Monetary Policy Forward Guidance and the Business Cycle*

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Abstract

Monetary authorities often express their views about the economic outlook for the economy, the important factors influencing that outlook, and the possible consequences for monetary policy. This kind of monetary policy communication has come to be known as *forward guidance*. Evidence suggests that forward guidance has influenced asset prices. This paper investigates whether forward guidance has influenced the real economy. We have two main contributions. First we extend the traditional interest rate rule used to summarize monetary policy in these models to include forward guidance. Second, we estimate a New Keynesian model with this rule and use it to quantify the historical effects of monetary policy forward guidance. On the latter we find that more than half the business cycle variation in the federal funds rate before the financial crisis is accounted for by forward guidance. This suggests that traditional interest rate rules are miss-specified. Forward guidance explains about 9% of output fluctuations at business cycle frequencies, but much more in certain episodes.

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1 Introduction

Monetary authorities often express their views about the economic outlook for the economy, the important factors influencing that outlook, and the possible consequences for monetary policy. This kind of monetary policy communication has come to be known as *forward guidance*. Forward looking individuals' expectations of future policy actions influence their current choices and forward guidance seeks to help economic agents form these expectations. Explicit monetary policy forward guidance is a hallmark of US monetary policy since the onset of the financial crisis, but its use is not new to this period. The Federal Open Market Committee (FOMC) has been using forward guidance implicitly through speeches or explicitly through formal FOMC statements and congressional testimony since at least the mid-1990s.[1]

Rudebusch and Williams (2008) describe the modern history of explicit forward guidance before the financial crisis. From 1983 to 1999 the FOMC's views about the future policy path were put to a vote at each meeting. The vote was on the expected direction of future changes in the stance of policy between meetings. However, this information was only made public after the following meeting, when it was outdated and presumably of limited use to the public. Following the May 1999 meeting the FOMC began including explicit language about the future stance of policy in its meeting statements. The statement after that meeting included "the Committee ... adopted a directive that is tilted toward the possibility of a firming in the the stance of monetary policy." The language guiding expectations would change over time as the FOMC sought a way of maintaining transparency without confusing markets and adjusted to the evolving policy environment. But, language of one form or another describing the expected future stance of policy was to be a fixture of statement language going forward.[2]

While language that can be construed as forward guidance has been used for some time, it remains unclear whether such language has influenced the economy. The principle empirical issue is that statement language may just rationalize agents' expectations – it may not be "news." Two studies by Bernanke et al. (2004) and Gürkaynak et al. (2005) strongly suggest

[1] From the beginning of his tenure as chairman of the FOMC, Alan Greenspan's speeches and Congressional testimony were studied to discern the direction of future policy. We discuss examples below.

[2] Here are some examples. At the start of 2000, the direct signals of policy inclinations were replaced with language describing the "balance of risks" regarding the FOMC's mandated goals of maximum employment and price stability. The FOMC included "... the Committee believes that policy accommodation can be maintained for a considerable period" in its August 2003 statement. In January 2004 the forward looking language was "the Committee believes that it can be patient in removing its policy accommodation" and in May 2004 they used "policy accommodation can be removed at a pace that is likely to be measured." As inflation fears became elevated, in the December 2005 the statement included "further policy firming may be needed."

that FOMC statements have contained news about the future path of policy prior to the financial crisis. The findings of the latter paper are particularly striking. It studies the behavior of federal funds rate futures in symmetric 30 and 60 minute windows surrounding the release of FOMC statements. By focusing on short windows, Gürkaynak et al. (2005) control for macroeconomic conditions. This is crucial. It is natural that expectations of future federal funds rates will change in response to new information pertinent to expected future economic activity and inflation. Not controlling for this information could lead to incorrectly attributing economic effects to forward guidance that are in fact due to the factors driving revisions to expectations of growth and inflation. Focusing on the narrow window surrounding the release of statements keeps the economic information available to market participants essentially fixed. Of course this identification strategy also has the drawback that it ignores communications of forward guidance between meetings.

Using this methodology and data covering announcements from July 1991 through December 2004, Gürkaynak et al. (2005) find that FOMC statements are associated with significant affects on federal funds futures and on Treasury yields. By using a factor-based approach they decompose changes in asset prices around announcements into "target" and "path" factors, where the latter is interpretable as the forward guidance component of FOMC statements. They find that 75 to 90 percent of the explainable variation in five- and ten-year Treasury yields is due to the path factor rather than to changes in the federal funds rate target. Information about what the policy rate is likely to be, either through explicit statements about the path that differ from prior market expectations, or new clarity about the FOMC's economic outlook, should affect anticipated future federal funds rates. Therefore this evidence strongly suggests that forward guidance, broadly conceived, has had an impact on asset prices prior to the financial crisis.

These findings are certainly suggestive that forward guidance, when carefully applied, can have an economically meaningful impact. However they leave open the question of whether forward guidance has had an economically meaningful *macroeconomic* impact. The purpose of this paper is to address this question and we do so within the context of a New Keynesian (NK) dynamic stochastic general equilibrium model (DSGE). We have two main contributions. First we extend the traditional interest rate rule used to summarize monetary policy in these models to include forward guidance. Second, we estimate a DSGE model with this rule and use it to quantify the historical effects of monetary policy forward guidance. On the latter we find that more than half the business cycle variation in the federal funds rate before the financial crisis is accounted for by forward guidance. This strongly suggests that traditional interest rate rules are miss-specified. Forward guidance explains about 9% of output fluctuations at business cycle frequencies, but much more in certain episodes.

We introduce monetary policy forward guidance into an otherwise standard interest rate rule by supposing that agents receive information about future values of the intercept term in the rule. Essentially, we introduce monetary policy "news" shocks. Introducing monetary policy news shocks without additional restrictions can lead to strange and seemingly implausible dynamics. For example, news that the funds rate several quarters out will be higher than otherwise predicted by the model's interest rate rule can lead to the funds rate falling contemporaneously. A high future funds rate lowers current activity which with a conventional interest rule implies a lower current setting for the funds rate. We resolve this problem by adopting a factor structure for the monetary policy signals.

The remainder of the paper proceeds as follows. In the next section we describe our new interest rate rule. After this we describe the rest of the macroeconomic model, its estimation and our findings. The last section concludes.

2 An Interest Rate Rule with Forward Guidance

Summarizing monetary policy with a parsimonious rule for setting the policy rate as a function of current or expected economic conditions is a longstanding practice in macroeconomics. See for example rules specified in Taylor (1993, 1999) and Reifschneider and Williams (2000). This section describes our new approach to modeling monetary policy with an interest rate rule that includes forward guidance.

We consider interest rate rules for the average policy rate over quarter t, r_t, of the following form:

$$\widehat{R}_t = \rho_R \widehat{R}_{t-1} + (1-\rho_R)\left(\phi_\pi \widetilde{\pi}_t + \phi_y \widetilde{y}_t\right) + \sum_{j=0}^{M} \xi_{t-j,j}, \tag{1}$$

The variables $\widetilde{\pi}_t$ and $\widetilde{y}_t$ are the policy-relevant inflation and output gaps that will be defined precisely below. Parameters ρ, ϕ_π and ϕ_y determine the degree of interest smoothing and how the policy rate responds to typical changes in macroeconomic conditions. We refer to the policy prescribed only by the lagged policy rate and the two gaps as "normal policy." For any variable x, $\widehat{x}$ denotes deviation from steady state.

The distinguishing feature of (1) is the last term involving the $M+1$ disturbances, $\xi_{t-j,j}$ for $j = 0, 1, \ldots, M$. The first of these, $\xi_{t,0}$, is the usual monetary policy disturbance that appears in conventional interest rate rules. The remaining disturbances are *forward guidance shocks*, because they are revealed to the public before they are applied to the interest rate rule. Agents see $\xi_{t,j}$ in quarter t, and it applies to the rule j quarters hence. Gather all these shocks into the vector $\Xi_t \equiv (\xi_{t,0}, \xi_{t,1}, \ldots, \xi_{t,M})$. Each realization of Ξ_t influences the expected path of interest rates. We wish to map expectation revisions, which are uncorrelated over time by construction, into realizations of Ξ_t; so we assume that Ξ_t is also uncorrelated over time. For M sufficiently large and under rational expectations, this is without loss of generality.[3] Its variance-covariance matrix in quarter t is Ω_t. The inclusion of these forward guidance shocks distinguishes our specification from conventional interest rate rules. While the forward guidance shocks themselves are unique to us, the practise of including exogenous shocks to the interest rate is commonplace. These shocks are not to be interpreted literally. Rather they absorb the effects of information that because of the practical need for parsimony we cannot include in the analysis. The most similar recent work is that of Laséen and Svensson (2011) which considers the theory of forward guidance.

The traditional contemporaneous unanticipated policy shock term $\xi_{t,0}$ captures the Fed's response to extraordinary events that warrant a rapid but temporary deviation from the normal policy prescription, such as 9/11 or the Asian currency crisis of the late 1990s. The remaining $\xi_{t,j}$ terms is intended to identify what we call *active forward guidance*. This is forward guidance that describes deliberate future deviations from normal policy. We refer to all other forward guidance as *passive forward guidance*. Passive forward guidance comes in two forms. It includes descriptions of the monetary authority's views about the outlook for the economy and communications about the nature of the normal policy. Forward guidance about the economic outlook influences expectations of rates j periods ahead only by changing expectations of $\widetilde{\pi}_{t+j}$ and $\widetilde{u}_{t+j}$. Passive forward guidance can be *revealing* in the sense that it tells market participants something of which they were unaware before it was communicated, but it can also be *confirming* in the sense that it merely reflects private agents' expectations back at them.[4] Active forward guidance is always revealing since it changes private expectations by announcing shifts in the intercept of the interest rate rule in advance.[5]

If our model does a good job capturing the expectations of market participants regarding the two gaps then the measured forward guidance shocks should reflect mostly active forward guidance. In practise it is likely that our model will not be perfect along this dimension. In this case we are likely to measure a mixture of active and passive forward guidance. Gürkaynak et al. (2005) identify effects of FOMC statements using changes in federal funds

[3]This is because at any point in time a time series variable can be decomposed into the sum of its expected value based on an earlier information set and an orthogonal innovation.

[4]Within the context of our model, all agents understand normal policy so that forward guidance about normal policy must always be confirming. Empirically one can imagine situations in which normal policy is described by the endogenous component of the interest rate rule only on average so that communications that describe deviations from this average policy response would be captured by our active forward guidance term.

[5]Kohn and Sack (2003) describe a taxonomy for forward guidance that is similar. They distinguish between "policy-inclination" and "economic-outlook" forward guidance. Loosely speaking the former corresponds to active forward guidance and the latter to passive forward guidance.

futures rates in short time intervals surrounding the statement releases. Since they do not condition on private sector expectations of future activity they identify both active and revealing passive forward guidance. Campbell et al. (2012) develop an empirical strategy aimed at identifying active forward guidance separately.

