to consider the identification of their effects. For

this, consider the change in the futures' contract rate for the nominal bond at some date $t^\star + h$, where $h > j$. This latter inequality ensures that $\vec{\xi}_{t,0}$ only influences $i_{t^\star+h}$ indirectly through its effects on $\Omega^c_{t^\star+h^\downarrow}$. (Here, $h^\downarrow$ is the greatest integer less than h.) Therefore, we can decompose the change in the forward rate into eight components.

$$\begin{aligned}\Delta_\varepsilon f^i_{t^\star}(h) &= \Delta_\varepsilon \bar{g}^i_{t^\star}(h) + \Delta_\varepsilon \bar{x}^i_{t^\star}(h) \\ &= \iota^{\vec{\xi}}_{t^\star}(h) + \iota^{\xi_0}_{t^\star}(h) + \iota^{s}_{t^\star}(h) + \iota^{n}_{t^\star}(h) \\ &\quad + \eta^{\vec{\xi}}_{t^\star}(h) + \eta^{\xi_0}_{t^\star}(h) + \eta^{s}_{t^\star}(h) + \eta^{n}_{t^\star}(h)\end{aligned} \tag{5}$$

The $\iota(h)$ shocks are defined analogously to those for j, but with $g_{t+h} \equiv g_{t+h^\downarrow}$. (That is, the systematic component of monetary policy is fixed between meetings.) The $\eta(h)$ shocks give the analogous decomposition for the surprise change in the term premium. Hanson and Stein (2015) strongly suggest that these last shocks are *not* identically zero for large values of h.

We are now prepared to characterize the results of regressing $\Delta_\varepsilon f^i_{t^\star}(h)$ on $\Delta_\varepsilon f^i_{t^\star}(j)$. In population, this yields the coefficient

$$\beta(h,j) \equiv \frac{\mathbb{E}\left[\Delta_\varepsilon f^i_{t^\star}(h)\Delta_\varepsilon f^i_{t^\star}(j)\right]}{\mathbb{E}\left[\Delta_\varepsilon f^i_{t^\star}(j)^2\right]}.$$

These expectations are taken by averaging over an infinite sample of meetings. Using the decompositions in (2.2) and (5), we can express this coefficient as a weighted average of four regression coefficients.

$$\begin{aligned}\beta(h,j) &= \frac{\sigma^2(\xi_{t^\star,j} + \iota^{\vec{\xi}}_{t^\star}(j))}{\sigma^2(\Delta_\varepsilon f^i_{t^\star}(j))}\beta^{\vec{\xi}}(h,j) + \frac{\sigma^2(\iota^{\xi_0}_{t^\star}(j))}{\sigma^2(\Delta_\varepsilon f^i_{t^\star}(j))}\beta^{\xi_0}(h,j) + \\ &\quad + \frac{\sigma^2(\iota^{s}_{t^\star}(j))}{\sigma^2(\Delta_\varepsilon f^i_{t^\star}(j))}\beta^{s}(h,j) + \frac{\sigma^2(\iota^{n}_{t^\star}(j))}{\sigma^2(\Delta_\varepsilon f^i_{t^\star}(j))}\beta^{n}(h,j).\end{aligned} \tag{6}$$

The weights in (6) sum to one, and the regression coefficients are defined with

$$\begin{aligned}
\beta^{\vec{\xi}}(h,j) &\equiv \frac{\mathbb{E}\left[(\xi_{t^\star,j}+\iota^{\vec{\xi}}_{t^\star}(j))(\iota^{\vec{\xi}}_{t^\star}(h)+\eta^{\vec{\xi}}_{t^\star}(h))\right]}{\sigma^2(\xi_{t^\star,j}+\iota^{\vec{\xi}}_{t^\star}(j))}, \\
\beta^{\xi_0}(h,j) &\equiv \frac{\mathbb{E}\left[\iota^{\xi_0}_{t^\star}(j)(\iota^{\xi_0}_{t^\star}(h)+\eta^{\xi_0}_{t^\star}(h))\right]}{\sigma^2(\iota^{\xi_0}_{t^\star}(j))}, \\
\beta^{s}(h,j) &\equiv \frac{\mathbb{E}\left[\iota^{s}_{t^\star}(j)(\iota^{s}_{t^\star}(h)+\eta^{s}_{t^\star}(h))\right]}{\sigma^2(\iota^{s}_{t^\star}(j))}, \text{ and} \\
\beta^{n}(h,j) &\equiv \frac{\mathbb{E}\left[\iota^{n}_{t^\star}(j)(\iota^{n}_{t^\star}(h)+\eta^{n}_{t^\star}(h))\right]}{\sigma^2(\iota^{n}_{t^\star}(j))}.
\end{aligned}$$

These four regression coefficients are the "pure" measures of policy responses of $f^i_{t^\star}(h)$ to Odyssean forward guidance, the current policy rate, Delphic forward guidance, and public news. The identifiable regression coefficient weights these with variance contributions. Of course, analogous decompositions can be derived for the responses of $f^r_{t^\star}(h)$ and $f^\pi_{t^\star}(h)$.

Regardless of the asset under examination, the identified responses of asset prices to short-dated nominal interest-rate futures conflate the responses that directly map into simple models' impulse-response functions for future policy shocks with responses to Delphic forward guidance and news shocks. Therefore, the interpretation of this "cleanly" identified coefficient is far from straightforward. The Hanson and Stein (2015) results cited above strongly suggest that the covariances of the $\iota(j)$ shocks with $\eta(h)$ shocks are not zero. Furthermore, the influence of public news shocks reveals that high-frequency measurement does not by itself solve the classical simultaneous equations problem. Rigobon and Sack (2004) emphasize this obstacle and propose avoiding it by using estimates of asset price responses from days *without* FOMC policy actions to remove the influence of $\beta^n(h,j)$ from $\beta(h,j)$. Below, we undertake an effort to account for $\beta^s(h,j)$ based on measures of the information that could possibly be included within Delphic forward guidance.

2.3 The FOMC's Delphic Forward Guidance

Unlike some inflation-targeting central banks abroad, the FOMC publishes no consensus forecasts of macroeconomic fundamentals and interest rates. Accordingly, the committee's post-meeting statements have historically lacked much quantitative

Table 1: Factor Structure of Short-Term FOMC Private Information

	Factors' Shares of Variance					
	CPI-Inflation		GDP Growth		Unemployment	
	Short	Long	Short	Long	Short	Long
Current quarter	80	0	68	0	99	0
Next quarter	26	42	33	13	77	19
Two quarters hence	10	71	58	4	47	51
Three quarters hence	14	87	3	77	36	63
Four quarters hence	13	77	9	66	30	67

content. Our approach to measuring Delphic forward guidance therefore does nothing with the statements themselves. Rather, we measure information that was available to FOMC participants but that was not in the public information set. Specifically, we take the forecasts for CPI inflation, GDP growth, and the unemployment rate contained in the committee's Greenbook and subtract the analogous consensus (that is, average) forecasts from the most recent Bluechip survey.[9]

The measured forecast differences cover the current quarter (the "nowcast") and the next four quarters. To keep our results interpretable, we reduce these 15 variables to 6 by conducting a factor analysis identical to that applied by GSS to the interest rate futures data. The factor analogous to the path factor, which by construction has no impact on the forecast of the current quarter's value, we call the "Long" factor. The other one is the "Short" factor. Table 1 reports the variance decompositions for these variables. With the exception of GDP growth one and two quarters into the future, these two factors account for the vast majority of observed variance.

Our next step uses these measures of FOMC private information to measure the information revealed in FOMC statements, as reflected in the following changes in market expected interest rates. Table 2 reports the associated regression estimates and Wald tests for the exclusion of groups of regressors. Asymptotic standard errors

[9]The Bluechip survey collects forecasters' responses at the beginning of each calendar month, and the results are published on or about the 10th of the month. We match each Greenbook with the current month's Bluechip forecast if the Greenbook publication date was on or after the 10th. Otherwise, we use the previous month's measure. Of course, public information that was not available to Bluechip's private forecasters will be incorporated into the Greenbook forecasts. This biases our procedure *against* finding substantial effects of FOMC "private" information on innovations in interest rates and forecasts.

Table 2: FOMC Revelation of Private Information

	Current Rate	Four Quarters Ahead
CPI Short Factor	-0.40	-1.25
	(0.79)	(0.99)
CPI Long Factor	-1.62	-4.99
	(5.37)	(6.72)
GDP Short Factor	-1.38	4.00
	(2.00)	(2.50)
GDP Long Factor	3.72	9.16**
	(2.68)	(3.36)
U Short Factor	-8.93	-11.13
	(5.04)	(6.31)
U Long Factor	-6.08	4.69
	(6.09)	(7.64)
CPI Short Factor Lag	0.53	0.37
	(0.77)	(0.96)
CPI Long Factor Lag	-0.73	3.48
	(5.32)	(6.66)
GDP Short Factor Lag	0.99	1.16
	(1.86)	(2.33)
GDP Long Factor Lag	-2.17	-11.13***
	(2.91)	(3.64)
U Short Factor Lag	-0.17	-1.65
	(5.22)	(6.54)
U Long Factor Lag	6.70	-3.11
	(6.02)	(7.54)
R^2	0.13	0.23
	Wald Tests	
All Variables	15.76	33.33**
Current Variables	8.52	11.08
Lagged Variables	4.47	19.34***
CPI Measures	1.01	1.78
GDP Measures	6.01	19.25***
U Measures	7.23	7.79

are reported below each regression coefficient. For both coefficients' t-statistics and the Wald tests, we calculated critical values using $100,000$ bootstrap replications that treat the meetings as identical. *The significance stars that accompany the coefficient estimates and Wald test statistics come from these bootstrap calculations.* Unsurprisingly, our reliance on bootstrapped critical values makes the results seem less "significant" than they otherwise would be. In that sense, our procedure is conservative. The regressions include twelve variables each, the six principle components from the current meeting as well as those from the *previous* meeting. These regressions might be relevant, because no theory requires the FOMC to reveal its information in a timely manner.

Table 2's first column reports the results from using the current policy rate as the dependent variable. The regression R^2 equals 0.13, and none of the estimated coefficients are statistically-significant. More importantly, none of the Wald tests indicate that the included variables have explanatory power. Overall, this absence of evidence for Delphic forward guidance influencing the current policy rate is a victory for the Kuttner (2001) procedure for measuring the current policy shock.

The second column reports results from using the four-quarter ahead futures contract rate as the dependent variable. Here, the R^2 is substantially higher, 0.23. Two of the GDP coefficients are statistically significant, those multiplying both meeting's Long factor. The former is positive, as we would expect if high expected GDP growth leads policy makers to signal tighter future policy. The latter coefficient is however negative. We do not find this too disturbing though, because the analogous coefficients on the two regressors which should have high correlations with the GDP long factor, the CPI and Unemployment ("U") in the table Long factors, have the expected signs. They have economically significant magnitudes, but they are measured imprecisely. The Wald test rejects the null hypothesis that all of the variables can be rejected at the five-percent level. So it does appear that Delphic forward guidance is associated with the statement. Perhaps more surprisingly, it appears that this guidance comes mostly from private information available in the previous meeting. The Wald test rejects the null that these variables can be excluded at the one percent level. On the other hand, the Wald test does not reject the null that the most recently obtained private information can be excluded. We interpret these results as indicating *latency* in the transmission of private information from the Federal Reserve's staff forecasters through FOMC participants and into the

committee's statement. It seems that participants digest newly acquired information between meetings before incorporating it into statements. This evidence certainly merits greater exploration.

The regression results in Table 2 provide one means of measuring short-run Delphic forward guidance: decompose the 4-quarter ahead futures rate into fitted values and residuals. The fitted values are our measure of short-run Delphic forward guidance. We emphasize "short-run" because the information used in its identification only covers the next several quarters.[10] Although we doubt that other variables are available that substantially add to our measure of private FOMC information about the economy's near-term performance, there could be other information about longer-run outcomes. Even if those outcomes are outside of the FOMC's control (e.g. the long-run real interest rate), the FOMC's information about them might still be revealed in post-meeting statements and thereby influence asset prices. Therefore, we refrain from applying any more structural interpretation to the regression's residuals.

Above, we discussed the possibility that Delphic forward guidance could be responsible for the counterintuitive effects of measured forward guidance on forecast revisions documented by Campbell et al. (2012). Table 3 provides evidence on that point. For the four forecasts of each variable available in our data, its first column reports estimated coefficients from bivariate regressions of the Bluechip survey's revision to that forecast (from the survey prior to the meeting to the one following it) on the four-quarter ahead futures rate itself. Each coefficient's asymptotic standard error is below it. The second column reports these regressions' R^2 measures. For the CPI forecasts, the regression coefficients and R^2's are all very close to zero. The coefficient for forecast of next quarter's GDP growth forecast is positive and statistically significant at the one percent level.[11] A naive reading of this would suggest that tightening monetary policy raises expected GDP growth. The coefficients for the remaining GDP forecasts are positive but not statistically significant. The forecast of next quarter's unemployment rate has a statistically significant (at the five percent level) and negative coefficient. The unemployment forecasts at other horizons have similar coefficients but they are

[10] Our tables omit this qualifier only because of space constraints.

[11] Just as with the estimates in Table 2, we tabulated statistical significance of all coefficients in this table using $100,000$ bootstrap replications.

Table 3: Bluechip Forecasts' Responses to Decomposed Monetary Policy

	Baseline Regressions		w/ Delphic Decomposition		
	Future Policy Rate	R^2	Delphic Component	Residual	R^2
CPI Inflation					
Next quarter	-0.01	0.00	0.54	-0.18	0.01
	(0.25)		(0.52)	(0.29)	
Two quarters hence	-0.10	0.01	0.22	-0.20	0.03
	(0.11)		(0.22)	(0.12)	
Three quarters hence	-0.06	0.01	0.14	-0.12	0.02
	(0.07)		(0.15)	(0.08)	
Four quarters hence	0.00	0.00	0.23*	-0.07	0.04
	(0.06)		(0.12)	(0.07)	
GDP Growth					
Next quarter	0.66***	0.03	2.88**	-0.01	0.12
	(0.36)		(0.72)	(0.40)	
Two quarters hence	0.27	0.01	1.75***	-0.18	0.14
	(0.20)		(0.40)	(0.22)	
Three quarters hence	0.07	0.00	0.66**	-0.11	0.07
	(0.12)		(0.23)	(0.13)	
Four quarters hence	0.06	0.00	0.29	-0.01	0.02
	(0.09)		(0.19)	(0.10)	
Unemployment					
Next quarter	-0.21**	0.05	-0.88***	-0.01	0.21
	(0.05)		(0.16)	(0.09)	
Two quarters hence	-0.19	0.02	-1.08***	0.09	0.19
	(0.11)		(0.20)	(0.11)	
Three quarters hence	-0.17	0.02	-1.28***	0.16	0.20
	(0.13)		(0.24)	(0.13)	
Four quarters hence	-0.18	0.02	-1.18***	0.12	0.17
	(0.12)		(0.24)	(0.13)	

measured less precisely. Again, a naive interpretation of this evidence would suggest that tightening monetary policy lowers the unemployment rate.

Table 2's remaining columns report the results from the analogous regressions that use the policy rate's decomposition into its short-run Delphic component and the associated residual. The CPI-forecast regressions have positive but imprecisely-measured coefficients multiplying the forward rate's Delphic component, and negative but imprecisely-measured coefficients multiplying the forward rate's residual. One of the coefficients multiplying the Delphic component is statistically-significant at the ten percent level, but otherwise inference from the simpler regression with only the forward rate itself remains unchanged.[12]The results from the GDP and Unemployment forecast regressions differ substantially from this result. The GDP forecasts for one, two, and three quarters out all have statistically significant and large coefficients multiplying the forward rate's Delphic component. The coefficients multiplying the residual component are all negative but small and not statistically significant. The same pattern is true for the Unemployment forecasts. The forward rate's Delphic component has negative and statistically-significant (at the one percent level) coefficients, while the residual component has coefficients that are much closer to zero and (with one exception) positive. In light of these results, it should be no surprise that the R^2 measures from these regressions are much higher than those for the CPI-forecast regressions. Nevertheless, substantial variance in the forecast revisions remains.

Overall, the results of Table 3 validate the Delphic hypothesis as applied to the revisions of Bluechip forecasts: the FOMC's statements reveal its private information (probably with a lag), and this influences expectations of short-run interest rates. The same information leads to substantial revisions of private forecasts, so we see forecasts of GDP growth and unemployment rising "in response to" increases in expected future policy rates. Of course, much remains to be uncovered; because the portion of the expected future policy rate that is unexplained by FOMC private information (about 80 percent of its variance) has no statistically-significant effect on short-term forecast revisions. We hope that better measurement of the FOMC's Delphic forward guidance that focuses more on medium-run and

[12]These regressions R^2s are very low, which is perhaps unsurprising since much more information is revealed over the month than the FOMC's forward guidance. Improving inference by including other measurable relevant variables, such as differences between data releases and their consensus expectations, is on our research agenda.

long-run economic outcomes combined with the inclusion of variables that are (theoretically) orthogonal to measured Delphic forward guidance but nevertheless relevant for private forecast revisions will yield a better understanding of how this residual's movements change expectations.

