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Abstract

We study the effects of information shocks on macroeconomic and term structure dynamics in an estimated medium-scale DSGE model for the US economy. We consider news about total factor productivity and investment-specific technology, as well as foresight about monetary policy. Our empirical investigation confirms the findings of previous studies on the limited role played by productivity news in this class of models. In contrast, we uncover a non-trivial role for investment-specific news and anticipated monetary policy shocks not only in the historical and variance decomposition of real economic variables but also for the overall dynamic behavior of the term structure of interest rates. We also document substantial qualitative differences in the dynamic responses of the macroeconomy and the bond yield term structure to anticipated and surprise structural and policy innovations.

Keywords: *News, Policy Foresight, Term Structure, DSGE Model*

JEL classification: E32, E43, E52

Non-technical summary

In standard models of business cycle fluctuations only unexpected changes in exogenous variables matter for aggregate dynamics. During recent years however, there has been a rising interest in analyzing the business cycle implications of agents' anticipation of future innovations impacting the economy. Our paper is part of these recent attempts at more explicitly modeling the expectation formation process, in order to assess empirically the importance of information shocks for macroeconomic and term structure dynamics.

We adhere to a benchmark medium-scale DSGE modeling framework which has been extensively used also by policy making institutions. One of the strengths of the model is that it performs very well empirically both in-sample and for forecasting, relative to comparable alternatives, with a particularly strong forecasting ability regarding inflation dynamics. For our purposes, this feature is essential because we are also interested in bond pricing issues, where expected inflation is one of the key drivers. Similar to standard methods in the literature, we build on the expectations hypothesis as an approach for modeling yields along the maturity spectrum.

As information shocks, we distinguish between productivity news, i.e. anticipated changes in future levels of total factor productivity, investment-specific technology news and anticipated monetary policy shocks.

We estimate the model on a sample of quarterly US macroeconomic aggregates containing the quarterly growth rates of real GDP, consumption, investment and the real wage, as well as inflation, hours worked and the effective nominal federal funds rate, in addition to four US government bond yield series for zero coupon bonds with maturities of 1, 3, 5 and 10 years. The data span the period 1971Q3 to 2008Q4. Estimation is performed using a two-step Bayesian ML procedure.

Our results confirm previous findings from the literature concerning the only limited role of technology news in determining business cycles fluctuations, when this type of information shocks is allowed to compete with other atemporal and intertemporal shocks, in particular with the exogenous risk premium. However, we find investment-specific news, as well as monetary policy foresight to play an important role in determining conditional forecast error variances of real, nominal and financial variables at different forecast horizons.

In addition, we document the fact that there has been a significant amount of foresight throughout the sample, however the anticipated component seems to very often be offset by the surprise component, the ultimate realization of the policy shock being close to zero. Economically, this situation reflects the fact that agents most of the time expect a certain interest rate change, which in the end does not materialize, the central bank actually following strictly the Taylor rule. A different possible interpretation is that agents have only noisy information about the evolution of inflation and the output gap, so their expectations about policy actions are noisy as well.

The micro-founded propagation channels implied by our modeling environment allow us to uncover substantial qualitative differences in the dynamic responses of the macroeconomy and the bond yield term structure to anticipated and surprise structural and policy innovations. For example, in response to an anticipation of a monetary policy tightening, investment and output decrease because agents foresee a higher discount rate in the future, which leads to a decrease in inflation. The central bank needs to react and decrease the rate in order to fight the mild ensuing recession, such that when the shock actually materializes, it only brings the rate marginally above the level prevailing prior to the policy announcement.

These effects are strongly depending on the model's inner structure and on the fact that agents have rational expectations, such that they can understand the general equilibrium mechanisms at work. Starting from this insight, we complete our analysis by examining the effect of the exact form of monetary policy conduct on the dynamic responses of the macroeconomy and the yield curve to anticipated news and policy foresight. In particular, we study the role of differing degrees of inflation targeting aggressiveness and gradualism in interest rate setting. We show that the way in which the central bank conducts its monetary policy has decisive quantitative but also qualitative implications for the dynamic responses of macroeconomic and financial variables.

1 Introduction

Modern macroeconomic models are characterized by a set of difference equations corresponding to the optimizing behavior of rational interacting agents and a set of prices such that, in equilibrium, markets clear. The major strength of this approach is that the economy is analyzed as a dynamic system, with a clear identification of exogenous shocks and fully specified transmission channels. So, unlike in reduced-form setups, there is an attempt at a clear theoretical distinction between the shock itself and the propagation mechanism throughout the economy. However, an important aspect was, at least until recently, not part of most of the benchmark modeling frameworks, namely the distinction between a *structural* and an *information* shock. The problem is that, in most standard models, the structural shock at the same time fulfills the role of the disturbance affecting a certain aggregate quantity and the difference between the realization of the quantity and its expected value, subject to a certain information set. One could indeed make a case that all structural shocks are unforecastable and, more starkly, that everything unforecastable is a structural shock (or measurement error), but at least since the seminal contribution of Beaudry and Portier (2004) we know that this distinction is both theoretically relevant and empirically plausible.

Proceeding along similar lines of reasoning, our paper is part of the recent attempts at using these insights in order to assess empirically the importance of information shocks for macroeconomic and term structure dynamics. In terms of the macroeconomic environment, we adhere to the medium-scale DSGE modeling framework of Smets and Wouters (2007), which, as documented inter alia by Wieland and Wolters (2010) performs very well empirically both in-sample and for forecasting, relative to comparable alternatives, with a particularly strong forecasting ability regarding inflation dynamics. For our purposes, this feature is essential because we are interested in bond pricing issues, where expected inflation is one of the key drivers. Indeed, using this model, De Graeve et al. (2009) show that the expectations hypothesis can explain a large portion of term structure volatility. We are able to confirm and generalize their findings in a framework with a more refined informational structure.

Like De Graeve et al. (2009), we model bond yields as affine functions of the aggregate state space, an approach introduced in this form by Ang and Piazzesi (2003) and extended in recent contributions of Lemke (2008) and Bekaert et al. (2010). We introduce information shocks according to the specifications used by Schmitt-Grohe and Uribe (2008) and further explored by Lorenzoni (2007) and Jaimovich and Rebelo (2009). If one is to adhere to the original ideas in the literature on information shocks, there is indeed not much leeway about how to precisely model the diffusion of information through the economy, except that one has to decide on a proper specification of the inter-temporal correlation between information flows and structural shocks. Leeper and Walker (2010) survey alternative possibilities in this regard. We adopt the parsimonious memory-less specification of Schmitt-Grohe and Uribe (2008) in order to not have to increase the number of estimated parameters, but also because at this point micro-evidence on information flows is rather scarce and it is not clear which approach would be more justified a priori.

As information shocks, we distinguish between productivity news, i.e. anticipated changes in future levels of total factor productivity, investment-specific technology news, i.e. anticipated changes in future levels of investment-specific technology and monetary policy news (alternatively: *foresight*), i.e. anticipated monetary policy shocks.

The examination of the empirical relevance of anticipated innovations to total factor productivity and investment-specific technology in the context of DSGE models already has a well established place in the existing literature. Schmitt-Grohe and Uribe (2008) is a prominent example of this strand of the empirical literature. In a traditional real business cycle macroeconomic environment augmented with real rigidities such as habits in consumption and leisure, variable capital utilization and investment adjustment costs the authors extend the traditional stochastic environment of the model by allowing for anticipated innovations to permanent and stationary neutral productivity, investment and government spending. On the basis of their Bayesian methodology the authors uncover an overwhelmingly large and robust role for anticipated innovations that are found to account for more than two thirds of US aggregate fluctuations.

Khan and Tsoukalas (2009) examine the quantitative importance of news shocks in the business cycle dynamics of the US economy by adopting a macroeconomic environment which is substantially richer than the model economy of Schmitt-Grohe and Uribe (2008), featuring an array of nominal and real frictions and allowing for the presence of anticipated innovations. The major message of this paper is that the empirical significance of anticipated innovations in the overall macroeconomic dynamics depends crucially on the stochastic structure of the economy. The authors find that allowing news shocks to compete with the full array of macroeconomic disturbances originally present in the Smets and Wouters (2007) model generates a negligible role for the anticipated innovations in the dynamic behavior of real variables such as real activity and investment growth and these results persist independent of the presence or absence of nominal frictions. The authors highlight the sizable importance of shocks generating comovement in real variables for the role played by anticipated macroeconomic innovations and document an increase in the importance of aggregate productivity news once these disturbances are absent.

In contrast, in a similarly complex macroeconomic environment, Fujiwara et al. (2011) find empirical evidence directly opposing the benchmark results of Khan and Tsoukalas (2009) and point to an important role played by total factor productivity news in the US business cycles. Their results may however be biased by the choice of a particular exogenous disturbance structure. More recently, Kurmann and Otrok (2010) focus on the other hand on uncovering the major driving forces behind the dynamic behavior of the slope of the US term structure of interest rates and identify news related to future total factor productivity as the most important stochastic driver thereof.

On the other side, attention has also been dedicated to the role of anticipated policy shocks on aggregate variables, albeit to a much lesser degree. Leeper et al. (2009) discuss the concept of fiscal foresight and very convincingly demonstrate that econometric inference may be misleading, if one does not account properly for anticipation effects, while Milani and Treadwell (2009) introduce monetary policy foresight and document a prominent role thereof for macroeconomic dynamics.

Similar to the research contributions mentioned above, we first introduce news shocks and foresight in a benchmark DSGE model, we build up the term structure of bond yields and estimate the resulting model with Bayesian methods. Section 2 contains an overview of the model and the stochastic structure. In Section 3 we discuss the estimation procedure and present the main estimation results. Section 4 is the core of the paper, where we discuss the role of news shocks for the macroeconomy and the term structure. In Section 5 we present the results of a series of counterfactual exercises and monetary policy scenarios.

2 The model

2.1 Model framework

The macroeconomic environment is designed along the lines of Smets and Wouters (2007) and is composed of households, final and intermediate goods firms and the central bank. The household sector consumes goods and services, decides on investment, provides labor on a monopolistically competitive labor market and rents capital to firms. Its utility function is non-separable in consumption and labor and features an external consumption habit. Firms decide on their optimal levels of capital and labor and sell differentiated goods on a monopolistically competitive market. The Calvo-type mechanism is present in price and wage reoptimization while non-reoptimized prices and wages are partially indexed to past inflation. Following De Graeve et al. (2009), the monetary policy reaction function features a time-varying inflation target that due to partial price and wage indexation alters the inflation and wage equations relative to the standard Smets and Wouters (2007) model. In what follows we describe the complete log-linearized macroeconomic model used in our analysis.

2.1.1 Aggregate demand

The economy's aggregate resource constraint is given by

$$y_t = c_y c_t + i_y i_t + u_y u_t + \varepsilon_t^g \qquad (1)$$

Aggregate output is absorbed by consumption c_t, investment i_t and resources lost due to variable capital utilization u_t.

The optimization problem of the economy's household sector gives rise to the following Euler equation that governs the dynamic behavior of consumption

$$c_t = c_1 c_{t-1} + (1 - c_1) E_t c_{t+1} + c_2 (l_t - E_t l_{t+1}) - c_3 (r_t - E_t \pi_{t+1}) + \varepsilon_t^b \qquad (2)$$

where $c_1 = \frac{\frac{h}{\gamma}}{1+\frac{h}{\gamma}}$, $c_2 = \frac{(\sigma_c - 1)\left(\frac{W_*^h L_*}{C_*}\right)}{\sigma_c\left(1+\frac{h}{\gamma}\right)}$ and $c_3 = \frac{1-\frac{h}{\gamma}}{\sigma_c\left(1+\frac{h}{\gamma}\right)}$.

The structural parameters in the consumption Euler equation relate to technological growth trend γ, the intertemporal elasticity of substitution σ_c and the strength of the consumption habit h. The term $\frac{W_*^h L_*}{C_*}$ designates the steady state labor income to consumption ratio. Current consumption c_t is expressed as a function of a weighted average of past and future consumption, expected hours growth $(E_t l_{t+1} - l_t)$ and the ex-ante real interest rate $(r_t - E_t \pi_{t+1})$. Following Smets and Wouters (2007) the disturbance ϵ_t^b is included to capture a possible wedge between the nominal interest rate controlled by the monetary authority and the return on assets held by the household sector.

Investment dynamics i_t is given by the investment Euler equation that expresses current investment as a function of a weighted average of past and expected investment as well as the value of installed capital q_t:

$$i_t = \left[\frac{1}{1+\beta\gamma^{1-\sigma_c}}\right] i_{t-1} + \left[\frac{\beta\gamma^{1-\sigma_c}}{1+\beta\gamma^{1-\sigma_c}}\right] E_t i_{t+1} + \left[\frac{1}{1+\beta\gamma^{1-\sigma_c}} \frac{1}{\gamma^2 \varphi}\right] q_t + \varepsilon_t^I, \tag{3}$$

with φ designating the steady state elasticity of the capital adjustment cost function and β the household discount factor. The shock ε_t^I is included in the investment Euler equation in order to capture disturbances to the investment specific technology.

The evolution of the value of capital follows:

$$q_t = \left[\frac{R_*^k}{R_*^k + (1-\delta)}\right] E_t mpk_{t+1} + \left[\frac{1-\delta}{R_*^k + (1-\delta)}\right] E_t q_{t+1} - (r_t - E_t \pi_{t+1}) - \varepsilon_t^b \tag{4}$$

where R_*^k stands for the steady state capital return and δ denotes the rate of capital depreciation. The current value of capital depends positively on the expected future marginal product of capital and the expected future value of capital and negatively on the real rate of return required by the household sector.

2.1.2 Aggregate supply

The model includes a Cobb-Douglas production function in which output is produced using capital services k_t^s and labor l_t. The log-linear version thereof is:

$$y_t = \phi_p \left[\alpha k_t^s + (1-\alpha) l_t + \varepsilon_t^a\right] \tag{5}$$

where α stands for the share of capital in production while ϕ_p is equal to one plus the fixed cost share in production. ε_t^a is an exogenous disturbance to total factor productivity.

