Revisions to Short Rate Expectations: Policy Surprises and Macroeconomic News*

Michael D. Bauer[†]

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Abstract

How do interest rates react to monetary policy actions and macroeconomic news? The conventional event study approach has several shortcomings, and this paper presents an alternative framework to answer this question, based on a dynamic term structure model that recognizes the heterogeneity of news events. My approach imposes no-arbitrage, parsimoniously captures the revisions to the entire expected short rate path, and integrates the analysis of different types of news. Policy actions are found to affect the entire yield curve, and the impact does not decline with maturity as suggested by previous studies. The impact of macroeconomic announcements reflects the fact that policy inertia plays an important role in how markets form expectations. Policy news lead to more varied effects than macro news, indicating that markets are surprised along more than one dimension by actions of the Fed.

Keywords: Term structure of interest rates, news, monetary policy surprises, macroeconomic announcements, policy inertia

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†Department of Economics, University of California, San Diego. E-mail: mbauer@ucsd.edu

1 Introduction

How do monetary policy actions affect the term structure of interest rates? Because of its high relevance to both market participants and policymakers this question has commanded considerable interest among researchers. The Fed controls the overnight interest rate, but the monetary transmission mechanism works through changes in interest rates at all maturities. Hence the effectiveness of monetary policy crucially depends on whether and how the Fed can impact interest rates other than the short rate. In a seminal paper Kuttner (2001) employs federal funds futures to measure monetary policy surprises. Using event study regressions he finds a significant effect of the surprises on yields at short and medium maturities, which however declines quickly with maturity. Other studies employing similar approaches come to the same conclusions (Poole and Rasche, 2000; Rigobon and Sack, 2004; Gürkaynak et al., 2005a; Hamilton, 2008): Policy surprises do affect interest rates, but the impact seems to decline with maturity.

A related literature analyzes how macroeconomic news affect the term structure, prominent contributions being Fleming and Remolona (1997), Balduzzi et al. (2001) and Faust et al. (2007). These studies assess which macro announcements affect interest rates and what the sign and size of the responses are. The empirical approach is similar: Yield changes are regressed on surprise measures, and the equation is re-estimated for several maturities. These studies find that some macro news have an important impact on yields whereas others do not, and that the effects vary according to the maturity of the yields considered.

The regression approach employed in both strands of literature has some important shortcomings. Most importantly it does not uncover the effects of news events on the entire term structure, but only the effects on individual securities. The cross-sectional restrictions required by no-arbitrage are ignored. Imposing no-arbitrage is more attractive theoretically, but also entails important practical advantages such as improvements in statistical precision and the ability to predict responses of additional securities.

For the case of monetary policy analysis, the regression approach is particularly problematic. The surprise measure, which is derived from changes in money market futures rates, and the dependent variable, usually the change in a bond yield, are both determined by the average change in the forward rate curve over a particular horizon. These regressions thus simply estimate the comovement between changes in forward rates at different maturities. Since the short rate naturally has a transitory component, the finding of decreasing explanatory power in the yield regressions of Kuttner (2001) and others is not surprising. It does not tell us anything substantial about the effects of monetary policy on the term structure.

Another shortcoming of the existing literature is that so far there has been no integrated analysis of the effects of both policy and macro news on the term structure of interest rates. The regression approach cannot be used to systematically compare different types of news in a common framework. Relevant questions are: What are the most important sources of volatility? How are rates across maturities affected by different types of news? What are the differences, if any, in the effects of policy actions and macroeconomic news?

This paper proposes a new way to study how policy actions and macro news affect interest rates. The object of interest is the *revision to the expected future path of the short rate* under the risk-neutral measure, since it captures the effects of a news event on the entire term structure. In order to parsimoniously capture the "revision", which is an infinite-dimensional object, I employ a three-factor affine dynamic term structure model (DTSM). In addition to the advantages of imposing no-arbitrage, in particular the *reduction in dimensionality* that the cross-sectional restrictions achieve, this allows me to *integrate in a common framework* the news about monetary policy actions and the various kinds of macroeconomic news.

The key to integrating the different types of news is to explicitly account for the heterogeneity of these different sources of interest rate volatility. I achieve this by allowing the second moments of the model to depend on the "news regime", i.e. the type of the news event that occurs on a given day. This is a simple but effective way to assess and compare the differential impact of policy actions and different macro news on interest rates.

In this way the paper also makes a contribution to the term structure literature: The *conditional structure* of my DTSM allows to identify and describe the different sources of interest rate volatility. News about monetary policy and about the economy are the main drivers of changes in interest rates, however existing DTSMs treat all trading days in the same way, for example when estimating the "vol curve", the term structure of volatility.[1] My model provides separate estimates of the vol curve for different types of news events, which reveals interesting differences. The conditional character of the DTSM tells us what really moves the market, and in which way it moves the market.

The DTSM used in this paper differs from conventional models in a second way: Only the risk-neutral dynamics are made explicit, but no pricing Kernel is specified. The reason is that the model is used to capture the changes in interest rates, but is not required to decompose these changes into changes in risk premia and changes in physical expectations of future short rates. It is therefore unnecessary to make explicit the risk-adjustment. The risk-neutral dynamics are specified so that the factors can be identified as level, slope and

[1] This also holds for regime-switching models such as Bansal and Zhou (2002) and Monfort and Pegoraro (2007), since they do not condition on observable information, i.e. do not distinguish between trading days.

curvature, in the spirit of Christensen et al. (2007), which is convenient for estimation and interpretation of the results.

The paper shows that monetary policy generally has strong effects on the entire term structure. The volatility caused by policy actions reveals that long rates move just as much as short rates. Importantly the revisions show various different shapes: Some actions of the FOMC only move the short end of the yield curve and barely have an impact on longer rates, some have a hump-shaped impact, yet others leave the short end unchanged and move only long rates. My findings show that the impact of monetary policy does not decline with maturity as suggested by previous studies (Kuttner, 2001; Gürkaynak et al., 2005b,a), but instead that this impact strongly depends on the individual policy event, on average is hump-shaped, and causes significant movements in long rates.

A key result is that there is significant heterogeneity between different sources of interest rate volatility. The hypothesis of equal second moments on days with policy actions and on days with different types of macro news is strongly rejected. More specifically the differences are the following: First, on days with macro news releases the vol curve is steeper at the short end and more back-loaded than on policy days. This indicates that markets expect the Fed to only sluggishly adjust the short rate in response to new information and constitutes evidence of policy inertia. Second, among the different types of news I consider, new employment reports are by and far the most important source of interest rate volatility. Third, revisions show much stronger comovement across horizons on macro news days than on policy day. This makes intuitive sense because on days with macro releases there is only one piece of new information, the data surprise. On policy days, on the other hand, there are several pieces of news – the current target choice and the information in the FOMC statement – which independently affect the market's short rate expectations.

