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Expectations and Risk Premia at 8:30AM: Macroeconomic Announcements and the Yield Curve*

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Abstract

We investigate the movements of the yield curve after the release of major U.S. macroeconomic announcements through the lenses of an arbitrage-free dynamic term structure model with macroeconomic fundamentals. Combining estimated yield responses obtained using high-frequency data with model estimates using monthly data, we show that bond yields move after announcements mostly because of revisions to expectations about short-term interest rates. Changes in risk premia are also sizable, partly offset the effects of short-rate expectations and help to account for the hump-shaped pattern across maturities. Most announcement responses are due to changes in expectations about the output gap.

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1 Introduction

At exactly 8:30 AM Eastern Standard Time, on the first Friday of the month, the U.S. Employment Report is released. The world's government bond markets react strongly and swiftly. The price reaction is as strong as it ever gets in these markets, and it is over in a few minutes. Something similar happens at the release times of other scheduled U.S. macroeconomic announcements. These times are evidently the most important information events in the bond markets. While several studies have recorded how the yield curve reacts during these events, little is known about why it reacts the way it does.

The stylized facts of how the yield curve reacts are well established. Bond yields across the maturity spectrum and related derivative prices show pronounced movements around the release times of news related to macroeconomic variables (see, inter alia, Fleming and Remolona, 1997; 1999; 2001; Green, 2004; Andersen et al., 2008; Pasquariello and Vega, 2007; Beber and Brandt, 2009 and the references therein). The strength of bond yield reactions depends upon the type of announcements with the non-farm payrolls number in the U.S. Employment Report being the most important.[1] In investigating the impact of announcements on bonds of different maturities, studies report that the largest yield movements tend to cluster around the intermediate maturities, leading to a pronounced hump-shaped announcement reaction curve (Fleming and Remolona, 2001; Balduzzi et al. 2001; Faust et al., 2007; Jiang et al., 2011 and the references therein).[2]

What explains these reactions to macroeconomic news? Theory tells us that the yield curve moves at these times because the announcements lead to revisions in investors' expectations of the path of future interest rates and to reassessments of the risks about those expectations. But applying the theory begs two unresolved and important questions. First, what information about macroeconomic fundamentals is contained in the announcements? Second, how does this information affect risk premia? The first question arises from the fact that the announcements are typically not directly about inflation or the output gap, which are presumably the fundamental factors behind the rate-setting behavior of the U.S. Federal

[1] Other important announcements include the ISM/NAPM survey and the unemployment rate.

[2] Nonetheless, the reaction is quite strong even at long maturities, a fact emphasized by Gurkaynak *et al.* (2005). Other studies that focus on the impact of news on bond yields and return volatility across maturities are, among others, Roley and Walsh (1985), Cook and Hahn (1987), Jones *et al.* (1998).

Open Market Committee (FOMC). Investors would need to infer from the announcements what the implications are for inflation, the output gap and the reaction of the FOMC. If we can map the information content of various and heterogeneous announcements to these fundamental variables, we can understand how investors revise their expectations in light of new information.[3] The second question is similarly important, since risk premia explain a rather large part of yield movements in arbitrage-free models of the term structure. In fact, only by taking account of risk premia can movements of the yield curve be reconciled with the expectations hypothesis of the term structure of interest rates (EH henceforth) as reported in recent studies (see, inter alia, Dai and Singleton, 2002; Duffee, 2002 and the references therein). However, it is not yet understood what happens to these risk premia when macroeconomic news arrive and to what extent these premia are responsible for the hump-shaped yield reaction patterns.

In this paper, we address the two questions by combining an arbitrage-free dynamic term structure model with high-frequency estimates of yield changes around the release times of major U.S. macroeconomic announcements. To the best of our knowledge, this is the first time that a full-fledged term structure model with macroeconomic risk factors has been linked to yield movements that are purposely taken only from periods of such high signal-to-noise ratios. The term structure model we fit belongs to the general class of affine arbitrage-free models of the term structure but at its core lies a monetary policy reaction function driven by fundamental macroeconomic variables, namely inflation and the output gap, as well as the long-run inflation objective of the central bank. These variables also represent risk factors for the pricing of bonds.[4] The risk premia are derived from market prices of risk that are affine in the state variables (see, inter alia, Gürkaynak and Wright, 2012; Duffee, 2012 and the references therein). In order to improve the accuracy of the estimates of bond yield reactions to news, we rely on real-time data to focus on 20-minute windows around announcements times. Furthermore, we consider a broad menu of announcements which are

[3]Our choice of a small menu of macroeconomic risk factors is further supported by the evidence that very few risk factors affect the dynamics of bond prices around macroeconomic announcements (see, inter alia, Balduzzi and Moneta, 2012 and the references therein).

[4]As detailed in Section 2, the monetary policy rule also includes a monetary policy shock, which also constitutes a fourth pricing factor. As such, the model is similar to one used by Hördahl and Tristani (2014) to explain yield movements in the United States and in the euro area.

known to be the most important ones in the literature and among market participants.

The empirical analysis proceeds in three steps. In the first step, we estimate the effects of announcement news shocks on yields of six maturities along the yield curve using intraday yield data. In order to minimize the noise associated with the bond yield responses to individual macroeconomic news, we assign announcements to five groups related to (i) the labour market; (ii) production; (iii) prices; (iv) the housing market; and (v) consumer behaviour.[5] We then estimate the parameters of the term structure model using monthly time-series data. In the third step, we combine the results obtained from the first two steps in order to estimate, for each group of announcements, the parameters that link the announcement news shocks to each of the macroeconomic risk factors. This enables us to map announcement surprises to shocks to macroeconomic risk factors, which in turn lead to yield changes because of revisions of expected future short-term interest rates and risk premia.

We find a number of interesting results: First, our estimates show a clear distinction between announcements that are relevant to output expectations and announcements that are relevant to inflation expectations. Indeed, all groups of announcements, with the exception of the one related to prices, largely inform output expectations. The announcements related to the prices group are found to inform inflation expectations.

Second, changes in bond yields are caused mostly by revisions to the expected path of future short-term interest rates. Moreover, changes in risk premia are sizable but typically move in the opposite direction, thus partly offsetting the expectations effect on the yield curve. Hence, an announcement that surprises on the side of a stronger economy would lead to reduced risk premia even as the yield curve steepens.

Third, the strength of the expected short-rate's yield effect relative to that of the risk premia changes with the maturity of bond yields. While at very short maturities, the two effects reinforce each other, the risk premia effect becomes relatively stronger at longer maturities. This finding help explaining the common hump-shaped pattern of yield curve reactions to macroeconomic news. In general, these movements in risk premia corroborate and shed further light on the well-known lack of empirical support for the EH.

[5]The formation of groups to reduce the noise associated with individual entities is similar in spirit and consistent with the conventional practice of portfolio construction routinely carried out in the asset pricing literature (see Fama and MacBeth, 1973).

Related literature Our study brings together two major strands of the literature on bond markets. The first strand is on the high-frequency reaction of bond yields to macroeconomic announcements (see, inter alia, Fleming and Remolona, 1997; 1999; 2001; Balduzzi et al. 2001; Green, 2004; Andersen et al., 2007; Pasquariello and Vega, 2007; Faust et al., 2007; Jiang et al. 2011). In this literature several aspects of bond markets are investigated around announcement times with special reference to volatility, trading and information dissemination and acquisition. The recurring theme is that the behavior of bond yields is best captured using data at the highest possible frequency, in some cases tick-by-tick. The second strand of the literature deals with modelling yield curves with arbitrage-free affine models that incorporate macroeconomic variables as risk factors (see, inter alia, Ang and Piazzesi, 2003; Bernanke et al. 2004; Diebold et al., 2006; Hördahl et al., 2006; Dewachter and Lyrio, 2006; Rudebusch and Wu, 2008; Bekaert et al., 2010). The aim of these studies is to explain the movements of the yield curve and reconcile them with macroeconomic models and investor preferences. Despite the intuitive appeal of this framework, some empirical studies have suggested that models of the kind used in this paper may impose overly strong restrictions on the joint distribution of bond yields and the macroeconomic risk factors (Joslin et al., 2014). Although term structure models based on yield-only factors provide a more parsimonious representation of the essential features of the term structure of bond yields, they offer little insight into the economic forces that drive the changes of interest rates. The main goal of this paper is to link changes in bond yields, associated with the arrival of new information about macroeconomic variables, to revision of investors' expectations and changes in risk premia. Hence, we prefer to trade off model parsimony, at the expenses of a potentially less-then-perfect fit of bond yields or factor dynamics, for the possibility of addressing this important question.[6] In addition, recent studies have shown that the restrictions imposed by models where the information in the macro variables is not captured by contemporaneous yields are statistically rejected and, most importantly, the risk premia generated by term structure model with macroeconomic factors are essentially identical to the ones implied by yield-only term structure models (Bauer and Rudebusch, 2015). It is important to emphasize

[6] As discussed in Section 4.2, our term-structure model is, in fact, able to capture, over the sample period explored in this study, the main time-series features of both bond yields *and* the macroeconomic risk factors.

that our major goal is to understand why bond yields change at announcement times and interpret our findings in terms of changes in risk premia and revisions of expectations about future short-term interest rates. This analysis would not be feasible if we limited ourselves to the framework of either one of the two strands of the literature.

Our study is closely related to those of Faust and Wright (2012) and Bansal and Shaliastovich (2012) and Kim and Wright (2014) who explore bond risk premia from similar perspectives. More specifically, Faust and Wright (2012) look at the predictability of bond risk premia and decompose the predictable returns into those earned in short windows around macroeconomic announcements (most of which are released at 8:30AM) and the predictable returns that are earned at other times. They find that the predictability of returns is due largely to price movements around news announcements and they propose a trading strategy that takes position in bonds only around news announcements.[7] Bansal and Shaliastovich (2012) investigate the predictability of bond (and foreign exchange) risk premia and propose a long-run risk model that associates risk premia with the volatilities of inflation and output-gap. Kim and Wright (2014) propose a no-arbitrage term structure model with jumps in which jump risk premia are allowed for. The authors find that their model can match the main stylized facts of the term structure of US rates and record that interest rate volatility exhibits a hump-shaped pattern on employment report dates. Our analysis differs from these studies in various respects: First, we do not focus on the predictability of bond risk premia. Second, we look at high-frequency responses of bond yields to a broad set of macroeconomic announcements and relate them to the revisions of expectations and risk premia in a arbitrage-free affine model with macroeconomic risk factors. Third, we directly explore high-frequency movements of bond yields that occur in periods of information events with the highest signal-to-noise ratios.

Our paper is also related to the recent studies by Lu and Wu (2009), Goldberg and Grisse (2013) and Gilchrist et al. (2015) which explore the fundamental relation between numerous macroeconomic releases and asset prices. Lu and Wu (2009) extract two systematic economic factors from a wide array of noisy and sparsely observed macroeconomic releases and find

[7] Balduzzi and Moneta (2012) also use intra-day returns from bond futures to precisely estimate the composition of portfolios mimicking the most important scheduled U.S. macro news. Their findings are supportive of a single latent factor driving returns around announcement times.

that the two factors predict more than 77 percent of the daily variation in LIBOR and swap rates from one-month to 10-years maturities. Our investigation also differs from this study in that our term-structure model directly incorporates macroeconomic risk factors (and their dynamics) instead of assuming that they are latent and estimated from a cross-section of various announcements. Furthermore, our announcement analysis is carried out at a very high frequency in order to improve the precision of the parameter estimates and aims at explaining only bond yield movements that occur at announcement times. Goldberg and Grisse (2013) document the time variation in the responses of the yield curve to macroeconomic announcements and find that it is explained by economic and risk conditions. Gilchrist et al. (2015) compares the impact of conventional and unconventional US monetary policy shocks on international bond yields. We build upon and improve those findings by using bond yields data sampled at a high frequency for a more accurate estimation of the yield curve response to various announcement shocks and, most importantly, we link the actual movements in bond yields with a full-fledged term-structure model for a better understanding of the main drivers of the observed yield changes.

The remainder of the paper is as follows: Sections 2 and 3 introduce the term structure model, discuss how it is adjusted to capture announcement effects and detail the empirical framework. Section 4 describes the data used in this study and reports the main empirical results. Section 5 discusses various robustness checks and a final section concludes.

2 A Macro-Finance Model of the US Term Structure with Announcement Data

We propose a model that explicitly links the term structure of interest rates to macroeconomic factors to provide some interpretation of the yield curve announcement effects in terms of macroeconomic fundamentals. We achieve this goal by employing a variant of the model used by Hördahl and Tristani (2014) to explain movements in US Treasury yields in which bond prices are determined by the underlying macroeconomic environment and investors' risk characteristics.[8] The remainder of this section describes in detail the features of the

[8] See also Hördahl *et al.* (2006) and Ang and Piazzesi (2003).

model.