Our attempt to place the results of Hanson and Stein (2015) within the context of Delphic forward guidance is summarized in Table 4. Its first two columns report regressions analogous to those reported by those authors. The dependent variables are the instantaneous forward nominal rates, real rates, and inflation compensation rates at the two, five, and ten year horizons calculated by Gürkanynak et al. (2006,?).[13] The independent variable is the same four-quarter ahead nominal futures rate examined in Tables 2 and 3. We comment further on the implications of this difference below. For now, note that our results are comparable to theirs. The future policy rate has large, positive, and statistically significant effects on both the nominal and real rates. These effects get smaller as the securities' horizons increase, but they do not disappear, even at a ten year horizon.

One important difference between our estimates and Hanson and Stein's is that these regressions' R^2s are much lower than those they report for their baseline case. This can be entirely attributed to our use of a different monetary policy indicator.[14] Hanson and Stein measured the stance of monetary policy with the nominal two-year zero-coupon yield from Gürkanynak et al. (2006). We were concerned that shocks to public news relevant for Treasury yield curves but not directly arising from monetary policy could be unduly contributing to the measured relationship between these asset prices. To examine this hypothesis, we estimated the regressions of Hanson and Stein using data from *five days before* each FOMC meeting. For recent meetings, this places the data within the "blackout period" during which staff and policymaker commentary on monetary policy developments is prohibited. Nevertheless, the coefficient estimates we obtain from those days similar to those reported in Hanson and Stein (2015). However, the estimates from the same days using changes in the forward rate we employ show no relationship between the two prices. For this

[13] The estimation with the 2-year rates uses a sample that starts only in 2004, when sufficiently many previously-issued Tips had aged into this maturity to enable measurement of the yield curve at this very short horizon.

[14] Hanson and Stein (2015) considered the robustness of their results to using a policy indicator very similar to that we employ, the three-quarter ahead Eurodollar futures rate. Their estimated coefficients and R^2s are correspondingly similar to those we report. Please see their Table 2 for more details.

Table 4: Treasury Price Responses to Decomposed Monetary Policy

	Baseline Regressions		w/ Delphic Decomposition		
	Future Policy Rate	R^2	Delphic Component	Residual	R^2
2-Year Instantaneous Forward					
Nominal	0.86***	0.30	0.47	0.72***	0.31
	(0.14)		(0.26)	(0.18)	
Real	1.04***	0.29	0.77**	0.75***	0.40
	(0.29)		(0.25)	(0.17)	
Inflation Compensation	-0.18	0.02	-0.31	-0.03	0.03
	(0.15)		(0.29)	(0.20)	
5-Year Instantaneous Forward					
Nominal	0.27**	0.06	0.14	0.31***	0.06
	(0.10)		(0.21)	(0.11)	
Real	0.23***	0.09	0.13	0.26***	0.09
	(0.07)		(0.15)	(0.08)	
Inflation Compensation	0.04	0.00	0.01	0.04	0.00
	(0.07)		(0.15)	(0.08)	
10-Year Instantaneous Forward					
Nominal	0.14*	0.03	-0.10	0.20***	0.05
	(0.08)		(0.16)	(0.09)	
Real	0.15**	0.06	0.02	0.18***	0.08
	(0.05)		(0.11)	(0.06)	
Inflation Compensation	-0.01	0.00	-0.12	0.02	0.01
	(0.05)		(0.11)	(0.06)	

reason, we believe the forward rate that we employ is a "purer" measure of FOMC policy intentions than is the two-year zero coupon nominal treasury rate.

The remaining columns of Table 4 report the results from the analogous regressions that decompose the future policy rate into its short-run Delphic and residual components. Here, the results are very striking. As one might expect, the short-run Delphic component has a large and statistically-significant effect on the 2-year instantaneous forward real rate. Unfortunately though, the sample is too short to precisely decompose that real effect into effects on the nominal rate and inflation compensation. However, the Delphic component has no measurable effects on any of the five-year or ten-year securities. In contrast, the residual component has large and statistically-significant (at the one-percent level) on the real and nominal forward rates at all three horizons. Just as in the original Hanson and Stein regressions, neither the Delphic component nor the residual has any effect on forward inflation compensation worth noting.

As we noted above, Hanson and Stein (2015) discussed two explanations for their findings, Delphic forward guidance (in their words, "the revelation of the Fed's private information about the future evolution of the economy."[15]) and changes in term premiums driven by yield-oriented investors. Although we cannot decisively eliminate the possibility of monetary policy impacting term premiums (nor do we wish to do so), we believe that the evidence in Table 4 favors an information-based interpretation. The Delphic component of the four-quarter-ahead futures rate increases rates at the short end of the yield curve but *not* at the long end. It could be that the strong economic fundamentals that underly a Delphic increase in expected policy rates increase demand for Treasuries that exactly offsets the flight of yield-oriented investors back to shorter-dated securities; but in that case we would expect the Delphic component to raise short interest rates much more than does the residual component. There is no evidence that this is the case. In an information-based story, the Delphic component only matters for short-dated securities simply because it is short-run information. The effects of the residual component on long rates can then be understood as the revelation of information about long-run outcomes. The standard deviation of this residual component is approximately 10 basis points. If we take these over eight meetings, this results in an annual standard deviation of revisions to the long-run real rate of $0.18\sqrt{8 \times 10^2} \approx 5$ basis points per year. This is

[15] See the third full paragraph of their page 430.

hardly so large that it would be the dominant factor in long-run rates. Nevertheless, further empirical scrutiny of such an information-based hypothesis is warranted.

2.4 Evidence from VARs

The reduced form empirical evidence discussed above has the advantage that it relies on relatively weak identifying assumptions, but this approach currently has little to say about the the impact of Odyssean forward guidance shocks on macroeconomic outcomes. However there is a nascent literature that addresses this issue by making stronger assumptions. This literature builds on the traditional approach to identifying monetary policy shocks using VARs pioneered by Bernanke and Blinder (1992) and reviewed by Christiano, Eichenbaum, and Evans (1999). The traditional approach measures monetary policy shocks with changes in a policy indicator, typically the federal funds rate, that are orthogonal to a particular information set defined by a subset of the variables included in the VAR. Unlike high frequency identification, then, this literature takes a stand on the nature of the monetary policy rule and in particular the information used by the Fed in making its policy choices.

The traditional approach ignores forward guidance because it implicitly assumes that $\xi_{t-j,j} = 0$ for $j > 0$ in the policy rule defined in (1). Ramey (2016) discusses the challenges to identifying monetary policy shocks when this assumption is violated and Campbell et al. (2012) find that a substantial fraction of the residual variation in an estimated policy rule is forecastable. So this assumption is not innocuous. The new monetary VAR literature allows that $\xi_{t-j,j} \neq 0$ for at least some $j > 0$ and makes a variety of assumptions to extract this information from different specifications of the policy rule.

Gertler and Karadi (2015) extract this information by using changes in four quarter ahead fed funds futures on FOMC days as instruments for the policy residuals with the one year treasury yield as the policy indicator. Like most of the new literature they focus on a sample that includes observations from before and after the funds rate attained its lower bound. Following a positive instrumented forward guidance shock real activity and prices fall. These findings are qualitatively consistent with the predictions of NK models. However Gertler and Karadi (2015) also find that the response of long term interest rate cannot be explained by the

expected path of short rates which is the principle channel through which forward guidance operates in NK models.

Barakchian and Crowe (2013) and Bundick and Smith (2015) also use high frequency data to identify forward guidance shocks in a VAR. They do so by using the cumulated sum of changes in fed funds futures on FOMC days as the policy indicator. Both papers find real activity contracts after a positive forward guidance shock. Barakchian and Crowe (2013) find counter-intuitive effects on the price level while Bundick and Smith (2015) find that prices fall. Bundick and Smith (2015)'s results are particularly noteworthy since they are based on a ZLB-only sample. Given their short sample the small standard error bands surrounding their estimates are surprising.

D'Amico and King (2016) use a sign restriction methodology to extract forward guidance shocks. They include survey expectations in VARs that include the 3-month T-bill rate as the policy indicator. Forward guidance shocks are identified as innovations in expected T-bill rates that drive them oppositely to survey expectations of output and prices. This identification strategy is attractive because it isolates shocks in which Odyssean dominates Delphic guidance. D'Amico and King (2016) also find that realized output and consumer prices decline in response to positive forward guidance shocks.

Finally, Zeev, Gunn, and Khan (2015) extract forward guidance from policy rule residuals using Barsky and Sims (2011)'s method of identifying news shocks. They first construct policy residuals as the difference between the federal funds rate and a pre-specified policy rule. Forward guidance shocks are then identified from a VAR as the linear combination of reduced form residuals that are orthogonal to the policy residuals and maximize the contribution to the policy residual's forecast error variance over a finite horizon. They find that after a positive forward guidance shock the federal funds rate does indeed rise gradually and is accompanied by declines in output and prices.

This literature is in its early stages and is subject to many of the perceived shortcomings of the traditional approach reviewed by Ramey (2016). Nevertheless the similarity in the findings across distinct identification strategies is striking. Taken at face value they generally support the view that forward guidance influences output and prices much as predicted by standard NK models, at least qualitatively. However there are limits to what can be accomplished with reduced form analysis.

Our ultimate goal is to quantify the impact of forward guidance on macroeconomic outcomes since the financial crisis. In principle an estimated VAR can be used to address this question, for example by simulating it under the assumption of no forward guidance shocks. However, conducting such an exercise does not guarantee that the lower bound on nominal rates will be respected. Furthermore the nature of forward guidance clearly changed during the ZLB period so there is a very short sample to work with. This not only stresses the limits of VAR analysis it also severely restricts the nature of the forward guidance one can consider.

Therefore, we address our question within the context of a fully-specified structural model. While such an approach inevitably requires even stronger assumptions than employed in the new monetary VAR literature, it does make it possible to consider a richer array of forward guidance and to impose the lower bound constraint when we consider our counterfactual exercise. The generally validating reduced form findings we have described above motivate us to do this within a NK setting.

3 The Model

We employ an enhanced version of the canonical medium-scale NK model pioneered by Christiano et al. (2005) and Smets and Wouters (2007). Our model incorporates many of the refinements that have been introduced since these seminal papers were written. In addition we model forward guidance building on Laséen and Svensson (2011) and Campbell et al. (2012), introduce a preference for safe and liquid assets as suggested by Fisher (2015), and employ Jaimovich and Rebelo (2009) preferences over consumption and work. Since much of the model's specification is familiar we emphasize the novel aspects of our framework together with a complete description of the underlying structural shocks, which is essential to understand the experiments discussed below. For a complete characterization of the model see the appendix.

3.1 Households

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

$$E_0 \sum_{t=0}^{\infty} \beta^t \varepsilon_t^b \left[U(V_t) + \varepsilon_t^s L(\frac{B_{t+1}}{P_t R_t}) \right]. \tag{7}$$

The period utility function U is specified as

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

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

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

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

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

These are the preferences introduced in Jaimovich and Rebelo (2009) except that we have modified them to include external habit formation in consumption.[16] These preferences include the parameter $\mu \in (0, 1)$ which controls the wealth elasticity of labor supply while preserving compatibility with balanced growth. The parameter $\varrho > 0$ determines the degree of habit formation and γ_H controls the Frisch elasticity of labor supply in the special case in which $\varrho = \mu = 0$. As $\mu \to 0$ and in the absence of habit formation these preferences reduce to the specification considered by Greenwood et al. (1988). In this special case labor supply depends only on the current real wage faced by households and is independent of the marginal utility of wealth. So as μ and ϱ get smaller, anticipated changes in income have smaller effects on current labor supply. Conversely as μ gets larger the wealth elasticity gets larger and in the polar case when $\mu = 1$ preferences reduce to the standard preferences

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

proposed by King, Plosser, and Rebelo (1988).

Jaimovich and Rebelo (2009) introduced their preferences because of their implications for the propagation of news about future production possibilities. With standard preferences news about improved production possibilities in the future raises current wealth thereby increasing current consumption and lowering labor supply. They found that allowing for flexibility in the short run effects of wealth on labor supply it was possible to generate business cycle co-movement in response to news about future production possibilities. We similarly include these preferences because of our focus on news about future settings of monetary policy, that is forward guidance. In NK models news about future settings of monetary policy influence current activity in part through wealth effects on labor supply.

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

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

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

Including this model feature allows the interest rate controlled by the central bank, R_t, to deviate from the return to installed capital. NK models typically maintain the assumption that these two rates of return coincide. Since the level of the federal funds rate is usually included as an observable in estimation, the assumption of equality potentially influences the values of parameters and the

business cycle decompositions derived from those parameters. We show below that a spread between private and government rates of return introduces discounting into the household's inter-temporal Euler equation for consumption which, as discussed by Del Negro et al. (2015) and McKay et al. (2015), is useful for understanding the impact of forward guidance in NK models.

A second reason for introducing "liquidity preferences" is that, as demonstrated by Fisher (2015), these preferences provide a simple micro-foundation for the ad hoc shock to the household's intertemporal consumption Euler equation introduced by Smets and Wouters (2007). This shock plays a crucial role in empirical NK models because it is one of the few sources of co-movement between consumption and investment and therefore in estimated models often appears as a major source of cyclical fluctuations. In our context this shock is the preference shifter ε_t^s in 7. We assume it evolves according to

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

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

Households own the installed capital stock K_t. This is assumed to evolve over time according to

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

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

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

The owners of installed capital can control the intensity with which it is utilized. Let U_t measure capacity utilization in period t. Then the effective amount of capital

services supplied to firms in period t is $U_t K_t$. We assume that increasing the intensity of capacity utilization entails a cost in the form of faster depreciation, given by $\delta(U_t)$. We assume the functional form

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

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

3.2 Goods Markets

Households own all goods producers. Perfectly competitive firms produce the composite final good Y_t that sells for price P_t. They produce the final good using differentiated intermediate inputs purchased from a unit mass of monopolistically competitive firms, with technology

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

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

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

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

Intermediate goods producer i produces Y_{it} using the technology:

$$Y_{it} = (K_{it}^e)^\alpha \left[A_t^Y H_{it}^d \right]^{1-\alpha} - A_t \Phi, \tag{8}$$

where H_{it}^d is composite labor input bought at wage W_t in a competitive market from the labor compositors described below, $K_{it}^e = U_{it} K_{it}$ is effective capital rented from households and Φ is the fixed costs of production, paid in final goods (the value of

Φ is chosen so that aggregate monopoly profits of intermediate goods producers are zero in steady state.) The term A_t^Y is the level of the neutral technology. This is a non-stationary process which evolves as

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

where $\nu_t \equiv \ln\left(A_t^Y/A_{t-1}^Y\right)$. We refer to ν_t as the *neutral technology shock*. The term A_t in (8) is the stochastic trend of equilibrium consumption and output measured in consumption units given by $A_t = A_t^Y \left(A_t^I\right)^{\alpha/(1-\alpha)}$, where A_t^I is the level of the investment-specific technology described below. We use z_t to denote the log growth rate of A_t: $z_t = \nu_t + \alpha\omega_t/(1-\alpha)$.

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

Perfectly competitive firms supply investment goods to households at price P_t^I in consumption units using a linear technology that transforms final goods into investment at rate A_t^I. The investment-specific technology A_t^I is a non-stationary process which evolves as

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

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

3.3 Labor Markets

We adopt Smets and Wouters (2007)'s strategy for introducing sticky wages into an environment that includes preferences that are non-separable in consumption and labor. Households' rent their homogenous labor in a perfectly competitive market to a unit mass of household-owned labor guilds at wage W_t^h. Each labor guild is endowed with a technology that allows it to differentiate the households' labor. They

rent this differentiated labor to the labor compositors, also owned by households, as monopolistic competitors. The labor compositors re-package the differentiated labor into the homogenous factor input H_t^s supplied to intermediate goods producers. The labor re-packaging technology is given by

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

where H_{it} is the differentiated labor of guild i and λ_t^w drives the guilds' mark-up over their marginal cost, W_t^h. We assume the *wage mark-up shock* λ_t^w follows an exogenous process similar to λ_t^p:

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

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

3.4 Central Bank and Government

The central bank sets the nominal interest rate on safe and liquid one-period government bonds, R_t, using a parametric specification of the monetary policy rule stated above in equation (1). Specifically,

$$\ln R_t = \rho_R \ln R_{t-1} + (1-\rho_R) \ln R_t^n + \sum_{j=0}^{M} \xi_{t-j}^j. \tag{9}$$

The parameter $\rho_R \in [0,1]$ governs the degree of interest rate smoothing and R^n is the *notional* target interest rate, that is the rate the central bank would choose in the absence of interest rate smoothing. Recall that the first of these disturbances, ξ_t^0, is the usual contemporaneous monetary policy disturbance while the remaining shocks are *forward guidance* shocks, because they are revealed to the public before they are applied to the policy rule. Agents see ξ_t^j in quarter t, and it applies to the rule j quarters hence. This approach to modeling forward guidance was introduced

by Laséen and Svensson (2011) and studied previously by Campbell et al. (2012), Del Negro et al. (2015) and Zeev et al. (2015). Gather all monetary policy shocks into the vector ε_t^1,

$$\varepsilon_t^1 \equiv \left(\xi_t^0, \xi_t^1, \ldots, \xi_t^M\right)'. \tag{10}$$

Each realization of ε_t^1 influences the expected path of interest rates. We wish to map expectation revisions, which are uncorrelated over time by construction, into realizations of ε_t^1; so we assume that ε_t^1 is also uncorrelated over time.