The fact that revisions in response to policy events come in various shapes parallels the findings of Gürkaynak et al. (2005b) who use principal component analysis to show that more than one factor is needed to describe monetary policy actions. Based on my model we can parsimoniously capture what happens on a policy day to the entire term structure, namely by describing the revision to the entire expected short rate path caused by the policy action. This is an improvement upon the target and path factors that Gürkaynak et al. (2005b) use to describe policy events, since it incorporates no-arbitrage and thus enables us to predict changes in yields and forward rates at any maturity. Based on this insight I develop a horizon-specific policy surprise measure and show its empirical success in predicting changes in the yield curve for U.S. treasury securities from near-term money market futures.

Finally the model provides a convenient and theoretically appealing framework for estimating the impact of macroeconomic announcements on the terms structure. Importantly, my estimates of the "term structure of announcement effects" are consistent with no-arbitrage. The key empirical findings: First, the case for policy inertia is strong. And second, the hypothesis of no response of far-ahead forward rates, which the DTSM allows me to test, is rejected for most announcements, supporting the "excess-sensitivity" evidence documented in Gürkaynak et al. (2005a).

The paper is structured as follows: The model is introduced and estimated in Section 2. Section 3 presents estimates of the term structure of volatility conditional on the type of news event. Section 4 assesses comovement of rate changes in response to news events. In Section 5, after illustrating some specific instances of policy actions, I develop a new measure for monetary policy surprises and document its empirical success. Section 6 estimates the effects of macroeconomic data surprises on the term structure. Section 7 concludes.

2 Term structure model and estimation

2.1 Risk-neutral dynamics

Denote the rate for an overnight default-free loan between days t and $t+1$, the short rate, by r_t.[2] It is assumed to be determined by three latent factors: $r_t = X_{1t} + X_{2t} + X_{3t}$. Assuming absence of arbitrage implies that there exists a risk-neutral measure $\mathbb{Q}$ that prices all assets. The factor dynamics under $\mathbb{Q}$ are specified as follows:

$$\begin{aligned} X_{1t} &= X_{1,t-1} + \varepsilon^{\mathbb{Q}}_{1t} \\ X_{2t} &= \rho X_{2,t-1} + \varepsilon^{\mathbb{Q}}_{2t} \\ X_{3t} &= \theta_1 X_{3,t-1} + \theta_2 X_{3,t-2} + \varepsilon^{\mathbb{Q}}_{3t} \end{aligned}$$

$$\varepsilon^{\mathbb{Q}}_t \overset{\mathbb{Q}}{\sim} N(0, V_{r(t)}), \quad E^{\mathbb{Q}}(\varepsilon^{\mathbb{Q}}_r \varepsilon^{\mathbb{Q}\prime}_s) = 0, \, r \neq s$$

where $\varepsilon^{\mathbb{Q}}_t = (\varepsilon^{\mathbb{Q}}_{1t}, \varepsilon^{\mathbb{Q}}_{2t}, \varepsilon^{\mathbb{Q}}_{3t})'$ is a martingale difference sequence (m.d.s.) under $\mathbb{Q}$, and the parameters ρ, θ_1 and θ_2 satisfy stationarity restrictions.[3] Conventional DTSMs usually include three factors, since these explain the vast majority of variation in bond yields (Litterman

[2] I abstract from the facts that the overnight rate in the U.S., the effective fed funds rate, deviates from the target set by the monetary authority, and that the target has a step-function character. Both simplifications are inconsequential since I do not include observations of the short rate – inference is based on observed futures rates, which corresponds to average forward rates over a month (fed funds futures) or a quarter (Eurodollar futures).

[3] For the AR(1) process the restriction is $|\rho| < 1$. For the AR(2) process stationarity requires $|\theta_2| < 1$, $\theta_2 + \theta_1 < 1$ and $\theta_2 - \theta_1 < 1$, see Marmol (1995). I also assume that the roots of the AR(2) process are real.

and Scheinkman, 1991; Balduzzi et al., 1996). The specification here implies that the three factors are a priori identified as level, slope and curvature, in the spirit of Christensen et al. (2007). The first factor, which follows a random walk, corresponds to a level factor since shocks change expected future short rates at all horizons by the same amount. Empirically, far-ahead forward rates show a lot of variability (Gürkaynak et al., 2005b), which suggests that the short rate should have a unit root under $\mathbb{Q}$, since otherwise the model would imply that these forward rates are close to constant. The second factor serves as a slope factor since the effect of a shock declines with the horizon. The third factor has a hump-shaped impulse-response function, provided that the roots are sufficiently close to one. As noted by Backus et al. (1999), yield dynamics are hump-shaped, which is also evident from the shape of the term structure of volatility (Piazzesi, 2005). Hump-shaped dynamics can be generated either by an AR(2) factor[4] or by having a "central tendency" structure, where one factor reverts to another (Balduzzi et al., 1998; Christensen et al., 2007). Compared to existing models, our factor dynamics are most similar to those of Christensen et al. (2007), with the differences that their model includes a central tendency and is in continuous time.

The key novelty in the above specification is the inclusion of observable variance regimes: The shocks $\varepsilon_t^{\mathbb{Q}}$ have a time-varying variance-covariance matrix $V_{r(t)}$. The function $r(t)$ maps the calendar day t into one of R different variance regimes, according to the type of news that take place on that day. Specifically, we will set $R = 4$, the four regimes being FOMC announcement days, BLS employment report days, CPI/PPI days, and days with new retail sales data.[5] This formalizes the idea that market participants know what type of news occur on each day, thus I speak of "observable variance regimes". Note the difference between this approach and "regime-switching" term structure models such as the ones of Bansal and Zhou (2002) and Monfort and Pegoraro (2007): Those models treat the state variable that determines the regime as unobservable, whereas in our context everybody can observe which type of news event takes place on a given day and thus knows the value of the state variable. This greatly simplifies modeling and estimation, and is an obvious modeling choice if the goal is to condition on the different sources of news.

[4]Another example of a term structure model that includes an AR(2) factor is the one of Startz and Tsang (2007).

[5]This assumes that only one event takes place on a given day, whereas in reality some days have more than one major news events. However these days are few in number, hence this simplifying assumption is inconsequential. The use of intraday data is a way to improve the precision of the estimates, however I leave this to future work.

2.2 Revisions to short rate expectations

The expected path of the short rate under $\mathbb{Q}$ determines the entire term structure at a specific date. For the forward rate contracted at date t for a loan from $t+n$ to $t+n+1$ we have $f_t^n = E_t^{\mathbb{Q}} r_{t+n}$, up to Jensen inequality terms.[6] Yields, forward rates, and money market futures rates, which will be considered in more detail below, are simply averages of these one-day forward rates. New information that moves the term structure is captured by the revision to the expected short rate path under $\mathbb{Q}$, that is

$$\{(E_t^{\mathbb{Q}} - E_{t-1}^{\mathbb{Q}}) r_{t+n}\}_{n=0}^{\infty},$$

which I simply call a "revision". Intuitively, this corresponds to the change in the forward rate curve, since $f_t^n - f_{t-1}^{n+1} = (E_t^{\mathbb{Q}} - E_{t-1}^{\mathbb{Q}}) r_{t+n}$. Changes in all interest rates are determined by the revision on that day, which incorporates both changes in short rate expectations under the physical measure and changes in risk premia.