Active forward guidance is primarily motivated by a desire by the monetary authority to clarify its intentions in unusual times. For example, it may want to clarify its intentions when market participants do not have experience with the monetary authority's behavior in unusual times. This appears to have been the case when the FOMC inserted "the Committee believes that policy accommodation can be maintained for a considerable period" into the August 2003 statement. Former FOMC vice-chairman Donald Kohn describes the rationale for that language in Kohn (2005):

> Markets appeared to be anticipating that inflation would pick up steam soon after the expansion gained traction, and therefore that interest rates would rise fairly steeply. This expectation was contrary to our own outlook. We saw economic slack and rapid productivity growth keeping inflation down for some time ... We thought that our reaction to a strengthening economy would be somewhat different this time than it had been in many past economic expansions and unlike what the markets seemed to anticipate.

The fact that the FOMC had a different outlook for the economy is irrelevant from the perspective of measuring active forward guidance. Communicating this would be passive forward guidance about the outlook. However, because the dynamic of strong growth with subdued inflation was unusual, the FOMC felt it necessary to clarify its intentions. Our measure of active forward guidance should pick this up.

The attainment of the zero lower bound (ZLB) on the federal funds rate is clearly such an unusual situation. At the ZLB private agents can have difficulty forming expectations because traditional interest rate rules no longer apply and market participants have no experience with monetary policy at the ZLB (other than from history books). This clearly presents the FOMC with a strong motivation to engage in active forward guidance and they appear to have done so. FOMC minutes have revealed discussions by the FOMC of strategies for unwinding the large expansion of the balance which should clarify the likely behavior of the FOMC when that time comes. This is a form of active forward guidance, which presumably explains why release of minutes in which such discussions occurred have garnered so much attention since the attainment of the ZLB.

Passive forward guidance is motivated by many considerations. The monetary authority may just wish to explain its actions thereby enhancing its transparency. There may also be times, such as the episode highlighted in Kohn (2005), when the monetary authority has a different view of the economic outlook than private agents and wants to ensure that they are aware of this. Generally, the motivation for passive forward guidance is to aid private agents in forming accurate expectations thereby facilitating decision-making and the smooth functioning of the economy.

To limit the number of parameters to be estimated we give Ω_t a factor structure:

$$\xi^{t,j} = \mathcal{A}_j f_t^C + \mathcal{B}_j f_t^F + u^{t,j}. \tag{2}$$

The variables f_t^C and f_t^F are *i.i.d. current policy shock* and the *forward guidance factor*, and disturbances $u_{t,j}$ are uncorrelated across both j and t. By assumption, $\alpha^0 = 1$, $\beta^0 = 0$, and $u_{t,0} \equiv 0$ so the current policy shock can be read off of the contemporaneous federal funds rate and the forward guidance factor only influences future values of the federal funds rate. We also assume $\alpha^j = 0$ for $j > 0$ so that the current policy shock corresponds to the usual interest rate rule disturbance. The direct effect of an innovation to the forward guidance factor on the future policy rate and the term structure is captured in the β^j coefficients. The net effects on the economy of forward guidance factor innovations depend on the entire model structure, for example through the interest smoothing term. Consequently it is difficult to interpret these coefficients; we use impulse response functions to determine the dynamic effects of forward guidance.

The forward guidance shocks reflect all the new information the monetary authority considers that influences its expected future policy rate path and is not already captured in the lagged policy rate and the gap variables. As "news," it is natural for the factors to be unpredictable. Still, one might imagine that forward guidance is influenced by the current inflation and output gaps. We have experimented somewhat with allowing for this dependence but did not find much evidence for it. The current gaps (and current forward guidance settings) do influence the expected future path through the lagged policy rate term. One advantage of our framework is that it allows for more interesting policy rate dynamics, such as a hump shaped path following news. While we think our approach is a natural first step in modeling forward guidance in a DSGE framework, we do think it is worthwhile to consider other specifications but leave this for future work.[6]

[6] For example, forward guidance could be reflected in second order dynamics in the interest rate rule.

3 The Model

The model resembles other medium-scale empirical NK frameworks in most ways.[7] There is a single representative household that owns all firms and supplies the economy's labor. Final goods are produced with differentiated intermediate goods which themselves are produced with capital and differentiated labor. The intermediate goods market and the labor market are monopolistically competitive. Prices of both kinds of differentiated inputs are sticky and are indexed to ensure the existence of a stationary equilibrium.[8] Hence standard forward-looking Phillips curves connect wage and price inflation with the marginal rate of substitution between consumption and leisure and marginal cost, respectively. Other frictions include investment adjustment costs and internal habit-based preferences. The adjustment costs are specified in investment's growth rate and consumption preferences depend on the quasi-difference of current and lagged consumption. The combination of these features is very close to Christiano et al. (2005), Smets and Wouters (2007), and many other models. The model has two main features which distinguish it from other NK frameworks: the interest rate rule and the inclusion of a financial accelerator mechanism.[9] We begin by describing these features and then briefly describe the other key equations of the model and the shocks that drive fluctuations.

3.1 Monetary Policy

The interest rate rule is given by (1). The inflation gap in (1) is defined by

$$\widetilde{\pi}_t \;=\; \frac{1}{4}\sum_{j=-1}^{2} E_t\widehat{\pi}_{t+j} - \widehat{\pi}^*_t, \tag{3}$$

Equation (3) says the inflation gap is the deviation of a four quarter average of inflation from the time-varying inflation anchor $\hat{\pi}^*$. The model's inflation anchor varies exogenously and follows an AR(1) process. It is included to account for low frequency movements in inflation and should not be interpreted as a policy lever. Furthermore, as we discussed further below, including a time-varying inflation anchor identified off of inflation expectations data allows long run inflation expectations to become unhinged in the model if this is the case in the

[7] The model is used at the Federal Reserve Bank of Chicago for forecasting and policy analysis.

[8] Each period individual wage and price have a constant probability of being able to optimally reset their wage or price otherwise they index their wage or price to its value in the previous period.

[9] The model and estimation involve some other unique features but these are not important for understanding the workings of the model. With some very minor exceptions, knowledge of existing medium scale NK models is sufficient for understanding our results. We describe the additional novel features of our framework below.

data. The four quarter moving average of inflation includes both lagged, current and future values of inflation. The monetary authority uses the structure of the model to forecast the future terms.

We follow Cúrdia, Ferrero, Ng, and Tambalotti (2011) by defining the output gap in (1) as follows:

$$\widetilde{y}_t = \frac{1}{4}\sum_{j=-1}^{2} E_t\widehat{x}_{t+j}. \tag{4}$$

$$[1+\lambda(1-L)^2(1-F)^2]\widehat{x}_t = \lambda(1-L)^2(1-F)^2\widehat{y}_t \tag{5}$$

where L and F are the lag and lead operators and λ is a smoothing parameter. Equation (4) defines the output gap as a four quarter moving average of detrended model output. The monetary authority detrends output using the filter given by (5). This detrending approximates the Hodrick-Prescott filter. So, for example, setting $\lambda = 1600$ corresponds to defining the output gap as the cyclical component of model output where the cycle is of approximate frequency 6 to 32 quarters. The moving average of filtered output has the same lead-lag structure as inflation and so also includes forward looking terms. By including forward looking terms for inflation and the output gap in the interest rate rule we eliminate news about the inflation and output gaps up to two quarters ahead from our forward guidance shocks.

3.2 Financial Accelerator

The model incorporates a financial accelerator following Bernanke, Gertler, and Gilchrist (1999) and Gilchrist et al. (2010). To this end, we introduce risk neutral entrepreneurs who at the end of period t purchase capital goods, $\overline{K_t}$, from the capital installers at the price Q_t, using a mix of internal resources, given by end of period net worth, N_t, and borrowing B_t, such that

$$Q_t\overline{K_t} = N_t + B_t$$

In the next period, $t+1$ entrepreneurs optimally choose the rate of utilization, u_{t+1}, and rent the effective capital stock $K_{t+1} = u_{t+1}\overline{K_t}$ to the goods producing firm, receiving in return the gross rental rate of capital ω^k_{t+1}. At the end of period $t+1$ they resell the remaining capital stock, $(1-\delta)\overline{K_t}$ back to the capital producers at the price Q_{t+1}.Therefore, the expected real return accruing to an entrepreneur per unit of capital purchased at time t

is given by

$$E_t[1+r^k_{t+1}] = E_t\left[\frac{\omega^k_{t+1}u_{t+1} - \frac{a(u_{t+1})}{\Gamma_{t+1}} + (1-\delta)Q_{t+1}}{Q_t}\right], \tag{6}$$

where $\frac{a(u_{t+1})}{\Gamma_{t+1}}$ corresponds to costs of utilization, and δ is the constant depreciation rate. This equation replaced the usual capital accumulation equation that appears in business cycle models with complete markets.

We assume that the spread or external finance premium – the ratio of the equilibrium return to capital and the expected real interest rate – is an increasing function of entrepreneurs' leverage according to

$$\frac{E_t[1+r^k_{t+1}]}{E_t[\frac{1+R_t}{\pi_{t+1}}]} = F\left[\frac{\overline{K_t}\ Q_t}{N_t}\right] e^{\nu_t}, \tag{7}$$

with R_t the nominal interest rate, π_{t+1} the gross inflation rate and $F(1) = 1$, $F' > 0$, $F'' > 0$.[10] The spread shock, e^{ν_t}, can be viewed as a disturbance to credit supply, moving the external finance premium beyond the level dictated by entrepreneurial net worth. This disturbance behaves similarly to shocks to the marginal efficiency of investment in other NK models.

In Bernanke, Gertler, and Gilchrist (1999), equation (7) arises from imperfections in private financial intermediation, due to lenders' costly state verification of the returns realized by entrepreneurs' projects. When deriving equation (7) from the microfoundations of the contracting problem, as in Christiano et al. (2009), the external finance premium depends on primitives such as monitoring costs and the variance of idiosyncratic shock affecting entrepreneurial returns. Here, instead we parameterize the steady state level of $F\left(\frac{K\ Q}{N}\right)$ as well as its elasticity τ, as independent parameters.

Entrepreneur's survive to the next period with probability ζ. With probability $1-\zeta$ they exit, and their net-worth is partly consumed and partly transferred to new entrepreneurs to keep their population size constant. The resulting law of motion for entrepreneurial net worth is given by

$$N_t = \zeta\left\{\overline{K}_{t-1}\ Q_{t-1}[1+r^k_t] - E_{t-1}[1+r^k_{t-1}]B_{t-1}\right\} + (1-\zeta)\Gamma_t + \varsigma_t \tag{8}$$

where Γ_t is the transfer from exiting to new entrepreneurs. ς_t is a shock to net worth, that can arise for instance from time-varying survival probabilities. We embed equations (6) through 8 in our model, together with independent laws of motion for the spread and net worth shocks, ν_t and ς_t.