2.1 The Macroeconomy

The modelling approach adopted in this section is consistent with a New Keynesian framework. The model includes two equations describing the evolution of inflation, π_t, and the output gap, x_t, as follows:

$$\pi_t = \mu_\pi E_t [\pi_{t+1}] + (1 - \mu_\pi) \pi_{t-1} + \delta_x x_t + \varepsilon_t^\pi, \tag{1}$$
$$x_t = \mu_x E_t [x_{t+1}] + (1 - \mu_x) x_{t-1} - \zeta_r (r_t - E_t [\pi_{t+1}]) + \varepsilon_t^x, \tag{2}$$

with ε_t^π and ε_t^x denoting respectively supply and demand shocks which are assumed to be normally distributed with zero means and with variances equal to σ_π^2 and σ_x^2, respectively:

$$\begin{aligned} \varepsilon_t^\pi &= \phi_\pi \varepsilon_{t-1}^\pi + \upsilon_t^\pi, \\ \varepsilon_t^x &= \phi_x \varepsilon_{t-1}^x + \upsilon_t^x, \end{aligned}$$

and where r_t is the short-term nominal interest rate. Although this setup is quite simple, it nevertheless incorporates a number of standard channels of transmission of macroeconomic shocks and monetary policy.[9] To close the model, it is assumed that agents' perceptions of the Federal Reserve's behavior can be described by the following monetary policy rule:

$$r_t = (1 - \rho) \{\beta (\pi_t - \pi_t^*) + \gamma x_t\} + \rho r_{t-1} + \eta_t \tag{3}$$

where π_t^* is the perceived inflation target and where η_t is a monetary policy shock that is serially uncorrelated and normally distributed with zero mean and variance equal to σ_η^2. The perceived inflation target is assumed to follow the dynamics

$$\pi_t^* = \phi_{\pi^*} \pi_{t-1}^* + \varepsilon_t^{\pi^*},$$

with uncorrelated $\varepsilon_t^{\pi^*} \sim N(0, \sigma_{\pi^*}^2)$ .The inflation target is an unobservable variable that can be understood as the perceived target that investors have in mind when pricing bonds, as

[9] For example, inflation can increase because of demand shocks that raises output above potential and create excess demand, or because of supply shocks (such as cost-push shocks) that directly impact prices. The central bank can counteract unwanted movements in inflation due to shocks by changing the short-term interest rate, thereby stimulating or restricting aggregate demand.

it is jointly estimated as part of a system that includes bond yields across a wide range of maturities. Equation (3) is a variant of the Taylor (1993) rule, where the policy rate responds to deviations of inflation from the inflation target and to the output gap. The policy rule also allows for interest rate smoothing, which seems to be an important feature of actual interest rate data.

In order to solve for the rational expectations equilibrium, the model is written in state-space form and solved using standard numerical methods (Hördahl et al., 2006 and the references therein).[10] As part of the solution, we obtain the law of motion of the state variables, denoted $\mathbf{Z}_t$,

$$\mathbf{Z}_t = \mathbf{M}\mathbf{Z}_{t-1} + \Sigma\boldsymbol{\xi}_t, \tag{4}$$

where $\mathbf{Z}_t = [x_{t-1}, \pi_{t-1}, \pi_t^*, \eta_t, \varepsilon_t^\pi, \varepsilon_t^x, r_{t-1}]'$, $\mathbf{M}$ is a 7×7 matrix of parameters and $\boldsymbol{\xi}_t$ is a 7×1 vector of normal, serially and mutually uncorrelated, error terms. We also obtain an equation for the levels of the observable macroeconomic factors, $\mathbf{X}_t = [x_t, \pi_t]'$ in terms of $\mathbf{Z}_t$,

$$\mathbf{X}_t = \mathbf{C}\mathbf{Z}_t, \tag{5}$$

and for the short-term interest rate as a function of the state variables,[11]

$$r_t = \boldsymbol{\Delta}'\mathbf{Z}_t. \tag{6}$$

2.2 The Term Structure

Equations (4) and (6) define that the state vector follows a first-order VAR and the short-term interest rate is a linear function of the state vector $\mathbf{Z}_t$, respectively. As a result, the closed-form bond-pricing solutions can be easily obtained in line with the vast literature on affine models of the term structure of interest rates.[12] First, we need to impose the assumption of absence of arbitrage opportunities and specify a process for the stochastic

[10] In particular, we use the methodology based on the Schur decomposition (Söderlind, 1999).

[11] Full model details are reported in the Appendix.

[12] However, standard affine models are typically based on unobservable state variables, and both the short-rate equation and the law of motion of the state variables are postulated exogenously. On the other hand, in our framework, the state variables are macroeconomic factors, and their law of motion as well as the short rate equation are obtained endogenously as functions of the parameters of the underlying structural macroeconomic model.

discount factor. We choose a standard specification for the stochastic discount factor (with a log-normal Radon-Nikodym derivative), and assume that the market prices of risk λ_t are affine in the state vector (Duffee, 2002)[13]

$$\lambda_t = \lambda_0 + \lambda_1 \mathbf{Z}_t. \tag{7}$$

Given this setup, the continuously compounded yield y_t^n on a zero coupon bond with maturity $n = 1, .., m$ can be written as an affine function of the state vector as follows:

$$y_t^{(n)} = A_n + B_n' \mathbf{Z}_t, \tag{8}$$

where the A_n and B_n' matrices can be derived using recursive relations.[14].

2.3 Adjusting the Model to Capture Announcement Effects

We map announcement surprises to the macroeconomic risk factors and the yields in the model described in the following fashion. We first estimate the parameters of the model described above and assume that these correspond to the values that investors have in mind when making economic decisions. As an announcement relative to a macroeconomic variable j is made at time t, the unanticipated shock $S_{j,t}$, computed as the difference between announcement realization and their corresponding forecasts, will induce investors to instantaneously update their perceptions about the state of the economy, and therefore also their forecasts about the relevant macroeconomic variables, and consequently adjust their pricing of bonds across the entire maturity spectrum. Yields can move because new information

[13] A microfounded stochastic discount factor is not exploited in this study because the term structure model is specified at the aggregate level, without any explicit assumptions on its microfoundations. While this leaves us unable to directly link prices of risk and risk premia to individuals' preferences, it provides added flexibility to capture important features of the data. The stochastic discount factor m_{t+1} is defined as $m_{t+1} = \exp(-r_t)\,\psi_{t+1}/\psi_t$, where ψ_{t+1} is the Radon-Nikodym derivative assumed to follow the log-normal process $\psi_{t+1} = \psi_t \exp\left(-\frac{1}{2}\lambda_t'\lambda_t - \lambda_t' \boldsymbol{\xi}_{1,t+1}\right)$. See Hördahl *et al.* (2006) for further details.

[14] In particular, defining $\bar{A}_n \equiv -nA_n$ and $\bar{B}_n' \equiv -nB_n'$, we can write

$$\bar{A}_{n+1} = \bar{A}_n - \bar{B}_n'\Sigma\lambda_0 + \tfrac{1}{2}\bar{B}_n'\Sigma\Sigma'\bar{B}_n,$$
$$\bar{B}_{n+1}' = \bar{B}_n'(\mathbf{M} - \Sigma\lambda_1) - \Delta',$$

with initial conditions $\bar{A}_1 = 0$ (the short rate mean is subtracted from all yields initially) and $\bar{B}_1' = -\Delta'$. Full details are reported in the Appendix.

leads investors to update their perceptions about the future path of the short-term interest rate, but also because of shifts in risk premia.

In order to capture the effects of announcements on bond yields, we treat the announcement surprises as sources of shocks to the macroeconomic risk factors. At a specific announcement release time t, macroeconomic risk factor i will be shocked by $u_{i,t}$, as the surprise $S_{j,t}$ corresponding to the macroeconomic variable j is made public. For example, the output gap factor (x) will move by $u_{x,t}$ as a non-farm payrolls (NFP) surprise of size $S_{NFP,t}$ is released at time t, and so on. In general, several announcements may be relevant for all, or some, of the macroeconomic risk factors. We can gauge the impact on macroeconomic risk factor i from a shock $S_{j,t}$ to the macroeconomic variable j by estimating the factor's sensitivity parameter α_{ij} to such a shock, [15]

$$u_{i,t} = \alpha_{ij} S_{j,t}. \tag{9}$$

The model yield expression in (8) implies that the change in the yield of an n-period bond over a short intraday time interval h that spans an announcement is given by[16]

$$\Delta y_{j,t}^{(n)} = B_n' \Delta \mathbf{Z}_{j,t+h}, \tag{10}$$

where $\Delta y_{j,t}^{(n)} = y_{j,t+h}^{(n)} - y_t^{(n)}$ is the observed yield change of maturity n associated with announcement surprise j. It is important to emphasize that $\Delta \mathbf{Z}_{j,t+h} = \mathbf{Z}_{j,t+h} - \mathbf{Z}_t$ contains the shocks $u_{i,t}$ for each macroeconomic risk factor due to the announcement surprise $S_{j,t}$, hence equation (10) can be written as

$$\Delta y_{j,t}^{(n)} = B_n' \alpha_j S_{j,t}, \tag{11}$$

where α_j is a vector containing the sensitivity parameters linking any of the macroeconomic risk factors to the shocks affecting the macroeconomic variable j.

[15] In our empirical investigation, we consider the responses of three macro factors: inflation, the output gap, and the perceived inflation target. Since our data set does not include monetary policy announcements, we restrict the responses so that the monetary policy shock is unaffected by all macro announcements. This also helps us reduce the number of parameters to be estimated, which is already sizeable given the number of announcement types we consider.

[16] We consider h to be negligible compared to n, so that we can set $B_n = B_{n-h}$.

3 The Empirical Framework

We obtain estimates of the key parameters discussed in Section 2 in three steps. In the first step, we estimate the responses of bond yields to macroeconomic announcement shocks using high-frequency data as in Fleming and Remolona (2001). In the second step, we separately estimate the term structure model, described by equations (1)-(8), by adopting the maximum likelihood (ML) methodology and using a monthly set of data. In the third step, we combine the two set of estimates to obtain the factor sensitivity parameters α_j defined in (9). In what follows, we discuss the details of the empirical framework adopted in each of the three steps.

3.1 Step 1: Bond Yield Responses to Announcement Shocks

We estimate the responses of bond yields to macroeconomic announcement shocks by replicating the procedure introduced by Fleming and Remolona (2001). More specifically, we define the macroeconomic announcement shock j at time t, $S_{j,t}$, as the difference between announcement realization, $A_{j,t}$ and its corresponding prevailing forecast, $F_{j,t}$. Since all macroeconomic announcement shocks are expressed in different measurement units, we follow the existing literature and standardize by dividing each of the shocks by their sample standard deviation, σ_j (see, inter alia, Andersen et al. 2003; Pasquariello and Vega, 2007 and the references therein):

$$S_{j,t} = \frac{A_{j,t} - F_{j,t}}{\sigma_j}. \tag{12}$$

In order to minimize the noise associated with the bond yield response to individual announcement news, we assign the individual macroeconomic announcements to five groups made up of two or three announcements that are likely to have similar informational content with respect to underlying macroeconomic broad group.[17] Hence, "announcement j" should be understood as "announcement group j". We then estimate the impact of macroeconomic announcement shocks for each group on bond yields with the following regression:

$$\Delta y_{j,t}^{(n)} = \phi_j^{(n)} S_{j,t} + e_{j,t}^{(n)}, \tag{13}$$

[17] For example, we group CPI and PPI inflation announcements into one category that can be viewed as being informative about overall inflationary pressures in the economy. The exact construction of the announcement groups is explained in detail in Section 4.1.

where $\Delta y_{j,t}^{(n)}$ denotes the 20-minutes changes in bond yields with maturity n computed on the dates when macroeconomic variable j announcements are released, $\phi_j^{(n)}$ are maturity-specific reaction parameters and $e_{j,t}^{(n)}$ is a zero-mean, serially uncorrelated error term.[18]

3.2 Step 2: Term Structure Model

We estimate the term structure model presented in Section 2 by ML, and we construct the likelihood function using a Kalman filter methodology. To implement the ML estimation of the model, we first define a vector $\mathbf{W}_t$ containing the observable contemporaneous variables,

$$\mathbf{W}_t \equiv \begin{bmatrix} \mathbf{Y}_t \\ \mathbf{X}_t \end{bmatrix},$$

where $\mathbf{Y}_t = \left[y_t^{(1)}, ..., y_t^{(m)} \right]'$ is the $m \times 1$ vector of zero-coupon yields and $\mathbf{X}_t = [x_t, \pi_t]'$ is a 2×1 vector containing the two macroeconomic fundamentals. We define the observation equation as

$$\begin{aligned} \mathbf{W}_t &= \begin{bmatrix} \mathbf{A} \\ \mathbf{0} \end{bmatrix} + \begin{bmatrix} \mathbf{B} \\ \mathbf{C} \end{bmatrix} \mathbf{Z}_t \\ &\equiv \mathbf{K} + \mathbf{H}'\mathbf{Z}_t, \end{aligned}$$

and the state equation as

$$\mathbf{Z}_t = \mathbf{M}\mathbf{Z}_{t-1} + \mathbf{v}_t.$$

By introducing a vector of measurement errors corresponding to the observable variables $\mathbf{W}_t$, and making assumptions about their covariances, we can express the log-likelihood function based on the forecasts of the states and the associated Mean Square Errors (MSE) that are generated by the Kalman filter (see Hördahl and Tristani, 2014). The full specification of the model is reported, to save space, in the Appendix.

3.3 Step 3: Factor Sensitivity Parameters

In the third step, we estimate the factor sensitivity parameters α_j in equation (9) by combining the model-based bond yield responses in equation (11) with the actual yield responses

[18] In the empirical analysis we have also estimated equation (13) with an intercept term. The results, not reported to save space, are qualitatively and quantitatively similar to the ones reported in the subsequent Section 4.

in equation (13) to obtain[19]

$$\phi_j^{(n)} S_{j,t} = B_n' \alpha_j S_{j,t}$$

for announcement group j and bond maturity n, which can be rewritten as

$$\phi_j^{(n)} = B_n' \alpha_j. \tag{14}$$

Stacking the yield responses to announcement group j for all maturities into an $m \times 1$ vector $\Phi_j = \left[\phi_j^{(1)}, ..., \phi_j^{(m)}\right]'$, and the macroeconomic risk factor loadings for the same maturities into a $m \times 2$ matrix $\mathbf{B}$, we have that

$$\Phi_j = \mathbf{B}' \alpha_j + \varepsilon_j. \tag{15}$$

where ε_j is a cross-sectionally uncorrelated error term. Hence, we estimate α_j by regressing the yield responses Φ_j from the announcement analysis on the loadings $\mathbf{B}$ that are obtained from the estimation of the term structure model.