The above specification of the $\mathbb{Q}$-dynamics leads to a simple closed-form solution for the revision:

$$(E_t^{\mathbb{Q}} - E_{t-1}^{\mathbb{Q}}) r_{t+n} = \begin{cases} \varepsilon_{1t}^{\mathbb{Q}} + \rho^n \varepsilon_{2t}^{\mathbb{Q}} + \frac{\phi_1^{n+1} - \phi_2^{n+1}}{\phi_1 - \phi_2} \varepsilon_{3t}^{\mathbb{Q}} & \phi_1 \neq \phi_2 \\ \varepsilon_{1t}^{\mathbb{Q}} + \rho^n \varepsilon_{2t}^{\mathbb{Q}} + (1+n) \phi_1^n \varepsilon_{3t}^{\mathbb{Q}} & \phi_1 = \phi_2, \end{cases} \tag{1}$$

where ϕ_1 and ϕ_2 are the roots of the characteristic equation of the AR(2) process. The derivation of these expressions is given in Appendix A. We see that a shock to X_{1t} leads to a parallel shift in the term structure, that shocks to X_{2t} die out exponentially, and that shocks to X_{3t} lead to a hump-shaped revision. Thus the shocks are naturally labeled level, slope and curvature shock, respectively.

2.3 Physical distribution of revisions

The revision is a linear combination of the risk-neutral innovations:

$$(E_t^{\mathbb{Q}} - E_{t-1}^{\mathbb{Q}}) r_{t+n} = b_n' \varepsilon_t^{\mathbb{Q}},$$

where b_n denotes the loadings on the factor shocks for the revision at horizon n, given in equation 1. Thus under $\mathbb{Q}$, revisions and thus rate changes are Gaussian m.d.s. with variance

[6] We can safely ignore these since we exclusively consider *daily changes* in interest rates, e.g. $f_t^n - f_{t-1}^{n+1}$. Thus we ignore only the difference in the Jensen inequality terms for maturities n and $n+1$, which is negligibly small. Furthermore for money market futures rates there are no Jensen inequality terms, since their payoffs are linear functions of future short rates.

$b_n' V_{r(t)} b_n$. If we were to specify a pricing Kernel, this would pin down the change of measure and provide us with the physical distribution of rate changes. This paper is not concerned with identifying and estimating risk premia, thus we can abstain from choosing a pricing Kernel and from estimating the physical factor dynamics, which is statistically challenging (Kim and Orphanides, 2005). However in order to estimate the model, we still need to specify the distribution of revisions under the real-world, physical measure $\mathbb{P}$.

The presence of risk premia generally leads to predictability of rate changes. Defining the forward risk premium $\Pi_t^n = (E_t^{\mathbb{Q}} - E_t) r_{t+n}$ we have

$$(E_t^{\mathbb{Q}} - E_{t-1}^{\mathbb{Q}}) r_{t+n} = (E_t - E_{t-1}) r_{t+n} + \Pi_t^n - \Pi_{t-1}^{n+1}.$$

Whereas the first component, the revision to $\mathbb{P}$-expectations, is a m.d.s. under $\mathbb{P}$, the change in forward risk premia, $\Pi_t^n - \Pi_{t-1}^{n+1}$, introduces drift and serial correlation.[7] In order to deal with the drift I allow the revisions to have non-zero mean, which can differ across maturities.

With regard to serial correlation, first note that the autocorrelation of daily changes in money market futures has been found to be very small and economically insignificant (Hamilton, 2007). More importantly though, the sample I use consists only of days with particular news events. Since between any two event days there are numerous days that are not included in the sample, rate changes in my sample do not exhibit any significant serial correlation (evidence not shown). Thus we can safely assume that rate changes are serially uncorrelated.[8]

Hence we obtain the following distributional properties of the revisions under $\mathbb{P}$:

$$(E_t^{\mathbb{Q}} - E_{t-1}^{\mathbb{Q}}) r_{t+n} = a_n + b_n' \varepsilon_t$$

$$\varepsilon_t \sim N(0, V_{r(t)}), \quad E(\varepsilon_r {\varepsilon_s}') = 0, \, r \neq s$$

Note that the physical innovations ε_t have the same variance-covariance matrix as the risk-neutral innovations, a consequence of the diffusion-invariance principle (Piazzesi, 2009). In sum, under the physical measure, revisions are Gaussian with mean a_n, no serial correlation and variance $b_n' V_{r(t)} b_n$.

[7] For the case of constant risk premia this term is a constant, possibly non-zero. If forward risk premia are on average increasing with maturity, which is intuitively and empirically plausible, we have $E(\Pi_t^n - \Pi_{t-1}^{n+1}) < 0$. In general we cannot assume that either mean or serial correlation are zero.

[8] Even if there was some serial correlation and our model was misspecified in this respect, we could still give a Quasi-Maximum-Likelihood interpretation to our estimates.

2.4 Money market futures

This paper uses money market futures, specifically federal funds futures and Eurodollar futures, for parameter estimation and all subsequent empirical analysis. These instruments are very liquid and provide a detailed picture of the forward rate curve. News events are quickly reflected in futures rates, which is why these are often quoted in the financial press. Another advantage over using treasury yields is that we do not need to extract a zero curve and forward rates from observed bond prices, since rates for a fixed set of maturities are directly available.

Federal funds futures, which were introduced by the Chicago Board of Trade (CBOT) in October 1988, settle based on the average effective fed funds rate over the course of the contract month. Denote the futures rate at time t of the i-month-ahead contract by $FF_t^{(i)}$. Letting $m(t)$ be the day of the month corresponding to calendar day t, and M the number of days in a month (for simplicity assumed to be 31), settlement is based on the average short rate from $t + iM - m(t) + 1$ to $t + (i + 1)M - m(t)$, the settlement rate. The cost to enter the contract is zero and the payoff is proportional to the difference between the futures rate and the settlement rate.[9] Hence the pricing equation is

$$0 = E_t^{\mathbb{Q}} \left(FF_t^{(i)} - \frac{1}{M} \sum_{n=iM-m(t)+1}^{(i+1)M-m(t)} r_{t+n} \right) \tag{2}$$

and the daily change in the futures rate is accordingly determined by the average revision over the relevant horizon:

$$\Delta FF_t^{(i)} = M^{-1} \sum_{n=iM-m(t)+1}^{(i+1)M-m(t)} (a_n + b_n' \varepsilon_t) = \mu_{FFi} + h_{FFi,t}{}' \varepsilon_t \tag{3}$$

where μ_{FFi} and h_{FFi} are the averages of a_n and b_n, respectively. Note that μ_{FFi} is a parameter to be estimated, whereas $h_{FFi,t}$ is a vector of loadings determined by the parameters of the risk-neutral dynamics and depending on t through the day of the month.[10] An explicit expression for $h_{FFi,t}$ is given in Appendix B. I use the one- to six-month-ahead fed funds futures contracts, denoted by FF1 to FF6 – contracts of longer maturity are not sufficiently liquid.