The assumption of a one-period lag in the use of newly installed capital gives rise to the following relation between capital services k_t^s, the existing stock of capital from the previous period k_{t-1} and the capital utilization rate u_t:

$$k_t^s = k_{t-1} + u_t. \tag{6}$$

Optimal capital utilization implies a positive relation between the capital utilization rate u_t and the marginal product of capital mpk_t

$$u_t = \left[\frac{1-\psi}{\psi}\right] mpk_t, \tag{7}$$

where ψ measures the elasticity of capital utilization costs with respect to capital while firm cost minimization implies a negative relation of the marginal product of capital with the capital-labor ratio and a positive relation with the real wage

$$mpk_t = -\left(k_t^s - l_t\right) + w_t. \tag{8}$$

Capital accumulation is a function of both investment and the stochastic disturbances affecting the investment specific technology and is given by:

$$k_t = \left[\frac{1-\delta}{\gamma}\right] k_{t-1} + \left[1 - \frac{1-\delta}{\gamma}\right] i_t + \left[1 - \frac{1-\delta}{\gamma}\right]\left[1 + \beta\gamma^{(1-\sigma_c)}\right]\gamma^2\varphi\varepsilon_t^I. \tag{9}$$

The assumption of Calvo price setting and partial indexation to lagged and target inflation in combination with firm profit maximization yields the following New Keynesian Phillips curve:

$$\pi_t = \pi_1\pi_{t-1} + \pi_2 E_t\pi_{t+1} + \pi_3\left[\left(1-\iota_p\right)\bar{\pi}_t - \beta\gamma^{1-\sigma_c}(1-\iota_p)E_t\bar{\pi}_{t+1}\right] - \pi_4\mu_t^p + \varepsilon_t^p, \tag{10}$$

where $\pi_1 = \frac{\iota_p}{1+\beta\gamma^{1-\sigma_c}\iota_p}$, $\pi_2 = \frac{\beta\gamma^{1-\sigma_c}}{1+\beta\gamma^{1-\sigma_c}\iota_p}$, $\pi_3 = \frac{1}{1+\beta\gamma^{1-\sigma_c}\iota_p}$ and $\pi_4 = \pi_3\frac{(1-\xi_p)\left(1-\beta\gamma^{1-\sigma_c}\xi_p\right)}{\xi_p((\phi_p-1)\epsilon_p+1)}$. The parameter ξ_p stands for the degree of Calvo price stickiness, ι_p designates the degree of partial indexation of non-optimized prices, ϵ_p measures the curvature of the Kimball goods market aggregator and $\bar{\pi}_t$ is the time-varying inflation target of the central bank. The price markup generated under monopolistic competition is μ_t^p and is given by

$$\mu_t^p = \alpha(k_t^s - l_t) + \varepsilon_t^a - w_t \tag{11}$$

Similarly, Calvo wage setting and partial wage indexation give rise to the following equation governing the evolution of real wages:

$$\begin{aligned} w_t = {} & w_1 w_{t-1} + (1-w_1)\left(E_t w_{t+1} + E_t\pi_{t+1}\right) - w_2\pi_t + w_3\pi_{t-1} + \\ & w_1\left[\left(1-\iota_w\right)\bar{\pi}_t - \beta\gamma^{1-\sigma_c}(1-\iota_w)E_t\bar{\pi}_{t+1}\right] - w_4\mu_t^w + \varepsilon_t^w \end{aligned} \tag{12}$$

where $w_1 = \frac{1}{1+\beta\gamma^{1-\sigma_c}}$, $w_2 = \frac{1+\beta\gamma^{1-\sigma_c}\iota_w}{1+\beta\gamma^{1-\sigma_c}}$, $w_3 = \frac{\iota_w}{1+\beta\gamma^{1-\sigma_c}}$, and $w_4 = w_1\frac{(1-\xi_w)\left(1-\beta\gamma^{1-\sigma_c}\xi_w\right)}{\xi_w((\phi_w-1)\epsilon_w+1)}$. The parameter ξ_w stands for the degree of Calvo wage stickiness, ι_w designates the degree of partial indexation of non-optimized wages, $(\phi_w - 1)$ is the steady state labor market markup and ϵ_w measures the curvature of the Kimball labor market aggregator. The wage markup generated under monopolistic competition is μ_t^w and is given by:

$$\mu_t^w = w_t - \left[\sigma_l l_t + \frac{1}{1-\frac{h}{\gamma}}\left(c_t - \frac{h}{\gamma}c_{t-1}\right)\right] \tag{13}$$

while the wage mark up shock is ε_t^w.

2.1.3 Monetary policy

The model is closed by specifying a monetary policy reaction function for the central bank. Following De Graeve et al. (2009) the Taylor rule is assumed to take the following form:

$$r_t = \rho_R r_{t-1} + (1-\rho_R)\bar{\pi}_t + \rho_R(\bar{\pi}_t - \bar{\pi}_{t-1}) + (1-\rho_R)(r_\pi(\pi_t - \bar{\pi}_t) + r_y(y_t - y_t^f)) + r_{\Delta y}(y_t - y_{t-1} - (y_t^f - y_{t-1}^f)) + \varepsilon_t^r \tag{14}$$

where y_t^f is defined as the level of output that would prevail under flexible prices and wages and in the absence of the two markup shocks. The central bank is assumed to gradually adjust it nominal interest rate to deviations of actual inflation from a time-varying inflation target and to changes in the level of the output gap. It also is assumed to respond to changes in the growth rate of the output gap. Parameter ρ_R is intended to capture the degree of monetary policy gradualism.

2.1.4 Asset pricing

Similar to De Graeve et al. (2009), we model bond yields as affine functions of the aggregate state space, with the stochastic discount factor of the households being the pricing kernel of the bonds - an approach also used in connection with state space models in recent contributions by Lemke (2008) and Bekaert et al. (2010).

The bond pricing equation implies the following expression for yields at different maturities:

$$R_t^n = c_0^n + E_t \frac{r_t + r_{t+1} + \cdots + r_{t+n-1}}{n} + \varepsilon_{t,R_n} \tag{15}$$

In the spirit of De Graeve et al. (2009), we thus impose the weak form of the expectations hypothesis and do not attempt at also letting the constant terms c_0^n be a function of the state variables, but rather let them be free parameters. This means that our model does also not explain average term premia - it is however a well documented fact that the size of the average term spread generated by macro-finance models is notoriously small and so we defer the question of whether news and policy foresight may change this to future research.

Deviations from the expectations hypothesis are still possible through time and are represented here by the exogenous disturbance variables ε_{t,R_n}, which thus capture fluctuations in the term premia.

2.2 Stochastic structure

As mentioned above, in each period, each of the continuum of households can draw upon an individual pool of available resources consisting of labor income, the return on accumulated savings and the return on the stock of capital which has been rented out to firms. The households decide on the optimal allocations of these available budgets by choosing current-period consumption, savings, hours worked, net capital investment and the utilization rate of capital. In addition to the resource constraint, the public information consisting of the whole history of macroeconomic aggregates and perfect knowledge about the complete set of prices, these decisions are affected by three exogenous shocks. First, there is an exogenous premium in the return to bonds ε_t^b, which reflects changes in the spread between the deposit rate and the risk-free rate set by the central bank. This is assumed to evolve stochastically according to the AR(1) process:

$$\varepsilon_t^b = \rho_b \varepsilon_{t-1}^b + \eta_t^b, \qquad \eta_t^b \sim N(0, \sigma_b) \tag{16}$$

An increase in the risk premium affects the inter-temporal allocation between consumption and savings - it creates an incentive to save more and consume less and, by increasing the effective real discount rate, it simultaneously decreases the expected value of capital, thus decreasing investment. These effects materialize differently compared to a pure preference shock, which would have affected consumption decisions, but not the future value of capital. Second, the technology by which investments are transformed into marketable capital is subject to the exogenous disturbance ε_t^I. Unlike the risk premium shock, we assume that news about future realizations of ε_t^I are available to agents up to T periods in advance. Investment-specific technology ε_t^I can thus be decomposed in a *news* component $\sum_{j=1}^{T} \eta_{t-j}^{I,j}$ and a *surprise* component $\eta_t^{I,0}$, the vector $\boldsymbol{\eta}_t^I$ following a multivariate distribution. It directly affects the effectiveness of capital investment in the current period and beyond - an increase in ε_t^I rendering capital investment more attractive - irrespective of whether the effect is anticipated or not. An essential parameter in this specification of news shocks is the inter-temporal variance-covariance matrix. Several specifications have been employed before in the literature, but we follow Schmitt-Grohe and Uribe (2008) and assume all off-diagonal elements to be zero. We summarize this by the stochastic process:

$$\varepsilon_t^I = \rho_I \varepsilon_{t-1}^I + \sum_{j=0}^{T} \eta_{t-j}^{I,j}, \qquad \begin{bmatrix} \eta_t^{I,0} \\ \vdots \\ \eta_{t-T}^{I,T} \end{bmatrix} \sim \boldsymbol{N}(\mathbf{0}_{T+1\times 1}, \boldsymbol{\Sigma}_{T+1\times T+1}^I) \tag{17}$$

Labor markets are assumed to feature monopolistic competition, which leads to the fact that wages are determined as a markup over the marginal product of labor. This markup is assumed to evolve exogenously according to:

$$\varepsilon_t^w = \rho_w \varepsilon_{t-1}^w + \eta_t^w - \mu_w \eta_{t-1}^w, \qquad \eta_t^w \sim N(0, \sigma_w) \tag{18}$$

An increase in the wage markup leads to tighter conditions in the labor market, a higher real wage rate and upwards pressure on inflation - through the marginal cost channel. The MA term in the process for the wage markup shock is included in order to capture high frequency fluctuations in observable wages.

Households rent the capital out to a continuum of firms, which decide on labor and capital inputs. Their production process is subject to a total factor productivity (TFP) shock, which we assume to follow the stochastic process:

$$\varepsilon_t^a = \rho_a \varepsilon_{t-1}^a + \sum_{j=0}^{T} \eta_{t-j}^{a,j}, \qquad \begin{bmatrix} \eta_t^{a,0} \\ \vdots \\ \eta_{t-T}^{a,T} \end{bmatrix} \sim \boldsymbol{N}(\mathbf{0}_{T+1\times 1}, \boldsymbol{\Sigma}^a_{T+1\times T+1}) \tag{19}$$

where $\sum_{j=1}^{T} \eta_{t-j}^{a,j}$ is the productivity news component and $\eta_t^{a,0}$ is the period-t surprise. An increase in productivity generates an immediate contemporaneous increase in output and it increases the marginal product of labor, thus initially decreasing aggregate hours worked.

In a monopolistically competitive goods market, firms set prices as a markup over marginal costs. Analogously to the wage markup, we assume that the price markup follows an ARMA process:

$$\varepsilon_t^p = \rho_p \varepsilon_{t-1}^p + \eta_t^p - \mu_p \eta_{t-1}^p, \qquad \eta_t^p \sim N(0, \sigma_p) \tag{20}$$

Similar to wage markup shocks, the MA term in the process for the price markup shock is included in order to capture high frequency fluctuations in observable inflation.

The government is assumed to finance its expenditures by lump-sum taxes imposed on the households and the fiscal policy target is to insure a balanced budget in each period. For the process of government expenditures we assume:

$$\varepsilon_t^g = \rho_g \varepsilon_{t-1}^g + \eta_t^g + \rho_{ga} \eta_t^{a,0}, \qquad \eta_t^g \sim N(0, \sigma_g) \tag{21}$$

The inclusion of the productivity innovations is substantiated by the possible impact of domestic technology developments on net exports which are part of exogenous spending in estimation.

Higher government spending is equivalent to an increase in aggregate demand and thus, in a Calvo sticky price world, lead to increases in output beyond the flexible price level, which generates upward pressure on inflation and an increase in the nominal interest rate.

We use a formulation of the monetary policy reaction function (the Taylor rule) which includes an inflation objective shock and a monetary policy shock. For the first, we assume:

$$\bar{\pi}_t = \rho_{\bar{\pi}}\bar{\pi}_{t-1} + \eta_t^{\bar{\pi}}, \qquad \eta_t^{\bar{\pi}} \sim N(0, \sigma^{\bar{\pi}}) \tag{22}$$

which means that the inflation target shock follows an AR(1) process. We deviate hereby from the specification in De Graeve et al. (2009) because if the inflation target is a unit root process it is by construction a dominating force for long-term bond yields, an assumption which we want to relax[1]. Also, we do not find it plausible that the long-run level of inflation, as targeted by the Federal Reserve, changes every period. Similar to the way the ECB formulates its policy objective, we consider the inflation target to be valid in the *medium run*, a concept which we believe is well captured by a reasonably persistent AR(1) process.

Finally, for the monetary policy shock, we assume:

$$\varepsilon_t^m = \rho_\varepsilon \varepsilon_{t-1}^m + \sum_{j=0}^{T} \eta_{t-j}^{m,j}, \qquad \begin{bmatrix} \eta_t^{m,0} \\ \vdots \\ \eta_{t-T}^{m,T} \end{bmatrix} \sim \boldsymbol{N}(\mathbf{0}_{T+1\times 1}, \mathbf{\Sigma}^m_{T+1\times T+1}) \tag{23}$$

where $\sum_{j=1}^{T} \eta_{t-j}^{m,j}$ is the component of the monetary shock that we attribute to foresight about future policy actions and $\eta_t^{m,0}$ is the contemporaneous surprise component. The nominal interest rate enters the agents' decisions in two ways: first, it affects the inter-temporal Euler equation and thus an increase in the real rate renders savings more attractive while depressing consumption and second, it affects the present value of capital, an increase in the real rate inducing a heavier discounting of future cash flows and thus decreasing the attractiveness of capital investment.

3 Estimation Results

3.1 Data and estimation methodology

The model is estimated on the basis of a data set containing both macroeconomic and government bond yield series for the US economy spanning the period 1971:Q3-2008:Q4. The observable[2] macroeconomic time series include the quarterly growth rates of real GDP, consumption, investment, and the real wage as well as inflation, hours worked and the effective nominal federal funds rate.[3] Similar to De Graeve et al. (2009) the model estimation also utilizes four US government bond yield series for zero coupon bonds with maturities of $1, 3, 5$ and 10 years.[4] Figures A.1 and

[1]The results are insensitive to this assumption and are not qualitatively affected when we let the inflation target be a unit root process.

[2]The macroeconomic and yield measurement equations adhere strictly to the ones in Smets and Wouters (2007) and De Graeve et al. (2009). For a definition and discussion of these measurement equations the reader is thus referred to these papers.

[3]The observable macroeconomic times series are extensions of the dataset originally used by Smets and Wouters (2007). The reader is referred to this paper for a discussion of data sources and transformations.

[4]US government bond yield data is obtained from the Gurkaynak et al. (2007) database.

A.2 contain plots of our observable macroeconomic and financial time series.

The estimation approach allows for a set of structural parameters that are fixed prior to estimation. The set of fixed structural parameters contains the government spending to GDP ratio, the rate of capital depreciation, the steady state markup in the labor market and the curvature parameters of the Kimball aggregators in the goods and labor markets. [5] In addition, we calibrate the capital share in production α to 0.3. Finally, in contrast to De Graeve et al. (2009) who estimate the free constants in the bond yield measurement equations, these constants are now set to the in-sample means of the respective observable bond yield series. Econometrically, the two procedures are equivalent.

Estimation is performed using a two-step Bayesian ML procedure. In a first step, the mode of the posterior distribution is obtained by maximizing the log posterior kernel that combines the assumed parameter priors with the data likelihood. Secondly, two MCMC chains of 500.000 random draws from the posterior are used to obtain the full posterior distribution of the estimated structural and shock parameters. A burn-in period discarding the first 20 percent of the draws is introduced in order to eliminate the influence of the randomly chosen starting values of the two MCMC chains while convergence of the chains is monitored through the Brooks and Gelman (1998) convergence diagnostics.

3.2 Priors and posterior estimates

The intertemporal elasticity of substitution follows a normal distribution with a mean of 1.5 and a standard deviation of 0.10 while the labor supply elasticity follows the same distribution with a mean of 2 and a standard deviation of 0.10. The strength of the external consumption habit is given a beta prior distribution with a mean of 0.7 and a standard deviation of 0.10. The investment adjustment cost follows a normal distribution centered at 5 with a standard deviation of 0.20 while the capacity utilization elasticity follows a beta distribution with a mean of 0.50 and a standard deviation of 0.15. One plus the share of the fixed costs in production follows a normal distribution with a mean of 1.25 and a standard deviation of 0.10.

We refer to Smets and Wouters (2007) for our choice of priors for the Calvo price and wage probabilities as well as for the price and wage indexation parameters with the first two coefficients following a beta distribution with a mean of 0.5 and a standard deviation of 0.1 while the latter two are also beta distributed with a mean of 0.5 and a slightly looser standard deviation of 0.15. Our prior distribution assumptions for the steady state inflation, the trend in technology, the rate of time preference and steady state labor similarly stick fully to Smets and Wouters (2007).

Our policy reaction function features an interest rate smoothing parameter that follows a Beta prior distribution with a mean of 0.75 and a standard deviation of 0.10. The Taylor rule reaction parameters corresponding to the level of the output gap and its growth rate are both given a normal distribution with a prior mean of 0.15 and a standard deviation of 0.10 while the inflation targeting

[5] The calibration of these parameters is the same as in Smets and Wouters (2007).

parameter follows a normal prior with a mean of 1.5 and a standard deviation of 0.5.

Turning to the parameters related to the stochastic processes, we adopt a beta prior distribution with a mean of 0.5 and a standard deviation of 0.2 for all autoregressive and MA parameters while the standard deviations of the unexpected shock components are all given a loose inverse Gamma prior with a mean of 0.5 and a standard deviation of 2. A notable exception in this respect is made for the standard deviation of the inflation objective shock which follows an inverse Gamma distribution with a mean of 0.10 and a standard deviation of 2.