The notional rate R^n is set according to

$$\ln R_t^n = \ln r_* + \ln \pi_t^* + \frac{\psi_1}{4} E_t \sum_{j=-2}^{1} \left(\ln \pi_{t+j} - \ln \pi_t^*\right) + \frac{\psi_2}{4} E_t \sum_{j=-2}^{1} \left(\ln Y_{t+j} - \ln y^* - \ln A_{t+j}\right) \tag{11}$$

The constant r_* corresponds to the steady state real interest rate and π_t^* is an exogenous inflation drift that could be interpreted as the central bank's intermediate target for inflation. The drift term is included to address inflation's low-frequency movements during our sample.[17] We call it the *inflation drift shock* and it evolves as

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

where π_* is steady state inflation. The last two terms in (11) correspond to the inflation and output gaps which drive the central bank's response to the economy's shocks with the parameters $\psi_1, \psi_2 \geq 0$ determining the elasticity of the response to these gaps. The inflation gap is a four-quarter moving average of the difference between twice and once lagged, current, and expected one-period-ahead log inflation and the contemporaneous value of the drift term. The output gap is a four-quarter moving average of the difference between twice and once lagged, current, and expected one-period-ahead log aggregate output and its stochastic trend. The constant y_* denotes steady state output in the model. Its inclusion in (11) guarantees that the gaps are closed and the steady state nominal interest rate on government bonds is $R_* = r_* \pi_*$.

The government issues bonds B_{t+1} and collects lump sum taxes T_t to pay for

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

government spending $G_t = A_t g_t$ in the final goods market. Therefore its one-period budget constraint is

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

We assume the government balances its budget every period, so government bonds are in zero net supply, $B_t = 0$, in equilibrium.[18] The *government spending shock* g_t evolves as

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

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

3.5 Equilibrium

Equilibrium is defined in the usual way. Agents optimize as described above and prices adjust to clear all markets except those for intermediate goods and composite labor. The constancy of the capital-labor ratio across intermediate good producers, Calvo pricing and wage setting, and our functional form assumptions for aggregating differentiated intermediate goods and labor, eliminates any heterogeneity from the log linearized equilibrium. At its core this is a real business cycle model and the first order conditions and resource constraints of the real side of the economy are the same. In addition to these equations the equilibrium is characterized by the wage and price Phillips curves derived from the Calvo price and wage setting schemes and the monetary policy rule.

In equilibrium households are always on their labor supply schedules and so they are willing to work at the going wage W_t^h. Guilds charge a mark-up over W_t^h but must deliver the differentiated labor demanded by the intermediate goods firms no matter the wage they have set. This demand is derived from the fact that intermediate good firms are contracted to deliver their goods to the final good firms no matter the price they have set. The wedges between revenues and costs for guilds and intermediate good firms, reflecting the absence of price adjustment to guarantee

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

market clearing, are made up with positive or negative dividends to the household. Otherwise profits are zero.

We study the solution to the log linearized equilibrium conditions of the detrended economy and apply econometric techniques that rely on linearity to estimate a subset of the parameters and to conduct our counterfactual experiment. One may question how such an approach can be squared with the ZLB. Without forward guidance shocks it is possible that at some dates the model's forecast would have the ZLB violated in the future even if it were not contemporaneously. For example, the forecasted evolution of the output and inflation gaps might dictate a negative nominal policy rate. We use data on expected future funds rates, which of course do not violate the ZLB, in our list of observables when we estimate our model. The forward guidance shocks give our model the flexibility to fit these data and thereby respect the ZLB.

One equilibrium condition is worth emphasizing at this stage because it illustrates some important differences between our model and standard NK models. Consider the log-linearized intertemporal Euler equation:

$$\hat{\lambda}_t = \theta_s\left(\hat{R}_t + E_t\left[\left(\hat{\lambda}_{t+1} - \hat{\pi}_{t+1} - \gamma_C \hat{z}_{t+1}\right]\right) + \hat{\varepsilon}_t^s + \left(1-\theta_s\right)\hat{\varepsilon}_t^b, \tag{12}$$

where $\theta_s \equiv R_*/R_*^P$ is the ratio of the gross rate of return on government bonds to private bonds (which correspond to the return to capital) in the steady state, λ_t is the shadow value of consumption (the detrended Lagrange multiplier on the household's budget constraint), π_t is the gross rate of inflation in the consumption price, and "hats" denote log deviations from steady state. With a positive steady state spread $R_*^P > R_*$ and $\theta_s < 1$. In this case both liquidity $\hat{\varepsilon}_t^s$ and $\hat{\varepsilon}_t^b$ appear in the Euler equation whereas in Smets and Wouters (2007) only $\hat{\varepsilon}_t^s$ appears.[19]

When $\theta_s < 1$ discounting is introduced into the linearized consumption Euler equation that is otherwise not present. McKay et al. (2015) and Del Negro et al. (2015) argue that the absence of such discounting explains the large effects of forward guidance that have been emphasized in the literature. For convenience set the shocks to zero and assume that from some finite date onward inflation and the policy rate equal their steady state values. Then the linearized Euler equation can be solved

[19]Equation (12) only holds for $\theta_s < 1$ since it is based on rescaling the variance of the liquidity preference shock by $\left(R_*^P - R_*\right)/R_*^P$. When $\theta_s = 1$ both shocks drop from the Euler equation but it is otherwise unchanged.

forward to obtain

$$\hat{\lambda}_t = \sum_{j=0}^{\infty} (\theta_s)^{j+1} \left(\hat{R}_{t+j} - \hat{\pi}_{t+j} \right). \tag{13}$$

In standard NK models the spread equals zero, $\theta_s = 1$, and the sum of the deviations from steady state of the real return on government bonds pins down consumption's shadow value. This has the perverse implication that ceteris paribus a credible commitment to change the policy rate tomorrow has the same impact as a commitment to do the same change 10 years out. With a spread, $\theta_s < 1$, the direct effects of expected future real rates on the shadow value of consumption decline with the horizon of the rate increase, with the rate of decline increasing in the size of the spread. Similar discounting is obtained by Del Negro et al. (2015) (perpetual youth), Gabaix (2016) (bounded rationality), and McKay et al. (2015) (incomplete markets). Del Negro et al. (2015) and McKay et al. (2015) find smaller effects of forward guidance with discounting.

4 Measurement and Estimation

Since our model shares many features of a typical real business cycle model we adhere to practice in that literature and calibrate parameters on the real side of the economy to first moments of the aggregate data where these are estimated by considering evidence over the post-WWII period. The remainder of the estimation relies on Bayesian methods and focuses on the 1993q1–2014q4 period.[20] This section briefly discuss our data and then presents our hybrid calibration-Bayesian estimation strategy with particular emphasis on how we identify the forward guidance signals.[21]

4.1 Data

Our Bayesian estimation uses 18 time series variables, including measures of output, consumption, investment, hours worked, the real price of investment, the real price of government consumption plus net exports, wage and consumer price inflation, average inflation expected over the next ten years, the federal funds rate (our

[20] The federal funds futures market operated before 1993q1 but was relatively illiquid before then.

[21] The discussion leaves out many important details. See the appendix for these details.

measure of the rate of return on the model's safe and liquid asset) and federal funds rate futures. Our calibration uses data measuring the capital stock and capital's share of aggregate income. Finally, we use changes in federal funds rate futures on FOMC days to center the priors in our estimation of forward guidance. This section describes how these variables enter into our analysis.

Our measurement of macroeconomic variables derives from three simple principles which set our analysis apart from most modern business cycle studies. First, we want to perform inference with a measure of labor input that best addresses demographic and other low frequency developments in the labor market. Second we want our measures of real quantities and prices to be consistent with the chain-weighting procedures used in the NIPA. Third, because it is implausible that any one measure of wages or prices is an adequate proxy for wages and prices in the model, we want to use multiple indicators of these objects in our estimation.

4.1.1 Hours

Empirical studies of medium-scale NK models typically measure labor input with hours per capita constructed from directly from estimates of hours worked from the BEA and the civilian population over the age of 16 obtained from the BLS. Such measures do not correspond well with business cycle models because of underlying low frequency variation. As a consequence the results obtained in these studies are difficult to interpret. In our context, measures of the output gap are directly affected by the measure of hours. This in turn affects the estimate of the coefficient on the output gap in the policy rule and consequently impacts our identification of forward guidance shocks. Clearly the measurement of hours is crucial to our analysis.

We use a simple procedure for overcoming this discrepancy between model and data.[22] Assume that hours per worker outside and inside the private business sector are the same. Then it is straightforward to show that hours per capita can be written

$$\begin{aligned} \frac{H}{P^{cps}} &= \frac{H^{pb}}{E^{pb}} \frac{E^{cps}}{LF^{cps}} \frac{LF^{cps}}{P^{cps}} \\ &= \text{Hours per worker} \times \text{Employment rate} \times \text{Labor force participation rate.} \end{aligned} \tag{14}$$

[22] See Francis and Ramey (2009), Galí (2005) and Ramey (2012) for related discussions of non-stationarity in per capita hours worked.

where H, which is not measured, denotes economy-wide civilian hours; H^{pb} and E^{pb} denote hours and employment in the private business sector obtained from the BLS' payroll survey; and E^{cps}, LF^{cps} and P^{cps} denote total civilian employment, the labor force and civilian population over the age of 16 obtained from the BLS' household survey.[23] Applying the log operator we obtain a simple additive decomposition of log per capita hours.

Figure 1: Total economy-wide log per capita hours worked

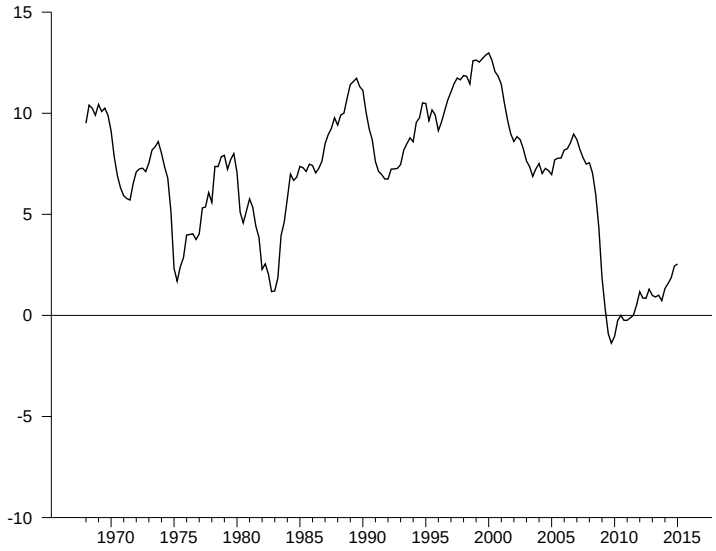
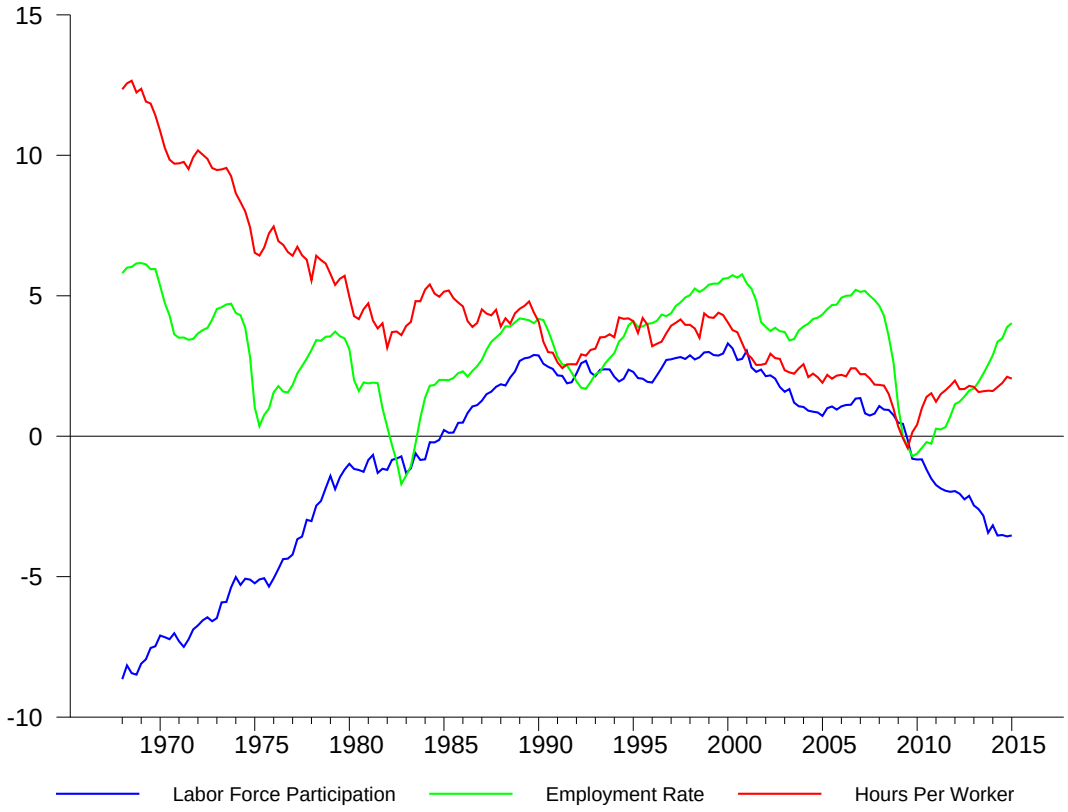


Figure 1 displays log per capita hours calculated using the right hand side of equation (14) over the period 1968q1 to 2015q1. One indication that this measure is problematic is that as of 2015q1 it is near the trough of the 1982 recession. While the labor market in 2015q1 arguably had some way to go to reach full employment, it seems unlikely that conditions early last year were representative of the trough of a major recession.

A clearer picture of the labor market is obtained by considering the three constituent parts of log hours per capita displayed in Figure 2. This figure

[23]It is standard in the literature to measure hours per capita using a measure of hours from the payroll survey and a measure of population obtained from the household survey. A similar decomposition of this measure of per capita hours reveals that it embeds the discrepancy in measures of employment in the two surveys. There is substantial variation in the survey discrepancy (see Aaronson, Rissman, and Sullivan (2004)) which further complicates the interpretation of results based on standard measures of per capita hours. We avoid this issue because the numerator and denominator in each ratio from which we build our per capita hours series are always obtained from the same survey.

Figure 2: The three components of per capita hours worked

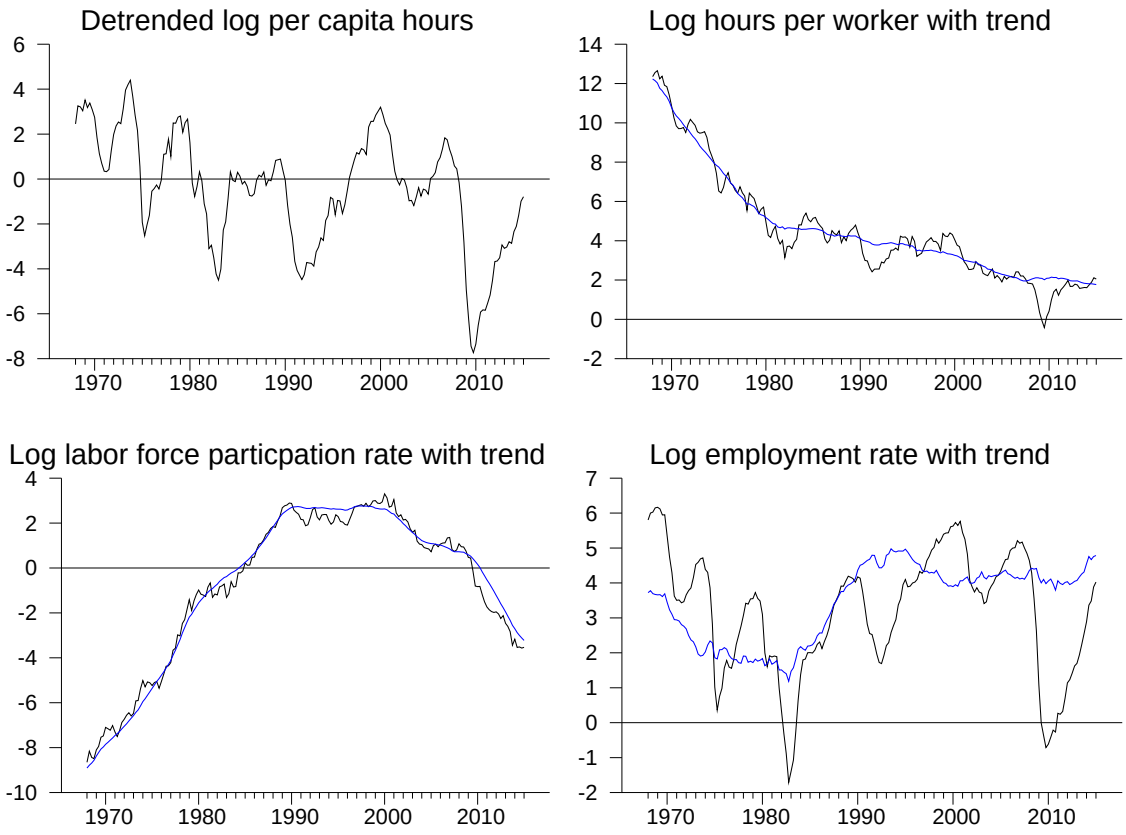


shows that per capita hours confounds low frequency movements in all three of its components. These movements can be attributed to a variety of demographic and social developments as well as changes in the underlying structure of the economy related to technological change and, perhaps, the growing role of international trade.