Eurodollar futures show deep liquidity for contracts expiring several years in the future. These contracts settle based on the 3-month LIBOR rate on the settlement date, which is the

[9] Note that we ignore the effect of marking-to-market, i.e. the fact that payments are made before settlement, however the evidence of Piazzesi and Swanson (2008) indicates that this effect is likely to be negligible in our context.

[10] Both means and loadings depend on the day of the month $m(t)$. For μ_{FFi} it is safe to ignore this dependence since we simply want to capture the average rate change for each contract.

last day of the relevant quarter.[11] Denote by $ED_t^{(i)}$ the rate of the i-quarter-ahead Eurodollar futures contract.[12] Letting Q be the days in a quarter (taken to be equal to 91) and $q(t)$ the day of the quarter for calendar day t, the pricing equation is $0 = E_t^{\mathbb{Q}}\left(ED_t^{(i)} - L_{t+iQ-q(t)}\right)$, where $L_{t+iQ-q(t)}$ is the 3-month LIBOR rate at the end of the relevant quarter. If we abstract from the credit risk inherent in LIBOR loans[13], we have $L_t = \frac{1}{Q}\sum_{j=0}^{Q-1} E_t^{\mathbb{Q}} r_{t+j}$. Hence

$$0 = E_t^{\mathbb{Q}}\left(ED_t^{(i)} - \frac{1}{Q}\sum_{n=iQ-q(t)}^{(i+1)Q-q(t)-1} E_t^{\mathbb{Q}} r_{t+n}\right) \tag{4}$$

which closely parallels equation 2, thus the rate changes are given by essentially the same formula as for fed funds futures – M is replaced by Q and $m(t)$ by $q(t)$.[14] I denote the mean rate change by μ_{EDi} and the loading for this contract by $h_{EDi,t}$. The contracts I consider are the ones that settle on the last day of the current and the next 15 quarters, denoted by ED1 to ED16.

2.5 Data and Estimation Method

The sample contains days between October 1988 (when fed funds futures started trading) and June 2007 (just before the recent turmoil in financial markets began) that fall into one of four regimes. The first regime contains days with FOMC announcements[15], and the other three regimes are BLS employment reports, CPI/PPI releases, and releases of retail sales numbers. Days that would fall into more than one category are excluded. This results in a sample with 799 days, with 148 days in the first, 215 days in the second, 316 days in the third, and 120 days in the fourth regime. I choose these specific four regimes in order to see how policy actions and news about the employment situation, about inflation, and about aggregate demand differ in their impact on the yield curve.

[11] For more details on Eurodollar futures please refer to http://www.cmegroup.com/trading/interest-rates/stir/eurodollar_contract_specifications.html (accessed 09/15/09).

[12] To clarify my terminology: The "one-quarter-ahead" contract, ED1, is a bet on LIBOR at the end of the current quarter, which is determined by the average expected short rate over the next quarter. This next quarter should be understood as the settlement quarter, since it is the expected value of the short rate over the course of this quarter that matters for the payoff.

[13] The credit risk resulting from commitment to a specific counter-party for three months instead of rolling over daily loans at the fed funds rate is measured by the LIBOR-OIS spread. Before August 2007 this spread was small and little volatile, hence we can neglect credit risk in our analysis.

[14] There is the slight difference that the relevant short rate horizon for Eurodollar futures starts one day earlier, the reason being that this horizon starts at the end of the quarter preceding the settlement quarter, whereas for fed funds futures it starts at the first day of the settlement month.

[15] Until December 2004 these are identified by Gürkaynak et al. (2005a). For the remaining period we take the days of the FOMC press release.

The model parameters can be estimated using Maximum Likelihood Estimation (MLE). The focus on rate changes and the assumed absence of serial correlation leads to a particularly simple estimation procedure. As is common in term structure model estimation I introduce idiosyncratic pricing errors, denoted by η_t, because otherwise a low-dimensional factor model predicts a singular covariance matrix for higher-dimensional data. Denote by Y_t the vector with daily changes in the futures rates, measured in basis points: $Y_t = (\Delta FF_t^{(1)}, \ldots, \Delta FF_t^{(6)}, \Delta ED_t^{(1)}, \ldots, \Delta ED_t^{(16)})'$. The number of measurements is thus $m = 22$. The empirical specification is

$$\underset{(m\times 1)}{Y_t} = \underset{(m\times 1)}{\mu} + \underset{(m\times 3)}{H_t'}\underset{(3\times 1)}{\varepsilon_t} + \underset{(m\times 1)}{\eta_t}, \tag{5}$$

where $\mu = (\mu_{FF1}, \ldots, \mu_{FF6}, \mu_{ED1}, \ldots, \mu_{ED16})'$, and $H_t = (h_{FF1,t}, \ldots, h_{FF6,t}, h_{ED1,t}, \ldots, h_{ED16,t})$. The pricing errors are assumed to be a Gaussian vector m.d.s., independent of ε_t, with contemporaneous covariance matrix R which is diagonal. Under these assumptions Y_t is serially uncorrelated and multivariate normal with mean μ and covariance matrix $\Sigma_t = H_t' V_{r(t)} H_t + R$. The log-likelihood function is

$$\mathcal{L} = \sum_{t=1}^{T} -\frac{1}{2}\{T\log(2\pi) + \log(|\Sigma_t|) + (Y_t - \mu)'\Sigma_t^{-1}(Y_t - \mu)\}.$$

For the purpose of numerical optimization I reparameterize $\mathcal{L}$ in order to ensure that the estimates are within the admissible parameter space: A Cholesky decomposition ensures positive definiteness of V_r in each regime. For the autoregressive root I take $\rho = \lambda^2/(1+\lambda^2)$, and similarly for ϕ_1 and ϕ_2. For the volatilities of the pricing errors I let $\sigma_{\eta,i} = e^{\zeta_i}$.

The four shock-covariance matrices V_1 to V_4 each have six unique elements, which amounts to 24 parameters. The other parameters to estimate are ϕ_1, ϕ_2, and ρ, as well as the 22 error variances and 22 means. The benchmark specification imposes $\phi_1 = \phi_2 = \rho$ and thus has 69 free parameters. The large number of parameters leads to a significant but manageable computational burden when numerically maximizing $\mathcal{L}$. Optimization is performed using simplex and a gradient-based algorithms in turn. I try several different starting values and each time reach the same global optimum. Thus, despite the large number of parameters, MLE is easily feasible. This stands in contrast to the problems that come with estimating the physical dynamics of a DTSM, which make it difficult to perform MLE in that context, as reported for example by Kim and Orphanides (2005), Duffee and Stanton (2008) and Duffee (2009). The fact that we focus on cross-sectional dynamics ($\mathbb{Q}$) and do not try to estimate dynamic properties of the short rate ($\mathbb{P}$) makes estimation a lot easier.

2.6 Parameter Estimates

Table 1 and Figures 1 and 2 show the estimation results. The table reports the estimates for ρ and for the shock volatilities and correlations in each of the four regimes. It also reports the energy contents of the three principal components for each shock covariance matrix V_r, as well as the log-likelihood values for the benchmark version of the model and for more and less restricted versions. I report in parentheses robust Quasi-Maximum-Likelihood standard errors as suggested by White (1982), obtained using numerical approximations for gradient and Hessian.