[10]Notice that that if entrepreneurs are self-financed, which rule out in steady state, $F(1) = 1$ and there is no external finance premium.

3.3 Price Phillips Curve

The log linearized price Phillips curve can be expressed as

$$\hat{\pi}_t^p = \frac{\beta}{1+\iota_p\beta} E_t \hat{\pi}_{t+1}^p + \frac{\iota_p}{1+\iota_p\beta} \hat{\pi}_{t-1}^p + \kappa_p \hat{s}_t + \epsilon_t^p$$

The variable $\hat{s}_t$ denotes intermediate goods producers' common marginal cost and ϵ_t^p is a shock to the elasticity of substitution between intermediate goods in the production of final goods, *i.e.* a price-markup shock. Producers unable to update their price with all current information are allowed to index their prices to a convex combination of last quarter's inflation rate with the steady-state inflation rate in the Phillips curve. The parameter π_{t-1}^p governs the share of lagged inflation in this rule. The introduction of the exogenous inflation anchor does not alter the dynamic component of inflation indexation. We do not separately identify the structural parameters underlying κ_p. Instead we estimate this parameter directly.

3.4 Wage Phillips Curve

Denoting nominal wage inflation by π_t^w, the log linearized wage Phillips curve can be written as

$$\widehat{\pi}_t^w + \widehat{j}_t = \kappa_w \widehat{x}_t + \beta E_t[\widehat{\pi}_{t+1}^w + \widehat{j}_{t+1}]$$

The variable $\widehat{x}_t$ equals the log-linearized ratio of the marginal disutility of labor to the real wage and is given by

$$\widehat{x}_t = b_t + \psi_t + \nu \widehat{l}_t - \widehat{\lambda}_t - \widehat{w}_t,$$

where b_t and ψ_t are disturbances to the discount factor and the disutility of working, respectively, $\widehat{l}_t$ is hours, $\widehat{\lambda}_t$ is the marginal utility of consumption and $\widehat{w}_t$ is the the real wage. Parameter ν is the inverse Frisch elasticity of labor supply. Variable $\widehat{j}_t$ arises from the indexation of wages to a weighted average of lat period's productivity-adjusted price inflation and its staedy state value:

$$\begin{aligned} \widehat{j}_t &= [\widehat{\pi}_t^p + \widehat{z}_t^*] - \iota_w[\widehat{z}_{t-1}^* + \widehat{\pi}_{t-1}^p] \\ \widehat{z}_t^* &= \hat{z}_t - \frac{\alpha}{1-\alpha}\widehat{\mu}_t, \end{aligned}$$

The parameter ι_w determines the indexation share of last period's productivity adjusted wages. The variable $\widehat{z}_t^*$ is the economy's technologically determined stochastic trend rate of growth with α equal to capital's share in the production function, z_t the growth rate of neutral technology, and μ_t the growth rate of investment-specific technology. The parameter ι_w

governs The wage Phillips curve says that nominal wage inflation (adjusted by trend growth) depends positively on future nominal wage inflation (also appropriately trend-adjusted), and increases in the disutility of the labor-real wage gap. Similar to our treatment of the price Phillip's curve we estimate κ_w directly.

3.5 Shocks

The model's business cycle fluctuations are driven by eight shocks in addition to the monetary policy shocks. With one exception noted below, these shocks are all assumed to be AR(1). For parsimony's sake, we group the model's non-policy shocks according to their impact on prices and quantities and their importance in driving aggregate fluctuations. Four non-policy shocks move output and GDP inflation in the *same* direction so we refer to these as *demand shocks*. One changes the households' rate of time discount (b_t). We call this the discount shock. Two are financial disturbances. The spread shock (ν_t) generates fluctuations in the external finance premium beyond the level warranted by current economic conditions, and the net worth shock (ς_t) generates exogenous fluctuations in private balance sheets. The fourth demand shock is a shock to the sum of government spending, net exports and the change in valuation of inventories inventories. The economics of this shock are identical to a pure government spending shock financed by lump sum taxes and so we refer to it as a government shock. Four shocks move real GDP and GDP deflator inflation in *opposite* directions on impact and so we call these *supply shocks*. These shocks directly change neutral technology ($\widehat{x}_t$), investment-specific technology ($\widehat{\mu}_t$), markups of intermediate goods prices (ϵ_t^p), and households' disutility from labor (ψ_t). The latter shock is assumed to be an ARMA(1,1), which is a parsimonious way of addressing low frequency movements in hours worked and high frequency variation in wages. We group other shocks that are usually of small importance into a residual category. The *residual shocks* include shocks that do not impact agent's decisions, including idiosyncratic shocks to the various price measures used in the estimation and measurement error in the interest rate spread we use to measure the external finance premium. We also include the idiosyncratic forward guidance shocks (the $u_{t,j}$'s), in this category.

4 Estimation

The model confronts data within the arena of a standard linear state-space model. Given a vector of parameter values, θ, log-linearized equilibrium conditions yield a first-order autoregression for the vector of model state variables, ζ_t:

$$\begin{aligned}\zeta_t &= F(\theta)\zeta_{t-1} + \varepsilon_t \\ \varepsilon_t &\sim N(0, \Sigma(\theta))\end{aligned}$$

Here, ε_t is a vector-valued innovation built from the model-based shock processes described above. Many of its elements identically equal zero.

Gather the date t values of the model variables for which we have empirical counterparts into the vector z_t. The model analogues to its elements can be calculated as linear functions of ζ_t and ζ_{t-1}. We suppose that the data equal these model series plus a vector of "errors" v_t.

$$\begin{aligned}z_t &= G(\theta)\zeta_t + H(\theta)\zeta_{t-1} + v_t \\ v_t &= \Lambda(\varphi)v_{t-1} + e_t \\ e_t &\sim N(0, D(\varphi))\end{aligned}$$

Here, the vector φ parameterizes the stochastic process for v_t. In our application, the only non-zero elements of v_t correspond to the observation equations for variables that are assumed to be measured with error. We assume that the interest rate spread used to identify the spread shock is measured with error. We also use multiple price indices to isolate a common inflation component that is identified with model-based consumption inflation. The idiosyncratic disturbances in inflation fit the high-frequency fluctuations in prices that are likely due to measurement error and thereby allow the price markup shocks to fluctuate more persistently. These errors evolve independently of each other. In this sense, we follow Boivin and Giannoni (2006) by making the model errors idiosyncratic.

An additional reason for using multiple price indices in estimation has to do with measurement. The numeraire in DSGE models is usually consumption. Under the common practise of including durables within the measure of investment, model-consistent measures of consumption prices do not correspond well with either of the measures commonly referenced by policy makers and market participants - core-PCE and core-CPI. This is an additional consideration that motivates our use of a factor structure to model all three consumption price series, the two popular core measures and the measure designed to be consistent with the model. Doing this delivers predictions for both core-PCE and core-CPI in addition to limiting the structural impact of high frequency fluctuations in inflation that are likely driven by measurement error. Our use of multiple price series is a component of our model's estimation that sets it apart from most other studies.

The other notable feature of the estimation involves the observation equation for the GDP deflator. We model its growth as a share-weighted average of the model's consumption and investment deflators. By modeling the GDP deflator in this way and including core-PCE as one of the price indices used to identify model-based consumption inflation our framework delivers predictions for two of the variables of most concern to policy-makers: core-PCE inflation and real GDP growth.

We denote the sample of all data observed with Y and the parameters governing data generation with $\Theta = (\theta, \varphi)$. The prior density for Θ is $\Pi(\Theta)$, which we specify to be similar to that employed by Justiniano, Primiceri, and Tambalotti (2011a). Given Θ and a prior distribution for ζ_0, we can use the model solution and the observation equations to calculate the conditional density of Y, $F(Y|\Theta)$. To form the prior density of ζ_0, we apply the Kalman filter. This choice of start date is driven by the availability of federal funds futures data. Bayes rule then yields the posterior density up to a factor of proportionality.

$$P(\Theta|Y) \propto F(Y|\Theta)\Pi(\Theta)$$

We analyze each model with its parameter values set to this posterior distribution's mode.

Our sample period is 1987q1 to 2007q2. The start date is governed by availability of federal funds futures data and the end date is chosen to exclude the crisis period to focus on a period of relative macroeconomic stability. The data used to estimate the model include real per capita GDP growth, nominal per capita consumption, nominal per capita investment, the level of per capita hours worked in the non-farm business sector, nominal compensation per hour worked in non-farm business, the GDP deflator, the deflator corresponding to our measure of consumption, the deflator corresponding to our measure of investment, core PCE, core CPI, ten-year ahead forecasts of core CPI, an interest rate spread, the ratio of private credit to GDP, the federal funds rate, and contemporaneous expectations of the federal funds rate 1 to 4 quarters hence.

Our measures of consumption and investment are intended to correspond to consumption and investment in the model. Therefore consumption is of non-durable and services and investment includes business fixed investment, residential investment, and personal consumption expenditures on durable goods. We take the ten-year ahead core CPI inflation forecasts from the affine term structure model described in Ajello, Benzoni, and Chyruk (2011). As described below, these expectations help identify the inflation anchor process. For the interest rate spread we use a weighted average of high-yield corporate and mortgage-backed bond spreads with the 10-year Treasury and an asset-backed bond spread with the 5-year Treasury; where the weights equal the shares of nonfinancial business, household mortgage, and household consumer debt in private credit. The interest rate spread helps to identify the spread shock. Our measure of private credit sums household and nonfinancial business credit market debt outstanding. We include household credit since because our measure of investment includes residential investment and durable goods consumption. Expected future federal funds rate data are derived from futures markets data. These data help identify the forward guidance shocks. Finally note that we include all components of aggregate expenditures except government spending, net exports and private inventory accumulation. This data is implicitly modeled as our government spending shock.

We identify the current policy, forward guidance, and inflation anchor shocks using data on the federal funds rate, federal funds rate futures, and our measure of 10 year inflation expectations derived from financial market data. The current policy shock moves the current rate more than future rates, while the forward guidance and the inflation anchor shocks move expected future federal funds rates more than the current rate. This difference is a key source of identification. Since the inflation anchor and forward guidance are exogenous, long run inflation expectations in a model obeying (1) are not influenced by forward guidance.[11] So, forward guidance shocks are identified from changes in futures rates larger than changes in the current rate that are not associated with changes in long run inflation expectations. Inflation anchor shocks are identified from similar changes in futures rates that occur when long run inflation expectations change as well.