The yield measurement errors follow a loose inverse Gamma distribution with a prior mean of 0.1 and a standard deviation of 2. As the model implied fit of the bond yields is given by the standard deviation of the yield measurement errors (i.e. they capture the wedge between the expectation hypothesis and actually observable yield data) the prior assumptions about these standard deviations might strongly influence the empirical ability of the model to track the historical evolution of yields. In particular, by adopting a tight small prior for the yield measurement errors it is numerically possible to generate a very good model performance in terms of capturing yield series behavior. Our desire to avoid such an "engineered" result justifies our adoption of a very loose prior for the standard deviations of the yield measurement error.

Finally, we follow Khan and Tsoukalas (2009) and stipulate the prior standard deviation of the anticipated shock components in such a way that the sum of the prior variances of the news shocks equals the prior variance of the respective unanticipated shock component. This assumption implies that news shocks are on aggregate as volatile as the corresponding surprise shocks. Our assumptions for the prior distributions of the standard deviations of the model's unexpected shocks in combination with the maximum horizon of 6 periods that we assume for all types of news shocks implies that the anticipated shock components are allowed to follow an inverse Gamma distribution with a mean of 0.2 and a standard deviation of 2. Tables[6] A.1 and A.2 provide the posterior mean estimates and corresponding confidence intervals for the structural and shock parameters.

3.3 Model fit

A close observation of the means of posterior distributions reveals that our estimates are largely in line with results reported originally for the US economy by Smets and Wouters (2007). In particular, we obtain close point estimates for the labor elasticity as well as the extent of partial price and wage indexation and Calvo price and wage stickiness. On the consumer utility side we obtain a visibly lower degree of intertemporal substitution as well as a smaller strength of the external habit in consumption relative to the original findings. There are three possible reasons for these differences: first, we use an updated sample which includes much more recent observations; second, we also use yield curve data as observables and third, our stochastic specifications include the various informational diffusion processes.

The estimated monetary policy reaction function features a substantial degree of interest rate

[6]Table and figure names which start with an *A* refer to the Appendix.

smoothing, aggressive responses to both inflationary developments and output gap growth while central bank reactions to trends in the level of the output gap are shown to be subdued. Finally, the standard deviations of the three types of anticipated shocks are estimated to be statistically significantly different from zero at all news horizons albeit smaller than the respective surprise shock component. We come very close also in terms of point estimates to Khan and Tsoukalas (2009) with technology news having a volatility of around .10 at all 6 anticipation horizons.

Table 1
Marginal Density

No News and Foresight	Full Model
-406.49	-312.58

Note: The Marginal Density is measured by the Laplace approximation.

To assess the overall empirical ability of the macro-finance model to capture important moments in the data over the historical time span that we consider, Table A.5 reports standard deviations of our observable macroeconomic and financial variables as obtained from the respective time series and as implied by the model. The model implied standard deviations are simple averages across 500 stochastic simulations of our model with a length equal to 100 periods plus the sample size and discarding the first 100 observations to eliminate the influence of initial conditions. For inflation and the Federal Funds Rate the model is able to simulate volatilities that come close to what is found in the data. Similar to Smets and Wouters (2007) the model seems to overpredict the volatility of real activity growth. On the financial side, our macro-finance model slightly underpredicts the volatilities for the four observable US government bond yields. When interpreting the results in Table A.5 it should be noted that the benefit of estimating the model on a joint sample of macroeconomic and financial data comes at the unavoidable cost of reducing the model's ability to track the historical volatilities of the observable macroeconomic variables compared to other studies that do not utilize financial time series.

The literature reports mixed results concerning the marginal empirical relevance of anticipation effects, so it is not clear a priori whether including news and foresight in the model should improve its overall in-sample empirical performance. In Table 1 we report comparative figures for two estimated variants of the model: the benchmark setup described above and a version of the model in which we fully abstract from both technology news and policy foresight. We report a decisive improvement in the marginal log-likelihood through the inclusion of anticipation effects and thus significant evidence in favor of our benchmark model.

Finally, in order to assess the stability of our estimation results to the particular sample choice, we follow Smets and Wouters (2007) and re-estimate the model on a sub-sample covering the period 1984Q1 to 2008Q4. Tables A.3 and A.4 contain the respective sub-sample prior and posterior distributions. The majority of the model parameters seem to be insensitive to the choice of the sample estimation period. Notable exceptions are the Calvo wage stickiness parameter, which decreases from .80 to .65 and the wage indexation parameters, decreasing from .62 to .40. Consistent with the results of Smets and Wouters (2007) and the general finding in the literature on the *Great Moderation* period, we also obtain significantly lower volatilities for all stochastic disturbances of the model, most notably for the case of the investment-specific technology shock. The volatilities of the anticipated components of all shocks are not affected by the sample selection. The only exception hereto is the two-period ahead monetary policy shock, which is less than half as volatile in the sub-sample. We attribute this to the fact that the *Great Inflation* period was also one in which monetary policy decisions were drastic at times and also at the forefront of the public's attention, thereby generating more pronounced anticipation effects.

4 The Role of News

4.1 Macroeconomic fluctuations

A substantial body of literature has been devoted to uncovering the major stochastic drivers behind the macroeconomic volatility of the US economy based on methodologies ranging from simple unrestricted vector auto-regressions to fully specified micro-founded modeling environments. A visible caveat of this existing literature has been the concentration of the research effort on uncovering the role of surprise innovations in macroeconomic aggregates while excluding the possibility of the existence of anticipation, policy foresight or announcement effects. In addition, there has been at best a modest research effort aimed at investigating the role of macroeconomic news and policy foresight not only in terms of macroeconomic volatility but also in terms of fluctuation in financial markets within a micro-founded framework. This subsection presents results that aim at filling this gap in empirical research.

Table 2 presents variance decompositions at various time horizons for output growth, investment growth, inflation and the Federal Funds Rate, computed at the mean of the obtained posterior distributions for the model's structural parameters and shocks. A close examination of the results presented in the table points to a substantial role of surprise monetary policy in determining the variance of macroeconomic variables across the horizon spectrum. Surprise monetary policy appears to be an important contributor to the variability of real activity growth explaining from 20.9 percent of its variance decomposition over the one-period horizon to 21.4 percent of output growth 50 periods ahead with the major stochastic sources of output growth variability being shocks to investment technology, the risk premium and government spending. A similarly significant role of surprise monetary policy is also apparent in terms of investment growth variability while naturally here the bulk of forecast error variance stems from investment specific shocks.

In line with De Graeve et al. (2009), long horizon forecast error variances for inflation and the Federal Funds Rate are most substantially stemming from disturbances to the central bank inflation objective while price markup shocks are the most important determinants of short horizon inflation

Table 2
Variance decomposition

	Output growth			Invest. growth			Inflation			Fed. Funds Rate		
	1	6	50	1	6	50	1	6	50	1	6	50
Structural shocks												
Technology	8.6	8.1	8.0	1.4	2.5	2.6	1.7	2.4	1.1	8.4	5.8	2.5
Risk premium	13.0	11.4	10.6	1.6	1.1	1.0	0.2	0.3	0.2	24.0	9.0	3.5
Gov.spending	27.3	23.1	21.7	0.4	0.7	0.7	0.2	0.4	0.3	4.0	3.2	1.6
Investment	21.5	18.5	17.8	81.1	64.2	58.5	0.3	0.6	0.4	6.0	11.1	5.2
Monetary policy	20.9	21.1	21.4	8.0	9.2	9.3	5.3	17.7	12.2	9.8	3.7	3.5
Price markup	1.8	3.0	2.9	1.0	2.4	2.2	77.9	33.4	15.3	5.4	3.3	1.4
Wage markup	0.0	1.3	1.5	0.1	0.2	0.4	5.4	9.7	4.9	1.4	2.1	1.1
Inflation objective	0.0	0.0	0.0	0.0	0.0	0.0	4.1	17.2	52.3	23.3	26.6	62.5
News												
Productivity	0.8	1.6	1.7	0.3	1.1	1.3	0.1	0.4	0.2	0.8	2.1	1.0
Investment	0.5	3.5	5.0	2.8	12.9	17.9	0.2	0.6	0.3	0.3	3.2	3.9
Monetary policy	5.7	8.4	9.4	3.2	5.5	6.0	4.7	17.3	12.9	16.8	29.8	13.6

Note: The variance decomposition is shown at a horizon of 1, 6 and 50 quarters respectively.

variability.

Our empirical findings concerning the role of news and policy foresight in macroeconomic volatility both comply with some of the already existing results in the literature and shed new light on the relative importance of these innovations. As mentioned, Khan and Tsoukalas (2009) consider a macroeconomic model very similar to ours and find a negligible role for news about total factor productivity and investment specific technology in the variance decomposition of the growth rates of output and investment. While our empirical results confirm their findings regarding the insignificant role of aggregate technology news for the variance decomposition of these two real variables our results disagree along other dimensions.

First, anticipated investment technology innovations play a small but nonetheless visible role in the long horizon variance decomposition of real activity growth that contrasts with a virtually non-existent contribution of this type of macroeconomic news in Khan and Tsoukalas (2009). This contrast is much more pronounced in terms of the variability of investment growth where our results point to a sizable 18 percent contribution to the long horizon variance of investment growth stemming from anticipated investment technology innovations compared with no aggregate role for these shocks in Khan and Tsoukalas (2009). It is worth noting that our results are obtained in the presence of both markup and risk premium shocks, factors cited by Khan and Tsoukalas (2009) as potentially explaining the insignificant role of news shocks in macroeconomic volatility.

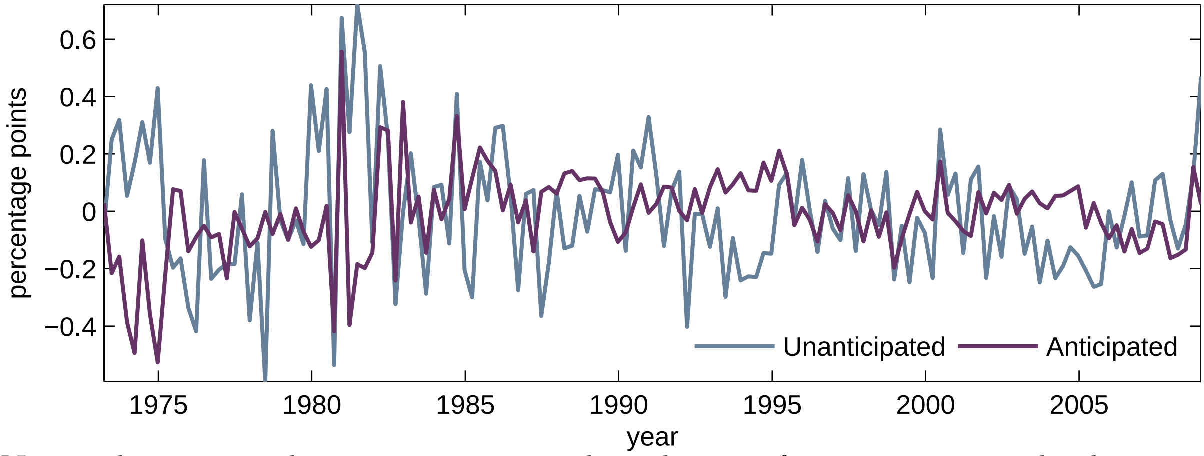
Second, we document a visible role for monetary policy foresight in determining both real activity growth and investment growth. Around 5 to 10 percent of the conditional variance of these variables across different forecast horizons can be attributed to variation in expectations about the future policy stance. In order to make the empirical relevance of this point more precise, in Figure 1 we also report the decomposition of the monetary policy shock in anticipated and unanticipated components. The results show that there has been indeed a significant amount of foresight throughout the sample, however the anticipated component seems to very often be offset by the surprise component, the ultimate realization of the policy shock being close to zero. Economically, it would mean that agents most of the time expect a certain interest rate change, which in the end does not materialize, the central bank actually following strictly the Taylor rule. A different possible interpretation is that agents have only noisy information about the evolution of inflation and the output gap, so their expectations about policy actions are noisy as well. Similar decompositions of investment technology and TFP news are depicted in Figure A.4.

While the role of policy foresight in determining the long run volatility of inflation and the policy instrument appear to be more subdued, foresight seems to account for between 17 and 30 percent of the short- to medium-term fluctuations in the Federal Funds Rate.

The historical contributions of the various model innovations - anticipated and unanticipated - to the observed path of the Federal Funds Rate, inflation and output growth in the US over the time sample that we consider are depicted in Figure A.5. Decompositions are computed at the posterior mean of the estimated parameters. A pronounced role of disturbances to the inflation objective in the overall variability of the central bank policy instrument are primarily found for a period starting in 1979 until the end of the 1980s. We attribute this to the more conservative monetary policy stance under Chairman Paul Volcker. Also, we note that the most substantial positive contribution of markup shocks to the Federal Funds Rate coincides with the periods of oil supply shocks and the "Great Inflation" throughout the 1970s. Not surprisingly, we find an equally depressing role of markup shocks in the periods with relative calm in inflationary developments thereafter. Technology shocks also seem to be an important historical contributor to the nominal interest rate, possibly through the effects on potential output. During more recent periods, our framework attributes the declines in short-term interest rates to a mix of demand, technology and inflation objective shocks.

When looking at the historical decomposition of inflation, an interesting feature of our analysis is the very substantial positive contribution of the inflation objective during the early 1980s, which seemingly contradicts the conservative monetary policy stance at the time. However, we note here that, as in the model of De Graeve et al. (2009), the inflation objective variable also has an interpretation as the market expectation of the inflation level. At the start of the 1980s the US had already experienced some years of high inflation levels, such that the expectations of the market (as identified here from the term structure of interest rates) were strongly detached from what we may think from today's perspective the inflation target of the Federal Reserve was. These patterns

Figure 1
Decomposition of the monetary policy shock



Note: The anticipated component corresponds to the sum of 1 up to 6 quarter ahead news.

resulted in strong upwards pressure on prices and wages, which however were counteracted by decisive monetary policy decisions, as can be seen from the negative contributions of (unexpected) monetary policy shocks to aggregate inflation during the same period. Seen through this lens, we interpret this period as exhibiting a misalignment between the monetary policy stance and the public perception thereof.

Interestingly, as soon as inflation came down and the central bank gained credibility, monetary policy foresight started having a significant contribution on the aggregate level of inflation for the next 10 years. Except for a brief period after 1994, the anticipations of the agents were indeed confirmed by subsequent policy actions.

The historical decomposition of the US output growth is more heterogeneous across the different macroeconomic innovations. Policy foresight has played a visibly positive role in the dynamics of real activity growth in the first half of the 1970s and has contributed negatively to output growth at the beginning of the 1980s coinciding with attempts to reign in the surging inflationary developments. Unlike the cases of the Federal Funds Rate and inflation, anticipated technology innovations now seem to feature more prominently in the historical path of US output growth with mixed direction and impact magnitude. However, the most prominent determinants of output growth seem to be unanticipated shocks, both on the monetary and the real front.

4.2 Term structure variability

Table 3 presents forecast variance decompositions at various horizons for the 3, 5 and 10 year US government bond yields as well as for the slope of the US yield curve proxied by the spread between the 10- and the Federal Funds Rate. The results are computed at the mean of the posterior distributions of the estimated structural parameters. An examination of the variance decomposition results reported for the three yield levels in consideration confirms the empirical finding of De Graeve et al. (2009) of the crucial importance of shocks to long-term inflation expectations in the variability of yields along the US term structure. Shocks to the central bank inflation objective capture from 85.1 percent to 96.1 percent of the forecast error variance at the 50-quarter ahead horizon for the 3-year and 10-year bond yield respectively. Stochastic changes to long-term inflation expectations feature prominently in the variance decomposition of yield levels even at very short forecasts horizon as indicated by the results for the 1-quarter ahead forecast error to which these shocks contribute by between 49.3 percent for the 3-year yield and 84.1 percent for the 10-year yield. The contribution of the rest of the structural shocks to the variance decomposition of US yield levels is heterogeneous and crucially depends on bond maturities and forecast horizons. While shocks to investment feature prominently in the variance decomposition of yield levels of shorter maturities and at shorter horizons their role is substantially more modest at the longer end of the maturity spectrum.