The shocks show important differences in variability and comovement across regimes. The shock variances are highest on days with a new employment report, and lowest on days with a new CPI or PPI report. Thus the release of a new employment report seems to have a bigger impact on short rate expectations than any other type of news event. Section 3 will consider vol curves and visualize the differences between regimes in terms of variability.

With regard to differences in comovement, the correlation between the shocks is generally higher on days with economic news than on policy days. This becomes particularly clear when we decompose the covariance matrix in each regime into its principal components (PCs) and show the energy content of each one: The first PC on policy days accounts for about 85% of the variance of the shocks, whereas for days with macro news the first PC accounts for 92-97% of the variability – factor shocks caused by macro news show stronger co-movement than shocks in response to policy news. Hence the revisions across maturities are more strongly correlated on news days, meaning that on days with macro news revisions tend to have more similar shapes than on days with policy actions. Section 4 will go into more detail about the differences in comovement that are implied by these estimates.

Are the differences between the news regimes statistically significant? In order to test the hypothesis $V_1 = V_2 = V_3 = V_4$ the model is re-estimated under this restriction ("equal V_r's"). Imposing this restriction leads to a significantly worse fit for the data. The log-likelihood is lower by about 187, which implies a likelihood-ratio statistic of 374. The number of restrictions and thus the degrees of freedom of the relevant Chi-square distribution is 18, leading to a minuscule p-value, hence we strongly reject the null of equal covariance matrices across regimes. The innovations to the term structure factors, i.e. the sources of interest rate volatility, have significantly different properties depending on the type of news causing them. In other words, the different sources of news show significant heterogeneity with regard to their impact on the term structure of interest rates.

For the AR(1) coefficient ρ we obtain an estimate of 0.9973. It is close to one because otherwise shocks to the transitory components would die out very quickly. The restriction that the roots of the AR(2) process, ϕ_1 and ϕ_2, are equal to ρ is not rejected, as is evident from the log-likelihood value for the unrestricted version of the model (reported on the bottom as "different roots").

Figure 1 shows estimates of the elements of μ, the mean rate changes for each contract, together with 95%-confidence intervals. All are significantly negative, ranging from -0.2 to -1. This negative drift in forward risk premia makes sense based on the intuition that term premia are on average increasing with maturity, because rate changes imply a decrease in maturity by one day and thus a decrease in the average risk premium. The restriction that the mean rate change across futures contract is the same ("equal means") leads to a likelihood-ratio statistic of 50 and hence is rejected. The restriction that $\mu = 0$ ("zero means") leads to a test statistic of 58 and is also rejected.[16]

Figure 2 shows point estimates and 95%-confidence intervals for the volatilities of the pricing errors. They generally decrease with maturity: The model fits the observed rate changes increasingly well for longer maturities.

2.7 Reality check: Persistence of the federal funds rate

Does the specification of the short rate as difference stationary make empirical sense? Do the parameter estimates imply dynamic properties for the short rate that accord with the evidence? As a reality check for the plausibility of model specification and estimation results I compare the model's implications with the empirical properties of the effective federal funds rate. The empirical autocovariance function of quarterly changes in the average fed funds rate, measured in basis points, is calculated over the sample horizon Oct-1988 to Jun-2007 – using quarterly averages avoids the problems that come with the discrete nature of changes in the target. The model-implied autocovariance function of quarterly changes in the average short rate is calculated by means of a simulation based on the model specification and estimates.[17]

Figure 3 shows the result. It turns out that the model-implied variability and persistence properties correspond well to those of the actual short rate. The variance is roughly the same, around 2000. The first autocovariance is a bit higher in the data, but in the ball-park of the one implied by the model – both are between 1000 and 1500. Both autocovariance series

[16] The 5%-critical values are 32.7 and 33.9, respectively, corresponding to degrees of freedom of 22 and 23.

[17] There are some caveats, neither of which undermine the usefulness of this exercise: First the model needs to be estimated on all trading days. The slight serial correlation of rate changes that was mentioned above is ignored in this estimation – its magnitude is very small and not economically significant anyways. Furthermore when re-estimating the model I only use one variance regime for simplicity, since here we only care about the average short rate dynamics across regimes. Finally the change of measure is ignored: The short rate process is simulated as if the risk-neutral and physical measure coincide.

remain positive until five lags and then turn negative. Since signs and even magnitudes of autocovariances are in accordance with data on the federal funds rate, my specification for the short rate and its model-implied properties based on estimates using money market futures appear to be plausible.

3 Term structures of volatility

The term structure of volatility, or "vol curve", captures the volatility of rate changes across maturities. By allowing for heterogeneity in the sources of interest rate volatility, the model in this paper allows for a conditional assessment of the term structure of volatility: We can estimate different vol curves for each news regime, since the shock covariance matrix is allowed to vary depending on the news regime. The covariance matrix of futures rate changes is given by $\Sigma_t = H_t V_{r(t)} H_t' + R$. Denote the covariance matrix of futures rate changes in regime r by Σ_r.[18] The model-implied vol curve corresponds to the square root of Σ_r.

Figure 4 shows for each of the four different news regimes the empirical and model-implied volatilities of money market futures rates. The first row shows vol curves for Eurodollar futures and the second row for fed funds futures. Each of the four columns corresponds to a specific news event. The panels show sample standard deviations of daily rate changes in basis points for each contract, together with 95%-confidence intervals based on a Chi-square approximation. The thick black lines are the model-implied volatilities.

The term structure model successfully captures the empirical volatilities: The shapes of the vol curves are closely replicated by the model, with model-implied vol curves generally within the confidence intervals and close to the point estimates of the empirical vol curves. The model specification allows enough flexibility to capture the hump shape of the vol curve (the back and the tail of the snake, see Piazzesi, 2001) and high volatilities of long forward rates (Gürkaynak et al., 2005b).

3.1 The effects of monetary policy

On the days in the first news regime policy actions by the Federal Reserve were the only major source of news. Interest rates moved when the FOMC's decision about the target or the content of the FOMC statement surprised market participants. The vol curves in the first column of Figure 4 visualize the variability of revisions caused by policy actions and thus inform us about the effects of monetary policy.

[18] Since the loadings H_t and thus Σ_t depend on the day of the month and on the day of the quarter, these need to be averaged out in order to obtain Σ_r.

The Fed's actions clearly had a *significant impact on interest rates across the entire maturity spectrum*, which is evident from the large variability of revisions at all maturities on policy days. Particularly striking is that the Fed, by means of its actions and words, can affect the long end of the term structure as much as it can affect the short end: The longest Eurodollar futures contract (ED16) has a maturity of about four years and shows similar variability (about 7 basis points) as the fed funds futures contracts, which represent the short end of the vol curve. The impact of policy actions on short rate expectations is *strongest at a horizon of one to two years*, resulting in a distinct hump-shape.