A natural objection to using forward guidance as a policy tool is that by doing so the monetary authority risks inflation expectations becoming unhinged. While (1) does not allow for this, our identification strategy should pick up such a connection if indeed it has ever occurred in our sample. In particular, it would have occurred if expected future federal funds rates fell more than the current rate at a time when financial market participants revised expectations of future inflation upward. Essentially, innovations to the inflation anchor would have to be negatively correlated with those of the forward guidance factor at such times. In our sample inflation expectations exhibit a secular downward trend so we strongly suspect that episodes of forward guidance raising long run inflation expectations are absent from our sample.

[11] Forward guidance does influence short run inflation expectations via the Phillips curve.

5 Findings

Our parameter estimates for the interest rate rule are reported in Table 1 and for the remaining parameters in Table 2.[12] Beginning with the normal component of the policy rule we see that the inflation anchor is very persistent. This reflects the downward trend in inflation over our sample. The rule displays a lot of interest rate smoothing, the inflation gap coefficient obeys the Taylor principle, and the output gap coefficient is much smaller than the one for inflation. These parameters are similar to previous estimates in the literature, e.g. Justiniano et al. (2011b). The forward guidance factor loadings are difficult to interpret since the dynamics of policy following a forward guidance factor shock depends on the endogenous response of policy.

The plausibility of the normal component of the policy rule depends in part on the nature of the output gap in the rule. Figure 1 demonstrates that the model's output gap is within the realm of plausibility. In particular its low frequency dynamics correspond well with the gap published by the Congressional Budget Office (CBO). The correlation of the of the model's gap with the CBO gap is 0.51. The relatively close association of the model's gap with the CBO gap is actually quite a remarkable result. DSGE models are notorious for yielding empirically implausible output gaps, see for example Vetlov et al. (2011). We are certainly not the first to obtain an empirically plausible model-based output gap, *e.g.* Justiniano et al. (2011b) are successful in this regard. Nevertheless having done so lends credibility to the policy implications derived from our estimated rule.

There are a lot of parameters in Table 2, but we focus on just a few. The first thing we highlight are the Phillip's curve slopes. The price slope is very small, about an order of magnitude smaller than reduced form estimates, *e.g.* Galí and Gertler (1999), Eichenbaum and Fisher (2007). The wage slope is also small, but because these are estimated with less precision, our estimate is consistent with reduced form estimates, such as those in Sbordone (2006).[13] Our estimates imply that there will be little endogenously generated wage or price inflation in the model. We have estimated versions of our model without forward guidance and find the slopes are more in line with reduced form estimates, so it appears as if modeling forward guidance has a substantial impact on two key parameters in NK models. Second, the estimated real rigidities as implied by the capacity utilization elasticity, investment adjustment costs, and habit are similar in magnitude to other estimates in the

[12] We have excluded from these tables the factor loadings for the common component of inflation, the volatility of the idiosyncratic forward guidance signals and non-policy shocks, and the volatility of the measurement errors in inflation and the spread.

[13] We estimated the Phillip's curve slopes directly and not the underlying structural parameters. By doing this we do not impose all the cross-parameter restrictions implied by our model.

literature, *e.g.* Justiniano et al. (2011b) and so they are relatively large. This imparts a lot of inertia in response to shocks. Lastly, the financial accelerator is estimated to be quite weak. In particular the elasticity of the spread with respect to net worth, τ, is estimated to be small. This is in part due to the relative absence of finance-related events in our sample. It has the implication that the net worth shock has virtually no impact on the model's dynamics. The spread shock is still influential. Its implications are very similar to models with shocks to the marginal efficiency of investment.

We now begin our analysis of the model's interpretation of the data given these parameter estimates, beginning with our estimates of forward guidance. Figure 2 shows the realizations of the contemporaneous policy shock and the forward guidance factor. To gauge the plausibility of these estimates, we relate the larger forward guidance factor shocks to specific communications by the Fed. We study three episodes: the large negative realization in 1991q3; the sharp reversal from a large positive to two large negatives in 1994q4-1995q2; and the period 2001q3-2002q3 during which there were three large negatives. The first episode occurs when there are no statements following FOMC meetings, the second pre-dates when FOMC statements included forward looking language, and the last episode comes in the era of explicit forward looking language in FOMC statements. Recall that we identify forward guidance using data on interest rate futures contracts going out four quarters. Consequently our identified forward guidance shocks reflect movements in expected interest rates over a one year horizon.

In 1991q3 there is a -44 bp realization of forward guidance. We have been unable to isolate specific communications by the Fed which may explain this realization. Incoming data during this period indicated a weakening economy and so we suspect that changes in futures rates which identify the forward guidance reflect revisions to the economic outlook. Before 1994 the market for federal funds futures was relatively thin. This may be a factor here as well.

There is a 51 bp realization of the forward guidance factor in the initial quarter of the second episode, 1994q4. This could reflect a response to congressional testimony by Greenspan on December 7. The New York Times interprets this testimony the day after as follows:

> In an unusually clear signal that the Federal Reserve will continue raising interest rates, its chairman, Alan Greenspan, said today that inflation might rise soon and that the economy was growing briskly.

Futures rates fell 15-20 bps the day of the testimony. Since the data on federal funds futures we use comes from the end of each quarter, it captures the market's reaction to this testimony.

The forward guidance turns sharply in the other direction in the first two quarters of 1995, with two realizations near 50 bps. On February 22 Chairman Greenspan gave testimony before the Senate Banking Committee. The next day the Wall Street Journal reported:

> Mr. Greenspan warned that inflation may still be a threat but added that the Fed might not raise interest rates again even if inflation starts to rise again.... Bond investors took the comments to mean that the Fed may be finished raising interest rates for the current economic cycle and may be close to declaring victory in its efforts to quell inflationary pressures before they become a serious problem.

In the evening of June 20 Greenspan gave a speech at the Economic Club of New York. Market participants interpreted this speech as indicating that the Fed was leaning toward easing. On June 22 the Wall Street Journal reported

> "The consensus in the bond market is that the Fed is leaning toward easing, and everyone is happy about it," said Jay Goldinger, chief investment officer at Capital Insight Inc., a Los Angeles investment management firm. ... Mr. Greenspan, who spoke at a dinner for the Economic Club of New York on Tuesday, "expressed greater uncertainty about the economic outlook than I've heard in some time," Mr. Berner said. He said he was particularly struck by Mr. Greenspan's belief that inflation pressures were easing. Mr. Greenspan has said many times that his primary goal is to keep inflation under control. The fact that he felt those pressures were easing leads Mr. Berner to interpret that a rate cut is in the offing.

The third episode begins with 9/11. The -46 bp realization of the forward guidance factor in 2001q3 appears to reflect this as futures rates fell sharply in the days following. In 2002q2 and 2002q3 the realizations were -71 and -42 bps. For thirteen meetings starting in December 2000 the FOMC statement included the language "the risks are weighted mainly toward conditions that may generate economic weakness in the foreseeable future." In January and February 2002 the incoming data had been strong and this motivated the FOMC to change its statement in March of that year to say that "the risks are balanced." The 2002q1 forward guidance factor is positive. The FOMC reversed itself three meetings later. At the August meeting the statement again referred to risks being "weighted mainly toward conditions that may generate weakness." In November the risks returned to being "balanced." Overall, this pattern of statements seems to be consistent with the forward guidance realizations.

We now turn to the economic impact of the estimated forward guidance. The model's dynamic responses to an increase in the forward guidance factor is displayed in Figure 3. These and similar plots display responses to one standard deviation innovations and the units are percent at quarterly rates. The forward guidance factor shock leads to a hump shaped response of the federal funds rate, rising to its peak four quarters after the shock and then declining back to zero at a similar speed. Concurrent to this path for the federal funds rate, GDP, consumption, investment and hours all follow similar hump shaped dynamics, declining in response to higher interest rates. Investment consists of the bulk of the drop in output. Core-PCE inflation falls immediately and stays below its initial level for almost three years. The responses of quantities are 100 times larger than for prices. This is a reflection of the estimated flat price Phillips curve. The responses of the quantities and prices to the traditional contemporaneous policy shock are qualitatively similar, but the dynamics of the federal funds rate are very different (not shown). The federal funds rate dynamics essentially are driven by the auto-regressive coefficient in the policy rule.

The dynamics of the federal funds rate following an innovation in forward guidance reflect our assumption of a common factor driving expected future interest rates. A positive realization of the forward guidance factor, through the factor loadings, raises expectations of future interest rates for the next four quarters. The importance of the common factor is easiest to understand by studying the response of the funds rate to the four quarter ahead idiosyncratic signal ($u_{t,4}$), shown in Figure 4. The idiosyncratic signal is independent of the other forward guidance shocks so its increase is not accompanied by increases of forward guidance at shorter horizons. The signal of a higher funds rate four quarter's ahead leads to lower current and future activity thereby lowering the contemporaneous funds rate via the interest rate rule's endogenous feedback. In the fourth quarter after the signal, there is a sharp increase in the funds rate. These dynamics seem implausible. An innovation in the forward guidance factor raises rates for the next four quarters through the factor loadings and so there is no sharp reversal in the funds rate.

Table 3 displays the contributions of shocks to key variables at business cycle frequencies. Three shocks dominate fluctuations: the discount, spread and neutral technology shock. The responses of key variables to these shocks are displayed in Figure 5-7. Seventy-five percent of GDP and hours fluctuations are demand driven (using our taxonomy described above) and even more than that for consumption and investment. Forward guidance accounts for 9 percent of GDP and hours fluctuations. The numbers for forward guidance are smaller for consumption and investment because these variables are positively correlated in response to forward guidance shocks. Forward guidance accounts for more than half of the variation in the federal funds rate. This means that the majority of movements of the federal funds are signalled before they are realized. Essentially the model interprets most federal funds movements as reflecting the Fed following through on its public statements about future policy. The other policy shocks account for essentially none of the variation in these variables.

The summary statistics in Table 3 mask the contributions of forward guidance in particular episodes, and these contributions are particularly revealing. This is demonstrated in Figures8-10. These figures display counterfactual simulations of the model to isolate the role of different shocks over the sample period. These are constructed by running the model from the initial period forward with one shock at a time using the estimated path of that shock. Figure 8 shows the dominating influence of forward guidance on the federal funds rate implied by the model. Three episodes are particularly revealing: the increase in rates in 1994, the march down in rates during and after the 2001 recession, and the subsequent slow march up of rates over the 2003-2006 period. The last period is particularly notable because this was during a period when the FOMC was using explicit forward looking language in its statements. The model seems to be interpreting this correctly. Figures 9 and 10 show that the forward guidance on interest rates had noticeable affects on GDP growth and core PCE inflation. Forward guidance drags down output considerably in 1994, gives a boost following the 2001 recession and then pulls it down in 2005. The magnitudes are large – in 1994 the peak contribution is close to -2 percent and in the 2000s the peak contributions are around 1 percent in absolute value. Forward guidance contributed ten basis points to core-PCE inflation in the 1991q3-1993q4 period before reversing its contribution over the subsequent four quarters. In the 2003-2005 period forward guidance lifts inflation by similar magnitudes. The small magnitudes for inflation relative to GDP reflect the estimated flat Phillips curve.