Table 3
Variance decomposition of yields

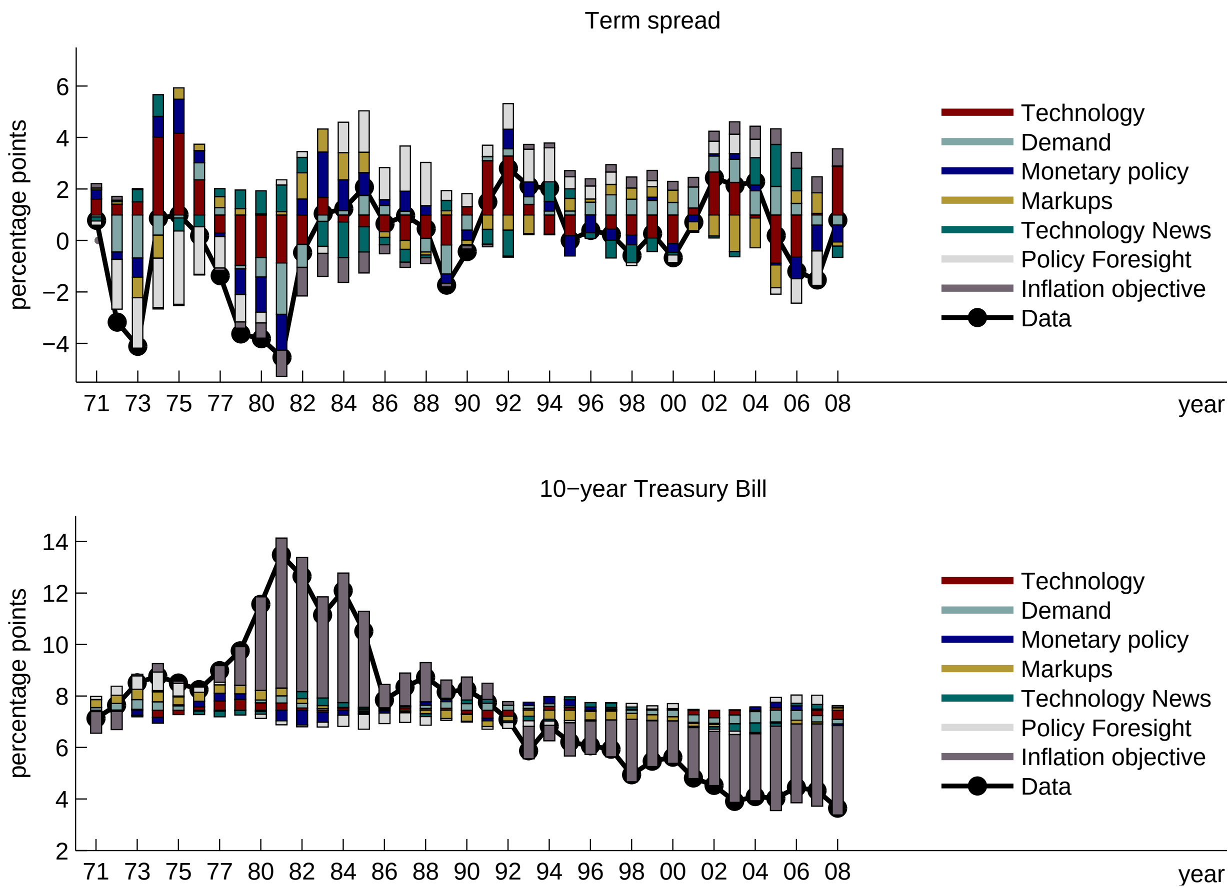
	3 years			5 years			10 years			Term spread		
	1	6	50	1	6	50	1	6	50	1	6	50
Structural shocks												
Technology	3.6	1.8	0.7	1.9	1.0	0.5	1.2	0.7	0.4	9.3	7.0	5.4
Risk premium	3.7	1.4	0.4	2.0	0.7	0.2	0.7	0.3	0.1	32.9	13.1	9.7
Gov.spending	2.9	2.0	0.8	2.2	1.5	0.6	1.3	1.0	0.4	3.5	3.0	2.6
Investment	9.5	6.3	1.9	5.0	2.9	0.9	1.2	0.5	0.4	6.2	15.7	14.2
Monetary policy	1.2	4.7	2.2	2.0	3.8	1.3	0.7	1.2	0.4	20.2	7.2	10.4
Price markup	1.3	0.5	0.3	0.4	0.1	0.2	0.2	0.1	0.3	7.3	5.0	4.0
Wage markup	2.1	1.4	0.5	1.1	0.7	0.3	0.6	0.4	0.4	1.1	2.3	2.2
Inflation objective	49.3	58.5	85.1	65.8	74.2	91.6	84.1	90.4	96.1	0.4	0.8	5.3
News												
Productivity	0.3	0.4	0.2	0.2	0.2	0.2	0.1	0.2	0.2	1.8	3.7	2.9
Investment	5.6	7.3	2.6	3.8	4.0	1.2	0.9	0.9	0.4	1.0	4.4	10.9
Monetary policy	19.9	15.5	5.1	14.9	10.8	2.9	5.8	3.8	0.9	16.3	37.8	32.6

Note: The variance decomposition is shown at a horizon of 1, 6 and 50 quarters respectively.

The lower end of Table 3 contains empirical results related to the role of macroeconomic news and monetary policy foresight in the variance decomposition of yield levels across the US term structure. The empirical conclusions overall point to a rather limited contribution of anticipated macroeconomic and policy effects on the variability of US bond yield levels, the exception being a rather medium effect of monetary policy foresight at shorter maturities and at shorter horizons.

The last three columns of Table 3 contain variance decomposition results for the term spread at three different forecasts horizons. An exact overview of the variance decomposition of the spread at different horizons can be found in Figure A.3. While shocks to the risk premium now appear as the main stochastic driver of the variability of the term spread accounting for approximately 30 percent of its variance at a one-period horizon, surprise monetary policy now assumes a much more prominent role compared to the case of bond yield levels. In particular, its contribution now ranges from 20.2 percent at the 1-quarter ahead horizon to 10.4 percent at the longer 50-quarter ahead horizon.

Figure 2
Historical decomposition of the bond yields



Note: Historical decompositions are computed at the posterior mean of the parameters. All variables are depicted in terms of annualized levels. The *Technology* component refers to the sum of productivity and investment-specific technology. The *Demand* component refers to the sum of government spending and risk premia.

In sharp contrast to the case of individual US bond yield levels we also uncover a substantially more prominent role of macroeconomic news and monetary policy foresight in the variability of the slope of the US government bond yield curve. News shocks are found to be the third most important stochastic driver of fluctuations at the short end and the dominant force in the long run. On a more disaggregated level, anticipated changes to the future stance of monetary policy appear to be the most prominent disturbance in the forecast error variance of the US term spread at medium and long horizons.

Our conclusions from examining Table 3 are confirmed by examining the historical decomposition of the 10-year Treasury Bill and the US yield curve depicted in Figure 2. Shocks to the inflation objective and markup shocks have historically had the most prominent role in determining the historical path of the long-term US government bond over the considered time period with only minor contributions by the rest of the model disturbances. The historically low 10-year government bond yield levels in the most recent years in our sample seem thus to have been primarily caused by strong downward revisions to long-run inflation expectations.

In contrast, the historical surge in the value of the 10-year US government bond in late 1970s and early 1980s appears to be the joint result of both positive contributions from shocks to price and wage markups and upward pressure on long-run inflation expectations. Anticipated technology news and monetary policy foresight do not appear to exhibit visible contributions to the historical trajectory of the 10-year US government bond yield over the considered time sample.

The historical decomposition of the slope of the US yield curve exhibits a more heterogeneous mix of contributing shocks. The yield curve inversion in the late 1970s seems to have been the joint consequence of the negative contribution of demand shocks and monetary policy. As in De Graeve et al. (2009), the main drivers of the term spread are technology-specific factors, both anticipated and unanticipated. Monetary policy foresight plays a more prominent role in the late 1970s and early 1980s, but also in more recent years, towards the end of the sample.

4.3 Impulse responses

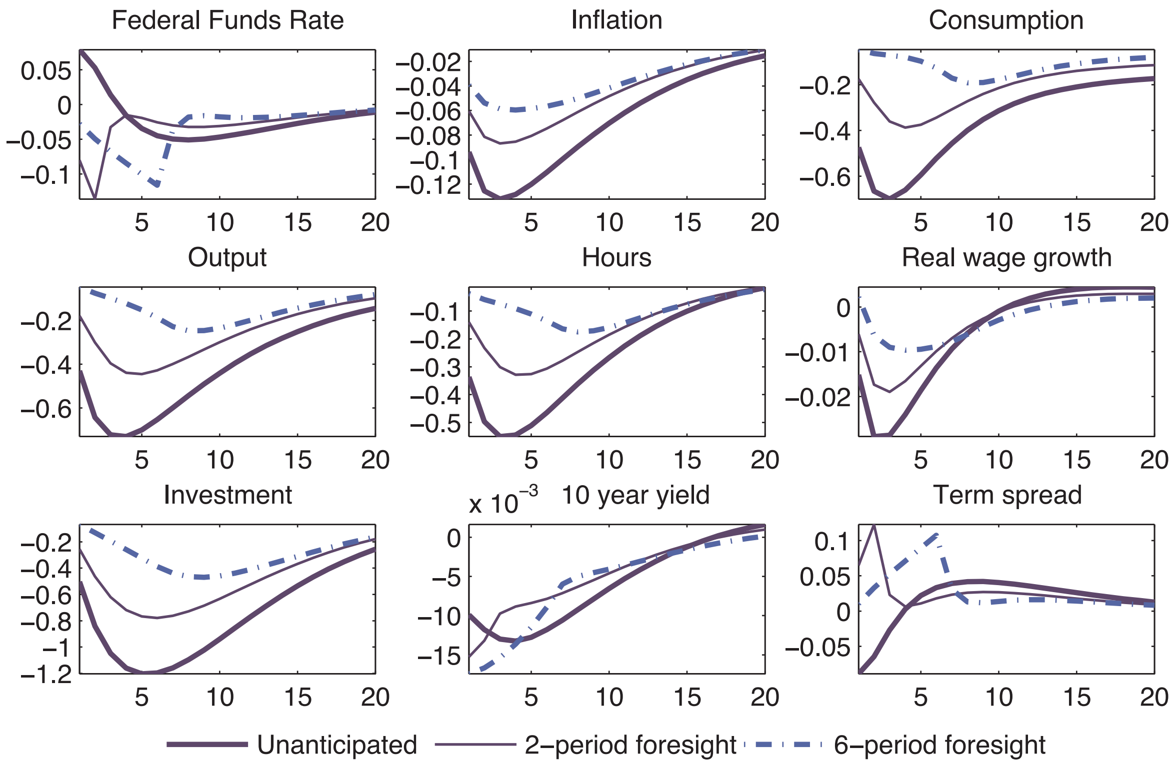
Figure 3 depicts the dynamic impulse response of a selection of macroeconomic and financial variables to anticipated and surprise changes in the stance of monetary policy[7].

The reaction of the macroeconomic variables to surprise monetary policy news qualitatively replicates results typically found in the literature. Surprise monetary policy tightening leads to an initial decline in real economic activity with an associated initial fall in consumption, investment and hours worked. We find evidence for a relatively protracted effect of surprise monetary policy shocks on real variables with output returning to its initial steady state after more than 5 years. The fall in the amount of the labor input exerts an upward pressure on the price markup through its positive effect on the marginal product of labor. The negative dependence of the current level of inflation on the current price markup explains the initial fall in price inflation in response to the surprise monetary policy tightening.

Inflation is found to return to its initial steady state 5 years after the positive monetary surprise. The implied initial increase in the Federal Funds Rate generates a positive response on impact of the 10-year US government bond yield level to the surprise monetary policy tightening. The stronger

[7]Figures A.6, A.7 and A.8 capture the respective impulse responses to the other structural shocks present in our model. Since they are however not part of the core of our analysis and are entirely in line with empirical results from previous research contributions, we restrict our focus to the effects of only the relevant subset of structural disturbances.

Figure 3
Impulse responses to monetary policy

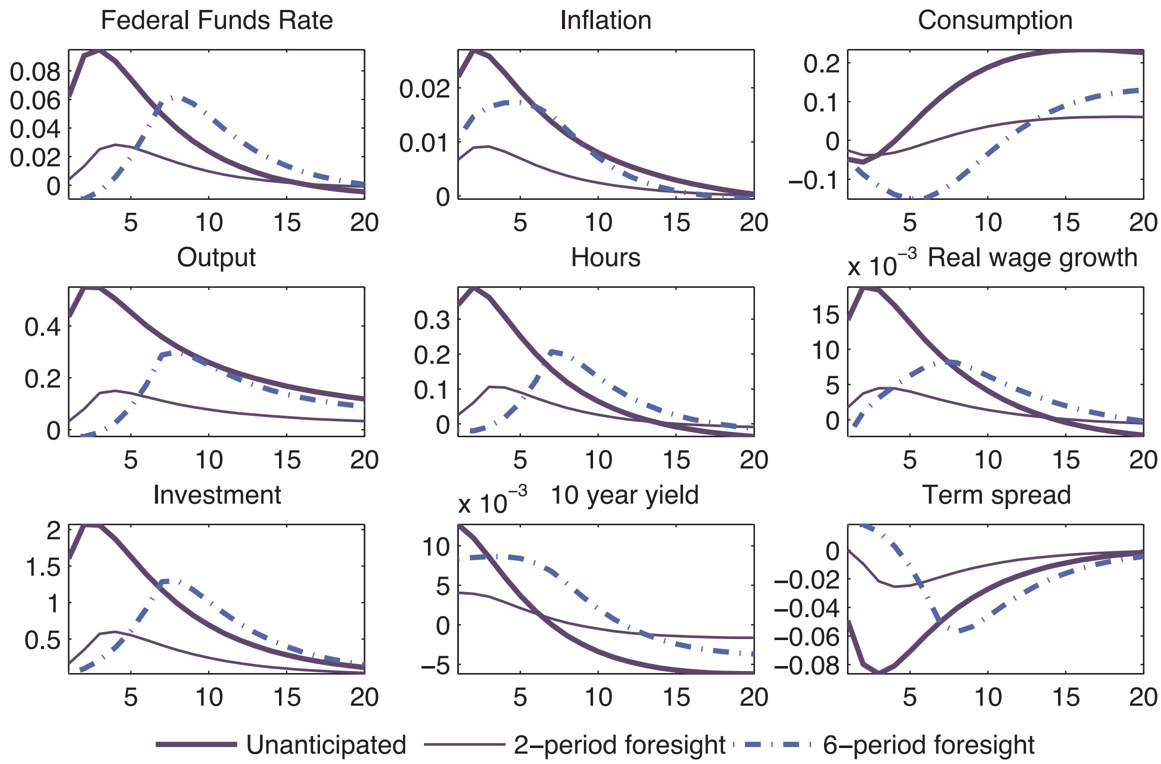


Note: The figure shows impulse responses to positive one standard deviation innovations.

influence of upward movements in the Federal Funds Rate in response to positive policy shocks on the shorter horizon 1-year government bond yield explains the initial flattening of the US yield curve following the surprise monetary policy tightening as indicated by the dynamic response of the term spread. The effect of monetary policy surprises on the term spread is found to be relatively short-lived with the term spread returning to its initial steady state after approximately 5 quarters.