These findings contrast with the conclusion suggested by Kuttner (2001) and Gürkaynak et al. (2005a) that the impact of monetary policy declines with maturity. These authors perform regressions of yield changes at different maturities on policy surprise measures, and find that regression coefficients and explanatory power (R^2) decline with maturity. However, this regression approach does not describe the impact of policy actions on the term structure, but instead estimates the correlation of rate changes at different maturities. Section 4.2 will show that my model reproduces these results, for which I will provide a new interpretation.

The bottom line is that Fed actions were highly effective in changing interest rates at all maturities. Since it is crucial for the transmission mechanism that the monetary authority can affect not only the overnight rate but also longer-term rates, the results indicate that monetary policy had potentially important effects on the economy.

3.2 Policy actions vs. macro news

Comparing interest rate volatility across news regimes, some important differences with regard to the level and the shape of the vol curves emerge. With regard to the level of volatility, futures rates are most volatile on days with a new employment report, evidenced by the high level of the vol curves in the second column. Evidently new information about the labor market is the biggest source of interest rate volatility, more important than news about monetary policy, the price level, or aggregate demand.

Considering the shape of the vol curves there is a striking difference between volatility caused by policy actions and volatility caused by macroeconomic news: On days with macroeconomic data releases the vol curves are steeply increasing at the short end and very back-loaded (the long end is at a higher level than the short end), resulting in a pronounced hump shape. On policy days however, futures rates at near-term and far-ahead horizons have similar volatility, and the hump shape is much less pronounced.

The shape of the vol curves corresponding to macro news constitutes evidence for policy inertia, the concept that changes in the stance of monetary policy are implemented by the

Fed by slowly adjusting the target rate towards the new desired level. Intuitively the hump shape is related to policy inertia because evidently market participants revise their short rate expectations by much less over the coming months than over longer horizons, indicating that they expect the Fed to act slowly in response to the news. Furthermore Piazzesi (2001) showed how the back of the snake, i.e. the hump shape, can be attributed to policy inertia in the context of a term structure model that incorporates monetary policy. Thus my evidence, the fact that macro news cause hump-shaped volatility, is distinctly in favor of policy inertia.

Notably my evidence stands in contrast to findings by Rudebusch (2006). We start from the same premise, namely that "changes in the path of expected future interest rates following the release of news about the state of the economy should reveal the degree of interest rate smoothing[19] because financial markets will expect an inertial central bank to distribute the policy rate changes over several periods" (p.26). The vol curves I estimate thus support the notion of policy inertia. Rudebusch however, based on a different empirical approach, concludes that the data speaks against policy inertia. Appendix C shows additional evidence in favor of policy inertia based on an approach more directly comparable to the one of Rudebusch and discusses possible reasons for the differences in our results.

The fact that vol curves on policy days are flatter and less hump-shaped than on days with macro news makes intuitive sense: On policy days, the Fed every so often surprises market participants with its choice of the target, as evidenced by Kuttner (2001), creating variability at the very short end of the term structure. This source of volatility pushes up the short end of the vol curve and accounts for the much flatter shape on policy days. My empirical analysis shows that the Fed not only creates volatility at the short end, but also has a significant impact on rates with longer maturities.

4 Comovement of forward rates

My framework allows us to compare the effects of news events also in terms of the comovement of rates at different maturities, since covariances are regime-dependent just like the vol curve. Stronger or weaker correlations across maturities tell us whether the revisions caused by a specific news event always look similar or whether they are rather varied in shape, and thus indicates whether there seem to be one or more independent sources of new information.

[19] Rudebusch uses the terms "interest rate smoothing" and "policy inertia interchangeably", whereas others, such as Piazzesi (2005) denote by "interest rate smoothing" the fact that the short rate is persistent, and use the term "policy inertia" to describe autocorrelated changes in the target federal funds rate, i.e. an inertial adjustment to the level desired by the Fed.

4.1 Principal component analysis

The comovement of the shocks to the term structure factors, measured by the off-diagonal elements of V_r, was shown in Section 2.6 to be stronger on days with macro news than on days with policy actions. The first PC accounts for the majority of variation in the shocks in the former case, whereas in the latter case the second PC contributes considerably to the variation.

Considering futures rates instead of shocks, note that the off-diagonal elements of the variance-covariance matrix of futures rate changes, Σ_r, measure the model-implied comovement of rates at different maturities, conditional on the news regime. A principal component analysis of this matrix[20] leads to the same conclusion as an analysis of the shock covariance matrix V_r. Stopping rules that help to determine the number of components describing common variance (Peres-Neto et al., 2005) imply that one component suffices on days with macro news, but that we need at least two components on policy days.[21]

The strong comovement of rate changes across the maturity spectrum implies that revisions caused by macro news usually come in similar shapes. Thus there seems to be one underlying source of volatility – a single factor is causing revisions. On the other hand the lower comovement on policy days indicates more varied shapes of revisions and thus independent sources of interest rate movements. This is consistent with the results of Gürkaynak et al. (2005a), who find that two factors are required to describe the variation in yields on days with policy actions.[22] However my analysis goes further in that it contrasts the effects of policy actions with the effects of macro news.

What causes the differences in comovement between regimes? If a particular news event usually has several pieces of new information which affect different parts of the term structure, then comovement in rate changes will be lower than for a news event with only one piece of information. On policy days markets learn the new target rate chosen by the Fed, as well as infer the Fed's intentions about future policy from the FOMC statement. The target decision affects the short end of the term structure, whereas the information in the statement affects medium and long maturities. This can create a variety of possible revisions to the expected short rate path, as I will further exemplify in Section 5.1, leading to lower comovement than on days with macro news.

[20] I also performed a principal component analysis of the empirical covariance matrix of the futures rate changes, conditional on the same news regimes. The same conclusions applied.

[21] The results are omitted for sake of brevity but can be obtained from the author upon request.

[22] These authors use a PCA of the empirical covariance matrix of changes in money market futures.

4.2 The regression approach reconsidered

The term structure model can be used to shed new light on the Kuttner-type regression approach common in the literature (Kuttner, 2001; Poole and Rasche, 2000; Gürkaynak et al., 2005b,a). I show that the model's implications are consistent with the regression results. Furthermore I provide a re-interpretation of the regression approach and use it to get another perspective on the differences between news regimes.

Let's consider regressions of rate changes in Eurodollar futures on a fed funds futures contract. I will use the FF3 contract, since it always has at least one FOMC meeting before delivery[23] and generally is a stronger measure of near-term policy surprises than the shortest contracts. This measure of the near-term policy surprise is closely related to the "Kuttner-shock", which is a scaled change in the spot-month fed funds futures contract. As is common in the literature, I separately regress, for each Eurodollar futures contract, the futures rate change on the surprise measure.

Figure 5 shows, separately for each news regime and for each contract, the estimated response coefficients with 95%-confidence intervals based on White standard errors, together with model-implied response coefficients. Also shown are empirical and model-implied R^2 for each regression. Appendix D shows the calculations underlying model-implied coefficients and R^2.