Equation (15) presents an empirical challenge. In fact, it cannot be estimated using conventional least square estimators since both regressor and regressand are obtained from prior estimations, and are therefore measured with sampling error. Although several methods have been proposed in the literature to take into account these type of biases (see, *inter alia*, Pagan, 1984 and Murphy and Topel, 1985, Lewis and Linzer, 2005, Dumont et al., 2005 and the references therein), equation (15) is particularly challenging since i) both generated regressor and regressand are included in the estimation and ii) the complexity of the first-step estimations, especially with regards to **B,** does not allow for an easy applicability of the corrections suggested in the literature.[20]

As asymptotic results applicable to this specific context are not available, we try to mitigate the effect of generated regressor and regressand biases in equation (15) by incorporating

[19]Here, we use the duration of the bonds in the yield response regressions (in Step 1) to match the zero-coupon yield responses implied by the macro term structure model (in Step 2).

[20]One obvious difficulty in applying Murphy and Topel's (1985) approach to our case is that the function generating the regressor must be known and twice differentiable in the parameter values (Murphy and Topel, 1985 p.374). Although the function generating the regressor and regressand can be written in closed form, the first derivatives of the same functions (with respect to the estimated parameters values) cannot be written in closed form. In fact in the case of **B** its values are constructed by means of a recursion (see Appendix for further details).

the uncertainty surrounding the values of Φ_j and $\mathbf{B}$ in the estimation of the parameters in α_j. More specifically, we compute the distribution of the parameter estimates by simulation using observations drawn from the distributions of both the estimated regressors and regressands. This procedure relies only on the assumption, relatively common in the literature on two-step econometric modeling, that both Φ_j and $\mathbf{B}$ are generated by models that are able to produce consistent estimates of both first-step parameters and their asymptotic covariance matrix (Murphy and Topel, 1985 p. 371).

4 Empirical Results

4.1 Data and Summary Statistics

We estimate the impact of announcements on bond yields using US Treasury bond data and US macroeconomic announcements. The US Treasury bond data are transaction-level data for the most recently issues (on-the-run) US Treasury securities obtained from GovPX, a joint venture setup by the primary dealers and interdealer brokers in 1991 (see, *inter alia*, Pasquariello and Vega, 2007; 2009 and the references therein). Our tick-by-tick dataset contains the best bid and offer tradable quotes and the price and size of each trade. We focus on on-the-run securities, since they are the ones characterized by greater liquidity and where the majority of informed trading takes place (Pasquariello and Vega, 2007). Bond yields changes on announcement dates are computed following Fleming and Remolona (2001), i.e. as changes in yields from the last transaction before the announcement time to the first transaction after the subsequent 20 minutes. Yields from transaction prices are used.[21] This relatively narrow time frame is chosen to pin down the genuine effect of macroeconomic announcements without any contamination from other sources (Ederington and Lee, 1993; Fleming and Remolona, 1999; Ghysels et al., 2012).

Data on macroeconomic announcements are real-time professional forecasts and realizations of 11 of the most relevant US macroeconomic fundamentals, namely (1) NAPM index, (2) Unemployment rate, (3) Nonfarm payrolls, (4) Industrial production, (5) Producer price

[21] We conducted a similar analysis using mid-quotes and the results, not reported to save space, are qualitatively and quantitatively similar to the ones discussed in this section.

index, (6) Retail sales, (7) Consumer price index, (8) Housing starts, (9) New durable goods orders, (10) New homes sales and (11) Consumer confidence index.[22] The data are obtained from Money Market Services (MMS) Inc.[23] We assign the individual macroeconomic announcements to five groups comprising two to three announcements that are likely to have similar informational content with respect to broad underlying macroeconomic data categories. We specify the five groups as follows:

1. *Labor market:* Unemployment rate and Nonfarm payrolls;
2. *Production:* NAPM index, Industrial production, and New durable goods orders;
3. *Prices:* Producer price index and Consumer price index;
4. *Housing market:* Housing starts and New homes sales;
5. *Consumer behavior:* Retail sales and Consumer confidence index.

In the first group we include the Unemployment rate (with an opposite sign, so that positive announcement surprises within this category represent higher-than expected improvements in the employment situation) and Nonfarm payrolls. The second group is meant to capture the overall state of the industrial sector: the NAPM index is based on a survey of purchasing and supply executives and encompasses a variety of sectors of the manufacturing sector; Industrial production measures output of the industrial sector of the economy; and New durable goods orders provides data on new orders received from more thousands of manufacturers of factory hard goods (durable goods). The third group captures price pressures in the economy as a whole by combining announcements on consumer and producer price indices. The fourth group reflects information relating to the housing sector. The last

[22] An important aspect of these macroeconomic releases is their characteristic of being widely and instantaneously disclosed to all market participants. Lock-up conditions are indeed imposed from government statistical agencies in order to guarantee the simultaneous release of key information to all market participants at regularly scheduled dates. See on this issue Fleming and Remolona (1999; 2001).

[23] The time series properties of the professional forecasts reported in the MMS database have been extensively investigated in previous studies (Fleming and Remolona, 1997; Andersen et al. 2003). As reported in Pasquariello and Vega (2007), MMS International has been recently acquired by Informa in 2003 and no longer exists. Action Economics LLC now provides commentary and analysis to support decision-making in the global fixed income and currency markets and also provides similar survey services.

group captures announcements relating to consumer behavior: Retail sales is an indicator that tracks the value of retail products sold to consumers in the past month, whereas the Consumer confidence index is an indicator based on a survey of thousands of households, meant to capture the financial health and the confidence of the average consumer.

We estimate the term structure model using monthly data on zero-coupon Treasury yields, inflation, and a measure of the output gap. The term structure data consists of zero-coupon yields available from the Federal Reserve Board (Gürkaynak et al., 2007). Nine maturities, ranging from 1 month to 10 years, are used in the estimation.[24] Inflation is computed as the month-on-month log-difference of consumer price index (CPI, seasonally adjusted). The output gap is computed as the quarterly log-difference of real GDP and the US Congressional Budget Office's estimate of potential real GDP. As the term structure model is estimated at the monthly frequency, we construct a monthly time series of the output gap by fitting an ARMA(1,1) model to the quarterly time series.[25]

The high-frequency dataset is constructed over the period January 1993 - December 2000. As discussed in Boni and Leach (2002) and Mizrach and Neely (2006) GovPX intermediated volume began to decrease in 1999 as alternative electronic trading venue came into being. For this reason we end our sample at the end of 2000.[26] In order to broadly match the sample period of the high-frequency dataset and guarantee an adequate amount of observations necessary for a reliable inference, the term structure model is estimated over the period

[24]We did not include, in both high frequency and model estimations, longer maturities, i.e. 30 years. This is because of the substantially lower liquidity characterizing this segment of the yield curve. In addition, as mentioned in Fleming (1997), the coverage of GovPX of the on-the-run 30-year bond was comparatively small, because of the lack of data provision from one of the brokers (Cantor Fitzgerald) with a strong presence in that maturity segment.

[25]More specifically, we forecast the output gap one quarter ahead, and compute one- and two-month ahead values by means of linear interpolation. This exercise is conducted in real time, i.e. the ARMA(1,1) model is estimated at the end of each quarter using data only up to that quarter. In the estimation process, inflation and the output gap are directly entered as deviation from their mean. We also subtract the sample mean of the short-term policy rate r from all yields.

[26]Although this sample period does not allow us to investigate the institutional change that occurred in early 2000 because of the migration of US Treasuries trading to electronic venues (Boni and Leach, 2002; Mizrach and Neely, 2006; Fleming and Mizrach, 2009), recent studies have shown that the 1990-2000 period is not much different from the more recent 2009-2010 period, in particular for medium- and long maturities which are the main focus of this study (see Swanson and Williams, 2012 and the references therein). See also Bauer (2015) for a recent empirical analysis over a similar sample period.

August 1987 to January 2006. We have chosen this specific sample period as it corresponds to the tenure of Alan Greenspan as Chairman of the Federal Reserve and because of the existing empirical findings that have suggested that the 1985-2007 period can be adequately treated as a single regime (Sims and Zha, 2006; Joslin et al. 2014 and the references therein).

Table I reports some preliminary statistics relative to bond yields (Panel A) and macroeconomic announcement shocks (Panel B) on the announcement dates. Macaulay durations are also computed and reported for all Treasury securities. The average duration estimates range between 3 months (3-month bill) and 91 months (10-year note). The figures reported in Table I, Panel A) show that, on average over the sample period, bond yields decreased after macroeconomic announcement and the changes have been generally more pronounced for the longer maturities. More specifically, bond yields changes around macroeconomic announcements range, on average, between 0.007 bps for the 3-month bill to 0.186 bps for the 10-year note.

The sample average of the non-standardized announcement shocks, together with their standard deviations and their maximum and minimum value are reported in Table I, Panel B). Over the sample period, six (five) announcements showed negative (positive) shocks on average. The number of negative signs should not be interpreted as evidence of a weakening economy, since one of the negative signs relates to the unemployment rate, and the average values are small relative to their standard deviations.

Table I also reports some sample statistics on the set of monthly zero-coupon bond yields (Panel C) and observable macroeconomic risk factors (Panel D) used in the estimation of the term structure model. On average, over the 1987-2006 period, the yield curve was upward-sloping, with 10-year yields exceeding the 1-month rate by 1.76%. Moreover, consistent with the evidence documented in the empirical literature (see Thornton and Valente, 2012 and the references therein), bond yields are highly correlated over time, with AR(1) parameters close to unity. As for the observable macroeconomic risk factors, the average month-on-month inflation rate of 0.25% corresponds to an annualized value of 3%. The output gap was slightly negative on average over the sample period.

4.2 Estimation and Economic Interpretation

We begin our empirical investigation by first estimating equation (13) to obtain the actual responses of bond yields to standardized macroeconomic shocks within each announcement group. The results are reported in Table II. In line with Fleming and Remolona (2001), announcement shocks for all groups impact significant on bond yields for all maturities. In fact virtually all of the parameter estimates $\phi_j^{(n)}$ are significant at the 1% statistical level. The labour market announcement shocks exhibit the largest impact across all bond maturities and all announcement shocks have a positive impact on bond yields. The next important announcements, in terms of impact on bond yields, are the ones related to prices and consumer behaviour, respectively; with magnitudes that range between one half and one third of the impact exerted by labor market announcements. Furthermore, across all announcement groups, there is a clear hump-shaped pattern of announcement effects: the same news elicits a larger reaction in terms of bond yield changes from intermediate maturities, with a peak generally associated with 2-year to 5-year maturity.[27]

The parameters of the term structure model are presented in Table III, Panels A) and B). The estimates are empirically plausible and in line with the ones recorded in the literature, including the responses to inflation deviations from the objective and to the output gap (β and γ). The policy rule is also characterized by some, albeit not extreme, interest rate smoothing, with a smoothing coefficient (ρ) just below 0.9. We also find evidence of backward-lookingness of inflation and the output gap, with μ_π and μ_x coefficients close to zero. This suggests that shocks to macroeconomic factors have a large impact on expectations of future values, which in turn play an important role for pricing bond yields in the model.

The fit of the model for the actual bond yields is showed in Figure 1. For all maturities reported in the four panels, the model is able to generate bond yields that are virtually indistinguishable from the actual ones.[28] Figure 2 displays the estimated dynamics of the

[27] In the spirit of Fleming and Remolona (2001) we tested the null hypothesis that intermediate maturities bond yield reactions are different from the equivalent reactions of short-term (3-month) or long-term (10-year) bonds. The results, not reported to save space but available upon request, confirm the validity of the hump-shaped announcement effect.

[28] Given the flexibility of the market price of risk specification, our model, like all essentially affine models,

risk factors implied by the term structure model. The fit is satisfactory, especially in light of the fact that the implied dynamics of the factors are jointly obtained with the dynamics of bond yields. Of the two observable macroeconomic factors, the model does a particularly good job in fitting the output gap. The dynamics of inflation differs when comparing the estimated model with the data. However, the model-implied year-on-year inflation dynamics capture the broad contours of the low-frequency movements in actual year-on-year CPI inflation. Similar to the evidence reported in Figure 1, the estimated policy rate, that in our framework is the one-month rate, the model fit is virtually identical to the actual data. The lower right-hand panel of Figure 2 displays the filtered perceived inflation target, which is an unobservable variable in the term structure model. The features of the estimated target rate seem plausible: it is quite persistent and it falls slowly from a level just below 3.2% to around 2.8% over the sample period, in line with the notion that the Federal Reserve gradually gained credibility in keeping inflation low during the Greenspan Era. Moreover, the estimated target level at the end of the sample (2.8% in CPI terms) is consistent with the anecdotal evidence at the time that the Fed had adopted an implicit PCE (personal consumption expenditures) inflation target of 2.5%.

Having estimated both actual bond yield responses and the term structure model in the first two steps of our empirical setup, we next estimate the factor sensitivities α_j for the five announcement groups in our sample. The results are reported in Table IV. The signs of the estimated factor sensitivities are as expected: Positive announcement shocks are all associated with upward revisions to inflation, the inflation target and the output gap state variables (as measured by the median sensitivities). However, the magnitude and the statistical significance of the responses vary across announcement groups and state variables. Among our five groups, announcements related to the labor market exhibit the greatest impact on both inflation and output gap with magnitudes that are at least twice as large as the sensitivities exhibited by the other groups. A one standard deviation upward shock in this group, for example, implies a 3.3 basis point (annualized) rise in the perceived inflation

is potentially prone to over-fitting (Duffee, 2010). We have checked the robustness of our results against this issue by computing maximal Sharpe ratios implied by our model estimates. The average value over the sample period is around 1.2 and this value is in line with the evidence recorded in existing studies (see, Adrian et al., 2013 and the references therein).

rate used by agents to price bonds, and an increase of 4.6 basis points for the output gap. While these numbers are quite small, they nevertheless imply sizeable increases in expected future inflation and output gaps. The prices group is the second most important set of announcements but, differently from the labor market, its effect is concentrated on inflation and the inflation target. Interestingly, albeit statistically significant, standardized shocks of this group move perceived annualized inflation less than shocks to announcements related to the labor market. The remaining three announcement groups only exhibit significant sensitivities to the output gap with magnitudes that are similar across groups.