Anticipated changes in the monetary policy stance generate differences in the dynamic responses of macroeconomic and especially financial variables both in terms of relative size and effect direction. Figure 3 also depicts impulse responses to 2-period ahead and 6-period ahead monetary policy foresight. The anticipation of a monetary policy tightening in the future and the implied higher real return on savings in the future forces economic agents to reduce their consumption as the monetary policy news arrives as indicated by the initial fall in consumption in reaction to both types of positive policy foresight. This reduction in consumption demand together with the implied fall in aggregate investment lead to an initial recession indicated by the on-impact response of output to the policy news. The policy foresight-induced initial slowdown in real economic activity together with the associated fall in price inflation force the central bank to respond in order to preserve macroeconomic stability by lowering the interest rate following its announcement about future monetary policy

Figure 4
Impulse responses to changes in investment technology

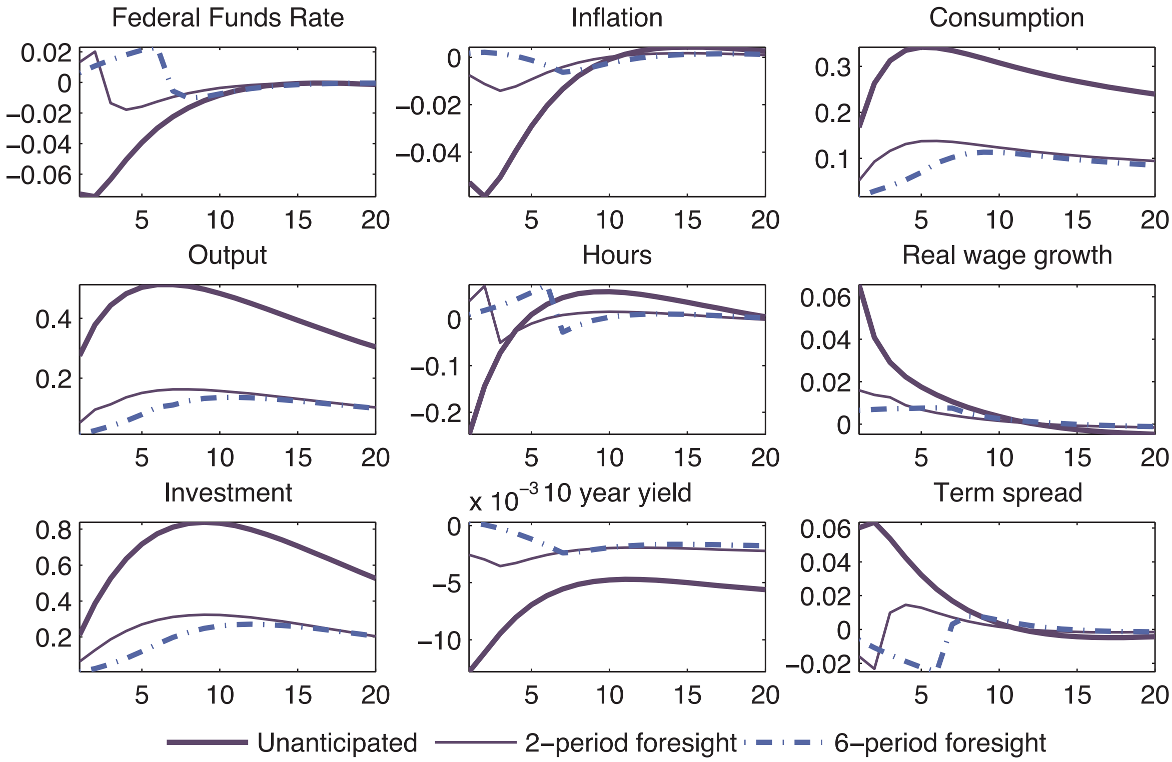


Note: The figure shows impulse responses to positive one standard deviation innovations.

actions. Note that due to the model-implied transmission channels this initial negative response of the monetary policy instrument in the case of positive policy foresight comes in sharp contrast to the monetary policy tightening following a positive policy surprise shock. Subsequently, the actions of the central bank return both output and inflation to their original steady state while the actual materialization of the monetary policy shock causes a slight overshooting of the policy instrument. Monetary policy foresight seems to generate different qualitative effects, not only in terms of the dynamic responses of macroeconomic variables but also in the behavior of the US term structure.

The anticipation of a future monetary policy tightening leads to an initial fall in the 10-year US government bond yield substantiated both by the negative initial reaction of the policy rate described above and by expectations of future lower inflation as a result of the anticipated policy rate hike that are fully priced in the nominal bond. Note again the sharp contrast between the initial response of the 10-year US government bond yield in reaction to monetary policy surprises and monetary policy foresight. While the initial positive response of the bond yield in the case of the former is fully rooted in the agents' observation of an unexpected hike in the policy rate, the negative response of the yield in the case of the latter has well defined general equilibrium underpinnings. These general equilibrium channels seem to exert a stronger impact on the initial

Figure 5
Impulse responses to total factor productivity



Note: The figure shows impulse responses to positive one standard deviation innovations.

negative response of the shorter horizon 1-year US government bond yield generating an initial steepening of the US yield curve in response to positive policy foresight again to be contrasted with the initial flattening of the yield curve in the case of surprise monetary policy tightening.

Figure 4 shows the dynamic impulse responses of the same selection of macroeconomic and financial variables to anticipated and surprise changes to investment specific technology. The results for the case of unexpected investment specific shocks confirm the general findings of Smets and Wouters (2007). Surprise enhancements of the efficiency with which capital and investment goods are produced lead economic agents to shift resources away from consumption, explaining the initial rise in investment. This efficiency-induced initial increase in investment seems to overcompensate the on-impact decline in agents' consumption demand leading to an overall initial rise in real economic activity. The associated increase in the labor input generates a decline of the price markup through its depressing effect on the marginal product of labor which in turn forces inflation to rise on impact in reaction to the surprise positive investment technology disturbance. Following its goals of maintaining macroeconomic stability, the central bank intervenes in reaction to this initial heating of the economy and raises the policy rate. This initial increase in the policy instrument and its relatively sluggish return to the original steady state (the Federal Funds Rate takes about

5 years to return to its original position) is fully priced in the expectations of private agents about the evolution of short-term rates in the future, generating the positive initial response of the 10-year government bond yield. The stronger effect of the on-impact rise in the policy rate on the shorter horizon 1-year US government bond yield compared to the 10-year nominal bond generates an initial flattening of the US yield curve, that is protracted and does not disappear fully even after 5 years.

The effects of anticipated changes to investment technology on macroeconomic and financial variables operate through general equilibrium channels and like in the case of monetary policy foresight there are differences in direction compared to surprise investment technology shocks. The anticipation of a greater efficiency of production of capital and investment goods in the future and therefore greater economic gains forces economic agents to postpone their investment actions, as evidenced by the initial slight downturn of investment. This initial investment decline is enough to lead to an on-impact fall in real economic activity and an associated decline in the use of the labor input in production. These effects are to be contrasted with the acceleration in real economic activity that we documented in the case of surprise positive shocks to investment technology. While the fall in the utilized labor exerts a positive impact the marginal product of labor the initial depletion of the capital stock due to reduced investment seems to overcompensate this effect and generates an overall deterioration in the marginal labor productivity. Through its marginal cost and price markup channels this leads to an initial rise in inflation.

The mild initial recession in real economic activity forces the central bank to cut its policy rate. As rational agents internalize in their expectations the increase in the Federal Funds Rate once the anticipated improvement in investment efficiency materializes, the 10-year US government bond yield exhibits an initial rise in response to positive investment technology news that takes an extended period of more than 15 quarters to die out. As the shorter horizon 1-year US government bond yield is much more strongly affected by movements of the current short rate than the 10-year government bond yield and the short rate falls in response to investment technology news, these anticipated disturbances generate an initial steepening of the US yield curve that contrasts with the initial flattening arising in the presence of only unexpected changes.

Figure 5 finally depicts the dynamic impulse responses of the same set of macroeconomic and financial variables to anticipated and surprise disturbances to total factor productivity. Again we generally confirm known results already found in the existing literature. Through the production function output, as well as consumption and investment exhibit an immediate increase, with the latter being substantiated by expectations of greater economic gains from production in an environment of enhanced total factor productivity.

The investment-induced rise in the capital stock of the economy, coupled with the initial drop in labor input, exert an upward pressure on the marginal labor productivity that through the price markup generates an initial drop in price inflation. The increased stock of total factor productivity increases the level of potential output of the economy creating a negative output gap. The central bank responds to this negative mismatch between potential production and actual real activity as well as to the drop in inflation by lowering the policy rate. The high degree of persistence inherent in the stochastic process for the aggregate technology shock implies a protracted period of negative output gaps and subdued inflation, forcing the central bank to maintain a loose monetary policy stance for an extended period of time. Rational agents internalize this into their expectations leading to a drop in the level of the 10-year US government bond yield and an overall steepening of the US yield curve substantiated by the strong downward pressure exerted by the policy rate on the shorter horizon 1-year government bond yield.

Similar to the two other types of anticipated disturbances that we consider, aggregate technology news seem to imply a different direction of impact on our selection of macroeconomic and financial variables compared to impulse responses to unexpected changes in the total stock of aggregate technology. We confirm the general finding of Khan and Tsoukalas (2009) of a positive initial comovement of output, consumption, investment and hours to 2-period ahead and 6-period ahead positive aggregate technology news. The rise in investment could be attributed to the rational expectation of the firm sector of increased capital gains in the future. This initial acceleration in investment activity generates expectations of a greater capital stock and therefore greater aggregate income, allowing economic agents to increase their consumption even before the favorable TFP news is materialized. These changes in investment and consumption demand are the main drivers of the rise in output in response to anticipated aggregate technology news. The initial increase in inflation in response to anticipated TFP growth, although quite subdued in size, can be attributed to the rise in labor input and therefore the depression of the marginal productivity of labor pushing the price markup downwards.

Another way to understand these effects is by noticing that in the case of an anticipated TPF news shock potential output does not actually change, which combined with the fact that consumption and investment increase, generate a positive output gap. The central bank reacts to this by increasing the rate.

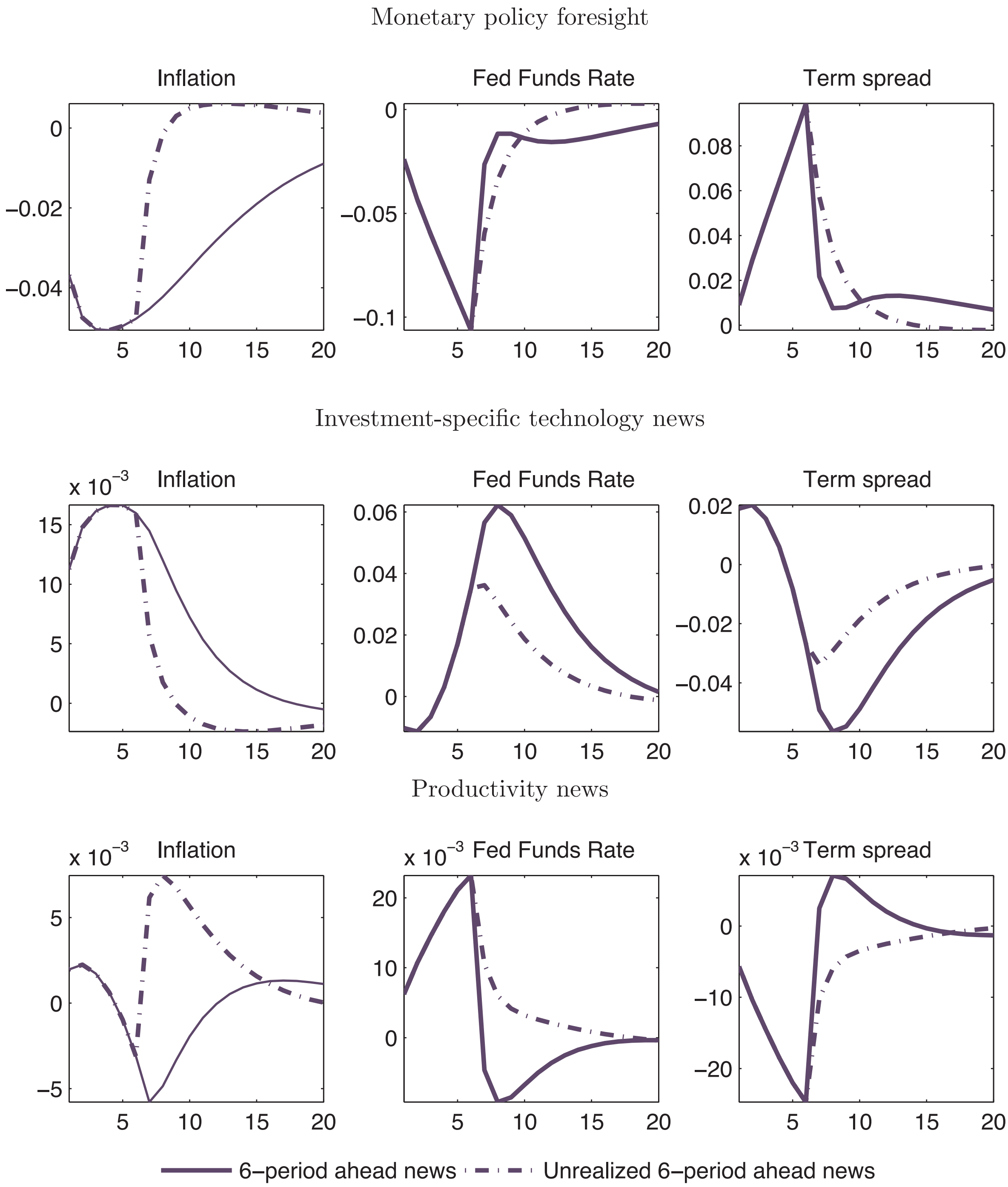
Rational agents understand the possibility of an occurance of a negative output gap in the future, once the positive TFP news materializes and the need for the central bank to react to this by loosening monetary policy. These expectations of lower short rates in the future in the face of anticipated aggregate technology shocks push the 10-year US government bond yield downwards on impact, thus flattening the US yield curve in contrast to its steepening in the face of surprise aggregate technology innovations.

5 Counterfactual Analysis

5.1 False News

Our analysis so far made an explicit assumption that anticipated macroeconomic and monetary policy announcements do materialize in reality and that therefore economic agents' actions have

Figure 6
False News



Note: The figure shows impulse responses to positive one standard deviation innovations.

been conducted in accordance with correctly substantiated expectations. In this exercise we take a step further and compare the dynamic responses of three variables of interest - the Federal Funds Rate, price inflation and the US yield curve slope - to macroeconomic news and policy foresight that turn out to be correctly anticipated and to news shocks that do not materialize at their expected time of impact. In particular, Figure 6 shows impulse responses of these three variables to 6-quarter ahead anticipated innovations to the monetary policy stance, investment specific technology and total factor productivity that truly materialize 6 quarters after hitting the economy and to the same 6-quarter ahead news that do not get realized. Whether the particular news shock materializes in reality or not does not alter the initial impulse magnitude and direction and this holds across the three variables of interest and across the three types of news shocks, which is true by assumption, given that economic agents have no way of verifying the correctness of the anticipated macroeconomic or policy signal, before the actual time of structural impact. As Figure 6 reveals however, falsely anticipated signals imply a much different subsequent dynamic path of our three variables of interest compared to truly materialized macroeconomic news and policy foresight. 6-quarter ahead announcements about the stance of future monetary policy that do not materialize at their expected time of impact seem to have greatest impact on price inflation as indicated in the first row of Figure 6. Once rational agents observe that the anticipated monetary policy tightening has not actually materialized, they revise their estimate of the expected real return on their savings downwards, thereby increasing the demand for final goods. The associated rise in real economic activity induces a revival of inflationary pressures in the economy, as indicated by the much quicker return of inflation to original steady states levels in case of false monetary policy foresight compared to the "true" policy foresight scenario. These developments have a direct implication on the dynamics of the US nominal yield curve slope. The non-materialization of the anticipated monetary policy tightening and the subsequent immediate reoccurrence of price inflation positively feed into the agents' long-term inflation expectations, pushing the inflation premia and longer-term bond yields upwards.