6 Conclusion

In this paper we show how to introduce monetary policy forward guidance into the kind of interest rate rule typically used in NK models. Our estimated model implies realizations of forward guidance that seem generally in line with the historical record. We find that forward guidance overall has had a relatively small impact on aggregate outcomes, but it has had noticeable effects in particular episodes.

References

Ajello, A., L. Benzoni, and O. Chyruk (2011). Core and 'crust': Consumer prices and the term structure of interest rates. Unpublished Working Paper.

Bernanke, B., M. Gertler, and S. Gilchrist (1999). The financial accelerator in a quantitative business cycle framework. In J. B. Taylor and M. Woodford (Eds.), *Handbook of Macroeconomics*, Volume 1, pp. 1341–1393. Elsevier B.V.

Bernanke, B. S., V. R. Reinhart, and B. P. Sack (2004). Monetary policy alternatives at the zero bound: An empirical assessment. *Brookings Papers on Economic Activity 2004*(2), pp. 1–78.

Boivin, J. and M. Giannoni (2006). DSGE models in a data-rich environment. Working Paper 12772, National Bureau of Economic Research.

Campbell, J., C. Evans, J. Fisher, and A. Justiniano (2012). Macroeconomic effects of fomc forward guidance. Working paper, Paper prepared for 2012 Brookings Institution conference.

Christiano, L., R. Motto, and M. Rostagno (2009). Financial factors in economic fluctuations. Working paper, Northwestern University.

Christiano, L. J., M. Eichenbaum, and C. L. Evans (2005). Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy 113*(1), 1–45.

Cúrdia, V., A. Ferrero, G. C. Ng, and A. Tambalotti (2011). Evaluating interest rate rules in an estimated DSGE model. Working Paper 510, Federal Reserve Bank of New York.

Eichenbaum, M. and J. D. Fisher (2007). Estimating the frequency of price re-optimization in Calvo-style models. *Journal of Monetary Economics 54*(7), 2032–2047.

Galí, J. and M. Gertler (1999). Inflation dynamics: A structural econometric analysis. *Journal of Monetary Economics 44*(2), 195–222.

Gürkaynak, R. S., B. Sack, and E. T. Swanson (2005, May). Do actions speak louder than words? The response of asset prices to monetary policy actions and statements. *International Journal of Central Banking 1*(1), 55–93.

Justiniano, A., G. E. Primiceri, and A. Tambalotti (2011a). Investment shocks and the relative price of investment. *Review of Economic Dynamics 14*(1), 101–121.

Justiniano, A., G. E. Primiceri, and A. Tambalotti (2011b). Investment shocks and the relative price of investment. *Review of Economic Dynamics 14*(1), 101–121.

Kohn, D. and B. Sack (2003). Central bank talk: Does it matter and why? In *Bank of Canada Conference Proceedings: Macroeconomics, Monetary Policy, and Financial Stability*, pp. 175–206. Bank of Canada.

Kohn, D. L. (2005). Central bank communication. Remarks delivered at the annual meeting of the American Economic Association. Philadelphia, January 1, 2005.

Laséen, S. and L. E. Svensson (2011). Anticipated alternative policy-rate paths in policy simulations. *forthcoming in the International Journal of Central Banking*.

Reifschneider, D. and J. C. Williams (2000, November). Three lessons for monetary policy in a low-inflation era. *Journal of Money, Credit, and Banking 32*(4), 936–966.

Rudebusch, G. D. and J. C. Williams (2008). Revealing the secrets of the temple: The value of publishing central bank interest rate projections. In J. Y. Campbell (Ed.), *Asset Prices and Monetary Policy*, pp. 247–284. University of Chicago Press.

Sbordone, A. (2006). U.S. wage and price dynamics: A limited information approach. *International Journal of Central Banking 2*(3).

Smets, F. and R. Wouters (2007). Shocks and frictions in US business cycles: A Bayesian DSGE approach. *The American Economic Review 97*(3), 586–606.

Taylor, J. B. (1993). Discretion versus policy rules in practice. *Carnegie-Rochester Conference Series on Public Policy 39*, 195–214.

Taylor, J. B. (1999). An historical analysis of monetary policy rules. In J. B. Taylor (Ed.), *Monetary Policy Rules*. Chicago: University of Chicago.

Vetlov, I., T. Hlédik, M. Jonsson, H. Kucsera, and M. Pisani (2011). Potential output in DSGE models. Working Paper 1351, European Central Bank.

Table 1: Monetary Policy Parameter Estimates

Parameter	Description	Mode
ρ_π	Inflation anchor persistence	0.986
ρ_R	Interest rate smoothing	0.827
ϕ_p	Inflation gap response	1.325
ϕ_y	Output gap response	0.107
σ_{f1}	Contemporaneous shock std. dev.	0.040
σ_{f2}	Forward guidance factor std. dev.	0.059
$\mathcal{B}_1$	Lead 1	1
$\mathcal{B}_2$	Lead 2	1.036
$\mathcal{B}_3$	Lead 3	0.896
$\mathcal{B}_4$	Lead 4	0.342

Note: The reported estimates are modal values from the posterior distribution of the estimates. Standard deviations are reported for the current policy shock and the forward guidance factors as well as factor loadings for the latter factor. The factor loading on the first lead of forward guidance, $\mathcal{B}_1$, is normalized to one.

Table 2: Parameter Estimates Excluding Monetary Policy

Parameter	Description	Mode
	Preferences and Technology	
α	Capital Share	0.158
δ	Depreciation rate	0.025
ι_p	Indexation Prices	0.060
ι_w	Indexation Wages	0.173
γ_{*100}	Steady state consumption growth	0.440
$\gamma_{\mu 100}$	Steady state investment-specific technology growth	0.595
$\mathcal{H}$	Habit	0.876
λ_p	Steady state price markup	0.100
π^{ss}	Steady state quarterly inflation	0.558
β	Steady state discount factor	0.997
$\mathcal{G}^{ss}$	Steady state residual expenditure share in GDP	0.220
ν	Inverse Frisch elasticity	1.602
κ_p	Price Phillip's curve slope	0.002
κ_w	Wage Phillip's curve slope	0.005
χ	Utilization elasticity	4.406
$\mathcal{S}$	Investment adjustment elasticity	7.085
B/N	Steady state borrowing to net worth ratio	1.114
$\mathcal{F}_{KN}$	Steady state spread	0.714
τ	Net worth elasticity	0.003
ζ	Entrepreneur survival prob	0.918
	Persistence of Demand Shocks	
ρ_b	Discount factor	0.745
ρ_υ	Spread	0.993
ρ_ς	Net worth	0.647
ρ_g	G+NX	0.982
	Persistence of Supply Shocks	
ρ_z	Neutral technology growth	0.075
ρ_μ	Investment technology growth	0.693
ρ_{λ_p}	Price markup	0.751
ρ_ψ	AR coefficient labor disutility	0.995
θ_w	MA average coefficient in labor disutility process	0.974

Note: The reported estimates (with two exceptions) are modal values from the posterior distribution of the estimates. For the non-policy shocks only the AR(1) (and in one case MA(1)) coefficient is displayed. Parameters not already described in the text correspond are described with the same notation in the technical appendix. The parameters δ and $\mathcal{G}^{ss}$ were calibrated.

Table 3: Decomposition of Shocks' Contribution to the Business Cycle

Variable	Disc.	Spread	Govern.	Neutral	Invest.	Labor Disutility	Price Markup	Infl. Anchor	Current	Forward Guidance	I.i.d. Signals	I.i.d. Error
GDP	0.32	0.35	0.05	0.13	0.02	0.01	0.01	0.01	0.00	0.09	0.01	0.01
Consumption	0.67	0.14	0.02	0.09	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.03
Investment	0.00	0.90	0.00	0.02	0.02	0.00	0.01	0.00	0.00	0.04	0.00	0.00
Real wage	0.12	0.06	0.00	0.12	0.01	0.49	0.09	0.01	0.00	0.06	0.01	0.04
Hours	0.33	0.38	0.05	0.10	0.01	0.01	0.01	0.01	0.00	0.09	0.01	0.00
Core PCE	0.02	0.02	0.00	0.00	0.00	0.04	0.50	0.13	0.00	0.00	0.00	0.27
Fed. funds rate	0.10	0.12	0.01	0.02	0.00	0.01	0.06	0.02	0.03	0.55	0.08	0.00

Note: The table reports the fraction of business cycle variation attributable to the indicated category of shock. Demand: Discount, Spread, Government (the Net Worth shock has been excluded since it accounts for virtually no fluctuations); Supply: Neutral Technology, Investment-Specific Technology, Labor Disutility, Price Mark-up; Monetary Policy: Inflation anchor, Current factor, Forward guidance factor, I.i.d. signal shocks; Measurement error on spread and inflation. Entries for quantities refer to log levels of the variables.