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

To do so we take advantage of work done at the Federal Reserve Board to address evolving demographic effects as well as other secular changes in the labor market

Figure 3: Detrending per capita hours



described in Aaronson, Cajner, Fallick, Galbis-Reig, Smith, and Wascher (2014), Fleischman and Roberts (2011), and Roberts (2014). The Board estimates variables that can be used to de-trend all three components of per capita hours.[24] We do not incorporate the estimation of these trends into our analysis. Instead we take them as given to construct an observable for per capita hours which is then used in the estimation of our model. Figure 3 displays the three components of per capita hours along with their trends and de-trended per capita hours which is derived as the sum of the differences between each component and its trend.

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

4.1.2 Aggregate quantities and prices

Our measure of capital needs to be economy-wide to be consistent with our measure of hours. Therefore our measure of capital is the net stock of fixed assets and consumer durables from the BEA which includes private non-residential and residential capital, government capital and the stock of consumer durables. Investment is measured consistently with this measure of the capital stock. Similarly the measure of capital income we use to calculate capital's income share augments the NIPA measure to include the service flows from government capital and the stock consumer durables. Our concept of capital is also inconsistent with the NIPA measure of real GDP which includes the service flows from the stock of residential capital but excludes the service flows from the stocks of consumer durables and government capital. Therefore the measure of GDP we use in estimation augments the NIPA measure to include these two service flows. Our measure of consumption includes the NIPA measure of consumption of non-durables and services plus the service flow from the stock of consumer durables. We measure the real investment price as the ratio of the price deflators corresponding to our measures of investment and consumption.

In our model consumption, investment and government spending are homogenous final goods when measured in consumption units. Real GDP as measured in the NIPA is a chain-weighted aggregate of these goods measured in their own units. If the model excluded government spending then we could calculate the growth rate of real GDP in the model using consumption and investment in their own units and inflation in the real investment price. With government consumption in the model as well, calculating real GDP growth in the model requires having on hand the real price of government consumption plus net exports. We now explain this.

The BEA measures real GDP growth using the Fisher ideal index. In our context the formula is

$$\frac{Q_t^{obs}}{Q_{t-1}^{obs}} = \left(\frac{\sum P_{j,t-1}^{obs} Y_{j,t}^{obs}}{\sum P_{j,t-1}^{obs} Y_{j,t-1}^{obs}} \right)^{1/2} \left(\frac{\sum P_{j,t}^{obs} Y_{j,t}^{obs}}{\sum P_{j,t}^{obs} Y_{j,t-1}^{obs}} \right)^{1/2}$$

where the superscript 'obs' denotes observable according to our measurement strategy. The summations are over $j = c, i, g$. P_j denotes nominal deflator for j and Y_j denotes real expenditures on j. We can rewrite the two terms in the formula

and make the translation to model variables and observable relative prices to arrive at:

$$\frac{Q_t}{Q_{t-1}} = z_t \left(\frac{c_t + e^{-\omega_t} i_t + g_t/\pi_t^{g,obs}}{c_{t-1} + i_{t-1} + g_{t-1}} \right)^{1/2} \left(\frac{c_t + i_t + g_t}{c_{t-1} + e^{\omega_t} i_{t-1} + \pi_t^{g,obs} g_t} \right)^{1/2}, \tag{15}$$

where $c_t = C_t/A_t$ and $i_t = I_t/A_t^I$. We identify Q_t/Q_{t-1} with our empirical measure of real GDP growth.[25] In deriving this formula we have used the fact that we identify the investment shock with the inverse of inflation in the real price of investment, as the model's linear investment technology suggests. The variable $\pi_t^{g,obs}$ denotes inflation in the real price of government consumption plus net exports.

Our model includes all the variables in (15) except for $\pi_t^{g,obs}$. To be consistent with our measurement of GDP, consumption and investment we measure $\pi_t^{g,obs}$ using the price deflator corresponding to the real quantity of government consumption (including the service flow from government capital) plus net exports, divided by the deflator corresponding to our measure of consumption. To measure GDP in the model we estimate an auxiliary regression for $\pi_t^{g,obs}$ modeled as an AR(2) independent of and not feeding into the structural equations of the model. That is, this variable is only used in measurement. It affects equilibrium outcomes through the identification of shocks, but not directly through agents' decisions.[26]

4.1.3 Wage and Price Inflation

In most empirical studies of medium-scale NK models, variables are measured with a single empirical counterpart. We measure wage and price inflation in our model with multiple empirical analogues.[27] Specifically, in the measurement equations each observable is expressed as a linear function of its model counterpart, plus a constant to reflect discrepancies in sample averages across different wage and price inflation measures, plus idiosyncratic measurement error. In the case of price inflation we include an additional variable in the measurement equations, discussed below. Our

[25] Edge et al. (2010) also measure model output using chain-weighting.

[26] To include this inflation rate as an exogenous shock would only have meaning if government consumption was endogenously determined, which it is not in our model. Apart from representing a major departure from standard medium-scale NK models, we think the presence of net exports in our empirical measure of G_t justifies treating government spending in the model as exogenous.

[27] See also Boivin and Giannoni (2006), Galí, Smets, and Wouters (2012) and Justiniano et al. (2013).

price measures are core CPI, core PCE and market-based PCE. For wages we use average hourly earnings of production and non-supervisory workers for total private industry from the payroll survey and the BEA's employment cost index for total compensation of all civilian workers.

We include an additional variable in the measurement equation for price inflation because the price of consumption goods in the model is conceptually different from the CPI and PCE measures we use in estimation. Model consumption is non-durable yet the CPI and PCE prices indices include prices of durable consumption goods. We address this incongruity by augmenting the measurement equations for price inflation to include linear functions of consumer durable nominal price inflation. The weights on model inflation and consumer durable inflation in the measurement equations are estimated. Consumer durable inflation is included in our measurement similar to how we include government plus net exports real price inflation to measure real GDP growth. It is modeled as an AR(2) independent of and not feeding into the structural equations of the model. Just as in the GDP case this inflation rate does affect equilibrium outcomes through the identification of shocks but not directly through agents' decisions.

Including multiple wage and price series has several advantages. First, as made clear by Justiniano et al. (2013), doing so in principle reduces the role of markup shocks in explaining cyclical fluctuations. In most empirical NK models these shocks play an outsized role in explaining labor market dynamics, yet they are difficult to interpret.[28] Second, inflation that enters the monetary policy rule is identified using three inflation series that are major inputs into actual monetary policy-making. This contrasts with the many studies that measure inflation instead using the GDP deflator, which is seldom referenced as a key input in policy formation. Third, as discussed by Barsky, Justiniano, and Melosi (2014) and Justiniano et al. (2013) it tends to reduce the trade-off between inflation and output stabilization which is a key factor driving whether or not the ZLB is binding in New Keynesian models.

4.1.4 Monetary policy variables

We measure expectations of inflation over the next ten years with the Survey of Professional forecasters survey measure. This variable helps us identify the inflation drift π_t^* in (11). The remaining variables we use to identify monetary policy are the

[28] This forms a major component of Chari et al. (2009)'s critique of NK models.

federal funds rate (quarterly average) and (end of quarter instantaneous) federal funds futures rates 1 to 4 quarters ahead (first sample) and 1 to 10 quarters ahead (second sample) based on Eurodollar and overnight interest rate swap data. These data inform the forward guidance signals. In our identification of these signals we use both the quarterly measures of future rates and the change in the futures rates in a day-long window around policy announcements. The changes on FOMC days are used to inform the priors in our factor representation of forward guidance, described below. The quarterly data are used in the actual estimation of the model.[29]

4.2 Calibration

We calibrate α, s_*^g, s_*^i (investment's steady state share of final goods), δ_0, π_*^g (the "steady state" value of inflation in the real government spending price), ω_*, z_*, and θ_s by matching the same number of targets calculated with our data to the model's steady state. Our targets include average values of capital's share of income, government and investment shares of nominal output, the capital-to-output ratio, real per-capita GDP growth, inflation in the real investment good price, inflation in the real government plus net exports price, and the federal funds rate. Using steady state conditions δ_1 is a simple function of the capital-to-output ratio, z_* and ω_* and the real return on capital is a simple function of δ_0, δ_1 and ω_*. Assuming a steady state inflation rate, $\pi_* = 2$, we obtain the nominal return on capital, R_*^P. The parameter θ_s is then calibrated to equal the ratio of the average gross federal funds rate in the first sample to R_*^P. In steady state β can be expressed as a simple function of δ_0, δ_1, ω_*, z_* and a given value of γ_C. We estimate γ_C along with the rest of the model's parameters using Bayesian methods and this yields a value for β. The calibrated parameter values and proximate targets are in Table 5.

4.3 Bayesian Estimation

We use Bayesian methods to estimate all the parameters except those fixed by the calibration described above (and a few others such as steady-state mark-ups) using the sample period 1993q1–2008q3, where the break-point is the last quarter

[29] The policy announcement dates are the same as in Campbell et al. (2012) plus all the regular meetings from 2012 through 2014 and 5/22/2013 which is the date of Chair Bernanke's testimony before the Joint Economic Committee, US Congress that is associated with the so-called taper tantrum.

Table 5: Calibrated Parameters

Parameter	Targets	Value
α	Capital's share of income	0.4
s_*^g	Government + Net Exports' share of nominal GDP	0.15
s_*^i	Investment's share of nominal GDP	0.26
δ_0	Capital:output ratio, quarterly	0.016
π_*^g	Government+net exports real price inflation	1.0025
ω_*	Investment real price inflation	1.0037
z_*	Per capita real GDP growth	1.0049
θ_s	Nominal federal funds rate	0.9867
δ_1	Steady state function of capital:output ratio, z_* and ω_*	0.016
β	Steady state function of δ_0, δ_1, ω_*, z_* and γ_C	0.9867

before the federal funds rate attained is effective lower bound. For the second sample, 2008q4–2014q4, we hold fixed every calibrated parameter as well as the other parameter values we estimate using the first sample, except for those associated with forward guidance and the variance of the inflation drift. We re-estimate the inflation drift's variance because the standard deviation of long run expected inflation in the second sample is many times smaller than it is in the first.[30] To implement these methods we formulate the system of log linearized equilibrium conditions in state-space form with the equilibrium implied by the parameter values characterized by the state equation and the mapping from model variables to the data summarized by the measurement equation.

The measurement equation is as follows, with the first equation being the log linearized version of equation (15) where the right hand side of that equation is

[30] Throughout we calibrate the persistence of the inflation drift to $\rho_\pi = .99$. We use a prior mean and variance for the inflation drift in the second sample that are smaller than we use for the first sample estimation. This is because the first sample estimate of the variance is relatively large to account for inflation's low frequency dynamics during this period.

summarized by the linear function f.

$$
\begin{aligned}
\Delta \ln Q_t^{obs} &= f\left(\hat{c}_t, \hat{c}_{t-1}, \hat{i}_t, \hat{i}_{t-1}, \hat{g}_t, \hat{\omega}_t, \hat{\pi}_t^{g,obs}\right) \\
\Delta \ln C_t^{obs} &= z_* + \Delta \hat{c}_t + \hat{z}_t \\
\Delta \ln I_t^{obs} &= z_* + \omega_* + \Delta \hat{\imath}_t + \hat{z}_t + \hat{\omega}_t \\
\log H_t^{obs} &= \hat{H}_t \\
\pi_t^{i,obs} &= \omega_* + \hat{\omega}_t + \varepsilon_t^i \\
R_t^{obs} &= R_* + \hat{R}_t \\
R_t^{j,obs} &= R_* + E_t \hat{R}_{t+j}, j = 1,2,3,4 \\
\pi_t^{obs,40} &= \pi_* + \pi_*^{40} + \frac{1}{40}\sum_{i=1}^{40} E_t \hat{\pi}_{t+i} + \varepsilon_t^{\pi,40} \\
\pi_t^{j,obs} &= \pi_* + \pi_*^j + \beta^{\pi,j} \hat{\pi}_t + \gamma^{\pi,j} \pi_t^{d,obs} + \varepsilon_t^{j,p}, \text{ with } \beta^{\pi,1} = 1, j = 1,2,3 \\
\Delta \ln w_t^{j,obs} &= z_* + w_*^j + \beta^{w,j}\left(\hat{w}_t - \hat{w}_{t-1} + \hat{z}_t\right) + \varepsilon_t^{j,w}, \text{ with } \beta^{w,1} = 1, j = 1,2 \\
\pi_t^{d,obs} &= \pi_*^d + \beta_{1,1}\pi_{t-1}^{d,obs} + \beta_{1,2}\pi_{t-2}^{d,obs} + \gamma_{1,1}\varepsilon_t^d + \gamma_{1,2}\varepsilon_t^d \\
\pi_t^{g,obs} &= \pi_*^g + \beta_{2,1}\pi_{t-1}^{g,obs} + \beta_{2,2}\pi_{t-2}^{g,obs} + \gamma_{2,2}\varepsilon_t^g + \gamma_{1,2}\varepsilon_t^g
\end{aligned}
$$

where ε_t^i and ε_t^π denote classical measurement error. Notice that our estimation respects the lower bound on the policy rate due to measuring expected future rates in the model, the $E_t\hat{R}_{t+j}$, using the corresponding empirical futures rates, $R_t^{j,obs}$. The $\pi_t^{j,obs}$ correspond to the three inflation indicators discussed above. The $w_t^{j,obs}$ are the real counterparts to the nominal wage indicators discussed above, where the nominal wages are deflated by core PCE.

4.4 Estimation of Forward Guidance

Our Bayesian estimation is similar to many other studies except that we introduce new methods to identify the forward guidance signals. These methods involve using changes in federal funds futures rates in one-day windows surrounding FOMC announcements, following the reduced form empirical literature, to inform model counterparts.

To explain our methodology it is helpful to introduce some notation. Using s_t to denote the model's state vector and y_t to denote the vector of observables (the left hand side variables in the equations listed above) the log linearized solution of our model can be represented in state-space form with the following state and

measurement equations:

$$s_t = \Gamma_0 s_{t-1} + \Gamma_1 \varepsilon_t^1 + \Gamma_2 \varepsilon_t^2 \quad (16)$$

$$y_t = A + B s_t + C u_t, \quad (17)$$

where the first $k+1$ rows of s_t contain the quarterly averages of the current policy rate and the expectations of the policy rate in quarter $t+1, ..., t+k$. In the first (second) sample estimation k equals four (twelve) and these expectations are given by $E_t \hat{R}_{t+j}, j = 1, 2, \ldots, k$. We gather the current policy shocks and the k signals revealed at period t about the policy implemented in the next k quarters into ε_t^1 (see also equation 10). Accordingly, the matrix Γ_1 has $k+1$ columns. The remaining structural (non-policy) shocks are contained in ε_t^2. Values of the economic model's structural parameters determine the matrices Γ_0, Γ_1, Γ_2, A, B and C and variance-covariance matrix of the shock processes.

To bridge forward guidance in the structural model with the reduced form empirical literature cited in section 2, we rely on the high frequency analysis of Gürkaynak et al. (2005). These authors document that the (intra-) daily changes in the current and expected federal funds rate, $\Delta_\varepsilon s_t^{(0:k)}$ with Δ_ε the first difference operator only for announcement dates, are well described by a two factor model

$$\begin{aligned} \Delta_\varepsilon s_t^{(0:k)} &= \Lambda f_t + u_t \\ E\left(\Delta_\varepsilon s_t^{(0:k)} \left[\Delta_\varepsilon s_t^{(0:k)}\right]'\right) &= \Lambda \Omega \Lambda' + \Sigma \end{aligned} \quad (18)$$

where f_t are the two factors, u_t the idiosyncratic errors, while the matrix Λ contains the factor loadings and is of dimension $(k+1) \times 2$.[31] Notice that the variance-covariance matrix of the data is then parsimoniously given as a function the loadings together with Ω and Σ, the variance-covariance matrices of factors and idiosyncratic errors, respectively.

The high frequency identification of forward guidance rests on the compelling premise that signals about the future path of interest rates are communicated by the FOMC on announcement days without any other news about the state of the

[31] The factors are constructed to be orthogonal to each other such that Ω is diagonal. Moreover, following Gürkaynak et al. (2005) normalization and identification restrictions are imposed on Λ to facilitate the interpretation of the factors.

economy. If our structural model were observed daily as well, these assumptions would imply that on FOMC announcements dates non-policy shocks (ε_t^2) are zero and that the state of the economy, s_{t-1} is unchanged, such that from equation (16) the structural model for those days would imply

$$\Delta_\varepsilon s_t^{(0:k)} = \Gamma_1 \varepsilon_t^1.$$

Hence, embedding the GSS factor structure within our structural model would establish a clear mapping between the structural policy shocks ε_t^1 and the reduced-form frequency factors and idiosyncratic errors. To see this invert the above and plug it into GSS's to obtain

$$\varepsilon_t^1 = \left[\Gamma_1^{-1}\Lambda\right] f_t + \Gamma_1^{-1} e_t$$

and

$$E\left(\varepsilon_t^1 \varepsilon_t^{1\prime}\right) = \Gamma_1^{-1}\Lambda\Omega\Lambda'\Gamma_1' + \Gamma_1^{-1}\Sigma\left(\Gamma_1\right)'. \tag{19}$$

Put differently, with a daily structural model augmented to include a GSS factor structure we could directly use the reduced form estimates of the factor loadings and covariances to inform their model-based counterparts. Combined with our structural parameters, which pin down Γ_1, this would inform the transmission of forward guidance signals.