Falsely anticipated innovations to investment specific technology, depicted in the second row of Figure 6, also appear to cause substantial differences in the dynamic behavior of the variables compared to correctly anticipated investment technology changes. The observation of a non-materialized anticipated improvement in the efficiency with which capital and investment goods are produced induces economic agents to immediately restart their postponed investment activities, pushing aggregate economic activity and associated labor input in production upwards. The beneficial impact of the renewed capital accumulation on the marginal productivity of labor seems to dominate the depressing effect of the rise in the amount of utilized labor, driving down the marginal cost and ultimately inflation. This channel is clearly shown by the much earlier and sharper decline of inflation towards steady state levels than in the case of truly materializing expected positive changes to investment technology. In the face of this much sharper negative inflationary development, the central bank intervenes in order to preserve price stability by loosening its monetary policy stance, thereby putting downwards pressure on shorter horizon US government bond yields and initiating an actual steepening of the US yield curve compared with a protracted further flattening of the US term structure in case of truly realized positive innovations in investment specific technology.

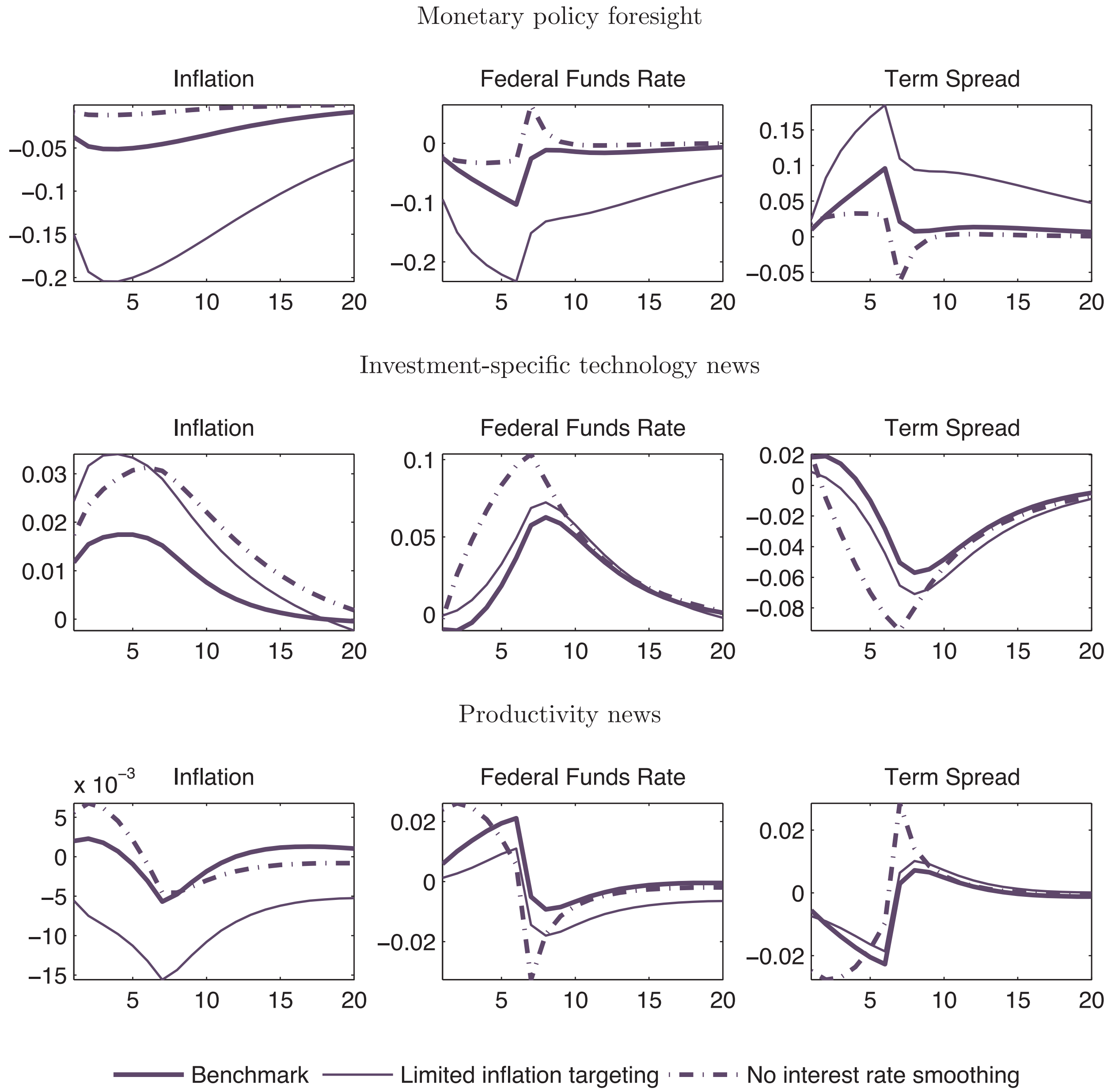
Finally, in the third row of Figure 6 we depict the impulse responses of the Federal Funds Rate, price inflation and the slope of the yield curve to realized and falsely anticipated signals about future total factor productivity. As already discussed, the anticipation of a more efficient aggregate production function in the future induces agents to invest more in an attempt to reap greater future economic gains as well as to consume more as the news arrives in anticipation of a greater aggregate income in the future. The non-materialization of the anticipated beneficial innovation to aggregate total factor productivity forces agents to cut back on their increased investment activities as well as their consumption demand leading to an aggregate activity slowdown. While the non-materialization of the positive TFP innovation has no effect on the productive potential of the economy, the above described slowdown creates a negative output gap forcing the central bank to intervene by cutting its policy instrument. The sharper increase in inflation in case of a false 6-quarter ahead positive TFP news can therefore be directly attributed to this change in the monetary policy stance. The need for the central bank to maintain a loose monetary policy stance over a certain period of time following the non-materialization of the expected positive TFP innovation is internalized in agents' expectations of the future evolution of the short rate slowing down the degree of US yield curve steepening compared to the dynamic behavior of the term structure slope in case of correctly anticipated positive TFP changes.

5.2 Policy Scenarios

As a final exercise we turn our attention to examining the impact of the way in which monetary policy is conducted on the dynamic responses of macroeconomic variables to anticipated news and policy foresight. Figure 7 presents impulse responses of inflation, the Federal Funds Rate and the US yield curve slope to three types of news, as well as the same impulse responses in the case of a central bank that attaches little attention to stabilizing inflation and in the case of no monetary policy gradualism. The results provide clear evidence pointing to the fact that the way monetary policy is conducted has sizable implications on the relevance and size of the macroeconomic impact of news and policy foresight.

The first row in Figure 7 depicts impulse responses of three selected variables to monetary policy foresight across the three kinds of monetary policy regime. The qualitative characteristics of the impulse responses are not affected by the particular monetary policy regime, however there are substantial differences in the impact magnitudes. In the case of limited inflation targeting, the central bank is less concerned with maintaining price stability and concentrates more on stimulating the initially subdued real activity by pursuing looser initial monetary policy. Hence, inflation is allowed to react more negatively in response to positive monetary policy foresight than in our

Figure 7
Effects of news under different assumptions about monetary policy



Note: In the *Limited inflation targeting* case we set the Taylor-rule coefficient $\phi_\pi = 1.01$ and in the *No interest smoothing* case we set the Taylor-rule interest rate smoothing parameter $\rho_R = 0$. The figures depict impulse responses to a one-standard-deviation 6-period ahead news shock.

benchmark case. The reduced importance of maintaining inflation stability has a clear implication for the dynamic response of the term spread. As the short rate now plunges more strongly and has a greater impact on the shorter horizon 1-year US government bond than on the longer horizon 10-year yield, the yield curve steepens more heavily in the absence of inflation targeting than in our benchmark scenario.

The absence of policy gradualism in the central bank reaction function has exactly the opposite effects: the initial recession in the wake of an anticipated positive monetary policy shock is caused by the expectation of a tighter future monetary policy stance, forcing economic agents to demand and consume less. In the case of no policy gradualism economic agents rationally foresee that monetary policy tightening will not last as long as in our benchmark case, they consume more, which causes a milder deflationary environment and does not force the central bank to react as strongly. The yield curve gets initially flatter than in the benchmark case, again due to the heavier impact that the policy rate exerts on the 1-year than on the 10-year government bond yield.

We report the same comparative exercise in the second row of Figure 7 for the case of impulse responses to investment specific technology news. The exact way in which monetary policy is conducted again has a significant influence on the way the three variables respond. In the case of little importance attached to price stability the central bank would have an incentive to cut its policy instrument more heavily in the face of investment specific news in order to stimulate the real economy, that otherwise in our benchmark case falls into a mild recession initially. The resulting acceleration in real activity and in investment activity in particular lead to faster capital accumulation, whose positive influence on the marginal productivity of labor seems to overcompensate the negative influence of the labor input. This pushes the price markup upwards and inflation more heavily downwards. The resulting subdued steepening of the yield curve in the presence of less inflation targeting is again the direct result of the influence of the movements in the policy rate on the shorter horizon 1-year yield as compared to the 10-year yield.

The absence of policy gradualism in the policy reaction of the central bank generates opposite effects on the impulse responses of the three variables. As the central bank is not constrained to at least partially follow the historical path of its policy instrument, it will have an incentive to react more strongly than in our benchmark case in order to avert the initial recession. The recession would thus be milder, causing inflation to have a more subdued initial rise due to the smaller initial change in marginal costs. Following a similar reasoning as above, the yield curve spread steepens more heavily in the absence of monetary policy gradualism and in the face of positive technology shocks than in our benchmark case.

The third row of Figure 7 depicts results for the case of impulse responses to anticipated positive changes to total factor productivity. In the absence of active inflation targeting the Federal Funds Rate would remain virtually unchanged on impact, compared to the benchmark case, exerting a smaller upward pressure on the 1-year government bond yield and causing the yield curve to flatten by less than in our benchmark case. In contrast, the absence of monetary policy gradualism enables the central bank to react more aggressively to the initial economic boom, in its attempt to stabilize the economy. This causes a more pronounced flattening of the yield curve than what is observed in our benchmark scenario, through its greater upwards pressure on the 1-year government bond yield.

6 Conclusions

Through recent decades, empirical macroeconomics has witnessed an abundance of economic research focused on uncovering the major forces behind business cycle fluctuations. This ranges from simple autoregressive approaches to intricately specified micro-founded frameworks aimed at studying the impact of structural innovations on economic dynamics. Our paper adds to this growing strand of literature by using a unified modeling framework that combines a standard medium-scale dynamic stochastic general equilibrium model featuring an array of nominal and real frictions with an affine term structure of government bond yields. In contrast to the majority of the existing literature, we use our macro-finance framework to study the implications for the joint macroeconomic and financial dynamics not only of surprise structural disturbances but also of anticipated macroeconomic and policy announcements by introducing news about total factor productivity, investment specific technology and future shifts in the stance of monetary policy.

Our empirical investigation confirms the findings of other existing studies on the limited role played by news about total factor productivity and investment specific technology in the overall variability of the US macro-finance economy. In contrast, we uncover a non-trivial role for anticipated changes in monetary policy not only in the historical and variance decomposition of real economic variables but also in the overall dynamic behavior of the term structure of interest rates. In particular, we identify monetary policy foresight to be the most important stochastic driver of the slope of the government bond yield curve. In addition, the micro-founded propagation channels implied by our modeling environment allow us to uncover substantial qualitative differences in the dynamic responses of the macroeconomy and the bond yield term structure to anticipated and surprise structural and policy innovations.

We complete our analysis by examining the effect of the exact form of monetary policy conduct on the dynamic responses of the macroeconomy and the yield curve to anticipated news and policy foresight. In particular, we study the role of differing degrees of central bank inflation targeting and gradualism in interest rate setting.

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Table A.1
Estimated model parameters

		Prior distribution			Post. distribution		
	Description	Distr.	Mean	Std.	Mean	10%	90%
σ_c	Intertemporal elasticity	Normal	1.50	0.10	1.07	0.97	1.17
σ_l	Labor elasticity	Normal	2.00	0.10	1.94	1.78	2.11
h	External habit	Beta	0.70	0.10	0.57	0.51	0.63
ψ	Capital utilization rate	Beta	0.50	0.15	0.62	0.48	0.75
Φ	Capital adjustment cost	Normal	5.00	0.20	5.05	4.75	5.34
ϕ_p	Fixed cost share	Normal	1.25	0.10	1.57	1.47	1.66
ξ_p	Calvo prices	Beta	0.50	0.10	0.60	0.55	0.64
ξ_w	Calvo wages	Beta	0.50	0.10	0.80	0.77	0.83
ι_p	Price indexation	Beta	0.50	0.15	0.29	0.20	0.36
ι_w	Wage indexation	Beta	0.50	0.15	0.62	0.46	0.76
ρ_R	Interest rate smoothing	Beta	0.75	0.10	0.86	0.83	0.90
ϕ_π	Inflation targeting	Normal	1.50	0.50	2.36	1.86	2.94
ϕ_y	Output targeting	Beta	0.15	0.10	0.02	0.00	0.03
$\phi_{\Delta y}$	Output growth targeting	Beta	0.15	0.10	0.35	0.25	0.45
$\bar{\pi}$	Steady-state inflation	Gamma	0.62	0.10	0.78	0.71	0.85
γ	Technology growth trend	Normal	0.40	0.10	0.45	0.42	0.48
$\bar{\beta}$	Rate of time preference	Gamma	0.25	0.10	0.32	0.27	0.38
$\bar{l}$	Steady-state labor	Normal	0.00	2.00	-0.32	-2.09	1.40
μ_p	MA price markup	Beta	0.50	0.20	0.95	0.93	0.96
μ_w	MA wage markup	Beta	0.50	0.20	0.98	0.98	0.99
ρ_{ga}	Correlation component	Normal	0.50	0.25	0.54	0.42	0.70
ρ_a	Technology	Beta	0.50	0.20	0.94	0.92	0.96
ρ_b	Investment	Beta	0.50	0.20	0.25	0.14	0.36
ρ_g	Government spending	Beta	0.50	0.20	0.93	0.92	0.95
ρ_I	Investment	Beta	0.50	0.20	0.51	0.44	0.58
ρ_ε	Monetary policy	Beta	0.50	0.20	0.33	0.18	0.48
ρ_p	Price markup	Beta	0.50	0.20	0.99	0.99	0.99
ρ_w	Wage markup	Beta	0.50	0.20	0.99	0.99	0.99
$\rho_{\bar{\pi}}$	Inflation target	Beta	0.50	0.20	0.99	0.98	0.99

Note: The posterior distributions are obtained after two chains of 500.000 Monte Carlo draws.

Table A.2
Estimated standard deviations of shocks

		Prior distribution			Post. distribution		
	Description	Distr.	Mean	Std.	Mean	10%	90%
σ_b	Preference	InvGamma	0.50	2.00	0.24	0.19	0.28
σ_I	Investment	InvGamma	0.50	2.00	0.61	0.50	0.72
σ_a	Technology	InvGamma	0.50	2.00	0.36	0.31	0.41
σ_g	Government spending	InvGamma	0.50	2.00	0.55	0.49	0.61
σ_p	Price markup	InvGamma	0.50	2.00	0.25	0.22	0.28
σ_w	Wage markup	InvGamma	0.50	2.00	0.34	0.30	0.37
σ_ε	Monetary policy	InvGamma	0.50	2.00	0.25	0.22	0.28
$\sigma_{\bar{\pi}}$	Inflation target	InvGamma	0.10	2.00	0.13	0.11	0.14
σ_{R_4}	1-year term premium	InvGamma	0.10	2.00	0.02	0.01	0.02
$\sigma_{R_{12}}$	3-years term premium	InvGamma	0.10	2.00	0.01	0.01	0.01
$\sigma_{R_{20}}$	5-years term premium	InvGamma	0.10	2.00	0.01	0.01	0.01
$\sigma_{R_{40}}$	10-years term premium	InvGamma	0.10	2.00	0.02	0.01	0.02
σ_a^1	Technology news 1qt ahead	InvGamma	0.20	2.00	0.08	0.05	0.12
σ_a^2	Technology news 2qt ahead	InvGamma	0.20	2.00	0.10	0.05	0.15
σ_a^3	Technology news 3qt ahead	InvGamma	0.20	2.00	0.07	0.04	0.09
σ_a^4	Technology news 4qt ahead	InvGamma	0.20	2.00	0.07	0.04	0.10
σ_a^5	Technology news 5qt ahead	InvGamma	0.20	2.00	0.07	0.04	0.10
σ_a^6	Technology news 6qt ahead	InvGamma	0.20	2.00	0.08	0.05	0.12
σ_I^1	Investment news 1qt ahead	InvGamma	0.20	2.00	0.11	0.05	0.17
σ_I^2	Investment news 2qt ahead	InvGamma	0.20	2.00	0.10	0.05	0.16
σ_I^3	Investment news 3qt ahead	InvGamma	0.20	2.00	0.07	0.04	0.09
σ_I^4	Investment news 4qt ahead	InvGamma	0.20	2.00	0.08	0.04	0.11
σ_I^5	Investment news 5qt ahead	InvGamma	0.20	2.00	0.08	0.04	0.11
σ_I^6	Investment news 6qt ahead	InvGamma	0.20	2.00	0.21	0.16	0.26
σ_ε^1	Policy announcements 1qt ahead	InvGamma	0.20	2.00	0.06	0.04	0.08
σ_ε^2	Policy announcements 2qt ahead	InvGamma	0.20	2.00	0.14	0.10	0.18
σ_ε^3	Policy announcements 3qt ahead	InvGamma	0.20	2.00	0.06	0.04	0.07
σ_ε^4	Policy announcements 4qt ahead	InvGamma	0.20	2.00	0.05	0.04	0.07
σ_ε^5	Policy announcements 5qt ahead	InvGamma	0.20	2.00	0.05	0.04	0.07
σ_ε^6	Policy announcements 6qt ahead	InvGamma	0.20	2.00	0.09	0.07	0.11

Note: The posterior distributions are obtained after two chains of 500.000 Monte Carlo draws.