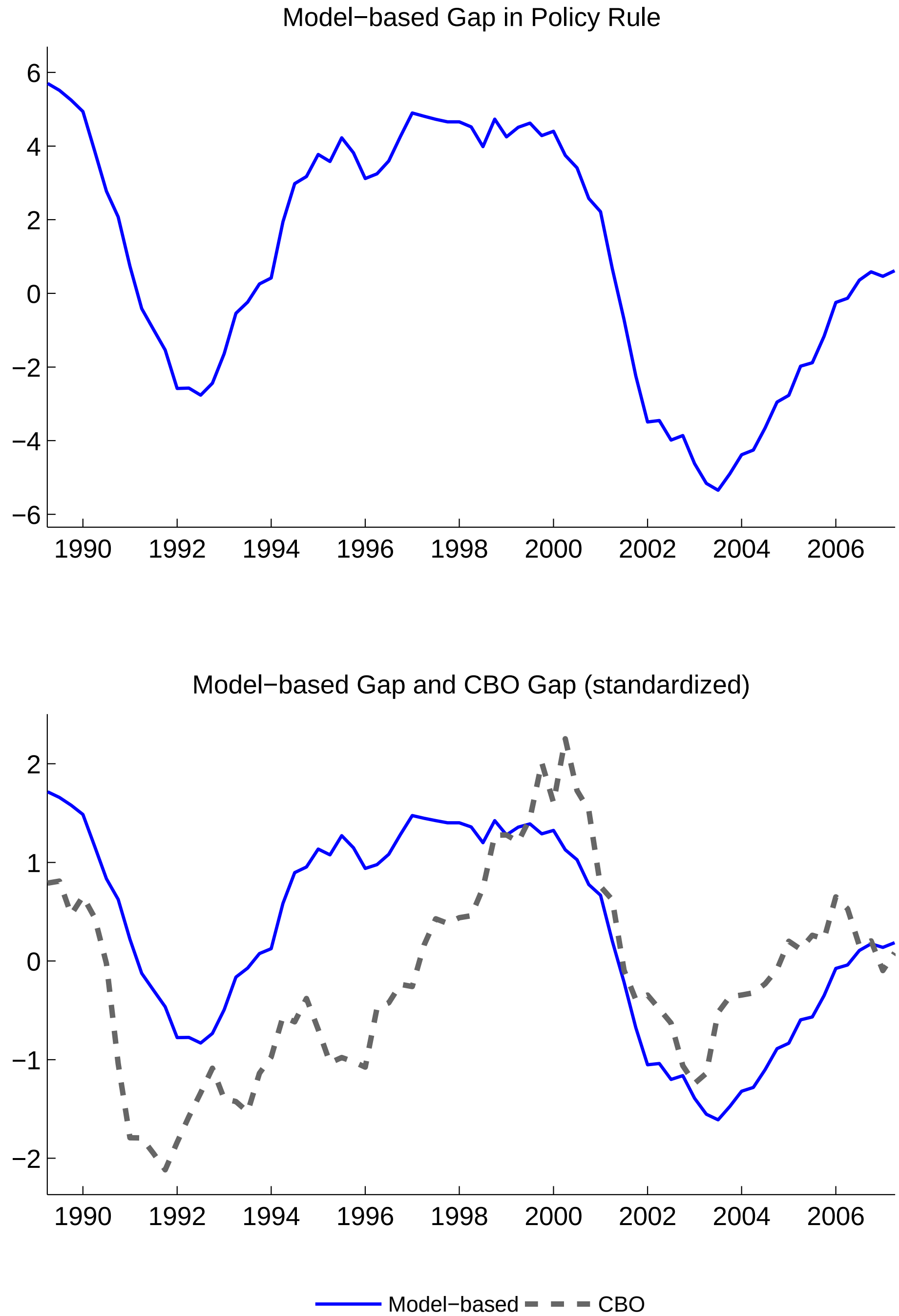

Figure 1: Model-based and CBO Output Gaps

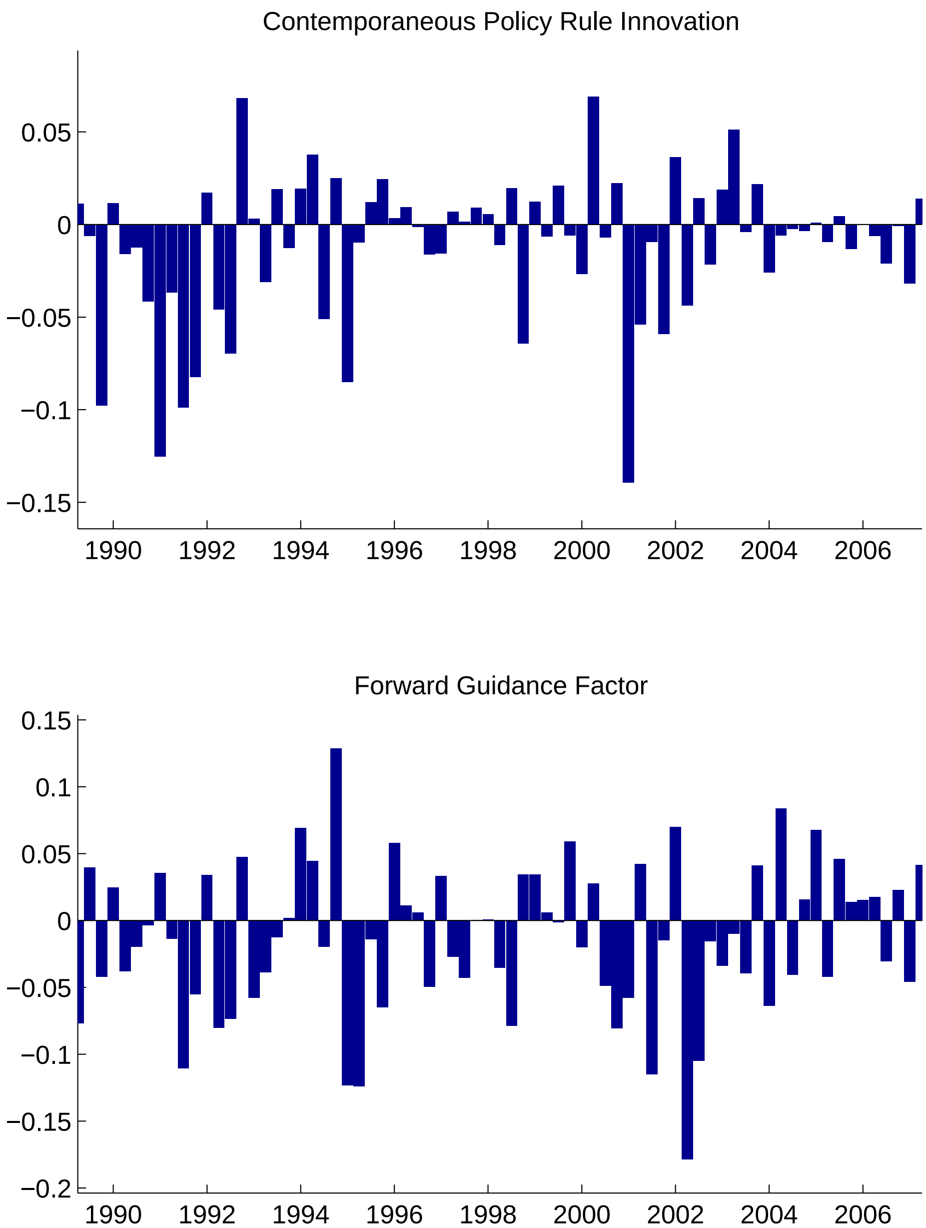

Figure 2: Estimated Contemporaneous Shock and Forward Guidance Factor

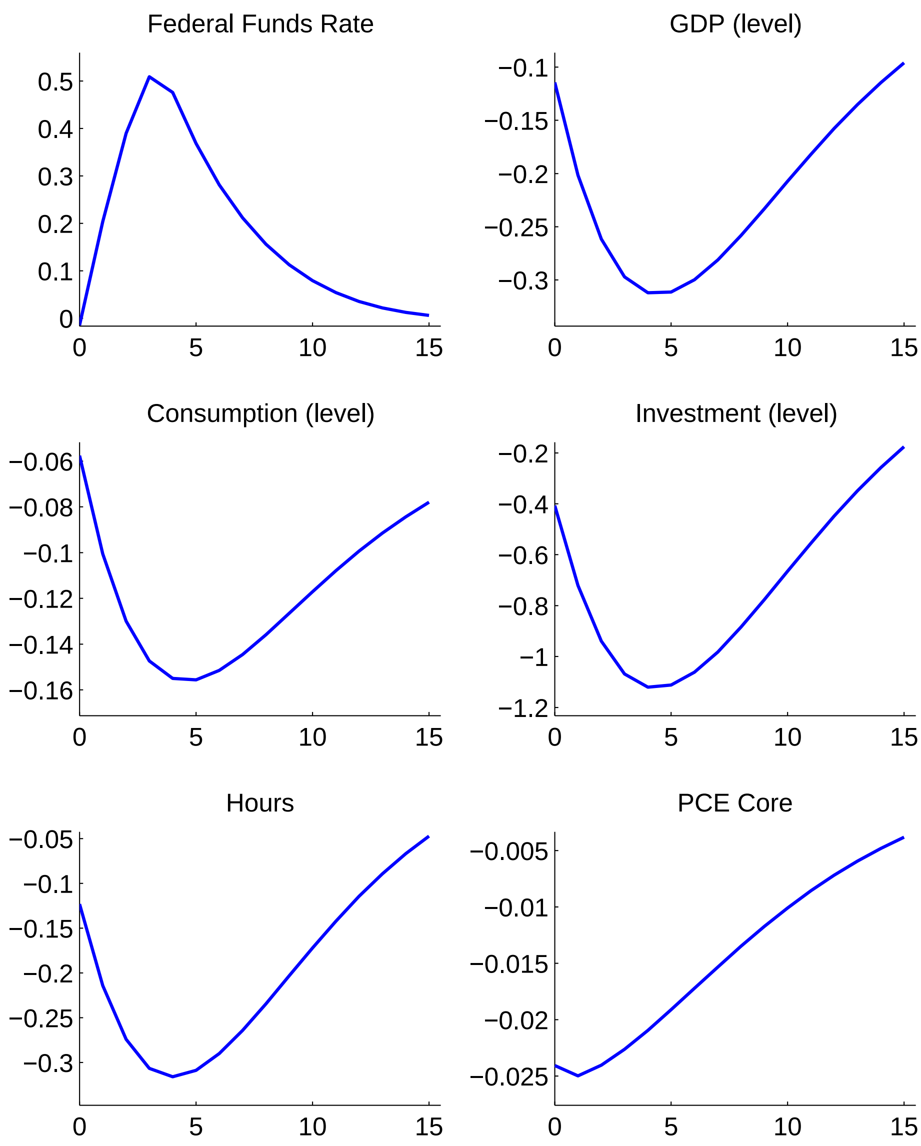

Figure 3: Impulse Responses to Forward Guidance Factor

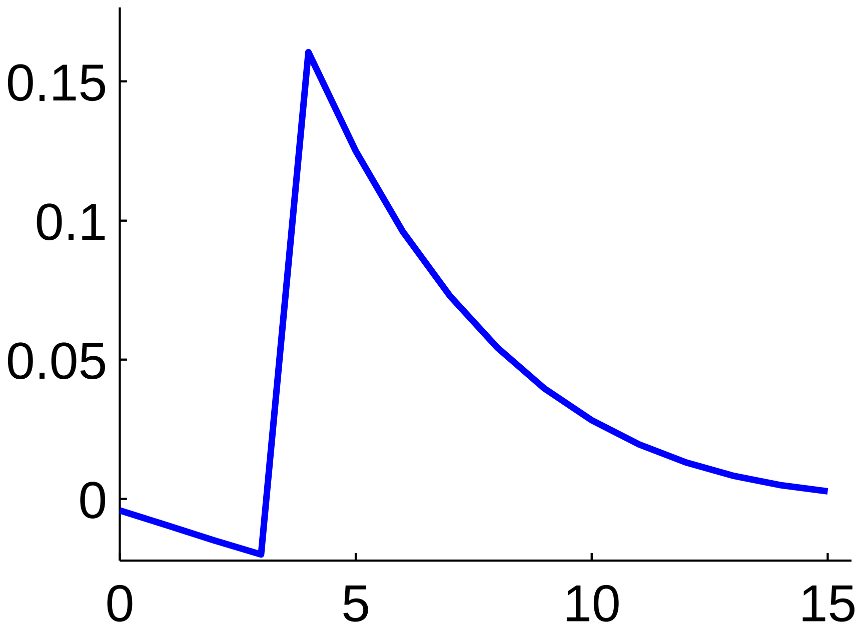