However, the structural model is cast at a quarterly frequency. Therefore, from one quarter to another non-policy shocks are realized as well, and most likely influence the expected path of policy through their impact on the expected path of the inflation and output gaps. Furthermore, it is also likely that additional forward guidance signals are communicated outside of announcement days. Consequently we do not expect equation (19) to hold exactly. Yet the compelling nature of the high frequency identification suggests that reduced-form estimates Λ, Ω and Σ using high frequency data should still be very informative about their model counterparts.

These considerations motivate our strategy for estimating the forward guidance signals. Specifically, in the first sample we estimate GSS's two factor model in high frequency and then use the resulting factor loadings to center a prior on Λ, Ω and Σ, which we now take to denote parameters of our business cycle model. We then

estimate Λ, Ω and Σ along with the model's other non-calibrated parameters. In the second sample we estimate a factor model based on the sample period 2009q1–2014q4.[32]

Note that this strategy differs from the one implemented by Campbell et al. (2012). In that paper the factor structure is put directly on the forward guidance signals ε_t^1. Here the factor structure is put instead on the reduced form signals $\Gamma_1\varepsilon_t^1$. The current approach has two key advantages. First, we are able to tie our estimation more closely to the reduced form empirical literature. Second, an impulse to forward guidance is much easier to interpret. For example, an idiosyncratic reduced form signal about the funds rate $h-$quarters ahead does not engender an endogenous policy reaction immediately in the opposite direction to counteract the ensuing increases in the output and inflation gaps, as occurs with the analogous structural signal (see for example Del Negro et al. (2015) and Zeev et al. (2015)). Instead it unleashes a vector of structural signals that ensures that in equilibrium only the expected policy rate h-quarters ahead changes with all other policy rates unchanged.

4.5 Parameter estimates

The resulting values of the model's key parameters (modes of the posterior distributions) are displayed in Table 6. Many of the parameter estimates are familiar from the literature, including small price and wage Phillips curve slopes. Note that the inferred value of the Jaimovich-Rebelo wealth effect parameter μ is .1, much lower than the value of 1 that corresponds to the standard preference specification. Evidently the best fit of the data requires that the short run wealth effects on labor supply be much smaller than is typically assumed.

5 The estimated model

This section describes our estimated model based on the structure of forward guidance we identify from the first sample. Our purpose is to demonstrate the properties of the model and to establish its plausibility as a tool for performing our

[32]Two factors account for 99.5% of the variance in the FOMC-day changes in futures rates over the second sample period and slightly less in the first sample.

Table 6: Key Estimated Parameters

Parameter	Description	Estimate
δ_2	Utilization sensitivity to capital's rental rate	.026
γ_C	Coefficient of relative risk aversion	1.01
κ_p	Price Phillips curve slope	.003
κ_w	Wage Phillips curve slope	.003
μ	Wealth effect in preferences	.10
ι_p	Lagged inflation's coefficient in price Phillips curve	.20
ι_p	Lagged inflation's coefficient in wage Phillips curve	.79
ϱ	Habit coefficient	.80
γ_H	Labor supply elasticity	.57
$S''(1)$	Investment adjustment costs	5.23
ψ_1	Taylor inflation gap elasticity	1.76
ψ_2	Taylor output gap elasticity	.42
ρ_R	Interest rate smoothing	.77
ρ_b	Discount rate shock serial correlation	.85
ρ_g	Government spending shock serial correlation	.90
ρ_s	Liquidity preference shock serial correlation	.85
ρ_i	Investment demand shock serial correlation	.73
ρ_ω	Investment technology growth serial correlation	.35
ρ_ν	Neutral technology growth serial correlation	.49

counterfactual policy experiments. We conclude this section by briefly considering the second sample, in particular how the model explains the Great Recesssion.

The sources of variation in several aggregate variables at business cycle frequencies implied by the model are shown in Table 7. Technology shocks play a prominent role in explaining fluctuations in all the real variables. Liquidity preference shocks are the prime driver of hours and discount factor shocks play a similar role for consumption. The markup shocks are included in the "All other" shocks category. They are essentially irrelevant for real activity. However price markup shocks account for about 60% of inflation fluctuations. Finally, current and forward guidance shocks explain 17% of the business cycle variation in the funds rate. Put differently, the model implies 83% of funds rate variation at business cycle frequencies is due to the endogenous component of the policy rule.

Most variation in the model is explained by the four shocks to the discount factor, investment-demand, liquidity preference, and neutral technology. Figure 4 displays responses of GDP, consumption, investment and hours to one standard deviation

Table 7: Percent of Variation at Business Cycle Frequencies by Shock

	Shocks					
Variable	Technology	Liquidity preference	Investment demand	Discount rate	Policy	All other
GDP	.61	.16	.11	.02	.02	.08
Consumption	.23	.24	.01	.46	.04	.02
Investment	.49	.08	.26	.11	.01	.05
Hours	.34	.49	.01	.00	.08	.08
Inflation	.07	.02	.12	.10	.00	.69
Fed. funds rate	.11	.38	.16	.06	.17	.21

Note: The technology shock category includes neutral and investment-specific shocks.

impulses to these shocks. The units of the responses are percentage point deviations from steady state at an annual rate. The figure demonstrates that business cycle co-movement is induced by the technology and liquidity preference shocks only. These shocks induce relatively large responses of all the variables. The discount factor shock induces large movements in consumption and investment in opposite directions with very little impact on GDP and hours. The investment demand shock has little impact on consumption and hours, somewhat large effects on GDP and very large effects on investment.

Figure 5 shows how inflation and the funds rate respond to the four main shocks (the funds rate is measured in percentage points so a response of .01 corresponds to 1 basis point.) The small responses of inflation reflects the small value of the price-Phillips curve slope. Notice that the funds rate falls in the aftermath of a positive technology shock. This reflects the fact that the short run response of output is smaller than the long run response due to the model's real rigidities and so the output gap turns negative. Inflation's small decline also contributes. The liquidity preference shock induces the largest movements in the funds rate. The funds rate drops to accommodate an increase in the demand for safe and liquid assets.

Figure 6 shows how the main aggregate variables respond to what Gürkaynak et al. (2005) call the target and path factor (these are identified by assuming the path factor does not impact the funds rate initially). The nature of these shocks is to unleash a sequence of forward guidance signals such that the equilibrium path of the funds rate is as stipulated by the factor structure. At the conclusion of the

Figure 4: Impulse responses of activity variables to main business cycle shocks

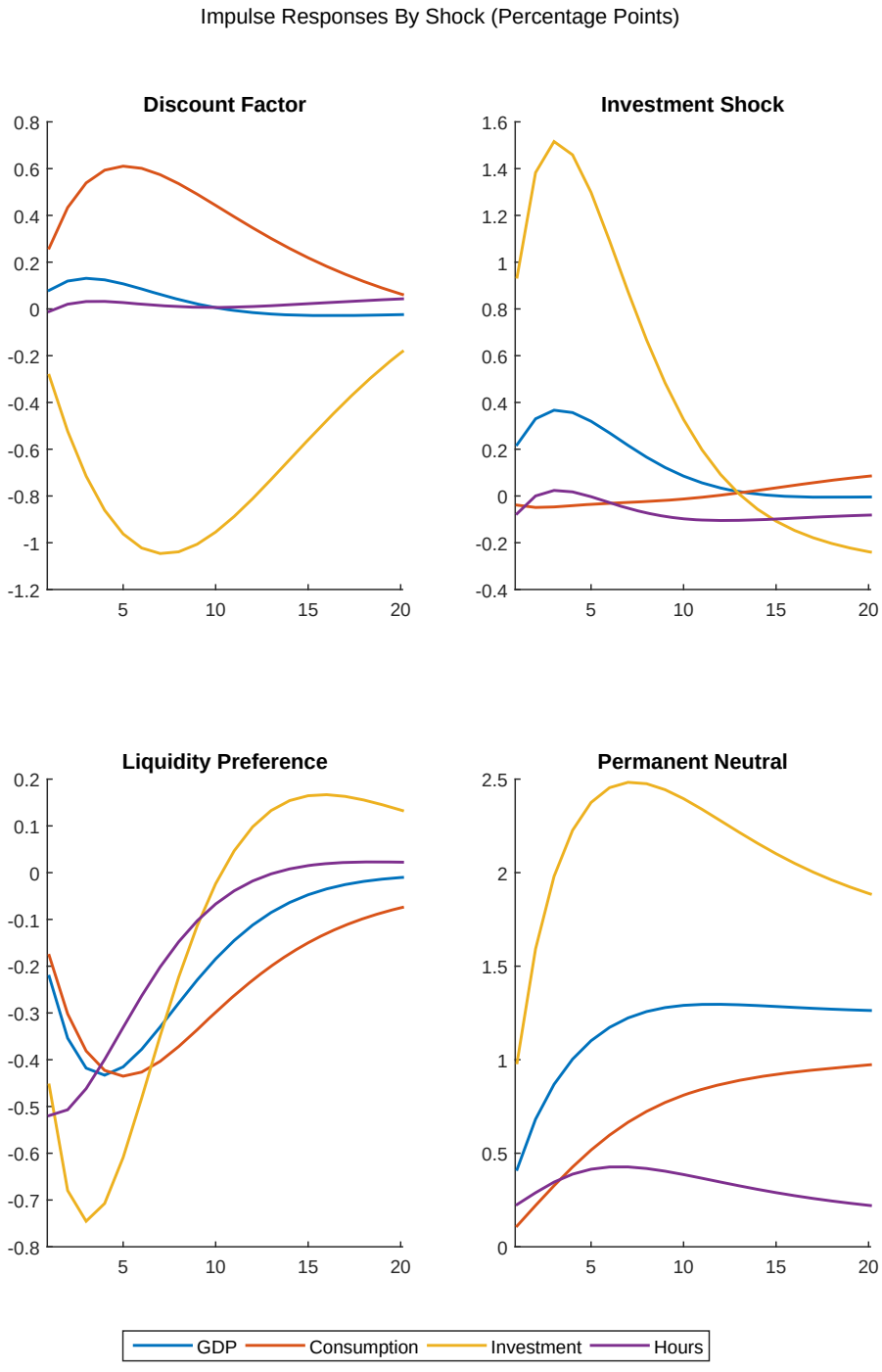


Figure 5: Responses of nominal variables to main business cycle shocks

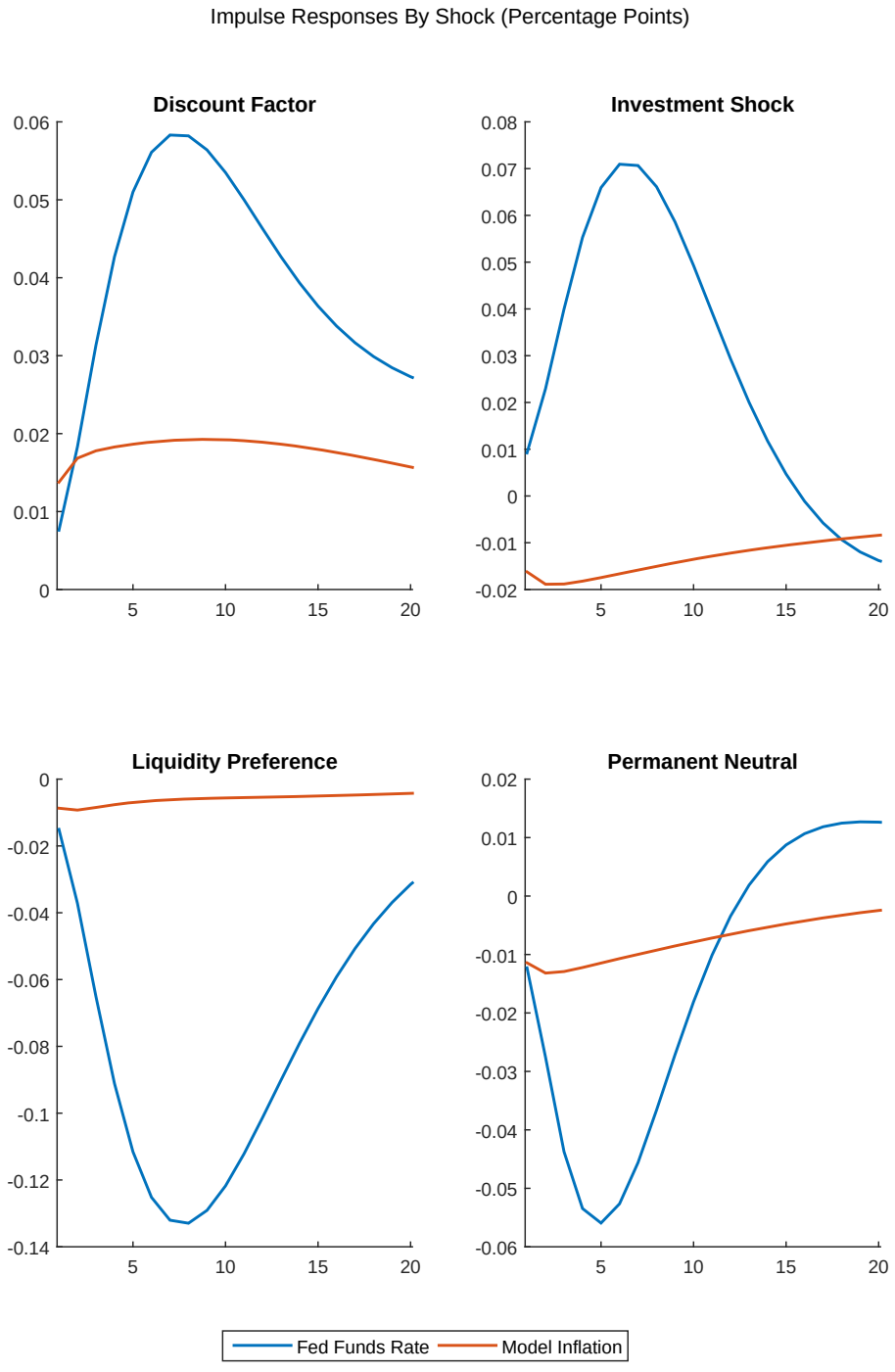
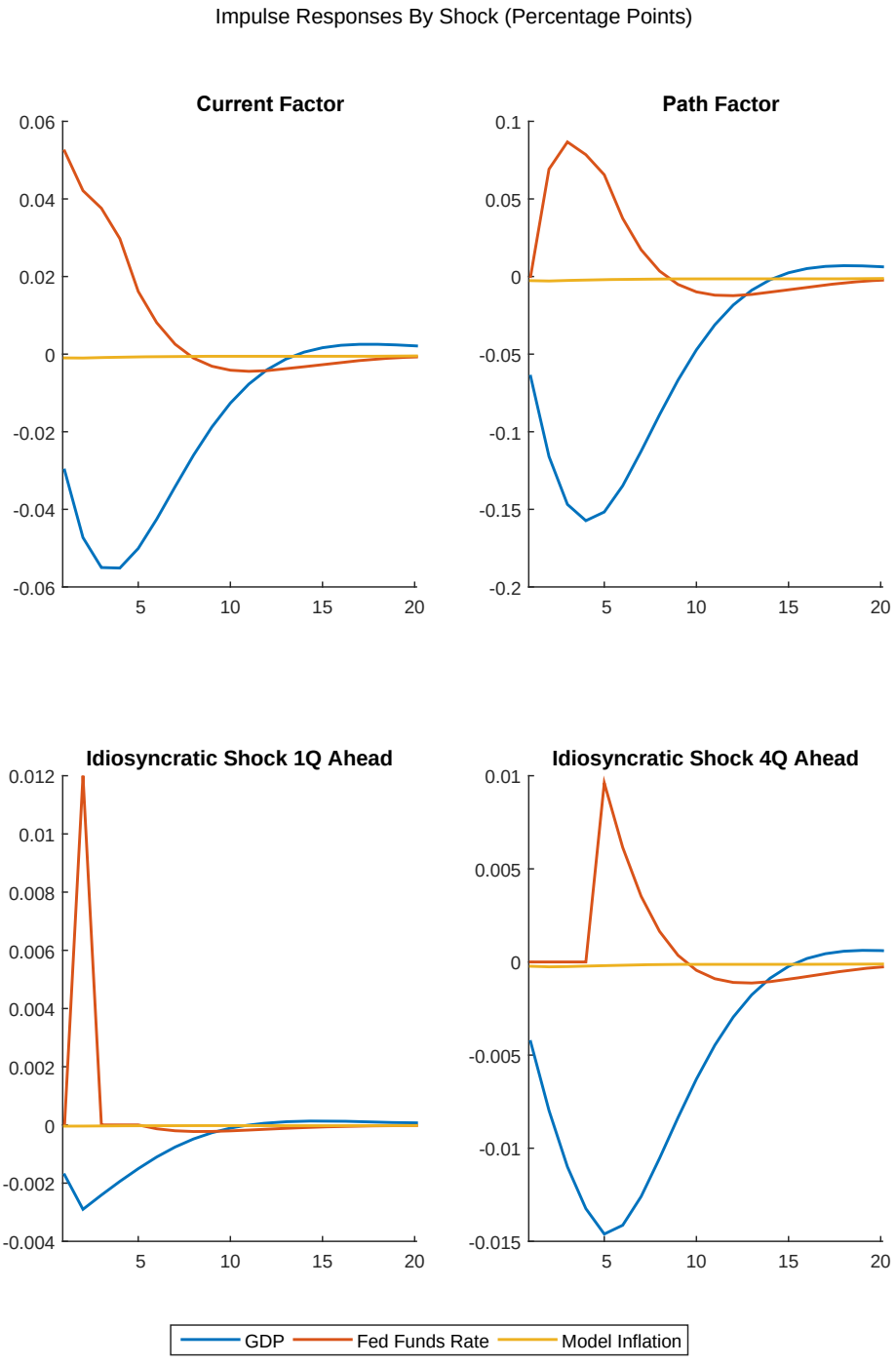


Figure 6: Responses to forward guidance shocks

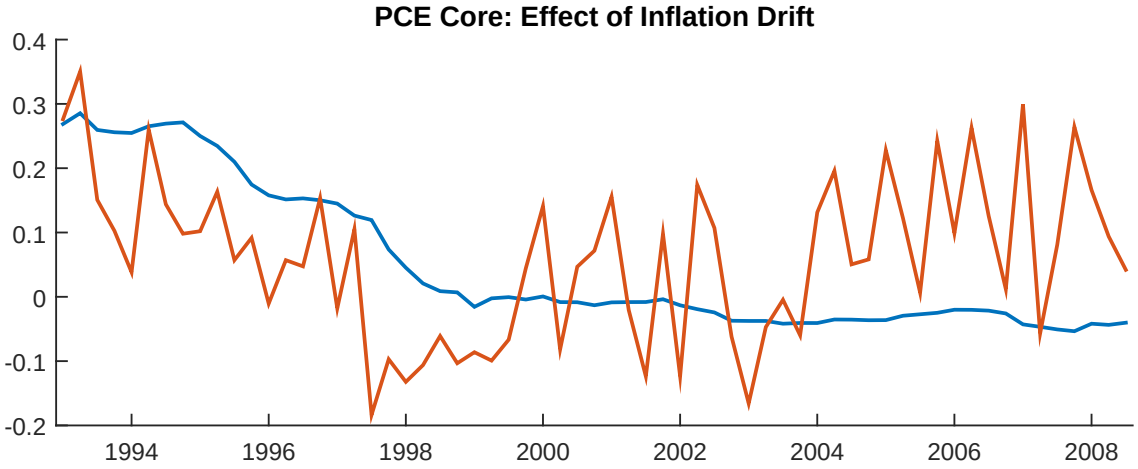


guidance the endogenous component of the rule is the sole driver of policy.