Table A.3
Estimated model parameters: Sub-sample estimation

		Prior distribution			Post. distribution		
	Description	Distr.	Mean	Std.	Mean	10%	90%
σ_c	Intertemporal elasticity	Normal	1.50	0.10	1.24	1.12	1.37
σ_l	Labor elasticity	Normal	2.00	0.10	1.90	1.76	2.05
h	External habit	Beta	0.70	0.10	0.64	0.56	0.73
ψ	Capital utilization rate	Beta	0.50	0.15	0.59	0.47	0.71
Φ	Capital adjustment cost	Normal	5.00	0.20	4.87	4.49	5.26
ϕ_p	Fixed cost share	Normal	1.25	0.10	1.61	1.50	1.71
ξ_p	Calvo prices	Beta	0.50	0.10	0.59	0.49	0.68
ξ_w	Calvo wages	Beta	0.50	0.10	0.65	0.56	0.72
ι_p	Price indexation	Beta	0.50	0.15	0.20	0.20	0.20
ι_w	Wage indexation	Beta	0.50	0.15	0.40	0.20	0.56
ρ_R	Interest rate smoothing	Beta	0.75	0.10	0.90	0.87	0.92
ϕ_π	Inflation targeting	Normal	1.50	0.50	2.43	2.01	2.88
ϕ_y	Output targeting	Beta	0.15	0.10	0.01	0.00	0.02
$\phi_{\Delta y}$	Output growth targeting	Beta	0.15	0.10	0.08	0.04	0.12
$\bar{\pi}$	Steady-state inflation	Gamma	0.62	0.10	0.65	0.55	0.75
γ	Technology growth trend	Normal	0.40	0.10	0.46	0.43	0.49
$\bar{\beta}$	Rate of time preference	Gamma	0.25	0.10	0.33	0.23	0.43
$\bar{l}$	Steady-state labor	Normal	0.00	2.00	-1.23	-2.89	0.11
μ_p	MA price markup	Beta	0.50	0.20	0.84	0.75	0.93
μ_w	MA wage markup	Beta	0.50	0.20	0.77	0.59	0.92
ρ_{ga}	Correlation component	Normal	0.50	0.25	0.49	0.32	0.70
ρ_a	Technology	Beta	0.50	0.20	0.86	0.82	0.91
ρ_b	Investment	Beta	0.50	0.20	0.25	0.10	0.39
ρ_g	Government spending	Beta	0.50	0.20	0.94	0.92	0.96
ρ_I	Investment	Beta	0.50	0.20	0.80	0.76	0.84
ρ_ε	Monetary policy	Beta	0.50	0.20	0.22	0.10	0.32
ρ_p	Price markup	Beta	0.50	0.20	0.99	0.99	0.99
ρ_w	Wage markup	Beta	0.50	0.20	0.98	0.96	0.99
$\rho_{\bar{\pi}}$	Inflation target	Beta	0.50	0.20	0.99	0.99	0.99

Note: The posterior distributions are obtained after two chains of 500.000 Monte Carlo draws.

Table A.4
Estimated standard deviations of shocks: Sub-sample estimation

		Prior distribution			Post. distribution		
	Description	Distr.	Mean	Std.	Mean	10%	90%
σ_b	Preference	InvGamma	0.50	2.00	0.21	0.16	0.26
σ_I	Investment	InvGamma	0.50	2.00	0.36	0.30	0.41
σ_a	Technology	InvGamma	0.50	2.00	0.28	0.21	0.34
σ_g	Government spending	InvGamma	0.50	2.00	0.48	0.42	0.55
σ_p	Price markup	InvGamma	0.50	2.00	0.21	0.18	0.24
σ_w	Wage markup	InvGamma	0.50	2.00	0.28	0.23	0.33
σ_ε	Monetary policy	InvGamma	0.50	2.00	0.12	0.10	0.14
$\sigma_{\bar{\pi}}$	Inflation target	InvGamma	0.10	2.00	0.09	0.08	0.10
σ_{R_4}	1-year term premium	InvGamma	0.10	2.00	0.02	0.01	0.02
$\sigma_{R_{12}}$	3-years term premium	InvGamma	0.10	2.00	0.01	0.01	0.01
$\sigma_{R_{20}}$	5-years term premium	InvGamma	0.10	2.00	0.01	0.01	0.01
$\sigma_{R_{40}}$	10-years term premium	InvGamma	0.10	2.00	0.02	0.01	0.02
σ_a^1	Technology news 1qt ahead	InvGamma	0.20	2.00	0.12	0.05	0.18
σ_a^2	Technology news 2qt ahead	InvGamma	0.20	2.00	0.12	0.05	0.19
σ_a^3	Technology news 3qt ahead	InvGamma	0.20	2.00	0.10	0.05	0.16
σ_a^4	Technology news 4qt ahead	InvGamma	0.20	2.00	0.09	0.05	0.13
σ_a^5	Technology news 5qt ahead	InvGamma	0.20	2.00	0.08	0.04	0.12
σ_a^6	Technology news 6qt ahead	InvGamma	0.20	2.00	0.09	0.04	0.13
σ_I^1	Investment news 1qt ahead	InvGamma	0.20	2.00	0.09	0.04	0.13
σ_I^2	Investment news 2qt ahead	InvGamma	0.20	2.00	0.09	0.04	0.13
σ_I^3	Investment news 3qt ahead	InvGamma	0.20	2.00	0.08	0.04	0.11
σ_I^4	Investment news 4qt ahead	InvGamma	0.20	2.00	0.09	0.04	0.13
σ_I^5	Investment news 5qt ahead	InvGamma	0.20	2.00	0.09	0.04	0.14
σ_I^6	Investment news 6qt ahead	InvGamma	0.20	2.00	0.16	0.11	0.22
σ_ε^1	Policy announcements 1qt ahead	InvGamma	0.20	2.00	0.05	0.03	0.07
σ_ε^2	Policy announcements 2qt ahead	InvGamma	0.20	2.00	0.06	0.04	0.07
σ_ε^3	Policy announcements 3qt ahead	InvGamma	0.20	2.00	0.05	0.04	0.07
σ_ε^4	Policy announcements 4qt ahead	InvGamma	0.20	2.00	0.04	0.03	0.05
σ_ε^5	Policy announcements 5qt ahead	InvGamma	0.20	2.00	0.04	0.03	0.05
σ_ε^6	Policy announcements 6qt ahead	InvGamma	0.20	2.00	0.04	0.03	0.06

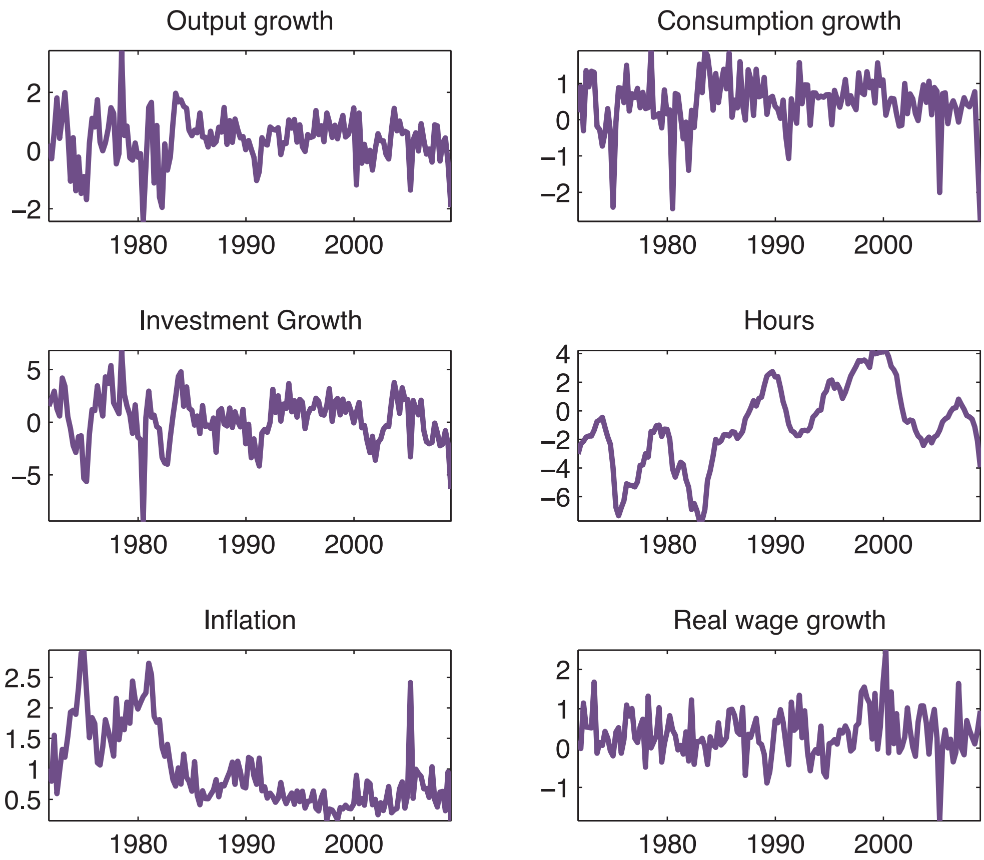
Note: The posterior distributions are obtained after two chains of 500.000 Monte Carlo draws.

Table A.5
Data and model-implied standard deviations

	Data	Model		Data	Model
Inflation	0.6415	0.7620	Federal Funds Rate	0.8682	0.7258
Investment growth	2.3271	2.3530	1 year yield	0.7438	0.6531
Hours	2.8126	2.3315	3 years yield	0.6903	0.5502
Output growth	0.8468	1.0604	5 years yield	0.6531	0.5009
Consumption growth	0.7454	0.7968	10 years yield	0.5956	0.4370

Note: Model-implied moments are obtained by using parameters and standard errors at the mean of the posterior distribution and are based on 500 simulations of time series of the same length as the data sample. 250 observations are drawn per simulation, the first 100 of which are discarded.

Figure A.1
Data plots: macro variables



Note: The observed real growth rates and the inflation rate are computed on a quarter-by-quarter basis.