The model-implied results closely correspond to the empirical results – model-implied regression coefficients are within the empirical confidence intervals, and model-implied and empirical R^2 are very close to each other.[24] Thus, by capturing the second moments of revisions, the model in a sense encompasses the regression approach common in the literature.

The correlation between the near-term policy surprise and other rates always decreases with maturity. This makes intuitive sense: The surprise measure corresponds to the average revision of expected short rates over a specific horizon at the short end of the term structure. The dependent variables measure the average revision over longer horizons. Since the short rate has transitory components, revisions to expectations generally are less correlated the further apart the horizons are. Hence the finding of Kuttner-type regressions that explanatory power decreases with maturity are not surprising at all.

That R^2 decreases more quickly for revisions caused by policy actions than for macro news

[23]Because the fed funds rate has a step-function character and only changes its level essentially every six weeks, the specification for the shortest fed funds futures contracts suffers from the problem that no rate change might occur until delivery.

[24]This holds for regressions not only for Eurodollar futures rates but also for yields (as in Kuttner, 2001) and forward rates (as in Gürkaynak et al., 2005b), as evidenced by additional calculations which I do not report here for sake of brevity.

reflects our previous finding of generally lower comovement on policy days.

With regard to the regression coefficients, an interesting difference between policy news and macro news emerges. In the case of policy surprises the regression coefficients are generally decreasing with maturity, whereas for macro news they show a distinct hump-shape. We saw above that vol curves to some degree are hump-shaped. For the policy news regime this hump shape is not reflected by the response coefficients. This indicates that the near-term policy surprise does not capture the effect of policy actions on the term structure, corresponding to our result that one factor is not enough to capture policy news. However, the near-term surprise measure apparently does a decent job in signaling the entire revision resulting from macro news.

5 Measuring monetary policy surprises

This section considers in more detail the revisions to short rate expectations that are caused by policy actions, i.e. monetary policy surprises.[25]

First the consideration of some specific days will show the variety of possible policy surprises. Then I undertake the task of predicting changes in long-term interest rates using short-term money market futures, which has been at the heart of numerous previous studies, using a new measure of policy surprises that naturally follows from the framework of this paper.

5.1 Specific examples of monetary policy surprises

To capture a monetary policy surprise we need to describe the revision to the expected short rate path. The model allows to parsimoniously describe the revision in terms of the values of the innovations to the term structure factors. Based on observed rate changes we can infer these factor shocks using a linear projection, as described in Appendix E.

Figure 6 shows the impact of policy actions on four different dates. It shows actual changes in Eurodollar futures rates and fitted changes implied by the revision on that day. The dotted horizontal line indicates how the long-run expectation of the short rate has changed in response to the policy action. On all four days the target federal funds rate was increased by 25 basis points. On the dates shown in the top row, the FF1 rate increased by 10 and 8 bps respectively, whereas on the dates shown in the bottom row it did not change at all.

[25] The difference between "policy surprise" and a "policy shock" is that while both are unanticipated, the latter is also exogenous. Clearly the changes in interest rates caused by policy actions are endogenous to the current economic situation.

The revisions have very different shapes, indicating that the impact of monetary policy on the term structure differed significantly, which fits in with the evidence from above. Since Kuttner (2001) we know that the target rate change is not a useful measure for the policy surprise, and our graphs confirm this. Furthermore, the change in a near-term fed funds futures contract is not a good indication of what happens to the term structure either, evidenced by the differences between the left and right column. This exemplifies the conclusion of Gürkaynak et al. (2005a) and our evidence from the previous section.

The bottom line is that *the entire revision* needs to be considered in order to understand the effect of the policy action on a particular day. The strength of the model is that it provides a detailed yet parsimonious description of the policy surprise, imposing the absence of arbitrage. This is achieved by having an underlying factor model for the short rate and imposing that rate changes must be due to revisions to the expected short rate path.

5.2 A horizon-specific measure for policy surprises

Although we can describe the revision resulting from policy actions graphically, many situations will require a numeric measure that summarizes the policy surprise. The state of the art is the approach of Gürkaynak et al. (2005a), henceforth GSS, namely providing two numbers, the "target factor" and the "path factor", which are derived from near-term money market futures. These are simply the first two principal components of the futures rate changes, rotated such that the target factor has a unit impact on the nearest-term futures contract and that both factors have the same impact on the furthest-out futures contract. This approach has several shortcomings: First, by being simply a statistical summary of rate changes at the short end, it lacks the advantages of a term structure model. In particular, it does not imply changes of rates at arbitrary maturities that follow from no-arbitrage. Second, the measure is hard to interpret – it is not at all obvious what a specific number for the path factor means intuitively. Third, it leaves open the question of how we can construct a univariate summary of the policy surprise for a certain purpose.

The regression approach commonly employed in previous studies evaluates the predictive power of policy surprise measures, derived from near-term money market futures, for changes in yields and forward rates. There is a natural way to construct such a policy surprise measure based on the framework in this paper: First the entire revision to short rate expectations is inferred from changes in near-term money market futures. Then the predicted change in the relevant interest rate can be calculated for any desired maturity. Importantly, this is possible because the no-arbitrage assumption allows us to predict changes in any security price that depends on the future path of the short rate. The predicted change can be interpreted as a horizon-specific policy surprise measure.

I construct this measure of monetary policy surprises for each day in the sample with a policy action. In order to back out the latent shocks and thus the revision I use the contracts FF1 to FF6 and ED1 to ED4. To compare the results with those of previous studies, I calculate the target and path factor of GSS, based on the same information set. The dependent variables are daily changes in the FF1 and ED4 futures contracts (to show the characteristics of target and path factor), changes in constant-maturity treasury bond yields at maturities two, five and ten years, as well as changes in six-month forward rates for loans maturing in two, five and ten years. Note that for each dependent variable a different horizon of the revision matters and thus a different surprise measure is constructed.

My sample contains the FOMC announcement dates from October 1988 to June 2007, excluding as before observations with employment reports, CPI/PPI news or new retail sales, and now also those that do not have yield data available. This leaves us with 148 observations. Data on yields and forward rates are those of Gürkaynak et al. (2006).

Table 2 shows the results. Numbers in parentheses are White standard errors. The first three columns provide regression coefficients and R^2 for for regressions using only the target factor. The next four columns show the same for regressions using both target and path factors. These results are comparable to table 5 of GSS – differences result from the sample choice and the information set used to construct the factors. The first section of the table shows that in fact the target factor has a one-for-one impact on the one-month-ahead fed funds futures contract, that the factors are orthogonal, and that both factors have the same impact on the longest futures contract.

In the last three columns we see the predictive power of the horizon-specific policy surprise measure. First and foremost, the slope coefficients are all statistically significant at the 1% level, and larger than those on either target or path factor. Treasury yields show a strong and significant response to policy surprises when the surprise is measured as I suggest. Furthermore the explanatory power of the univariate policy surprise measure that I constructed is about as large as that of target and path factors taken together: A univariate regression with my horizon-specific measure for policy surprises as explanatory variable explains the same about of variation in yields and forward rates as a multivariate regression using the target and path factors of GSS. This results from the fact that my policy surprises are constructed specifically for the horizon under consideration.