The idiosyncratic shocks are particularly informative regarding the impact of the dating of forward guidance and illustrate one of the advantages of our approach to identifying forward guidance. The idiosyncratic shocks correspond to a binding commitment by the central bank to not change rates for $k-1>0$ quarters, then increase the policy rate in quarter k, after which rates follow the rule. Like the shocks to the factors the idiosyncratic shocks unleash a sequence of signals that yield the paths in the plots as equilibrium outcomes. The 4q-ahead idiosyncratic shock is roughly the same size as the 1q-ahead shock, but it is also delayed by 4 quarters. As expected this delay leads to a larger response of GDP compared to the 1q-ahead shock, but the response is very small reflecting the small size of the shock.

Figure 7 shows an unconditional decomposition of core PCE inflation (orange) and the model's inflation drift shock (blue). By constraining the drift to be close to a random walk the model is able to account for the low frequency trend in inflation. Note that the drift shock is pinned down by the long run inflation survey expectations and the relatively high level of the blue line reflects the lag in expectations relative to realized inflation.

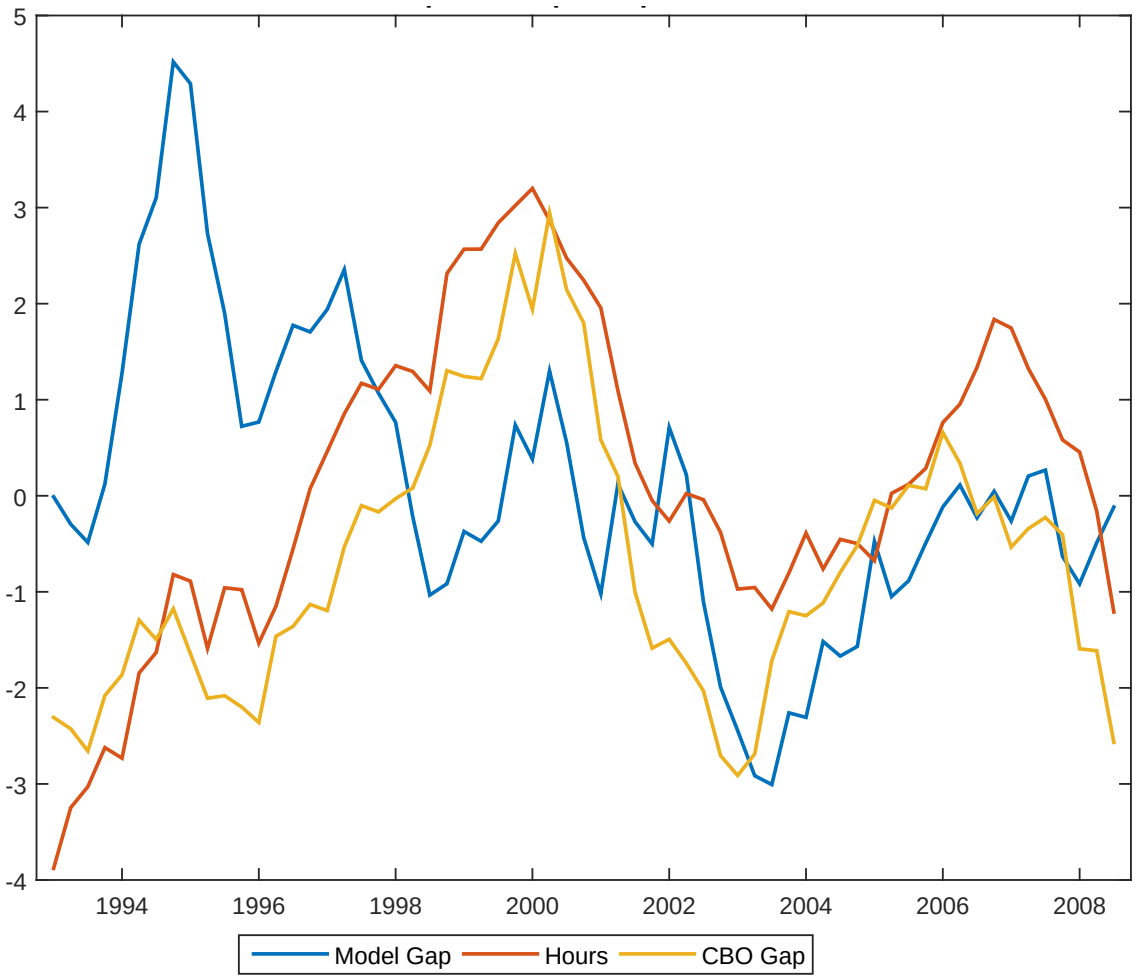
Figure 7: Contribution of Inflation Drift Shocks to PCE Core inflation



Note: Blue = drift, Orange = core PCE. Quarterly rates relative to steady state.

Figure 8 shows the model's output gap (deviation of output from its stochastic trend) along with the CBO output gap and our measure of hours. The model gap follows the contours of hours and the CBO gap after 1999. Before 1999 the model's gap is substantially larger than both hours and the CBO gap. The large positive

Figure 8: Model and CBO output gaps with hours, 1993q1–2008q3



Note: Gaps are in percentage point deviations from stochastic trend and potential. Hours is deviation from steady state.

model gap in 1994 is consistent with the FOMCs concerns about inflation during that time. Notice that after the 2001 recession the CBO and model gap follow each other quite closely. In both cases the expansion in the 2000s is not interpreted to have brought the economy much above its potential. The plausibility of the dynamics of the model gap in our view lend credibility to our estimated model.

We now consider how the model interprets the 2001 and 2008-2009 recessions. Figure 9 plots forecast error decompositions of log level GDP and hours plus the funds rate, conditional on the NBER business cycle peak in 2001q1 running through

to 2002q3, three quarters after the NBER-dated trough.[33] The red triangles indicate the conditional forecast; the blue dots the actual outcomes; and the bars indicate the contribution of the shocks to the forecast error. The contributions do not add up to the forecast error since the contributions of the other shocks are not displayed. At the business cycle peak the model forecasts GDP to rise above its steady state, hours to remain high, and hardly any movement in the funds rate. As realized output and hours come in lower than expected the funds rate drops sharply. Negative neutral technology and an increase in the demand for safe and liquid assets drove the recession with liquidity preference shocks driving most of the declines in hours.

Figures 10 and 11 plot forecast error decompositions corresponding to the Great Recession. We split this decomposition into two parts because of the sample split in our estimation. The decomposition in Figure 10 is conditioned on the state of the economy as of the NBER business cycle peak in 2007q3. Interestingly in the early part of the recession output and hours did not come in sharply below the forecast. Later on they do. The declines in output and hours are more than explained by sharp increases in the demand for safe and liquid assets as well as negative neutral technology shocks.[34] The sharp decline in the funds rate is not explained by the shocks displayed. It is driven almost entirely by shocks to the target and the path factor (not shown). The path factor, that is forward guidance about future interest rates that are orthogonal to movements in the funds rate target lift GDP and hours but are not enough to stave off the deepening of the recession.

Figure 11 is conditioned on the state of the economy as of 2008q4. An outward shift in the demand for safe and liquid assets is the major factor pulling down output and hours. With output there are largely offsetting shocks so the forecast error is small. Not shown is that, according to the model, forward guidance is actually a substantial drag on the economy starting in 2009q2.

It is instructive to compare these decompositions of the Great Recession to the one calculated in Christiano, Eichenbaum, and Trabandt (2015). Their model attributes a large portion of the Great Recession to a "consumption wedge" and a "financial wedge." The consumption wedge enters their model in the same way as

[33] We leave out inflation because it does not vary very much relative to the forecast and most of the forecast errors are due to price markup shocks.

[34] In 2008q3 the contributions of these two shocks to the decline in GDP are very large. Had it not been for large positive contributions to GDP from government spending plus net exports and its real price GDP would have plummeted much faster.

our liquidity preference shock. The financial wedge enters as the discount factor does in the investment Euler equation in our model. However their financial wedge, unlike our discount factor shock, does not appear in the consumption Euler equation. These differences notwithstanding the discount and liquidity preference shocks in our framework span the same space as the two wedges in Christiano et al. (2015). Since the discount rate appears in both the consumption and investment Euler equations our "wedges" are correlated. In the end we attribute the onset of the Great Recession mostly to the liquidity preference shock while Christiano et al. (2015) attribute it mostly to the financial wedge. Their result derives from calibrating their financial wedge to the bond spread estimated by Gilchrist and Zakrajšek (2012). The consumption wedge is essentially a residual. Another difference in our decompositions is that Christiano et al. (2015) do not use data on federal funds rate futures to inform their analysis.

6 Counter-factual policy analysis

This section describes our counter-factual policy analysis that is designed to shed light on the effectiveness of forward guidance since the financial crisis. We start by describing our methodology and then discuss our findings from implementing it. We conclude this section by demonstrating that our findings do not reflect Del Negro et al. (2015)'s forward guidance puzzle.

6.1 Methodology

Our model after being solved can be represented in state-space form summarized by equations (16) and (17). Values of the economic model's structural parameters determine the matrices Γ_0, Γ_1, Γ_2, A, B and C in the state-space model as well as the variance and covariance matrices of the shock processes. With these in hand, we can apply the Kalman smoother to recover estimates of s_t, ε_t^1, ε_t^2, and u_t.

We wish to construct a counterfactual series for y_t based on an alternative monetary policy "that keeps the interest rate as close as possible to the Taylor component of the policy rule while still respecting the effective lower bound." The difference between this counterfactual and the actual monetary policy the Fed implemented is our operational definition of forward guidance.

This construction begins in period 0. The state equations for the current and expected policy rate are

$$s_0^{(0:k)} = \Gamma_0^{(0:k)} s_{-1} + \Gamma_1^{(0:k)} \varepsilon_0^1 + \Gamma_2^{(0:k)} \varepsilon_0^2.$$

If the zero lower bound was not a constraint, it would be feasible to replace ε_0^1 with a vector of zeros. We call this result path for interest rates the *Taylor Ideal Path* (TIP), because the interest rate path would fit the Taylor rule exactly at all horizons. Let us consider the problem of choosing $\bar{\varepsilon}_0^1$ to minimize the distance between the actual path of interest rates and the TIP subject to the feasibility constraint that the interest rate for the current and the k future quarters are weakly positive. Since the difference the actual interest rate and the TIP equal to $\Gamma_1^{(0:k)} \varepsilon_0^1$, the program can be written as

$$\min_{\varepsilon_0^1} \quad \varepsilon_0^{1\prime} \Gamma_1^{(0:k)\prime} \Gamma_1^{(0:k)} \varepsilon_0^1$$

subject to the feasibility constraint: $\Gamma_0^{(0:k)} s_{-1} + \Gamma_1^{(0:k)} \varepsilon_0^1 + \Gamma_2^{(0:k)} \varepsilon_0^2 \geq .125$.[35] Here, s_{-1} and ε_0^2 come from step 2. Since the objective is quadratic and the constraint set is convex, this problem has a connected set of solutions and generically we expect the solution to be unique. We hypothesize that if the submatrix $\Gamma_1^{(0:k)}$ is full rank, then the solution is unique. Denote this unique solution with $\bar{\varepsilon}_0^1$. Given this we obtain $\bar{s}_0 = \Gamma_0 s_{-1} + \Gamma_1 \bar{\varepsilon}_0^1 + \Gamma_2 \varepsilon_0^2$ from the state equations.

In period 1, we choose ε_1^1 to solve the programming problem analogous to that above in 4 with $\bar{s}_0$ replacing s_{-1} and ε_1^2 replacing ε_0^2 in the feasibility constraint. We denote this programming problem's solution as $\bar{\varepsilon}_1^1$, and we use it to obtain $\bar{s}_1 = \Gamma_0 \bar{s}_0 + \Gamma_1 \bar{\varepsilon}_1^1 + \Gamma_2 \varepsilon_1^2$ from the state equations. Continue this recursively until the end of the sample yields $\bar{\varepsilon}_t^1$ and $\bar{s}_t$ for $t = \{0, ..., T\}$. We call the corresponding sequence of interest rates the *Taylor Maximum Fidelity Path* (TMFP).

We can calculate an alternative path for our observables given the TMFP $\bar{y}_t = A + B\bar{s}_t + Cu_t$. The difference between the actual data y_t and the *Taylor Maximum Fidelity Outcomes* $\bar{y}_t$ captures the effects of forward guidance.

[35] The effective lower bound is the midpoint of the 0–25 basis point range targeted by the FOMC over the second sample.

6.2 Results

We study this counterfactual policy using the shocks identified from the second sample after first estimating forward guidance and inflation drift variance over this period as described in Section 4. Recall that we center the prior for the forward guidance signals using a two factor structure estimated from 2009q1–2014q4 FOMC announcements. To begin, it is helpful to consider the empirical funds rate futures term structures from which the empirical forward guidance is identified. Figure 12 shows the empirical futures paths quarterly and by year. Through 2009 market participants saw liftoff around the corner. Starting in 2010 the expected duration of being at the lower bound extended a bit but liftoff was still seen as a few quarters ahead at most. By the end of 2011 expectations were than the funds rate would stay zero through 2013. This coincides with introduction of calendar-based guidance in August 2011. These plots demonstrate clearly that agents were repeatedly surprised by the amount of time spent at the lower bound.

The top left plot in Figure 13 shows the empirical funds rate path along with the TMFP path that emerges from minimizing the sum of the squared deviations from the Taylor component of the rule by choice of the forward guidance signals and subject the lower bound constraint. Notice that except for a small deviation in 2009 the paths for the current funds rate are almost identical under the two scenarios. Any differences in policy are reflected in the forward guidance. Figure 13 shows that before 2011 the guidance under the TMFP rate path was more accommodative than actually communicated by the Fed. Only starting in mid 2011 does the empirical guidance fall below the TMFP guidance. The differences begin appearing 4 quarters out with the largest differences at the longer horizons.

Figure 14 displays the information in Figure 13 as it is arranged in Figure 12. Comparing these plots to the empirical ones in Figure 12 illustrates that under the TMFP low rates for longer are communicated early on. However toward the end of the sample the implied TMFP communication is for lift-off much earlier than markets were actually projecting.

Figure 15 shows how the differences in monetary policy translate into differences in macroeconomic outcomes. By these measures the forward guidance communicated by the FOMC was counterproductive through most of 2011, leading to worse outcomes than under the TMFP. This is consistent with the more accommodative guidance early on in the TMFP case (and our forecast decomposition

of the Great Recession discussed above). From this perspective it would have been more effective for the Fed to communicate that it would be adhering quite closely to its historical policy rule and lifting off when that rule dictated doing so.

Toward the end of 2011 the Fed seems to have found its communications legs. By communicating that its policy would be looser than dictated by the rule alone it achieved more favorable outcomes than would have been the case otherwise. Interestingly the divergence in the outcomes occurs around the time the FOMC began using calendar-based forward guidance in August 2011.