Given the full set of parameter estimates reported in Tables III and IV, we can examine the transmission of macroeconomic shocks to interest rates and bond yields. The estimated model-implied responses of bond yield changes to the standardized macroeconomic announcement shocks are shown in Figure 3, along with the estimates of the high-frequency bond yield responses reported in Table II. The model captures the average responses well. Furthermore, it also replicates in sign and size the hump-shaped pattern generally seen in the data for all announcement groups.

As discussed in Section 2, the yield responses in Figure 3 are due to changes in the expected average short-term interest rate and/or changes in risk premia. Figure 4 provides a decomposition of the yield responses in order to identify the two components for each of the announcement groups. We can identify an uniform pattern: the expected interest rate effect dominates across all maturities. The risk premia component does affect yield responses but it moves in opposite direction of the expected interest rate effect, especially over medium- to long-term maturities.[29] [30]

[29] We report the 95% confidence bands for the two component of announcement effects in Figure A1 in the Appendix. In most of the cases, both the expected interest rates and the risk premia components of the yield responses are statistically significant and different from each other at conventional level over maturities longer than 2 years.

[30] We have also carried out the decomposition of announcement effects in the forward rate space rather than the yield space. The results show clearly that positive economic news raise the path of expected short-term interest rates quickly, as the Federal Reserve is seen as likely to respond by tightening monetary policy relatively soon. The expected short rate peaks after around one to two years and thereafter returns gradually towards the baseline level. Meanwhile, the forward premium peaks at around 2-3 years, suggesting that investors require additional compensation to bear risks associated with interest rate uncertainty over these horizons, as a result of unanticipated economic news. The effect on forward premia dissipates more

The relative importance of the state variables in terms of contributing to the overall yield responses is displayed in Figure 5. Consistent with the results reported in Table IV, the responses of bond yields for all announcement groups, except the one related to prices, are due mostly to perceived changes to the output gap. This effect is strongest for the groups related to production, housing market and consumer behavior, for which changes in the output gap account for nearly the entire response of bond yields. The impact is strong, but smaller in magnitude for announcements related to the labor market. The yield changes associated with announcements related to prices show even stronger responses that are due to perceived changes in the inflation target. This suggests that price-related announcements that significantly affect bond prices market have an impact because they induce investors to revise their views of the long-term inflation outlook, as captured by the inflation target, whereas revisions to inflation are seen as highly transitory and therefore less important for bond prices. The perceived changes to inflation do not account much for the response of bond yields across all of the announcement groups.

Announcements in all groups lead to substantial adjustments in risk premia, which account for the common hump-shaped pattern of yield curve reactions. At the same time, the behavior of risk premia across the curve depends critically on the nature of the information shock. In fact, when the yield curve moves because of output gap shocks (Figure 6), the movements at the short to intermediate maturities are dominated by revisions in the expected short-term interest rate. The risk premia component associated with output gap becomes gradually more important from the 4 year onward progressively reducing the effect of the expected short-term interest rate expectations. A similar pattern is recorded when the yield curve moves because of inflation shocks (Figure 7). However, the effect is less clear cut as the confidence bands of both expected short-rate effect and risk premia effect overlap making the inference about the driver of the overall effect more difficult. Differently, when the yield curve moves because of inflation target shocks (Figure 8), the movements across the entire curve are dominated by adjustments in risk premia as the expected short-term rate component associated is generally very small and close to zero across all announcement

quickly than for expected interest rates, and is generally zero at the 10-year horizon. The results, not reported to save space, are available from the authors upon request.

groups. However, this effect on risk premia is only statistically significant for price index announcements. This indicates that, as higher-than expected inflation news lead investors to revise their perceptions about the long long-term inflation outlook via the perceived target, they also require higher risk premia to compensate for this change.

Overall, the results reported in this section suggest that bond yield reactions around major macroeconomic announcements are mostly due to revision of expectations regarding the path of the future short-term interest rates. However, risk premia associated with macroeconomic risk factors are sizable, statistically significant with a different magnitude across the maturity spectrum. These risk premia move in the opposite direction of the effect exerted by the revision of expectations about short-term interest rates and the offsetting effect is stronger the longer the maturity of the long-term bond which give rise to the hump-shape pattern of the response of bond yields to macroeconomic announcement news.

5 Robustness

This section checks the robustness of the baseline results reported in Section 4. More specifically, we test whether our results change if we allow investors to update their perceptions about macroeconomic risk factors over time. We do so by conditioning the value of the factor sensitivity parameters to variables that proxy for different economic environments occurring at the time of the news releases. We also check whether the estimates of the term structure model suffer from small-sample bias due to well-known difficulties in accurately estimating the dynamics of highly persistent variables using data over relatively short periods of time. We show that our baseline results are robust to all these issues.

5.1 Conditional Factor Sensitivities

The results presented in the previous section have assumed that the factor sensitivity parameters α_j are time-invariant, so that investors always interpret a given announcement surprise in the same way. However, it may be reasonable to hypothesize that the updating mechanism varies over time. For example, one could hypothesize that the mapping from news surprises into perceived macroeconomic fundamentals would change depending on the economic environment at the time of the news arrival. In fact, investors might perceive an unemployment surprise differently depending on whether the Federal Reserve is in a tightening cycle or an easing cycle. Alternatively, bond markets might react differently to macroeconomic news if the economy is in recession or it is booming.

To check for the possibility that investors' perceptions of the information contained in announcement surprises might vary over time, we estimate a set of alternative models that allow the macroeconomic risk factor sensitivity parameters to depend upon various conditioning variables. Specifically, we first compute the impact of macroeconomic announcement shocks, per announcement group, on bond yields by means of the following regression:

$$\Delta y_{j,t}^{(n)} = \left(\phi_{j,c}^{0,(n)} + \phi_{j,c}^{1,(n)}\delta_{c,t}\right) S_{j,t} + e_{j,c,t}^{(n)}. \quad (16)$$

where $\delta_{c,t}$ is a dummy variable that equals 1 or 0 depending upon the value of some relevant conditioning variables c at time t.[31]. Then we estimate the conditional factor sensitivity parameters by combining the parameters from the term structure model (11) with parameters estimated in (16) to obtain the following set of equations,

$$\Phi_j^0 = \mathbf{B}'\alpha_{j,c}^0 + \varepsilon_{j,c}^0 \quad (17)$$

$$\Phi_j^1 = \mathbf{B}'\alpha_{j,c}^1 + \varepsilon_{j,c}^1, \quad (18)$$

where $\Phi_{j,c}^0 = \left[\phi_{j,c}^{(1)}, ..., \phi_{j,c}^{(m)}\right]'$ and $\Phi_{j,c}^1 = \left[\left(\phi_{j,c}^{0,(1)} + \phi_{j,c}^{1,(1)}\right), ..., \left(\phi_{j,c}^{0,(m)} + \phi_{j,c}^{1,(m)}\right)\right]'$. As discussed in Section 3.2, we compute the distribution of the parameter estimates by simulation using repeated draws from the distributions of both the estimated regressor and regressands based on the parameter estimates and their asymptotic covariance matrix obtained in the first step.

We consider the following conditioning variables:

1. Monetary policy stance: we follow Jensen et al. (1996) and define the monetary policy stance variable $\delta_{MP,t}$ as a directional rate-change dummy variable that takes a value of one if the previous change in the Fed's discount rate was an increase and zero if it was a decrease.

[31] This setup preserves the time invariant specification of the term structure model and of the pricing of bonds as a function of the macroeconomic risk factors.

2. Output gap: we define $\delta_{GAP,t}$ as a dummy variable that takes a value of one if the estimated output gap, calculated as discussed in Section 4.2, is positive and zero if it is negative.

3. Macro expectations disagreement: we follow Pasquariello and Vega (2007) and let $\delta_{DIS,t}$ take a value of one if the standard deviation of expectations across a range of important macroeconomic announcements is above the median in our sample, and zero if it is below.[32]

4. MOVE index: we let the variable $\delta_{MOVE,t}$ take a value of one if the Merrill Option Volatility Estimate (MOVE) index is above the median value in our sample, and zero otherwise.[33]

5. VIX index: we let $\delta_{VIX,t}$ take a value of one if the VIX implied volatility index on the S&P500 is above the median value in our sample, and zero otherwise.

The results of these exercises are reported in Tables AI-AV of the Appendix. The various tables report the difference between the sensitivities parameter $\alpha^0_{j,c}$ and $\alpha^1_{j,c}$, and its statistical significance between the two regimes, for each of these five conditioning variables.

Overall, we find that in the vast majority of the cases, our baseline results discussed in Section 4 are robust to the different conditioning variables. Across all cases, only few estimated factor sensitivities are statistically significantly different when including a conditioning dummy. We take this as a comforting indication that monetary policy stance, economic activity, investor disagreement, or market uncertainty do not substantially affect the way investors map observed announcement surprises into perceptions about the macroeconomic risk factors they use to price bonds.

[32] For further details, see Pasquariello and Vega (2007), Section 2.2.2. We thank Clara Vega for providing us with the standard deviation of expectations used in the empirical analysis.

[33] The MOVE index is a yield curve weighted index of the normalized implied volatility on 1-month options on Treasury bonds of various maturities.

5.2 Bias-Corrected Model Estimates

An additional concern relates to the possibility that the estimates of the affine term structure model suffer from small-sample bias due to well-known difficulties in accurately estimating the dynamics of highly persistent variables using data over relatively short periods of time. Bauer et al. (2012) show that this is a common problem with affine term structure models, and that the bias may result in substantial errors in estimated risk premia and expected future short-term interest rates. They suggest ways to correct for the small-sample bias using a so-called inverse bootstrap method. Unfortunately, their proposed methods are not directly applicable to our case, as it requires the assumption of bond yields being perfectly observable without error to invert the model for the latent state variables. In our case this assumption would not help in solving the problem since we are still be unable to quickly estimate the parameters from equation (4).[34]

We adopt an alternative approach to check for the robustness of our baseline results with respect to small-sample bias. This approach is similar to the bootstrap bias correction method suggested by Tang and Chen (2009). Specifically, we use our baseline model estimates (denoted $\hat{\theta}$) to generate N new samples of macro variables and yields (of the same length as the original sample) with the help of a parametric bootstrap procedure. For each new generated sample we reestimate the term structure model using ML, resulting in N sets of bootstrap parameter estimates $\hat{\theta}^*_B$, $B = 1, ..., N$. Letting $\bar{\theta}^*$ denote the median of the bootstrapped estimates, we obtain the bias-corrected estimator as

$$\hat{\theta}_{BC} = 2\hat{\theta} - \bar{\theta}^*.$$

We report the estimates corrected by the median of the bootstrapped distributions as Bauer et al. (2012) suggest that median-based corrections tend to perform slightly better in terms of capturing the true persistence for samples generated using a known data generating process. Moreover, earlier studies have argued that median-unbiased estimators have better properties when the distribution VAR estimator is highly skewed, which is typically the case in models for persistent processes (Rudebusch, 1992; Andrews, 1993).

[34] In fact, we need to solve the macro model first before extracting the VAR parameters (see the Appendix for details).

We implement the procedure described above for $N = 5,000$ generated samples to obtain bias-corrected parameter estimates of the term structure model. We find that the bias correction has very little impact on our results. In fact, as shown in Figures A2 and A3 of the Appendix, our results show that the bias-corrected responses of these variables are very close to the baseline estimates, and that they are always within the estimated 95% confidence limits of the benchmark responses.

6 Conclusions

This paper investigates the response of bond yields upon releases of macroeconomic announcement news. Theory tells us that the yield curve moves at these times because the announcements lead to revisions in investors' expectations of the path of future interest rates and to reassessments of the risks associated with such expectations. Our study aims at disentangling these two components by relying on a framework comprising an arbitrage-free dynamic term structure model with macroeconomic factors and with estimates of changes in the US yield curve during a 20-minute window around the release times of major US macroeconomic announcements. At the core of the term structure model is a monetary policy reaction function driven by macroeconomic variables as in a Taylor rule. These same variables also serve as the key factors that drive risk premia as announcement news are released.

We find several novel results. First, our estimates show a clear distinction between announcements that are relevant to output expectations and those that are relevant to inflation expectations. Second, there is a consistent pattern across announcement groups in that changes in bond yields are mostly caused by revisions of the expected path of future short-term interest rates. However, bond yields also react to announcement surprises because of risk premia responses. Changes in risk premia are less sizable and move in the opposite direction, thus partly offsetting the effect due to revisions in short-rate expectations. Third, the strength of the short-rate effect relative to that of the risk premia changes with bond maturity. At short maturities, the two effects reinforce each other, but the risk premia effect becomes relatively stronger at longer maturities, thus helping to account for the common hump-shaped pattern of yield curve reactions to macroeconomic news. Our results are robust to the explicit consideration of different states of the business cycle, different stances of the US monetary policy, the degree of disagreement among market participants about the announcement news and different levels of investors' risk appetite. The baseline estimates are also robust to potential small-sample biases in the estimation of the term structure model due to the difficulties in accurately estimating the dynamics of highly persistent variables.