Figure A.2
Data plots: bond yields

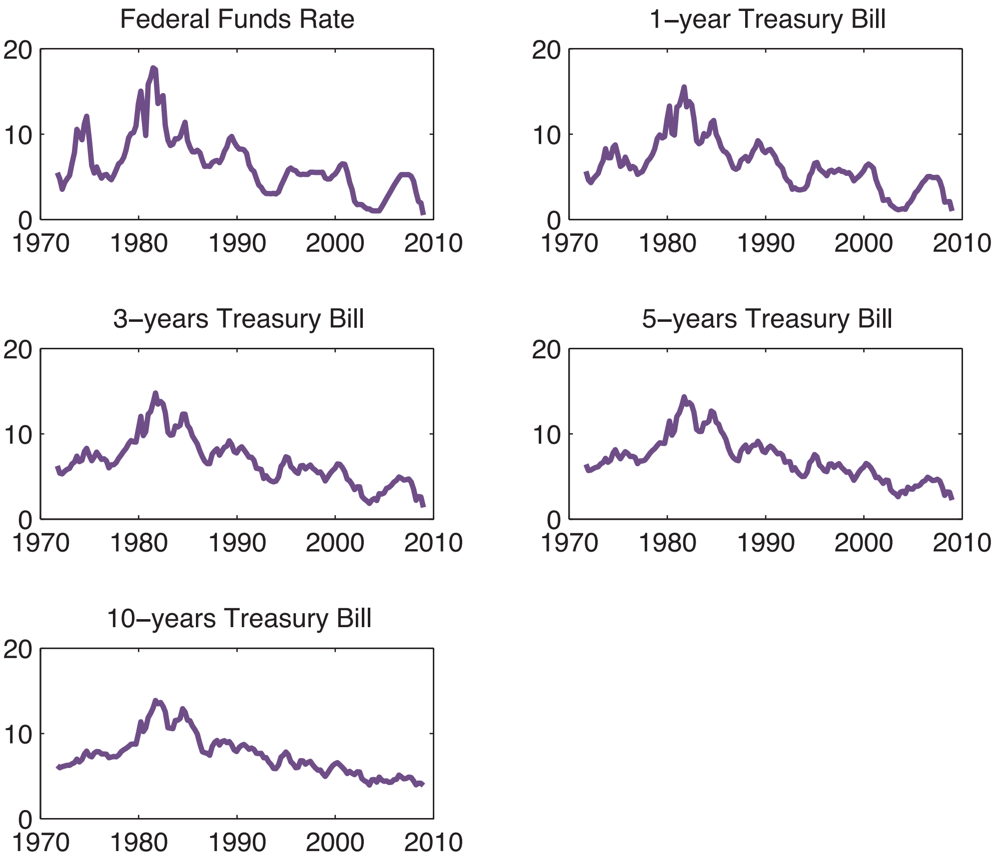


Figure A.3
Variance decomposition of the term spread

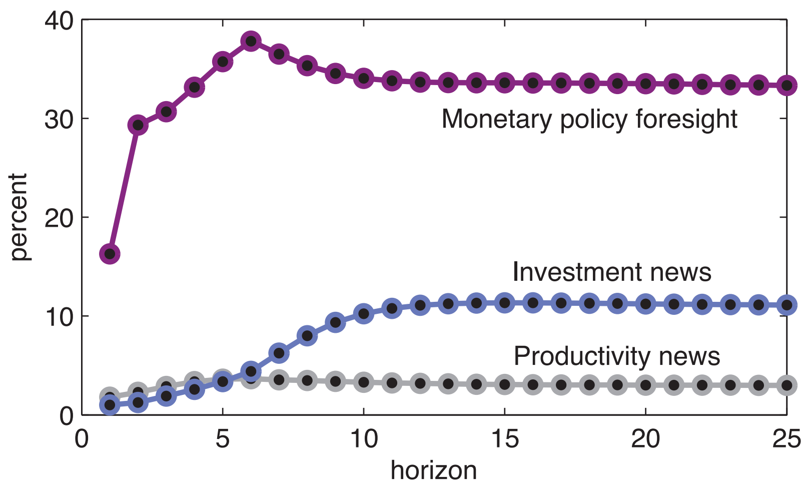
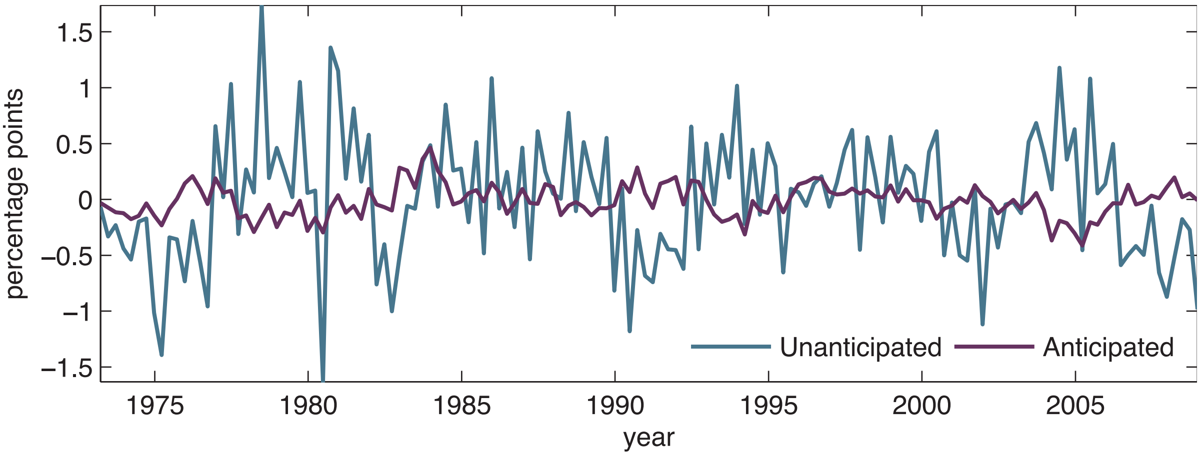
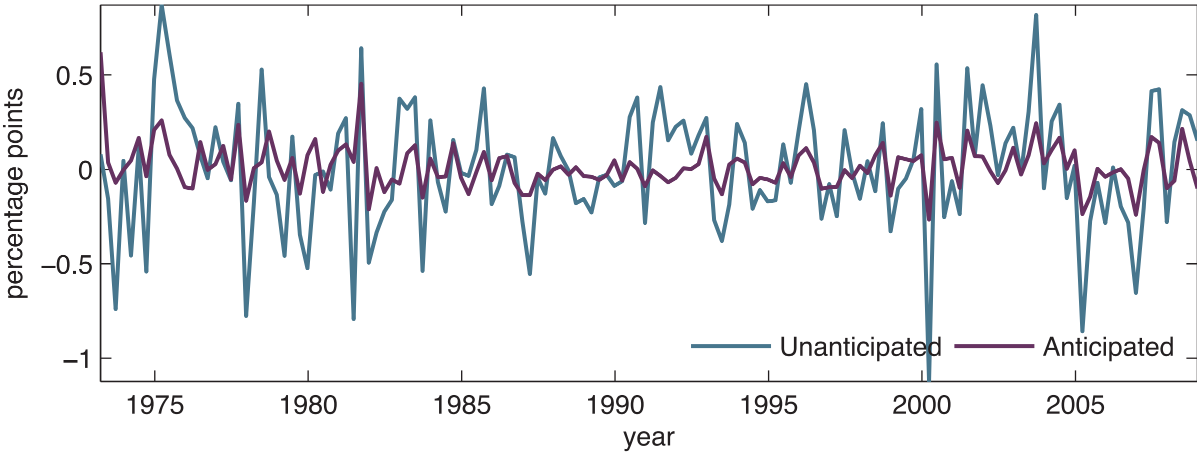


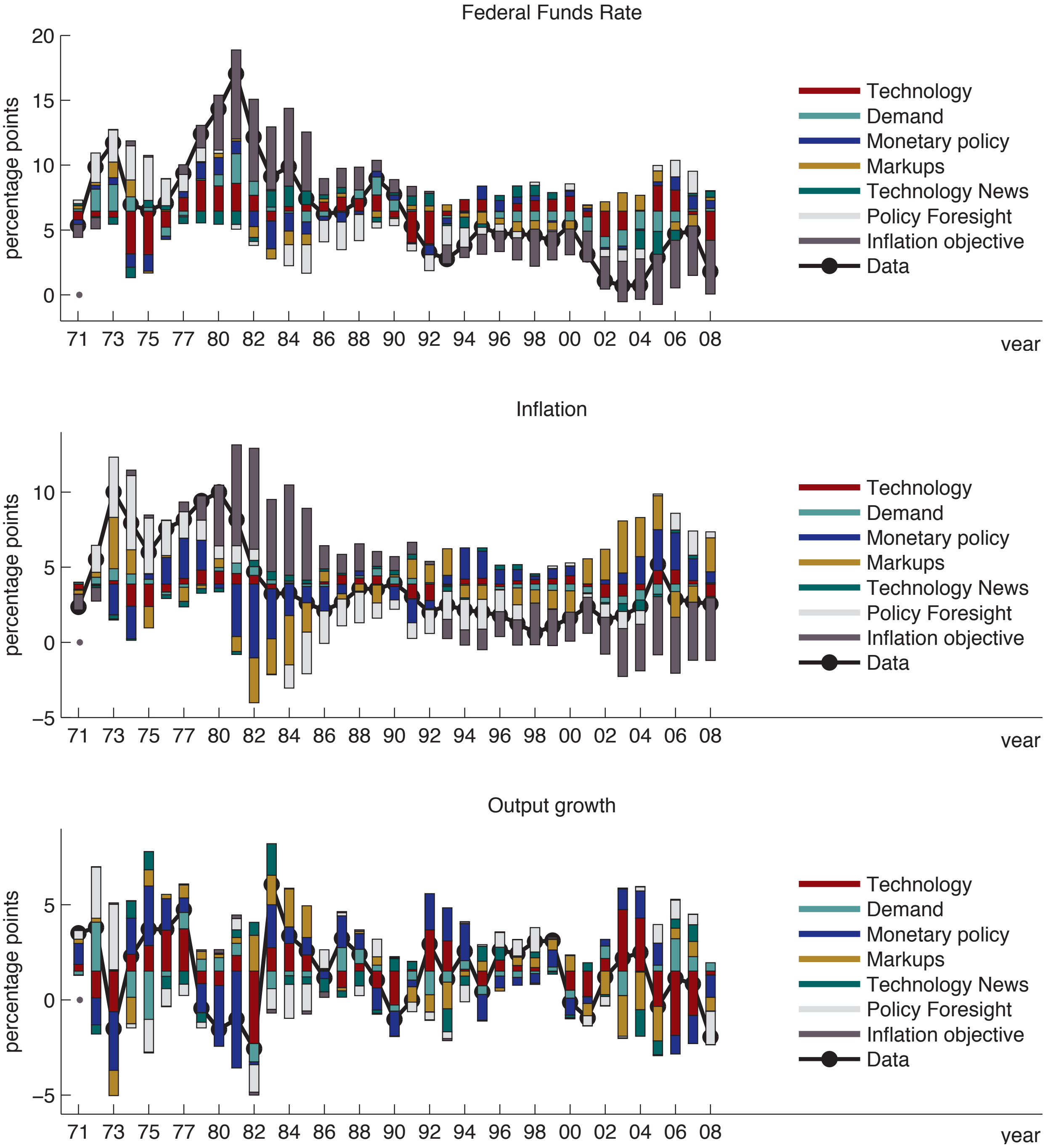
Figure A.4
Decomposition of technology shocks





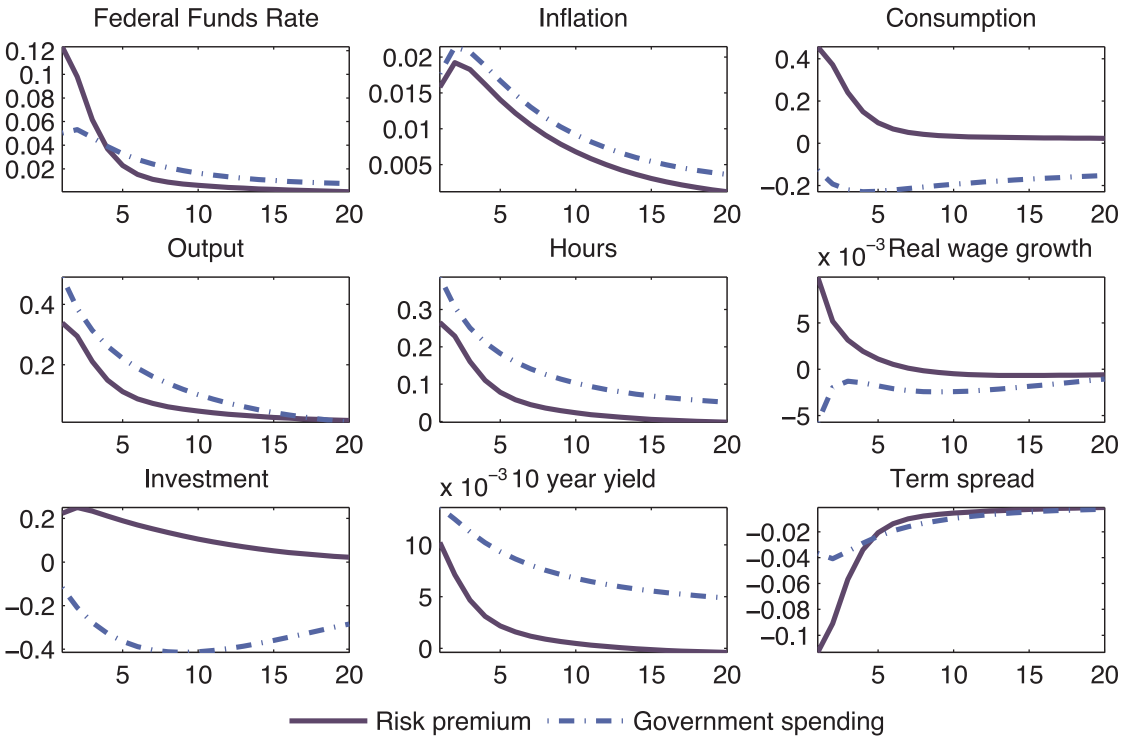
Note: The anticipated component corresponds to the sum of 1 up to 6 quarter ahead news.

Figure A.5
Historical decompositions



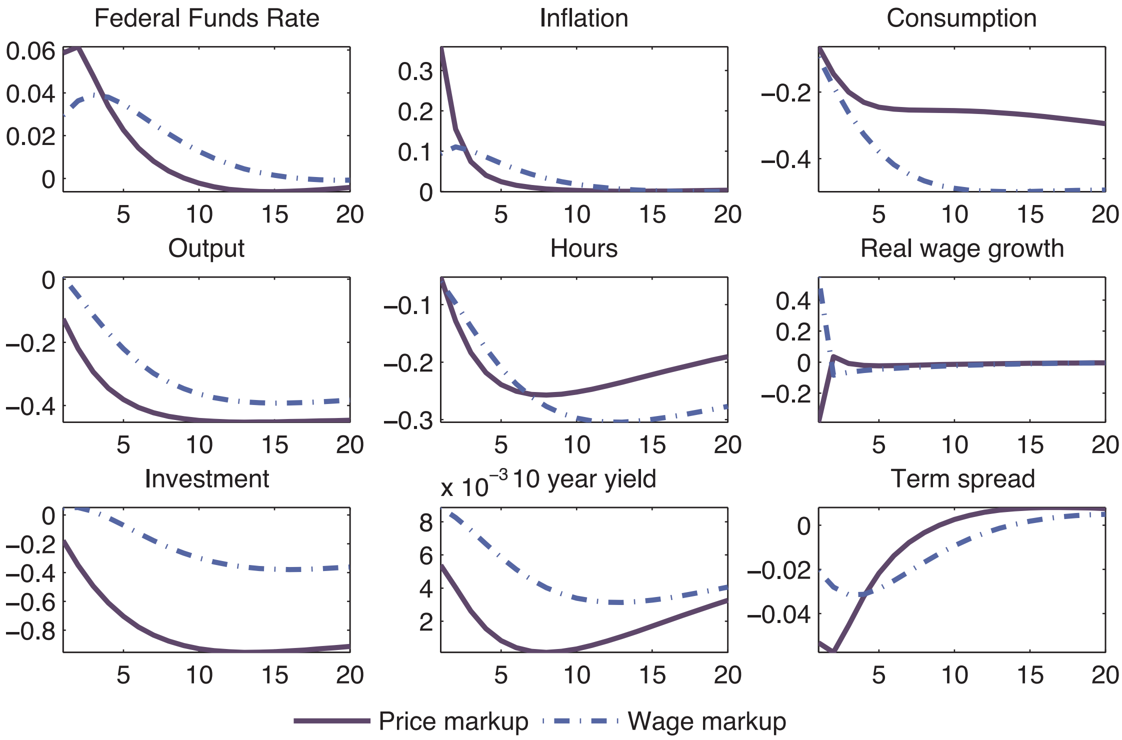
Note: Historical decompositions are computed at the posterior mean of the parameters. All variables are depicted in terms of annualized levels. The *Technology* component refers to the sum of productivity and investment-specific technology. The *Demand* component refers to the sum of government spending and risk premia.

Figure A.6
Impulse responses to demand shocks



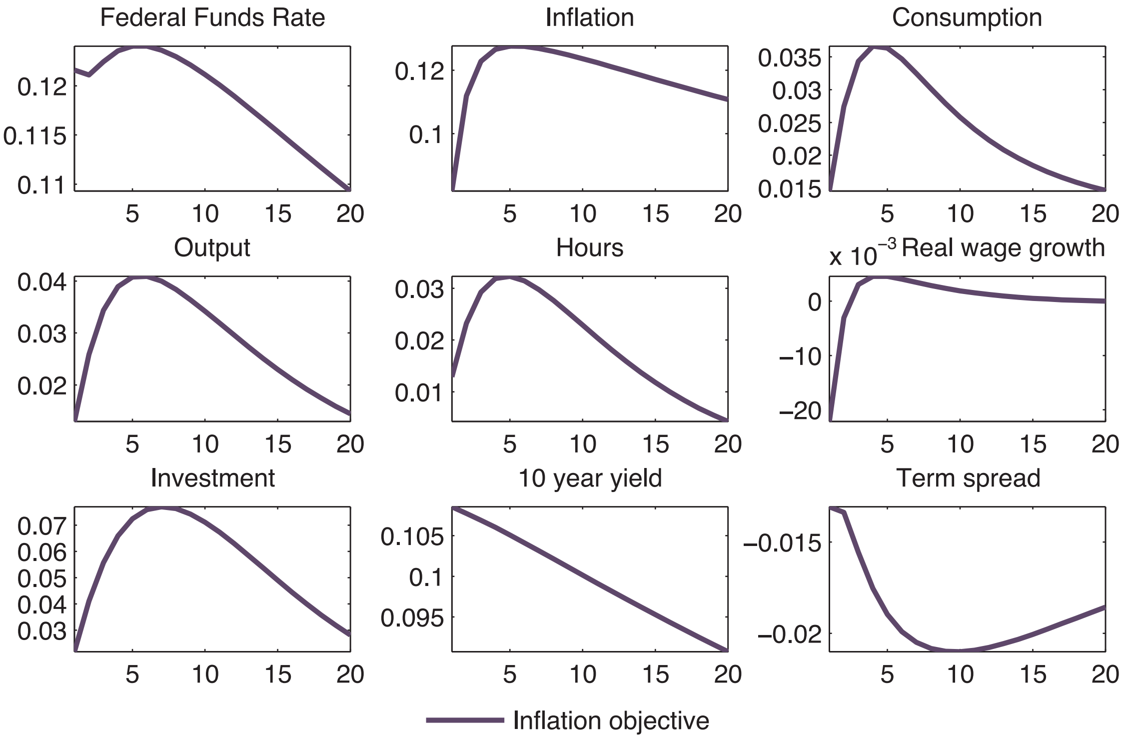
Note: The figure depicts impulse responses to positive one standard deviation innovations, computed at the posterior mean of the parameters.

Figure A.7
Impulse responses to markup shocks



Note: The figure depicts impulse responses to positive one standard deviation innovations, computed at the posterior mean of the parameters.

Figure A.8
Impulse responses to inflation objective shocks



Note: The figure depicts impulse responses to a positive one standard deviation innovation, computed at the posterior mean of the parameters.