6.3 The forward guidance puzzle

In our model extending a near zero interest rate peg for additional periods leads to initial responses of output and inflation that grow with the length of the extension. This is endemic to all NK models. Del Negro et al. (2015) show that in their estimated medium-scale NK model that an extension of a ten year zero interest rate peg for just one additional quarter generates extremely large and implausible initial responses of output and inflation. They call this phenomenon the "forward guidance puzzle." Their results suggest than the exploding responses to an extended interest rate peg are actually empirically relevant. In contrast, we find relatively modest effects of forward guidance based on our counterfactual experiment. As such our estimated model seems not to exhibit an *empirical* forward guidance puzzle, by which we mean at least for experiments that resemble the length of time at the zero lower bound observed in the data.

To show that this is indeed the case we reproduce the interest rate peg experiment Del Negro et al. (2015) use to define the forward guidance puzzle. Figure 16 matches Figure 4 from Del Negro et al. (2015) except that it is constructed using our estimated model. The experiment is to extend the ZLB by just one quarter from the model's forecast expected as of 2012q2. The baseline forecasts are the solid blue lines and are conditioned on fed funds futures rates for the next two years and a half, as observed at that point in time. The paths derived from extending the peg by just an additional quarter are the red dashed lines.

Del Negro et al. (2015) find that the response of output when the peg is extended a single quarter peaks in the first period (2012q3) declining gradually thereafter. In particular, they find that the predicted four quarter growth rate of GDP for 2012

jumps from 1.9 in their baseline to 3.5 under the peg (Table 4 in their paper). In stark contrast the effects of extending the peg in our estimated model are small, closely following the baseline forecast. Indeed, our comparable numbers for the four quarter growth rate of GDP in 2012 are 1.66 under the baseline and 1.81 under the extended peg. Clearly our model does not exhibit the explosiveness that is the dominant feature of the Del Negro et al. (2015)'s example.

Figure 16 demonstrates that the forward guidance puzzle is not a generic feature of estimated medium-scale NK models, at least in the range of interest rate pegs actually observed in the data. Eventually the responses of current variables will get implausibly large as an interest peg is extended, increasing the appeal of mechanisms that may counter the quantitative bite of these effects. Nonetheless, our results indicate that some models will deliver plausible responses of macro variables for empirically plausible pegs.

A natural question is what features of our model explain the discrepancy between our results and those of Del Negro et al. (2015). We highlight three key differences that might explain the absence of an empirical forward guidance puzzle in our setting: the inclusion of a spread between the interest rate controlled by the central bank and the rate of return on physical capital; Jaimovich-Rebelo preferences; and the data used to estimate the model.

Recall from the discussion in section 3.5 that the spread introduces discounting into the linearized consumption Euler equation that is otherwise not present. Just as in Del Negro et al. (2015) and Nakamura and Steinsson (2015) this discounting mitigates the effects of forward guidance. So the spread may be one reason why our estimated does not display a forward guidance puzzle. To gauge this, it is straightforward to eliminate the effects of the spread, while holding fixed the other parameters and the state conditioning the forecast, and redo the experiment plotted in Figure 16. When we eliminate the spread the predicted yearly growth rate of GDP in the first two years is roughly 0.2 and 0.4 percentage points higher than under the peg shown in 16. Otherwise the general contours of the paths are unchanged. So while clearly helping to dampen the effects of forward guidance, this model feature on its own does not explain the absence of implausible effects from forward guidance. Of course including the spread could change our parameter estimates and the conditioning state and this may be important.

Now consider Jaimovich-Rebelo preferences. These preferences with $\mu = 1$

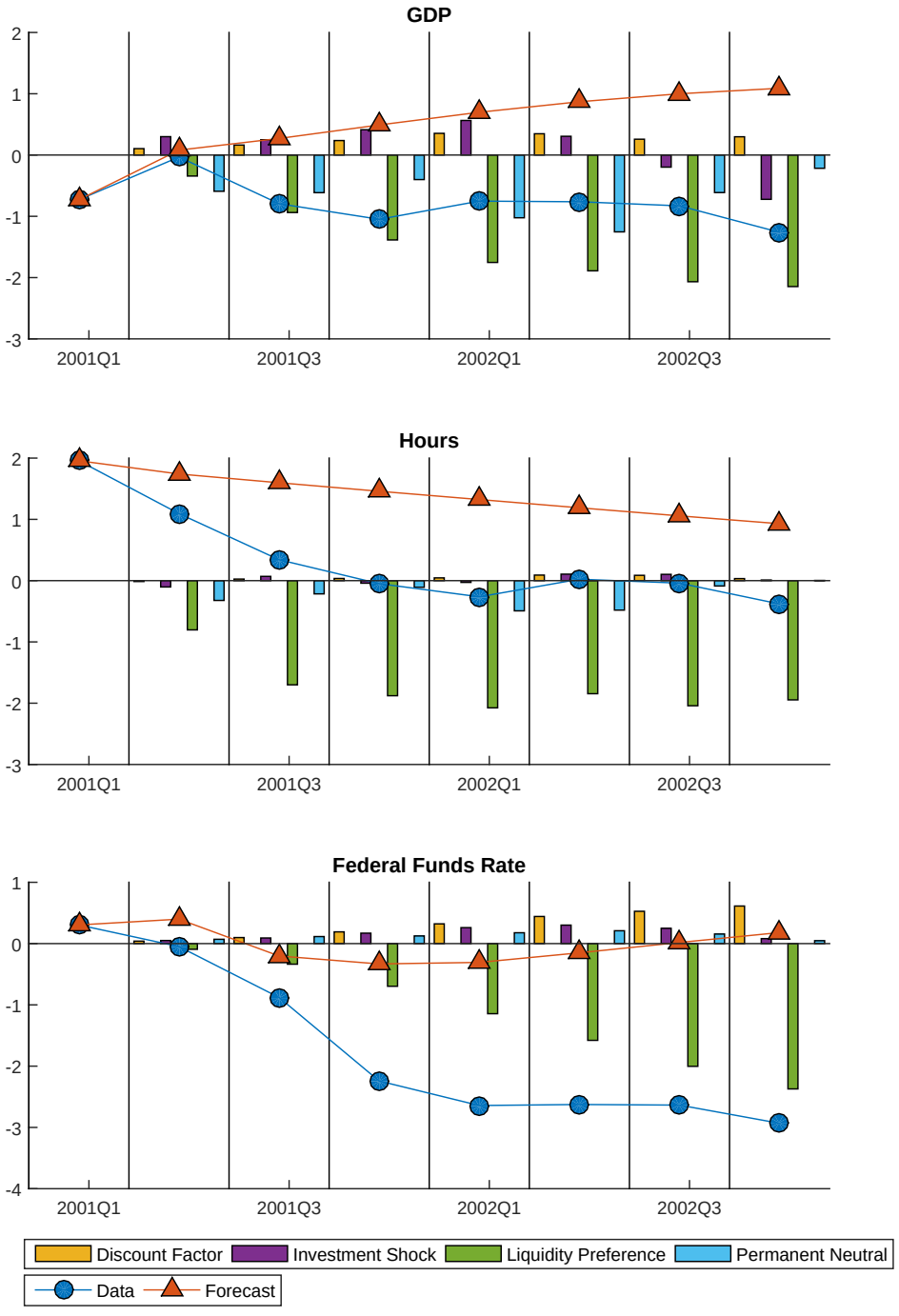
represent the standard specification. While we cannot isolate the effects of having estimated $\mu = .1 << 1$ we have reproduced our counterfactual after estimating our model after calibrating $\mu = .99$. When we do this we obtain somewhat larger effects of forward guidance as measured by the TMFP counterfactual experiment. When we redo the peg experiment we find the impact of eliminating the spread is similar to the model with μ estimated. So at least qualitatively including Jaimovich-Rebelo preferences also reduces the effects of forward guidance, but this model feature on its own does not explain the absence of the puzzle either and nor does the combination of Jaimovich-Rebelo preferences and the spread.

The third key difference is the data that we use for inference. Del Negro et al. (2015) use just 5 observables to estimate their model. Our estimation is based on a much richer set of data that includes 18 observables. Of particular interest is that we estimate our model with data on expected federal funds rates that identify the monetary policy rule in the first sample and the forward guidance signals in both samples. Hence, the discipline imposed by confronting the expected path of interest rates with data might have delivered a configuration of parameters, states and shocks that imply more plausible effects of forward guidance than had we omitted this data but used it post-estimation, as done by Del Negro et al. (2015).

7 Conclusion

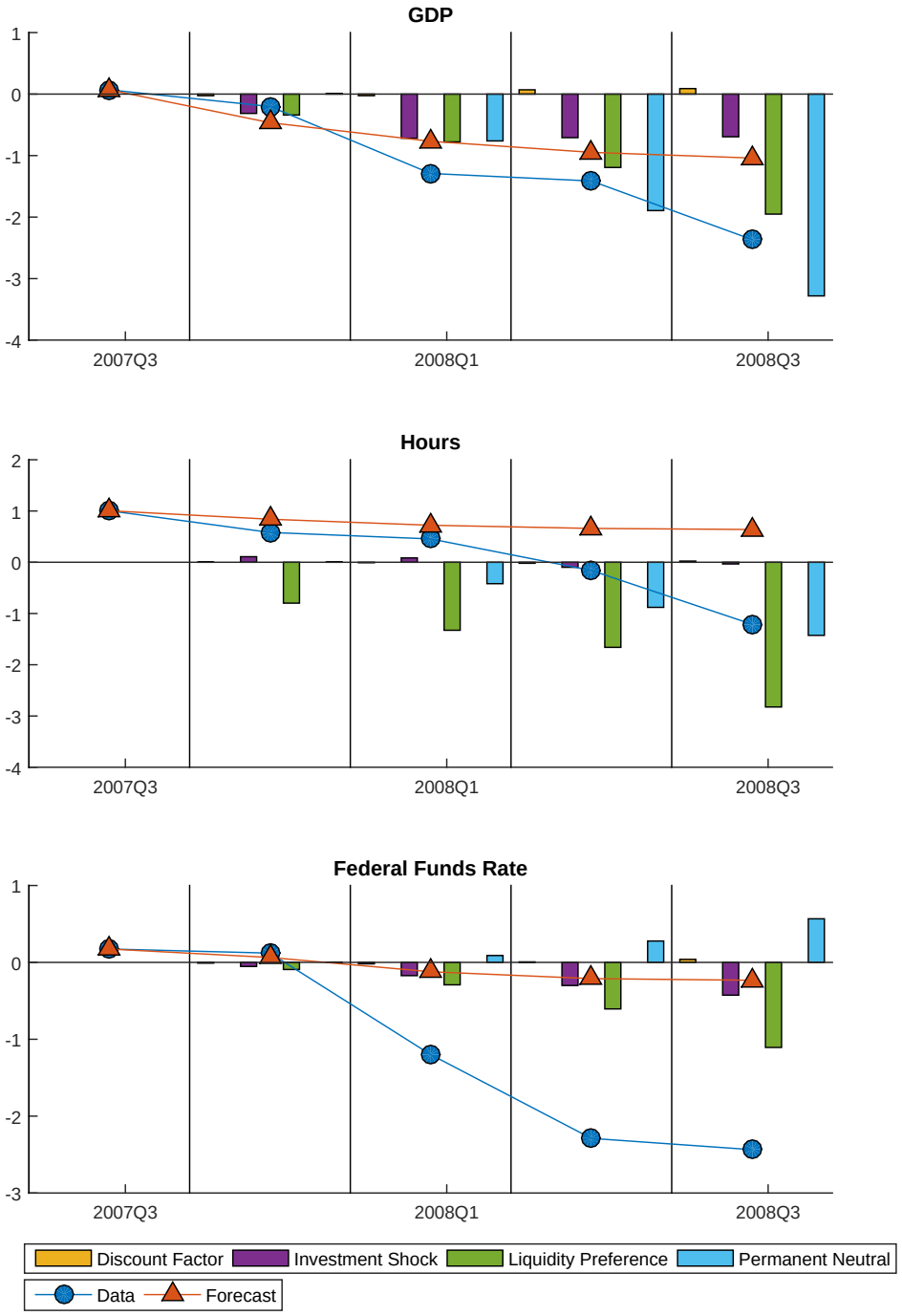
To be completed.

Figure 9: Shocks' contributions to 2001 recession



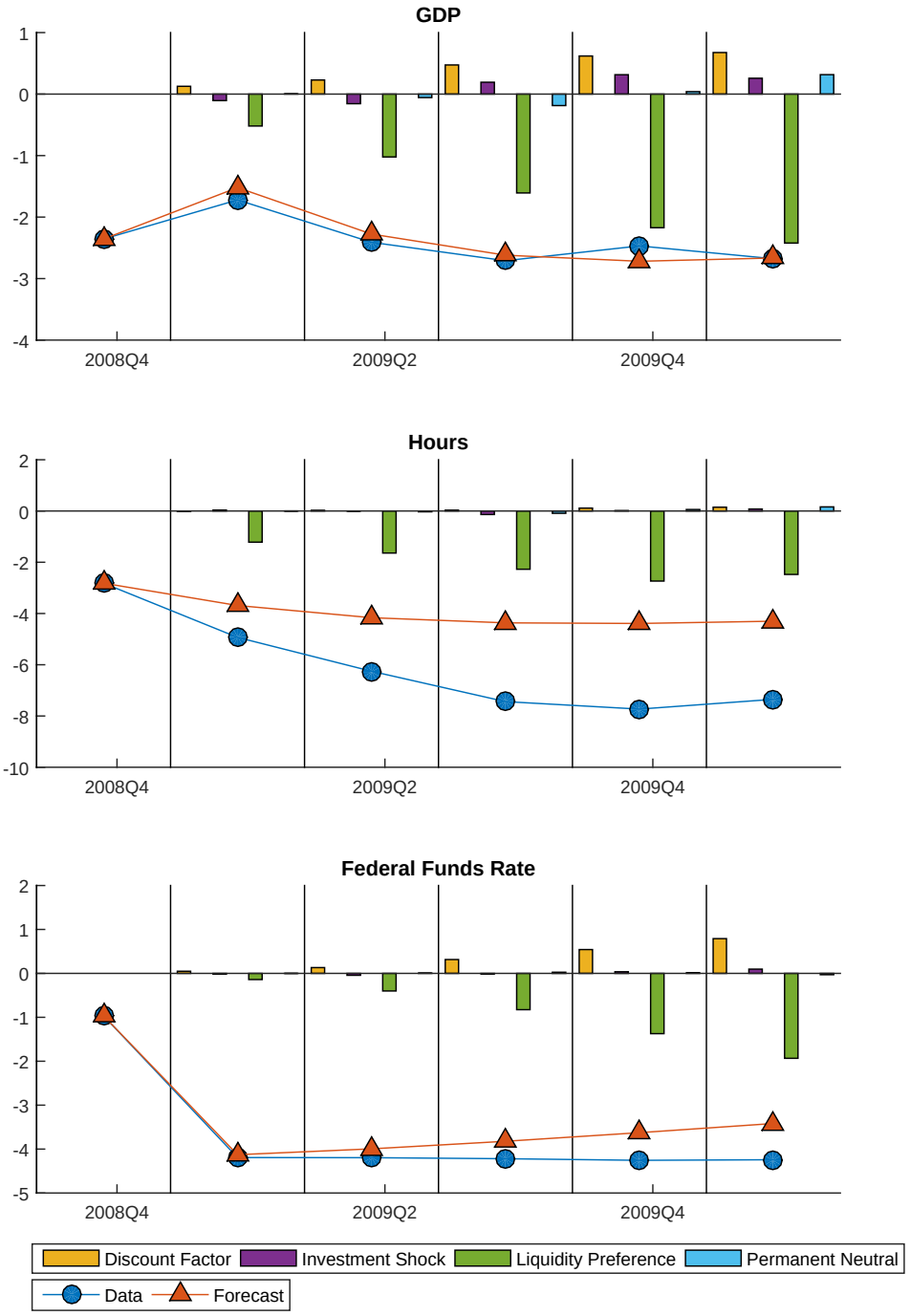
Note: GDP and hours are shown as log deviation from trend in percentage points. The funds rate is displayed as deviation from its steady state at an annual rate.

Figure 10: Shocks' contributions to Great Recession, part I



Note: GDP and hours log deviation from trend in percentage points. Inflation and ffr are quarterly rates relative to steady state.

Figure 11: Shocks' contributions to Great Recession, part II



Note: GDP and hours log deviation from trend in percentage points. Inflation and ffr are quarterly rates relative to steady state.