Figure 4: Response of Federal Funds Rate to Idiosyncratic Forward Guidance

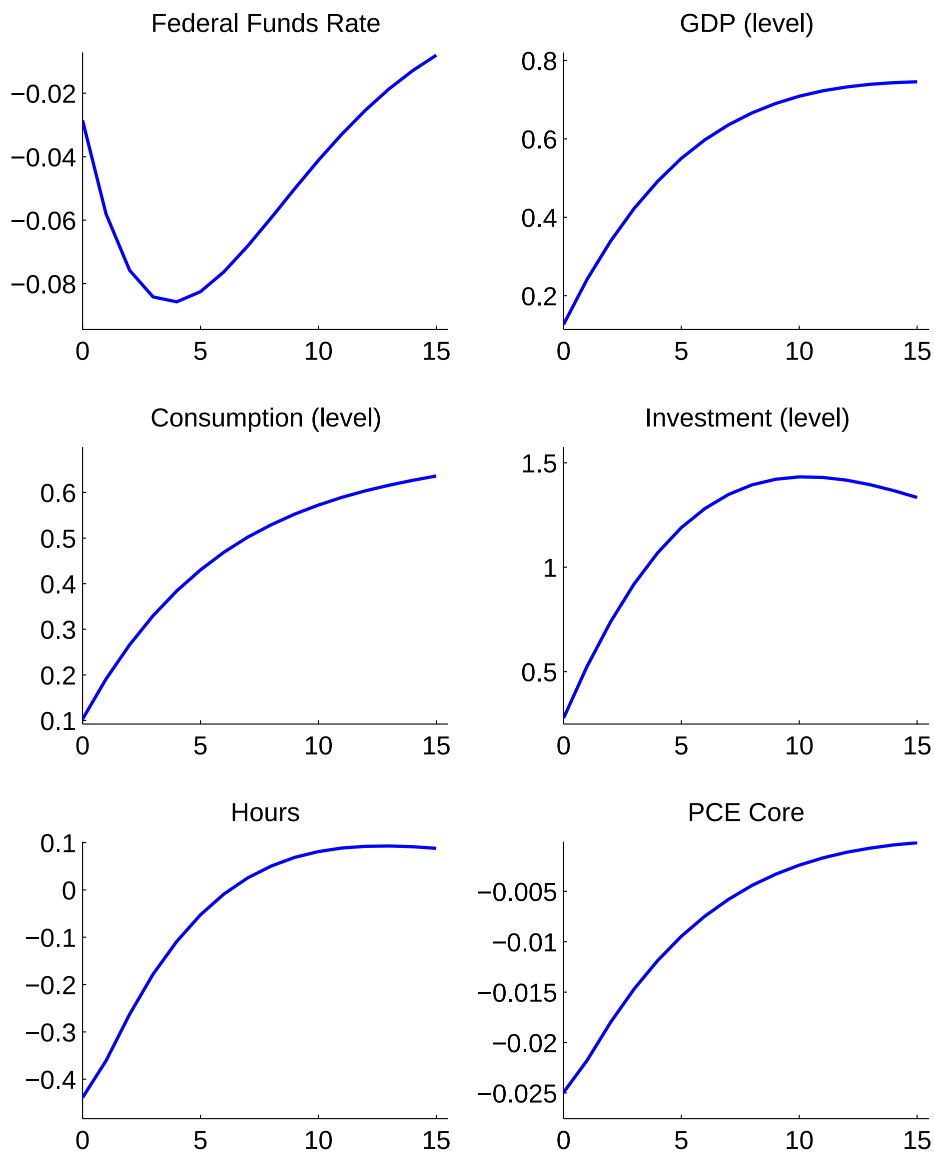

Figure 5: Impulse Responses to Neutral Technology Shock

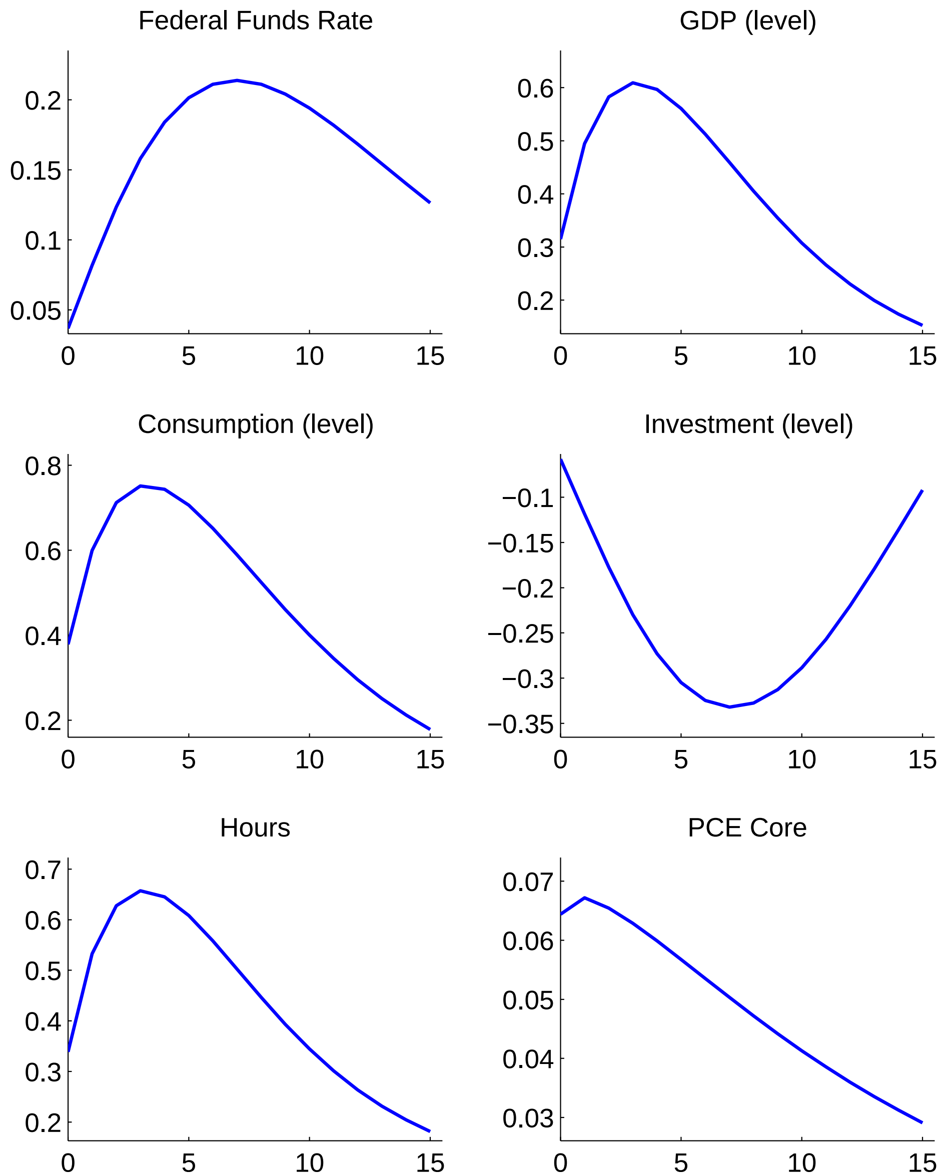

Figure 6: Impulse Responses to Discount Factor Shock

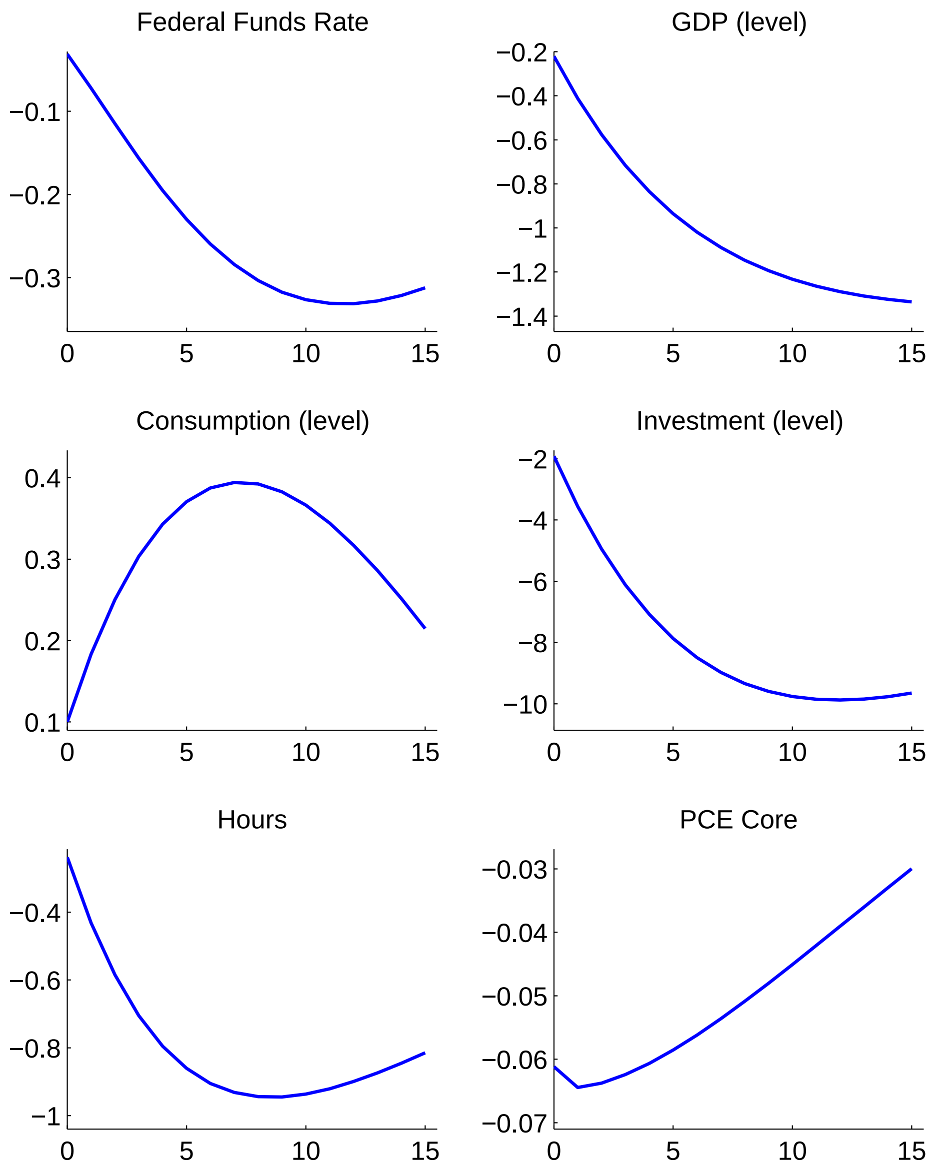

Figure 7: Impulse Responses to Spread Shock