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Table I. Summary Statistics

The Table shows the summary statistics of the data employed in the paper. Panels A) and B) report descriptive statistics of bond yields and macroeconomic announcement shocks computed on the announcement dates over the sample period January 1993 - December 2000. Panels C) and D) report descriptive statistics relative to the monthly data series used to estimate the affine model discussed in Section 2. The figures reported in Panels C) and D) are computed over the sample period August 1987 and January 2006. The average duration in Panel A) is computed as the time-series average of the McCauley duration for each of on-the-run benchmark bonds across the announcement dates. Duration is expressed in months. Average and St. dev of yield chg denote the time-series average and standard deviation of yield-to-maturity changes computed over the 20 minutes following the time of each announcement. Yield changes are expressed in terms of basis points. Average, Std dev, Min and Max in Panel B) denote the time-series average, standard deviation, minimum and maximum values of the non standardized macroeconomic announcement shocks recorded on the announcement dates. The units of the shocks are reported in the first column of Panel B). Average and Std dev of bond yields and AR(1) of bond yields in Panel C) denote the time-series average, standard deviation and first-order serial correlation coefficient of the zero-coupon yields used in the estimation of the macro term structure model. Average, Std dev, Min, Max and AR(1) in Panel D) denote the time-series average, standard deviation, minimum, maximum and first-order serial correlation coefficient of the two observable macroeconomic risk factors, respectively constructed as discussed in Section 4.2.

Panel A) Bond yields (announcement dates)

	Average duration (months)	Average yield chg. (bps)	St.dev. of yield chg. (bps)
3 months	3.00	−0.007	2.082
6 months	6.00	−0.029	2.459
12 months	11.95	−0.148	5.170
24 months	22.16	−0.024	4.475
60 months	52.79	−0.088	4.591
120 months	91.37	−0.186	4.101

Panel B) Macroeconomic announcement shocks (announcement dates)

	Average	Std. Dev	Min.	Max.
1. NAPM index	−0.251	1.834	−4.80	3.80
2. Unemployment rate (%)	−0.042	1.298	−0.40	0.30
3. Nonfarm payrolls (1000 jobs)	−3.646	120.397	−284.00	408.00
4. Industrial production (%)	0.070	0.243	−0.50	0.90
5. Producer price index (%)	−0.058	0.262	−0.80	0.60
6. Retail sales (%)	−0.055	0.402	−1.10	1.20
7. Consumer price index (%)	−0.024	0.111	−0.30	0.30
8. Housing starts (million)	0.009	0.068	−0.16	0.15
9. New orders durables (%)	0.112	2.589	−6.40	10.00
10. New home sales (1000 homes)	12.591	57.688	−139.00	126.00
11. Consumer confidence	0.891	4.431	−10.50	13.30

Panel C) Zero-coupon bond yields

Maturity	Average yield (% p.a.)	St.dev. of yield (% p.a.)	AR(1) of yield
1 month	4.57	2.01	0.99
3 months	4.62	2.01	0.99
6 months	4.69	2.03	0.99
1 year	4.93	2.06	0.99
2 years	5.26	1.95	0.99
3 years	5.52	1.85	0.99
5 years	5.85	1.69	0.98
7 years	6.13	1.60	0.98
10 years	6.33	1.49	0.98

Panel D) Macroeconomic risk factors

	Average	Std. Dev	Min.	Max.	AR(1)
Inflation (m-o-m CPI log-changes in %)	0.25	0.21	−0.50	1.37	0.29
Output gap (log-changes in %)	−0.82	1.58	−4.04	3.18	0.98

Table II. Impact of Announcement Surprises on Treasury Yields

The Table reports the estimates of the reaction of bond yields at different maturities to standardized macroeconomic announcement shocks. $\phi_1^{(n)}$ denote the slope parameter estimate in equation (13) of the main text where (n) denotes the maturity of the on-the-run benchmark. The estimation is carried out over the sample period January 1993 - December 2000. *,**,*** denote statistically significant at 10%, 5% and 1%, respectively.

	$n=$					
$\phi_1^{(n)}$	3 months	6 months	12 months	24 months	60 months	120 months
1. Labour market	1.794***	1.822***	3.308***	4.227***	4.000***	3.444***
2. Production	0.367***	0.674***	1.190***	1.533***	1.494***	1.275***
3. Prices	0.575***	1.036***	1.234***	1.447***	1.623***	1.627***
4. Housing market	0.266**	0.449**	0.801***	0.980***	1.008***	0.857***
5. Consumer behavior	0.513***	0.661***	1.239***	1.661***	1.702***	1.508***

Table III. Model Estimates

The Table reports parameter estimates of the macro-finance no-arbitrage affine model discussed in Section 2 of the main text. Panel A) reports the estimates for the parameters in equations (1),(2) and (3) of the main text. Panel B) shows the estimates of the parameters λ_1 in equation (7) of the main text. Figures in parentheses are asymptiotic standard errors based on the estimated Hessian. The estimation is carried out over the sample period August 1987 - January 2006.

Panel A) The macroeconomy

Parameter	Estimate	St.err. $\times 10^2$
ρ	0.891	(0.135)
β	1.444	(0.088)
γ	0.678	(0.053)
$\mu_\pi \times 10^2$	0.002	(0.012)
δ_x	0.015	(0.058)
μ_x	0.015	(0.082)
ζ_r	0.046	(0.069)
ϕ_{π^*}	0.995	(0.114)
ϕ_π	0.871	(0.211)
ϕ_x	0.963	(0.338)
$\sigma_{\pi^*} \times 10^3$	0.008	(0.000)
$\sigma_\eta \times 10^3$	0.282	(0.002)
$\sigma_\pi \times 10^3$	0.030	(0.000)
$\sigma_x \times 10^3$	0.030	(0.000)

Panel B) Market prices of risk: λ_1 $(\times 10^{-3})$ *parameters in:*

$$\begin{bmatrix} \lambda_{\pi^*,t} \\ \lambda_{\eta,t} \\ \lambda_{\pi,t} \\ \lambda_{x,t} \end{bmatrix} = \lambda_0 + \begin{bmatrix} \lambda_1^{(\pi^*,\pi^*)} & \lambda_1^{(\pi^*,\eta)} & \lambda_1^{(\pi^*,\pi)} & \lambda_1^{(\pi^*,x)} \\ \lambda_1^{(\eta,\pi^*)} & \lambda_1^{(\eta,\eta)} & \lambda_1^{(\eta,\pi)} & \lambda_1^{(\eta,x)} \\ \lambda_1^{(\pi,\pi^*)} & \lambda_1^{(\pi,\eta)} & \lambda_1^{(\pi,\pi)} & \lambda_1^{(\pi,x)} \\ \lambda_1^{(x,\pi^*)} & \lambda_1^{(x,\eta)} & \lambda_1^{(x,\pi)} & \lambda_1^{(x,x)} \end{bmatrix} \begin{bmatrix} \varepsilon_t^{\pi^*} \\ \eta_t \\ \varepsilon_t^{\pi} \\ \varepsilon_t^{x} \end{bmatrix}$$

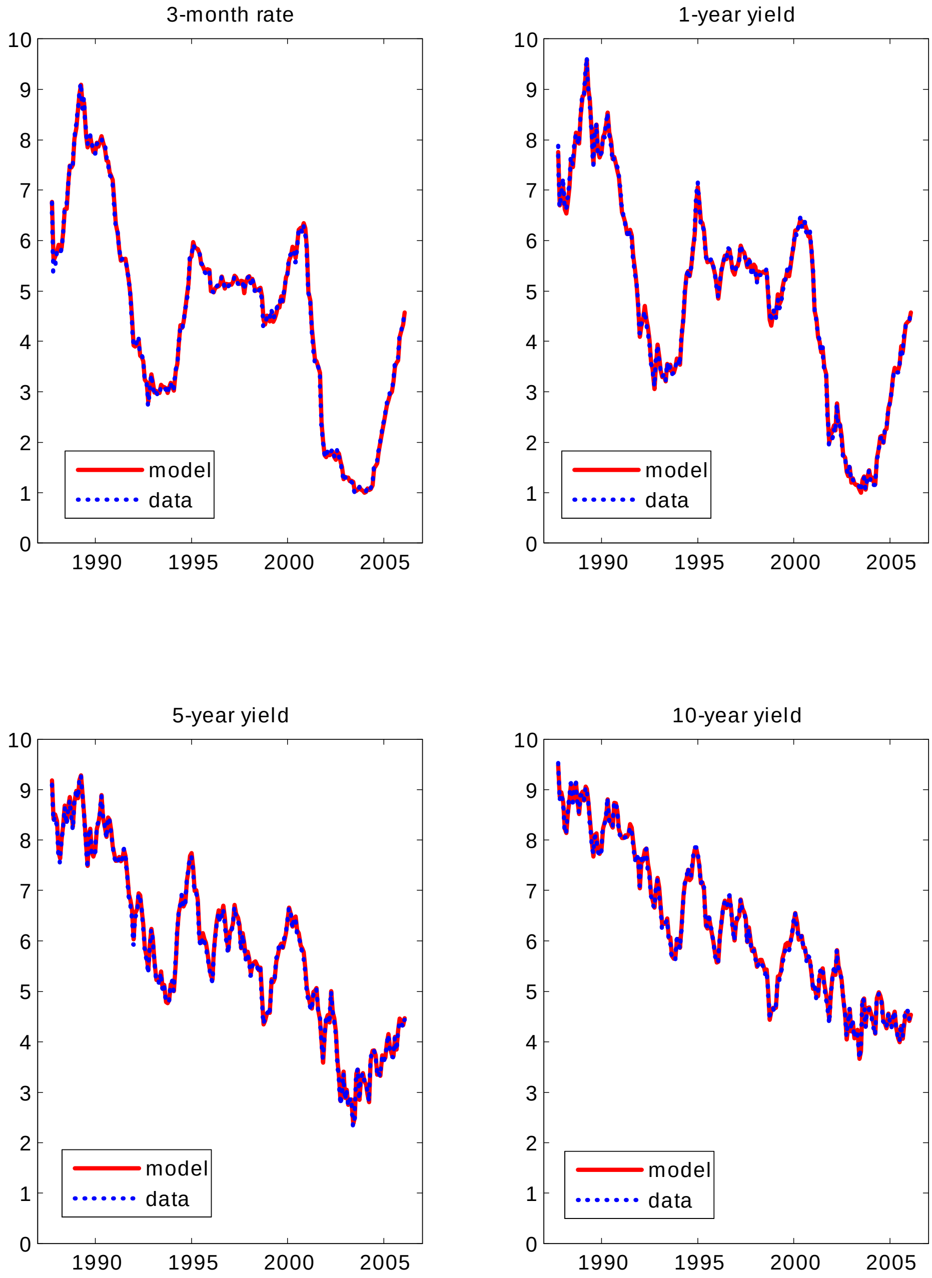
	driver of time-variation			
Priced risk	$\varepsilon_t^{\pi^*}$	η	ε_t^{π}	ε_t^{x}
inf. target shock $\left(\varepsilon_t^{\pi^*}\right)$	−0.046 (0.006)	−0.005 (0.011)	0.052 (0.006)	−0.167 (0.010)
policy shock (η)	−0.772 (0.002)	0.096 (0.005)	−1.001 (0.025)	−0.284 (0.005)
inflation shock (ε_t^{π})	−0.427 (0.001)	0.283 (0.003)	0.427 (0.004)	−0.930 (0.002)
output gap shock (ε_t^{x})	−0.160 (0.005)	−0.083 (0.009)	0.353 (0.006)	0.449 (0.005)

Table IV. Factor Sensitivities to Macroeconomic Announcement Surprises

The Table reports the estimates of the sensitivity parameters α_j of bond yields reactions to announcement shocks with respect to the three relevant macroeconomic risk factors (inflation target, inflation and output gap). The correspond to the slope parameter estimate in equation (15) of the main text, reported as the medianof the distribution of the parameter obtained by simulation using observations drawn from the distributions of both the estimated model-free yield responses Φ_j and the factor loadings B. The figures reported in the table are based on 100,000 draws. *,**, and *** denote statistical significance at 10%, 5% and 1%, respectively.