Figure 12: Empirical fed funds futures term structure quarterly, 2009–2014

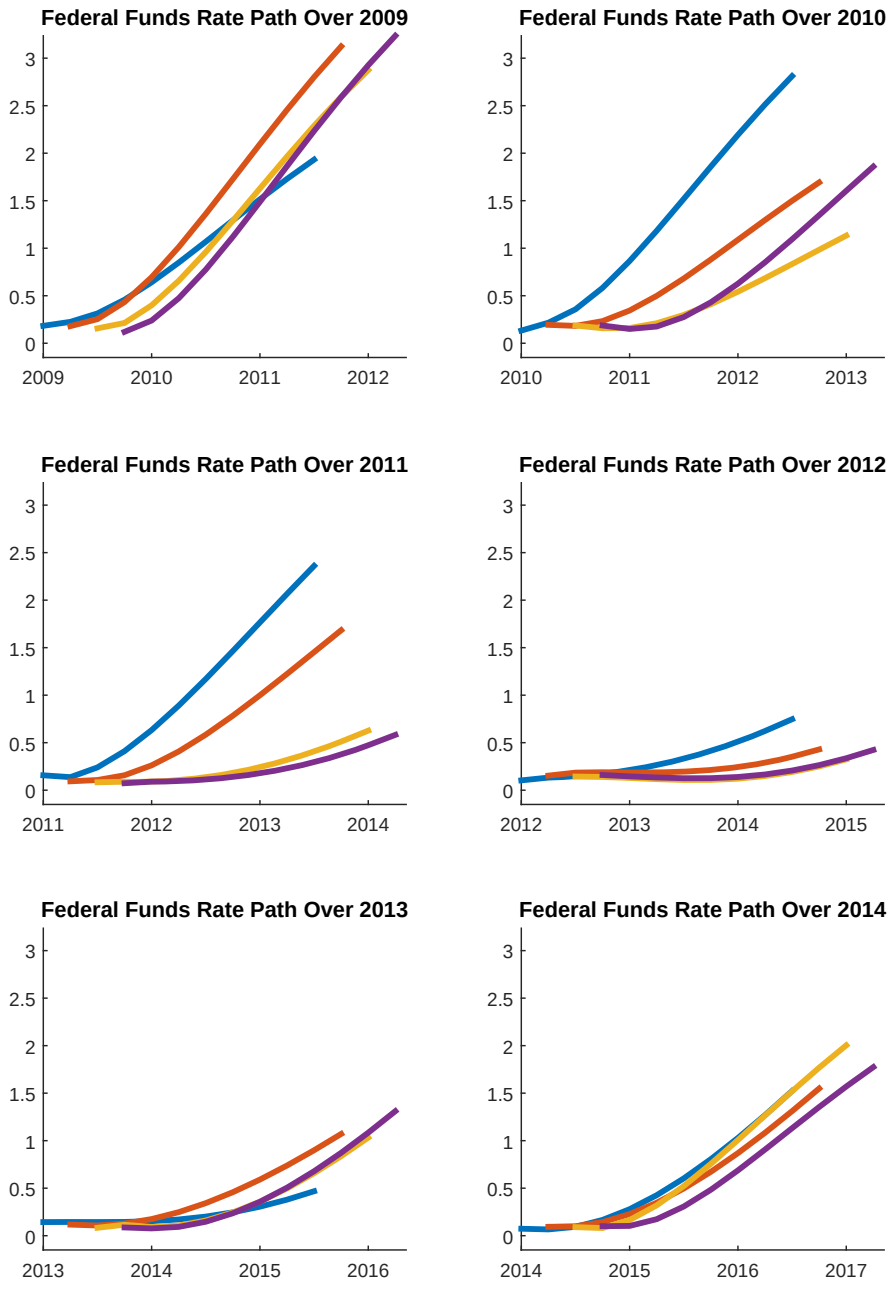


Figure 13: Actual and TMFP counterfactual funds rate paths

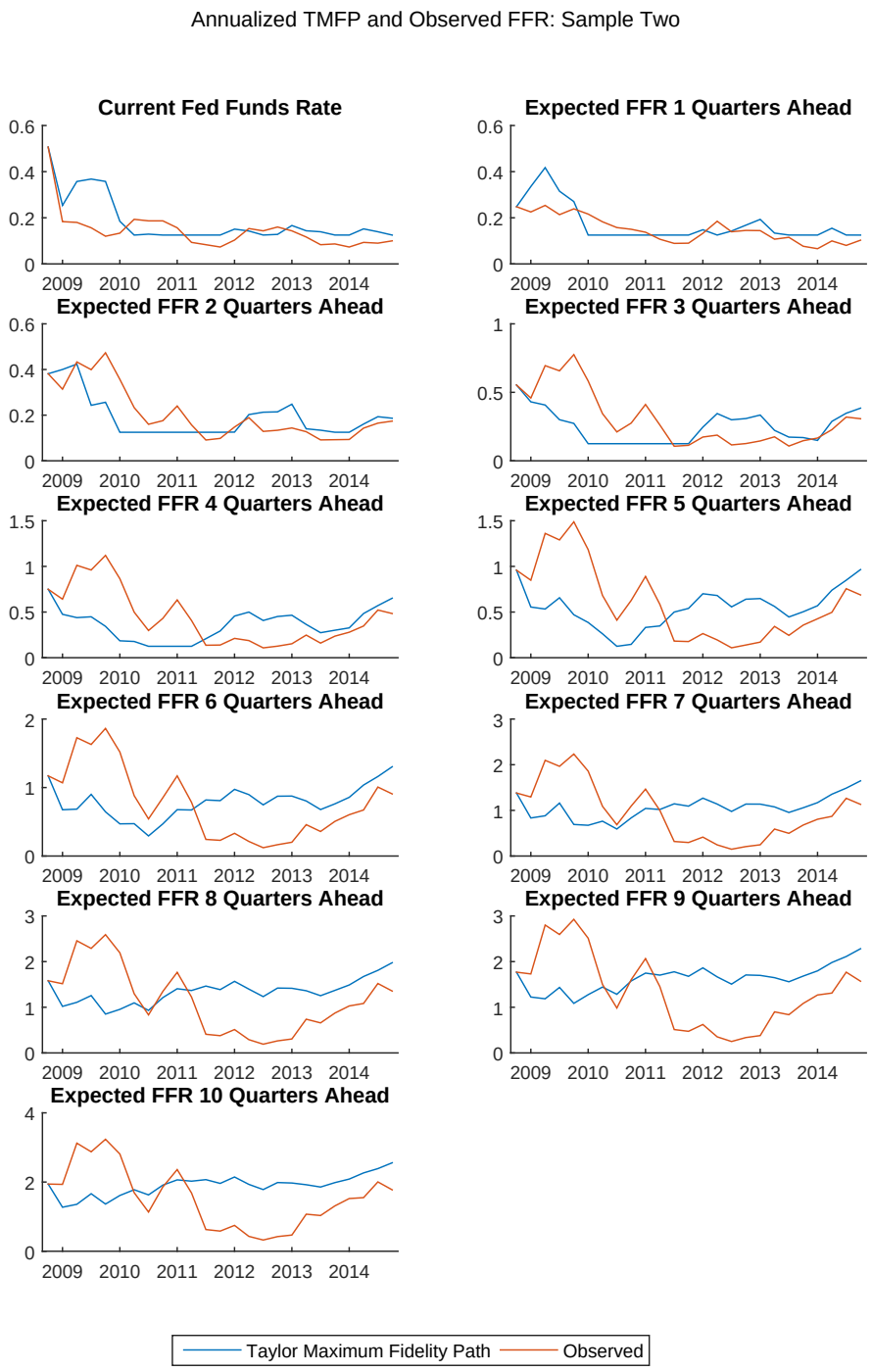


Figure 14: TMFP fed funds futures term structure

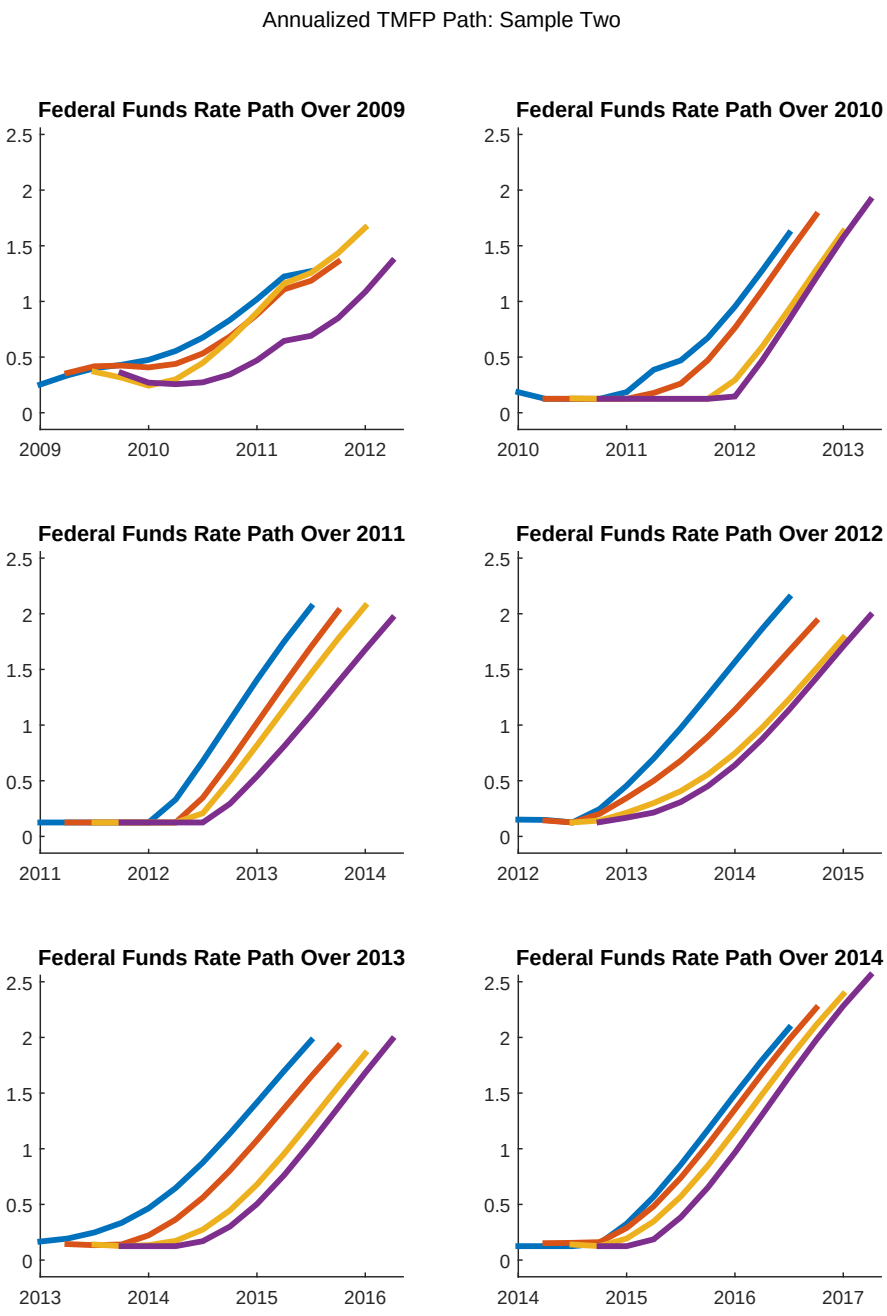
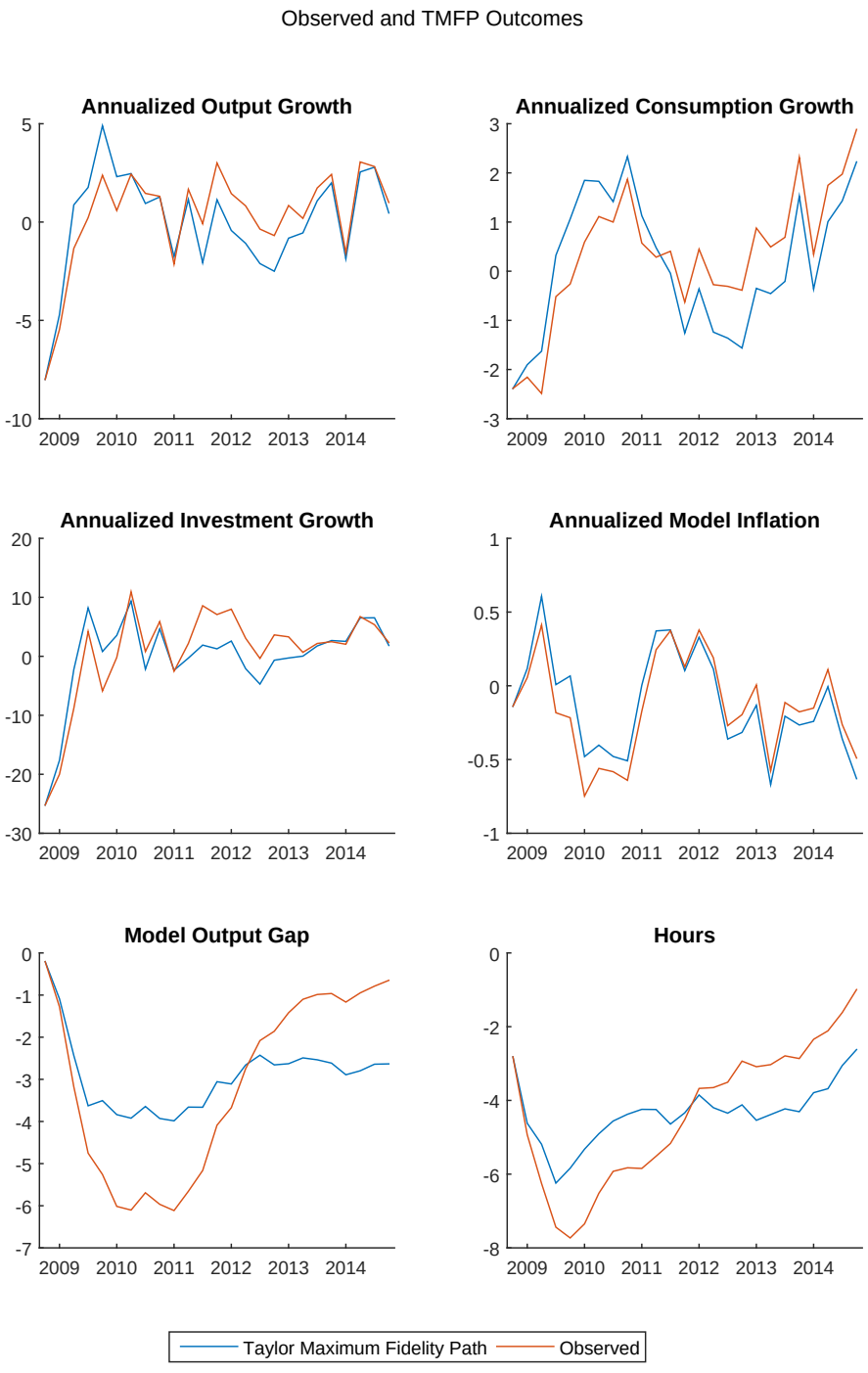
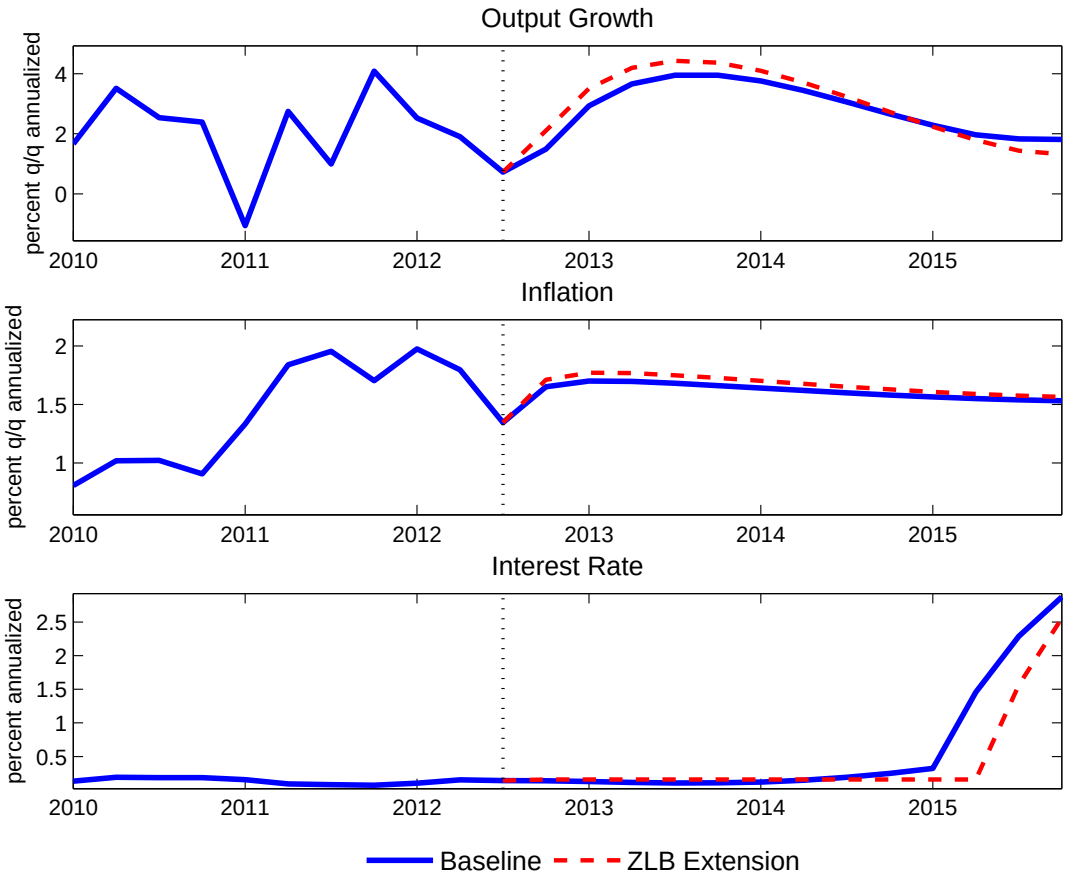


Figure 15: Actual and TMFP counterfactual outcomes



Note: Inflation is depicted relative to the 2% steady state.

Figure 16: The Del Negro et al. (2015) ZLB experiment



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