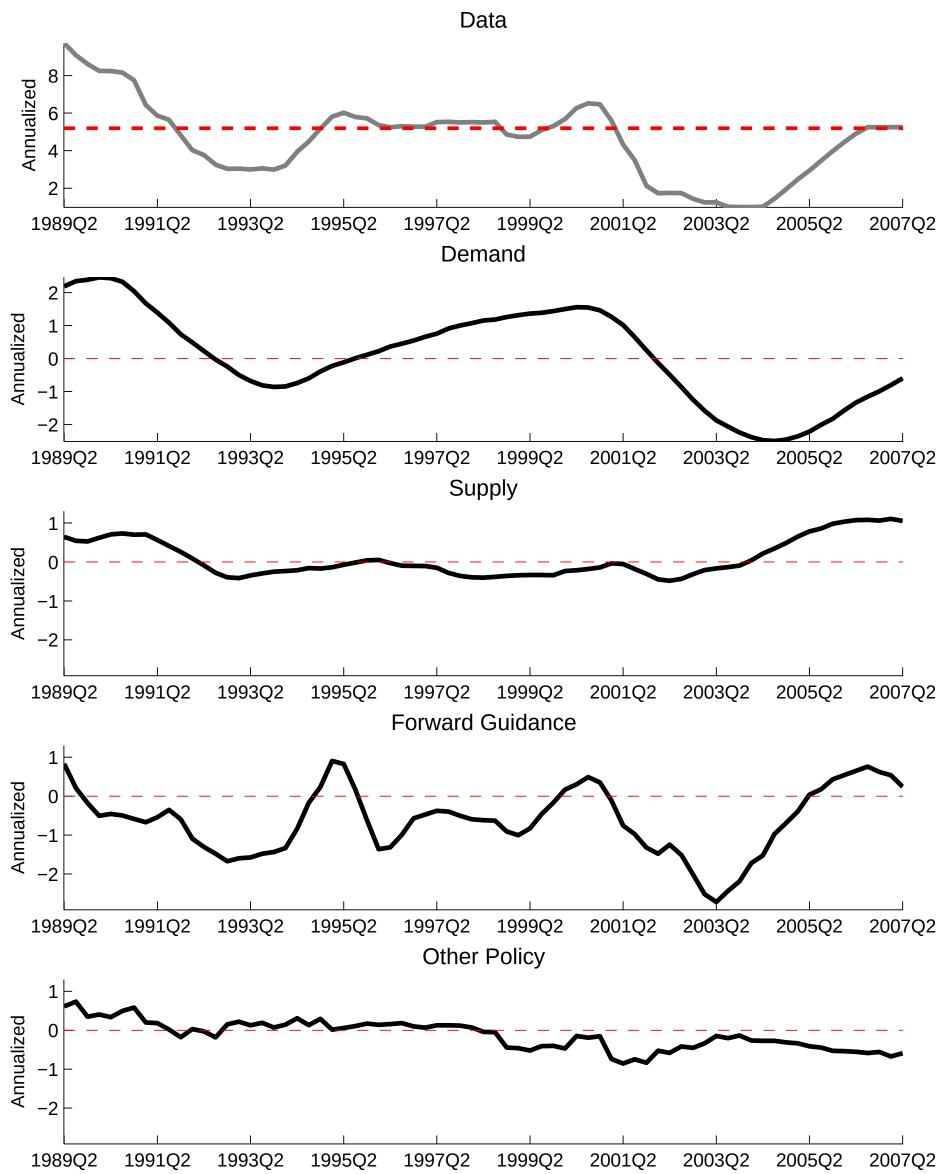

Figure 8: Decomposition of Shocks' Contribution to Federal Funds Rate

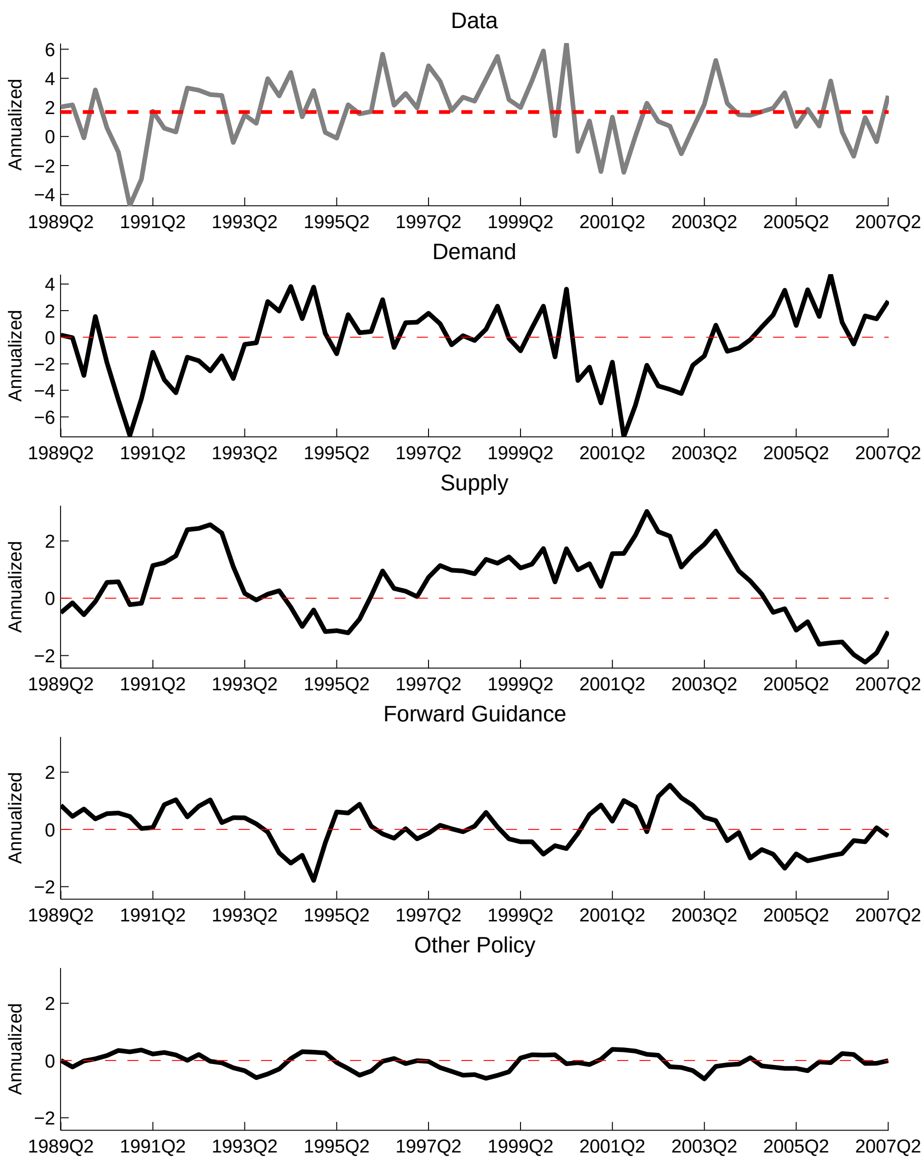

Figure 9: Decomposition of Shocks' Contribution to GDP Growth

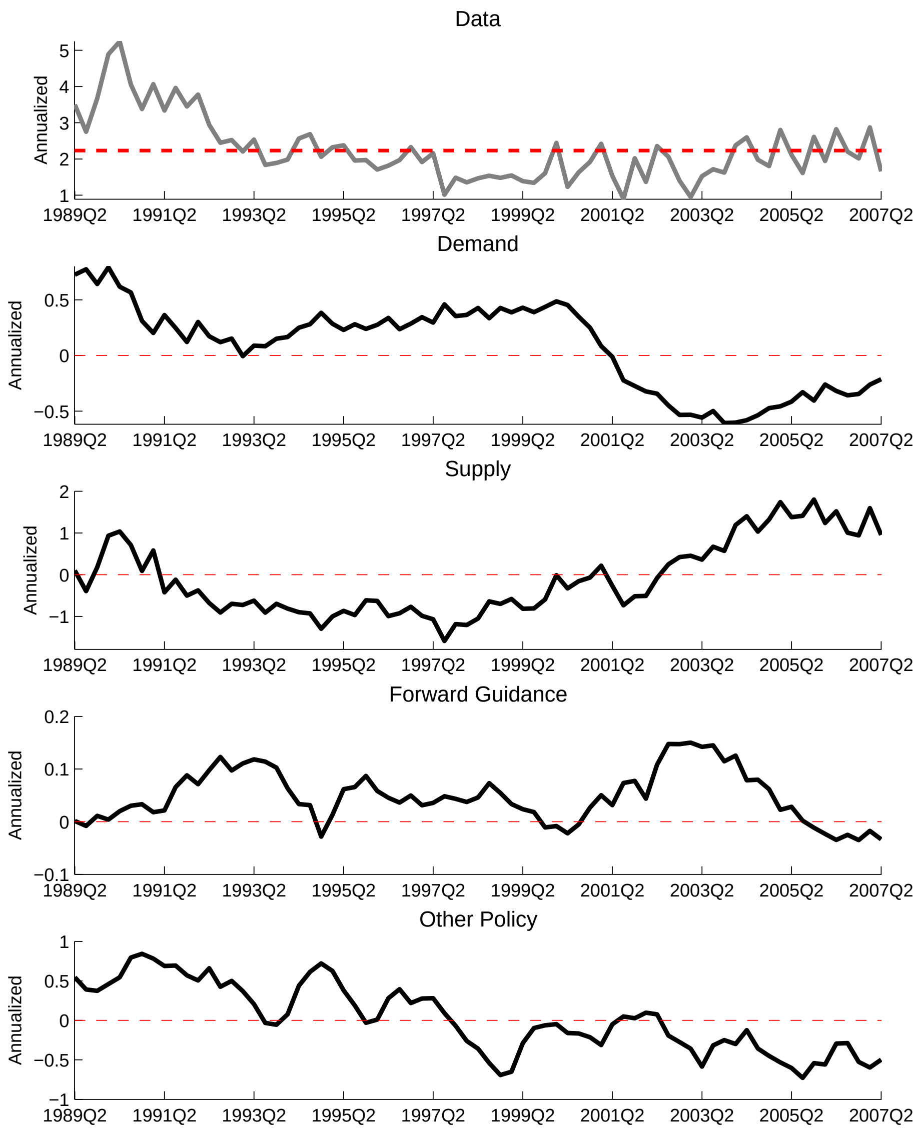

Figure 10: Decomposition of Shocks' Contribution to Core PCE Inflation