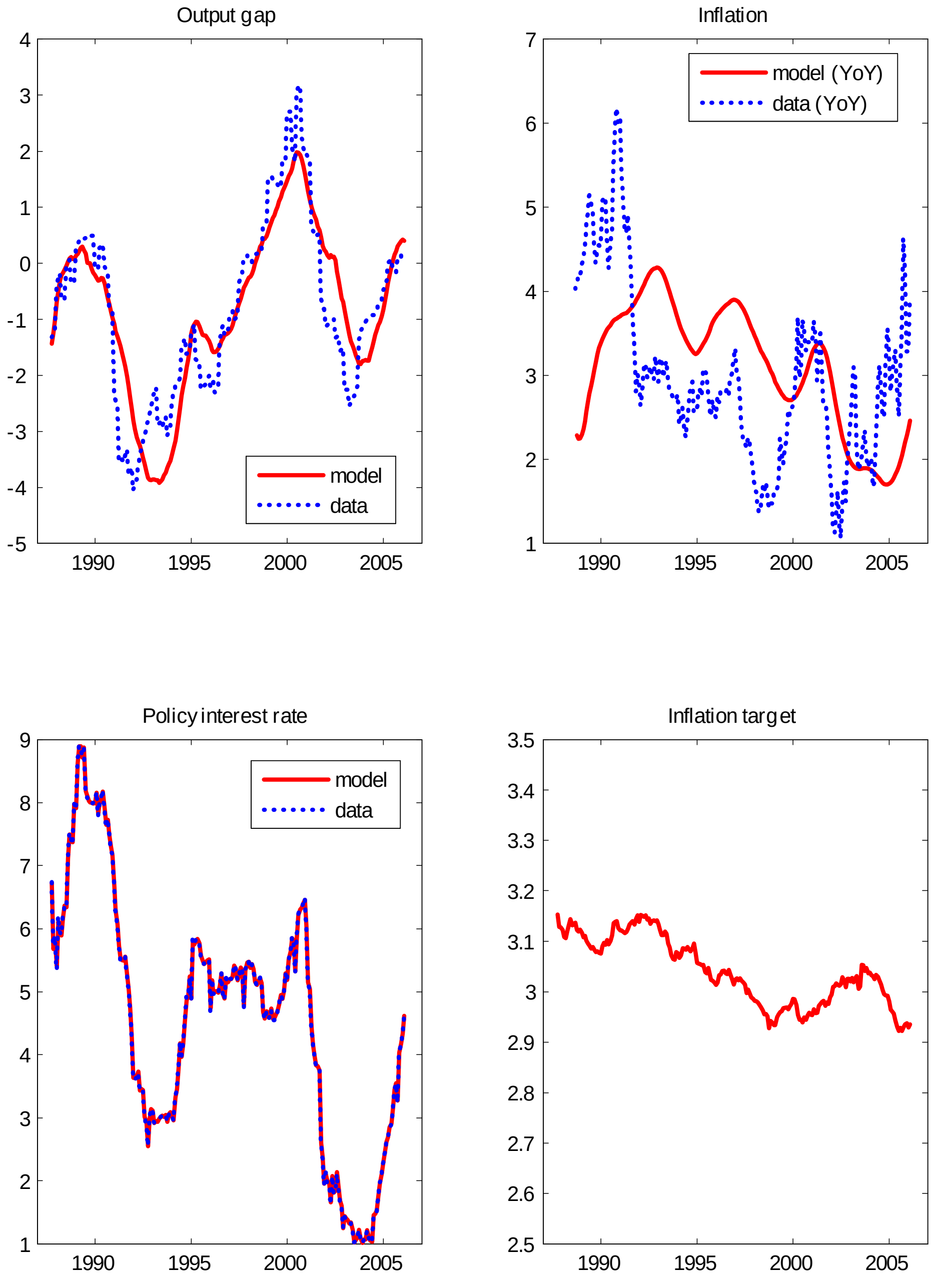
Announcement group	Macroeconomic risk factors		
	inflation target	inflation	output gap
1. Labor market	0.041	0.276**	0.382**
2. Production	0.001	0.027	0.199***
3. Prices	0.057**	0.185***	0.032
4. Housing market	0.005	0.029	0.118**
5. Consumer behavior	0.019	0.049	0.171**

Figure 1: Term structure model fit



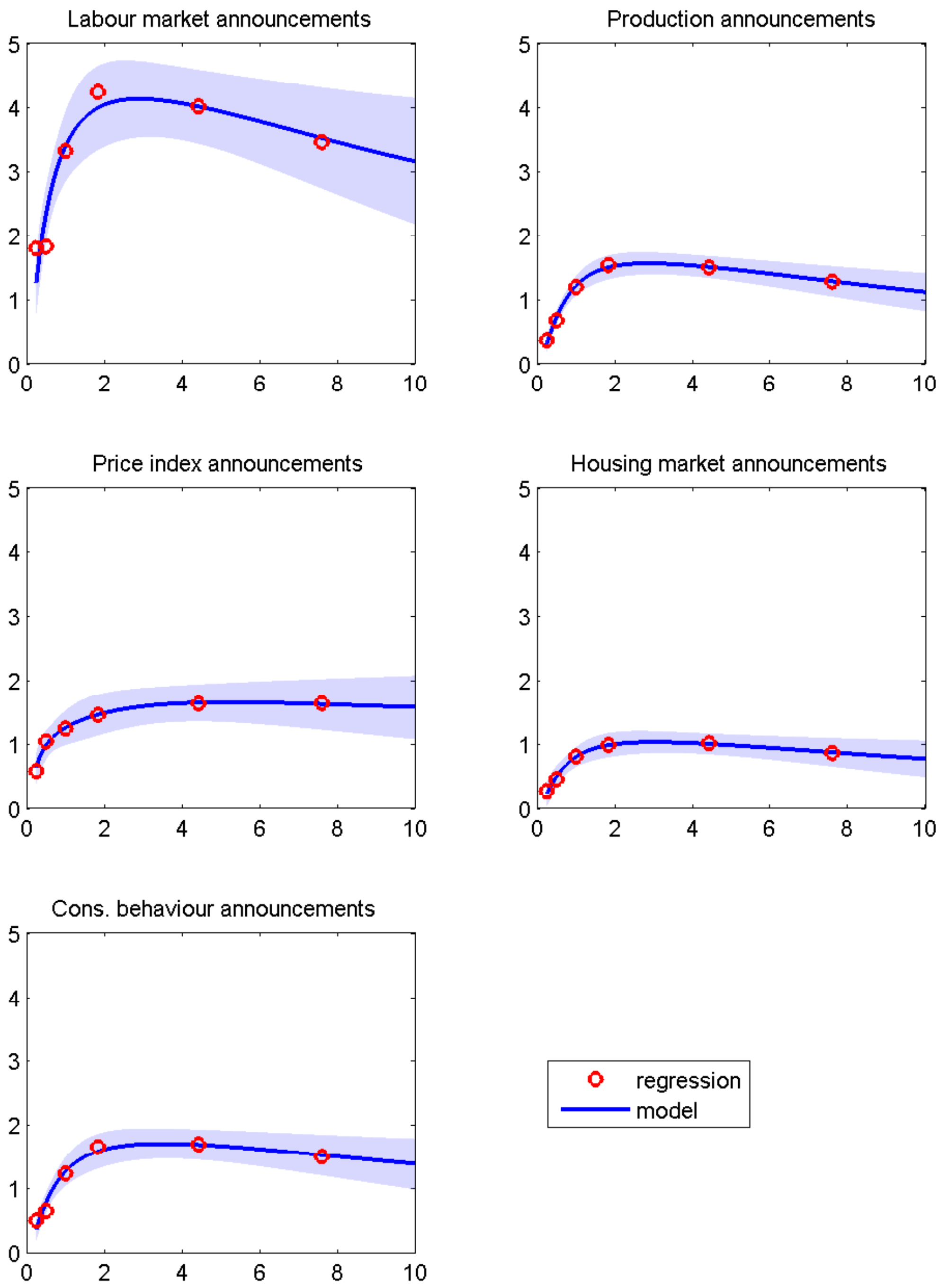
Solid lines show yields implied by the term structure model, based on the ML estimates obtained in the first estimation step. Dotted lines show the observed yield data (percent per year; monthly data).

Figure 2: Model factor dynamics



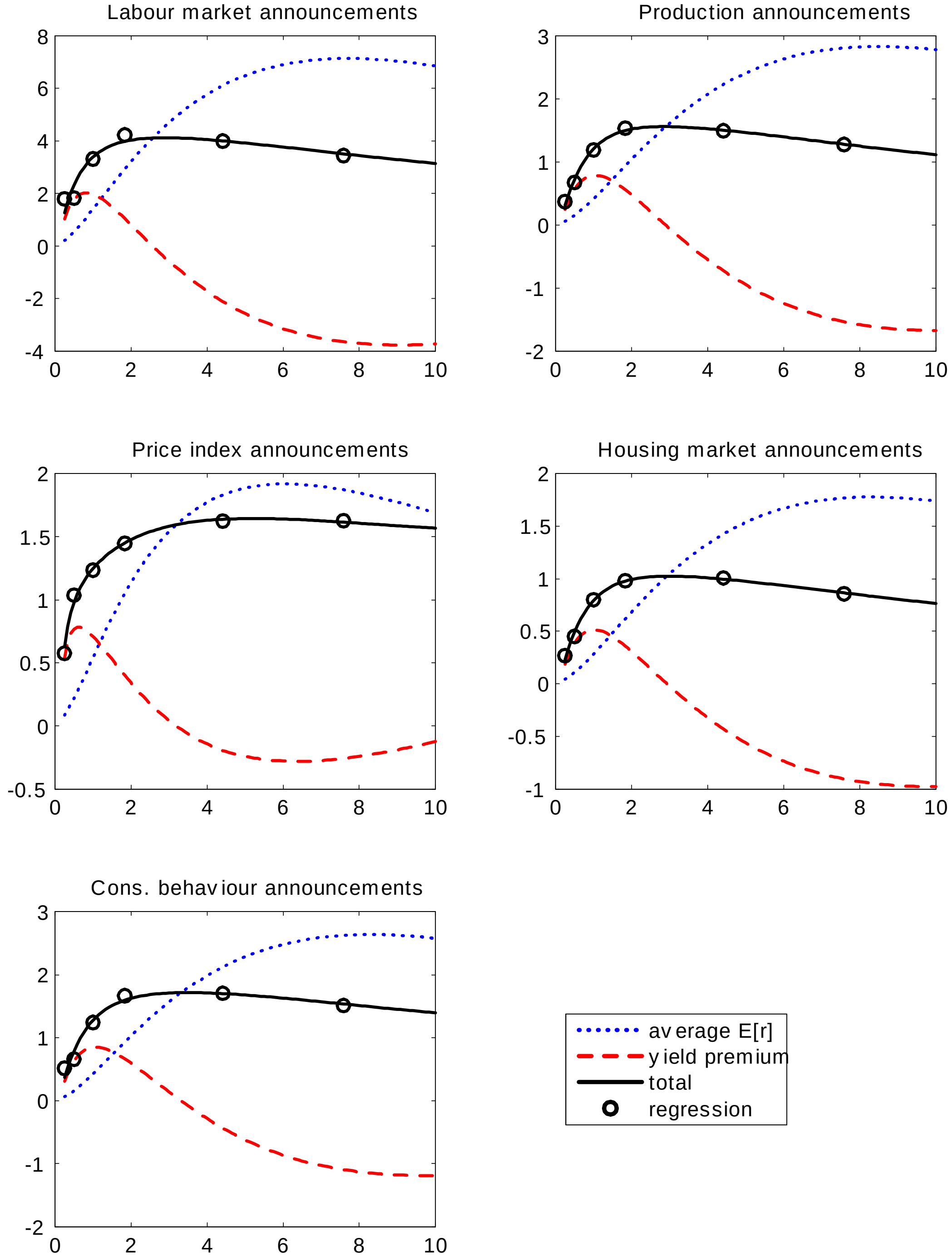
Solid lines show estimated factor dynamics implied by the model, based on the ML estimates obtained in the first estimation step. Dotted lines show observed macro and policy rate (1-month rate) data. Inflation figures have been converted to year-on-year rates.

Figure 3: Estimated term structure responses to macro announcement surprises



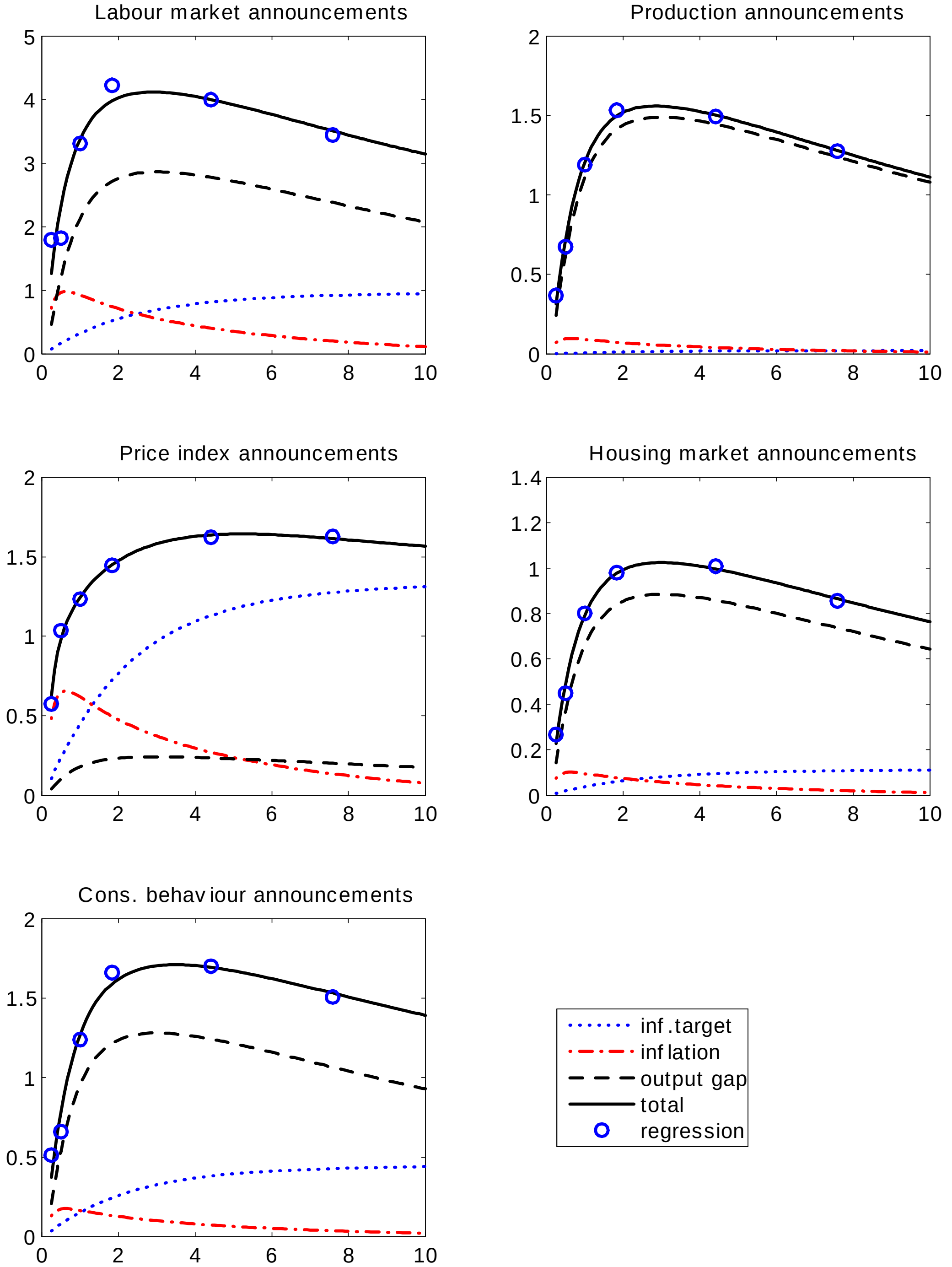
The curves show model-implied responses of the term structure of interest rates to macroeconomic announcement surprises (one standard deviation). The dots represent coefficients from OLS regressions of yield changes on announcement surprises. The vertical axis shows responses in basis points; the horizontal axis shows the maturity in years. Shaded areas represent 95 percent MC confidence bands based on 100,000 parameter draws,

Figure 4: Estimated term structure responses to announcement surprises and decomposition into average expected short rate and yield premium



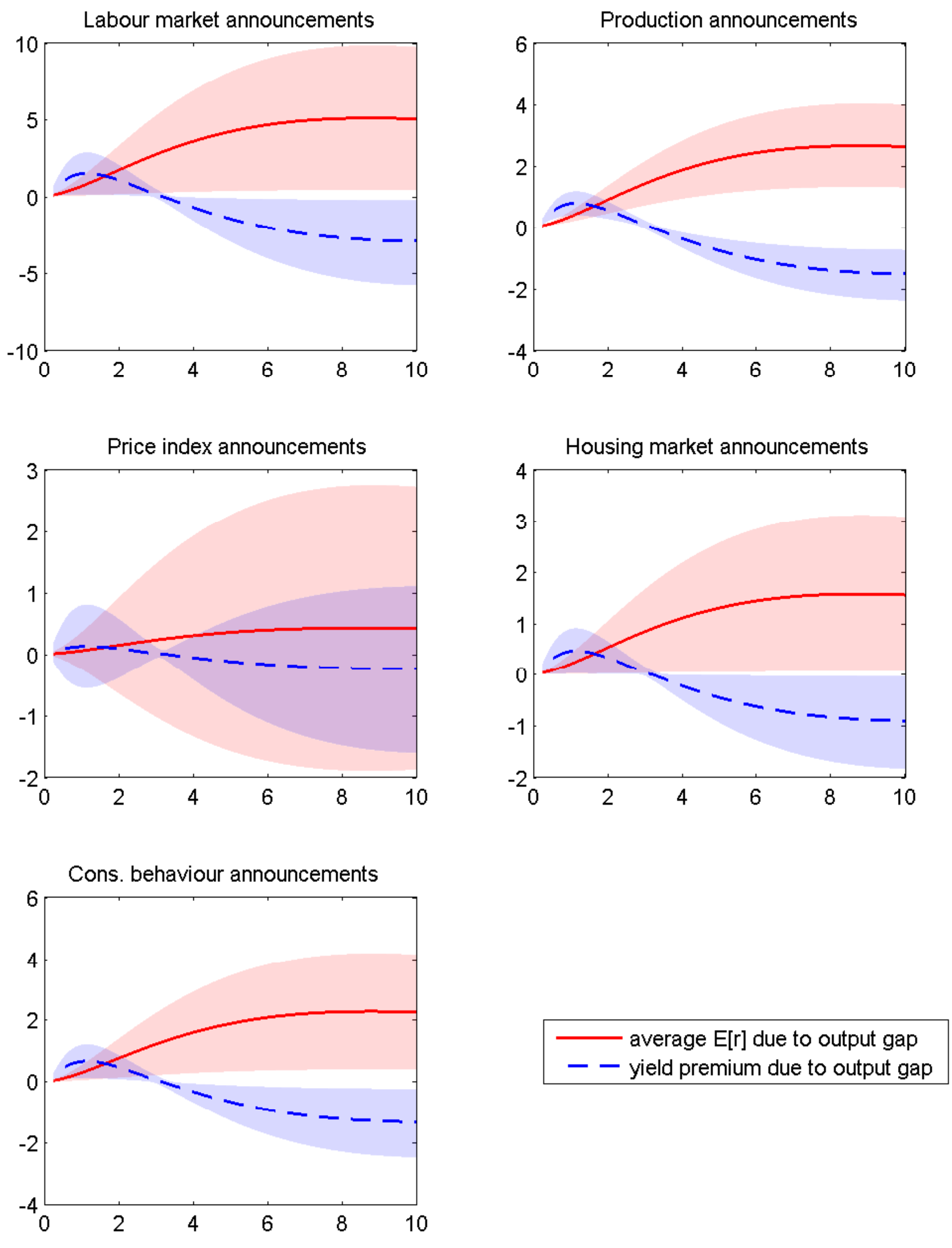
Bold solid curves are total responses to macro announcement surprises (same as in Figure 2). Dotted curves and dashed curves represent the components of the total responses that are due to the average expected short term interest rate and the yield premium, respectively. The circles represent coefficients from OLS regressions of observed yield changes on announcement surprises. The vertical axis measures the responses in basis points; the horizontal axis shows the maturity in years.

Figure 5: Estimated term structure responses to macro announcement surprises and decomposition by state variable



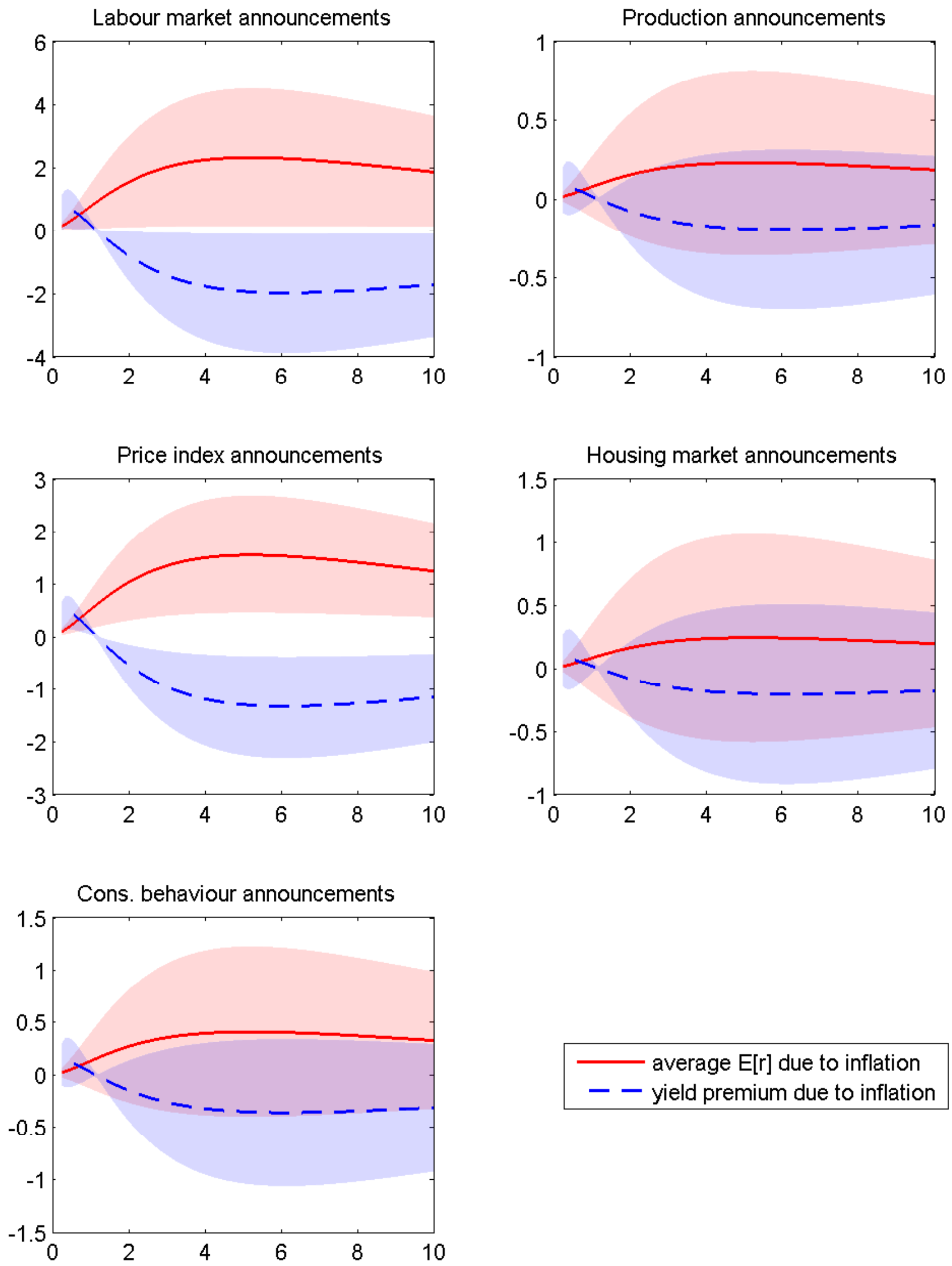
Bold solid curves are total responses to macro announcement surprises (same as in Figure 2). Dotted curves, dashed-dotted curves, and dashed curves represent the components of the total responses that are due to changes in the perceived inflation target, in inflation, and in the ouput gap, respectively. The circles represent coefficients from OLS regressions of observed yield changes on announcement surprises. The vertical axis measures the responses in basis points; the horizontal axis shows the maturity in years.

Figure 6: Average expected short rate and term premium announcement responses due to changes in the output gap



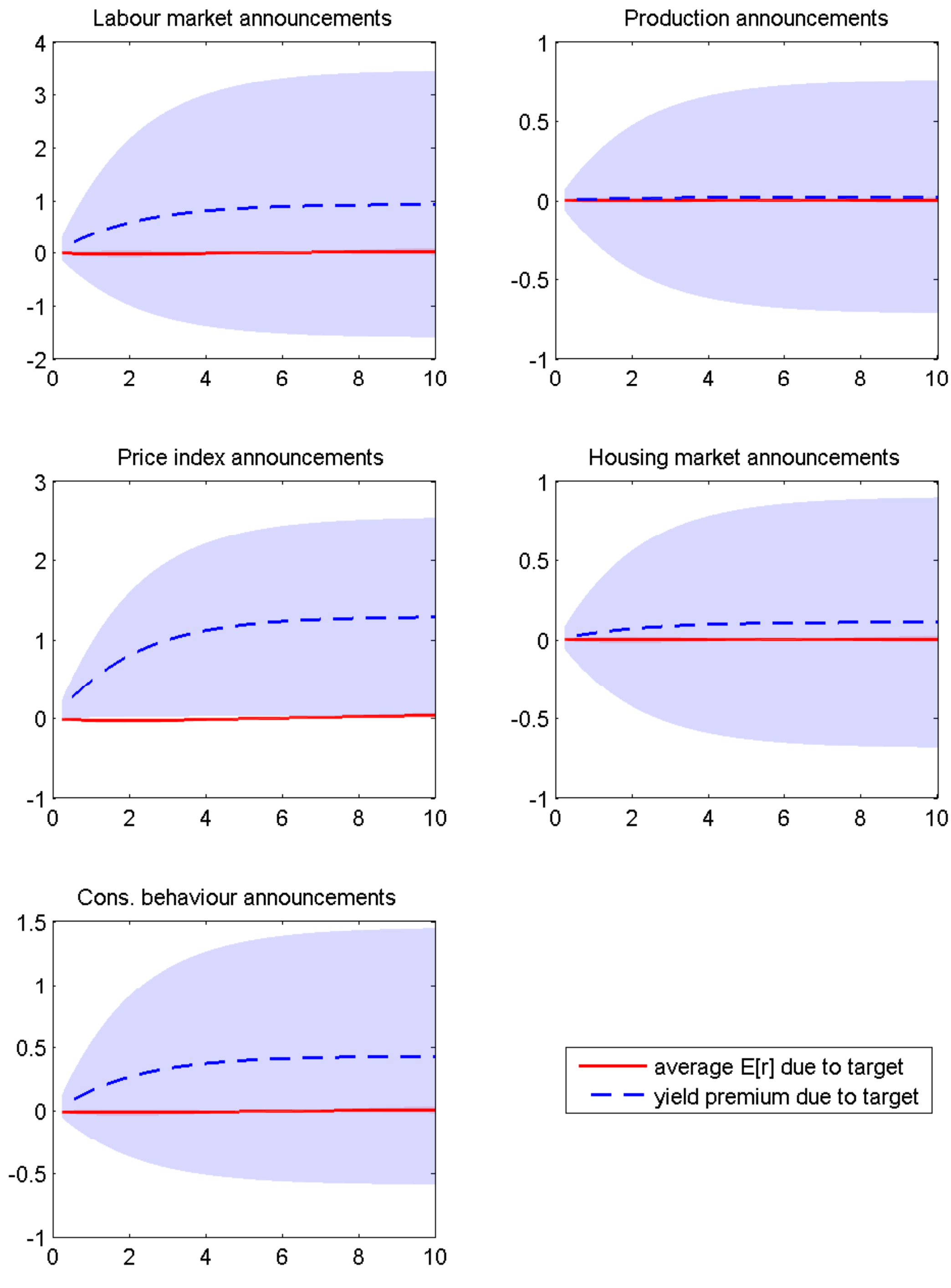
The curves show the model-implied responses of average expected short-term interest rates (solid curves) and of term (yield) premia (dashed curves) to changes in the perceived output gap as a result of macroeconomic announcement surprises (one standard deviation). The vertical axis shows responses in basis points; the horizontal axis shows the maturity in years. Shaded areas represent 95 percent MC confidence bands based on 100,000 parameter draws,

Figure 7: Average expected short rate and term premium announcement responses due to changes in inflation



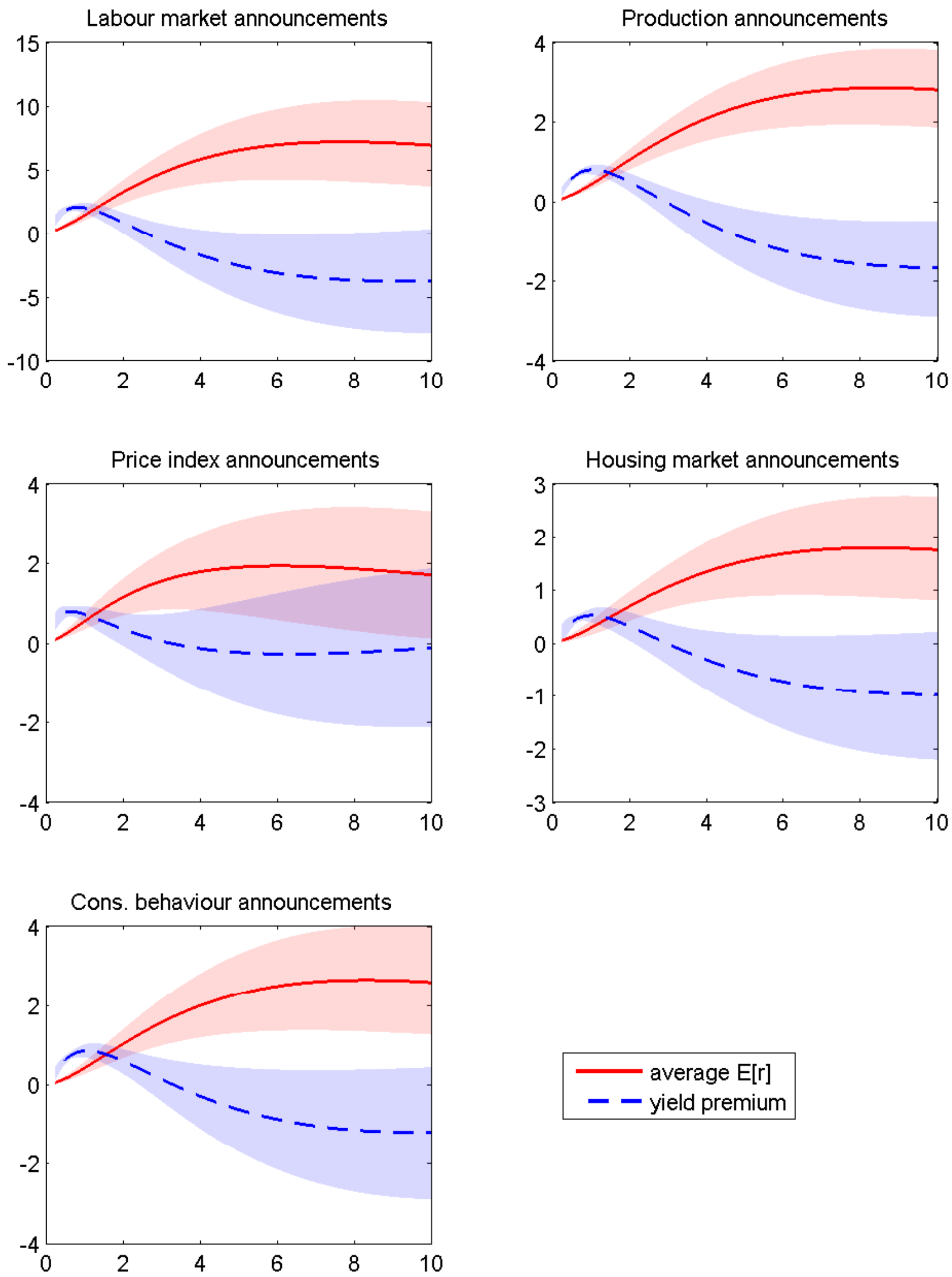
The curves show the model-implied responses of average expected short-term interest rates (solid curves) and of term (yield) premia (dashed curves) to changes in perceived inflation as a result of macroeconomic announcement surprises (one standard deviation). The vertical axis shows responses in basis points; the horizontal axis shows the maturity in years. Shaded areas represent 95 percent MC confidence bands based on 100,000 parameter draws,

Figure 8: Average expected short rate and term premium announcement responses due to changes in the inflation target



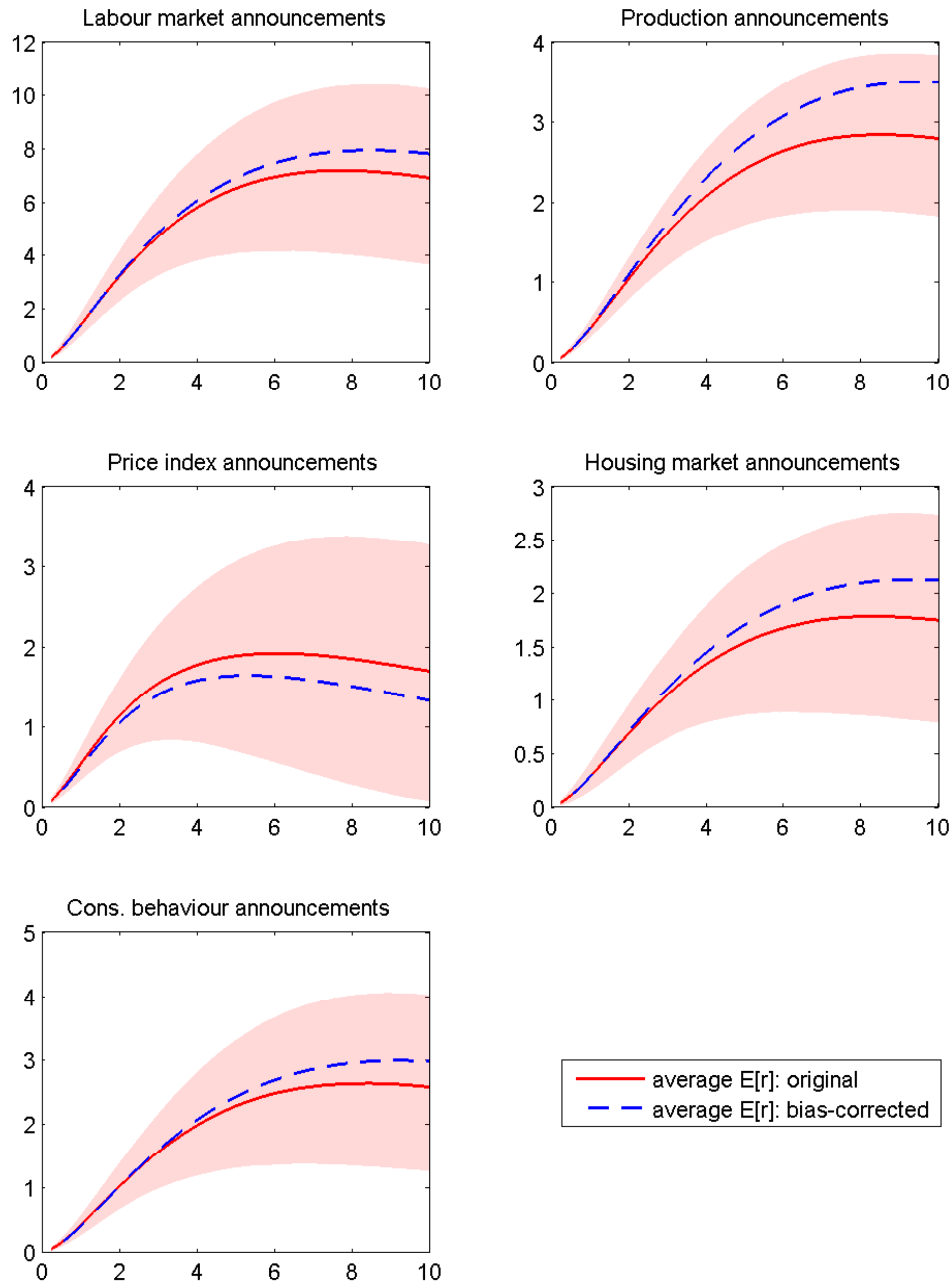
The curves show the model-implied responses of average expected short-term interest rates (solid curves) and of term (yield) premia (dashed curves) to changes in perceived inflation as a result of macroeconomic announcement surprises (one standard deviation). The vertical axis shows responses in basis points; the horizontal axis shows the maturity in years. Shaded areas represent 95 percent MC confidence bands based on 100,000 parameter draws,

Figure A1: Estimated responses of average expected short rate and term premium to announcement surprises



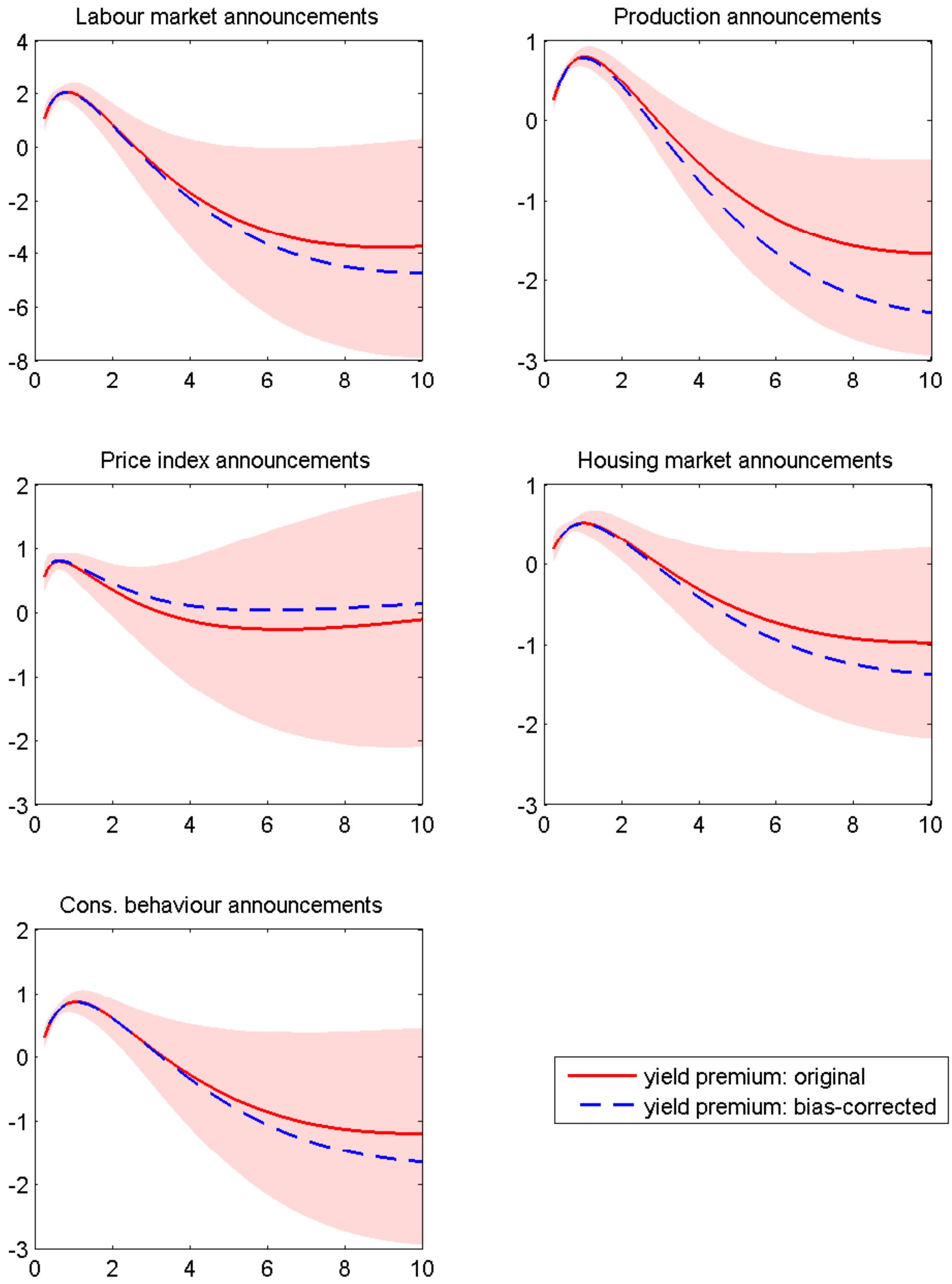
The solid curves show the model-implied responses of the term structure of average expected short rates (up to the horizon indicated on the horizontal axis) to macroeconomic announcement surprises (one standard deviation). The dashed curves represent the implied responses of the corresponding term (yield) premium. The vertical axis shows responses in basis points; the horizontal axis shows the maturity in years. Shaded areas represent 95 percent MC confidence bands based on 100,000 parameter draws,

Figure A2: Average expected short rate announcement responses: original baseline and bias-corrected estimates



The curves show the baseline estimates of model-implied average expected short-term interest rate responses (solid curves) to macroeconomic announcement surprises (one standard deviation) and 95 percent MC confidence bands based on 100,000 parameter draws. Dashed curves are median bias-corrected estimates based on ML estimation of the macro-finance model on 5,000 simulated samples and subsequent reestimation of the factor sensitivity parameters. The vertical axis shows responses in basis points; the horizontal axis shows the maturity in years.

Figure A3: Term premium announcement responses: original baseline and bias-corrected estimates



The curves show the baseline estimates of model-implied term premium responses (solid curves) to macroeconomic announcement surprises (one standard deviation) and 95 percent MC confidence bands based on 100,000 parameter draws. Dashed curves are median bias-corrected estimates based on ML estimation of the macro-finance model on 5,000 simulated samples and subsequent reestimation of the factor sensitivity parameters. The vertical axis shows responses in basis points; the horizontal axis shows the maturity in years.

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