The horizon-specific surprise measure proposed in this section can be used to predict changes in other securities, based on the fact that it captures the impact of the policy action on the expected short rate path. It does not only have intuitive appeal, but also is empirically successful when compared to target and path factors of GSS in terms of predictive power.

6 The impact of macroeconomic data surprises

Although there is agreement in the literature that macroeconomic announcements have an important impact on interest rates, "few studies examine their impact on the yield curve as a whole," as noted by Fleming and Remolona (1999, p. 1). These authors fill this gap by estimating the impact of announcements on yields of different maturities, in order to estimate the "term structure of announcement effects."[26] They find hump-shaped responses and attribute this to policy inertia. Gürkaynak et al. (2005b) perform a similar analysis, using forward rates instead of yields. The hump shape is clearly visible in their results as well, furthermore long forward rates react significantly to announcements. This is puzzling in the context of modern macro-models, and is thus termed "excess-sensitivity puzzle".

Regressing rate changes for different maturities separately on the macro surprise measure is unsatisfactory because it does not impose absence of arbitrage. This is not only a theoretical shortcoming, but also has two major practical disadvantages: First, without a term structure model that imposes no-arbitrage we cannot say anything about instruments other then the ones included in the regressions. Second, the separate regressions ignore cross-sectional restrictions which can help improve statistical precision.

My framework can provide estimates of the term structure of announcement effects based on a simple two-step procedure. The first step is to estimate the impact of a specific macro surprise, say a one standard deviation positive surprise in total payroll employment, on the latent factors. This is easily done by inferring the shocks for each day with macro news from futures rate changes (see Appendix E) and regressing each of the three shocks on the macro surprises.[27] The coefficients on the surprise measure in each of the three equations tell us the values of the three shocks that are typically associated with the specific macro surprise. In the second step we use these values to calculate the revision that is implied by these shock values. This "typical" revision corresponds to the term structure of announcement effects. Importantly, it is consistent with the absence of arbitrage.

I use data on six different macroeconomic data releases: Non-farm payroll employment, the unemployment rate, hourly earnings, Core CPI and Core PPI (Bureau of Labor Statistics,

[26]In the same paper the authors also develop a term structure model that incorporates the macro surprises and thus provides estimates of announcement effects that are consistent with no-arbitrage. My approach is fundamentally different in that no term structure factor is a priori identified with macro announcements.

[27]The regressions of all three shocks on the macro surprises constitute a system of Seemingly Unrelated Regressions (SUR). Since the explanatory variables are the same in each regression, equation-by-equation least squares is efficient in this case.

BLS) as well as retail sales (Department of Commerce). The sample consists of all days with at least one data release between October 1988 and June 2007, which did not have a policy action, i.e. an FOMC announcement. The surprise component in the data release is calculated as the difference between the actually released number and the value expected by the market. To measure the market expectation I take the median market forecast, which is compiled by Money Market Services the Friday before the announcement.[28] The impact of the data surprises is estimated by including a constant and all six surprise measures on the right-hand-side of the regressions, thus if there are several news releases on one day, their impact is singled out by estimating partial effects.

Table 3 shows the numerical results, including the response coefficients for the futures contracts FF2 and ED4 as well as for the two-year yield. Numbers in parentheses are White standard errors. All announcements have a significant effect on the short end of the term structure, evidenced by the response of the FF2 contract. Also, all announcements with the exception of Core PPI lead to significant responses of ED4 and the two-year yield. Based on these securities alone, the evidence suggests that there is a significant impact of all of these macro news on the term structure.

A more detailed and accurate answer requires consideration of the term structure of announcement effects. This is captured numerically by the responses of the shocks, shown in the last three columns of Table 3. The response of $\hat{\varepsilon}_{1t}$ measures the long-run response of short rate expectations, or "level impact" of the news, the response of $\hat{\varepsilon}_{2t}$ measures the "slope impact", and the response of $\hat{\varepsilon}_{3t}$ measures the "curvature impact." Figure 7 shows a graphical representation of these result: It plots the model-implied responses for all Eurodollar futures contracts, as well as the estimated long-run response. It also includes the estimated response coefficients and confidence intervals for separate regressions for each contract, corresponding to the conventional regression approach.

Comparing model-implied and unrestricted responses we see again that the model's restrictions seem empirically plausible: The no-arbitrage-restricted responses closely correspond to the unrestricted estimates of the response coefficients.

One obvious pattern in the responses is a distinct hump-shape. Most announcements show this pattern, leading to increasing responses up to maturities of one to two years, with a decreasing response thereafter. A curvature shock ε_{3t} leads to a hump-shaped revision, hence we see a hump shape in the term structure of announcement effects in those cases where this shock responds significantly to the data surprise.

[28] Rigobon and Sack (2006) advance some points why this surprise measure might be contaminated with a considerable amount of noise. It might pay off to use intra-day data in this context, and possibly to address the measurement bias problem with new econometric tools. I relegate both issues to possible future work.

Increasing response coefficients at the short end are evidence for policy inertia: The Fed is expected to act in response to the news, but not to immediately and fully adjust the target. Rather it will implement the new stance of monetary policy over a number of FOMC meetings, thus near-term responses are increasing in the horizon. The results here about the impact of macro news on short rate expectations add to the evidence on the term structures of volatility in Section 3 and make our case for policy inertia stronger.

Notably this analysis does not allow to distinguish between *intrinsic* and *extrinsic* policy inertia, as defined by Rudebusch (2006): The fact that markets expect a gradual response of the short rate to the macro news could be due either to an intentionally gradual adjustment on the part of the Fed (intrinsic inertia), or to persistence in the macroeconomic data (extrinsic inertia). If macroeconomic news is likely to be followed by news in the same direction, then even if the Fed immediately adjusts the fed funds rate to the new information, current macro news will predict subsequent changes in the short rate. In a recent study Hamilton et al. (2009) construct forecast of macro variables based on the news releases and in this way find some evidence for a deliberately measured pace of target rate changes on the part of the Fed, i.e. for intrinsic policy inertia.

The other important question is whether announcements move the long end of the term structure. My model allows us to assess this systematically by considering whether the release has a significant level impact. As we see in the right-most column of Table 3 this is the case for all announcements but the unemployment rate and hourly earnings. These two releases only move short rate expectations up to medium maturities, then their impact dies out. The unrestricted responses in Figure 7 also give some indication about the long-run impact of a specific announcement, however my approach allows us to actually *test* whether there are are long-run effects.

That most releases have a significant level impact is consistent with the excess-sensitivity puzzle of (Gürkaynak et al., 2005b). Our finding corroborates the evidence of these authors that forward rates do not revert to a natural rate, or differently put that the short rate under $\mathbb{Q}$ is not mean-reverting.

7 Conclusion

This paper introduces a coherent framework to describe and understand the impact of news on the term structure. The key question is: What are the effects of monetary policy surprises and macroeconomic announcements on interest rates? The framework integrates different types of news allowing for heterogenous sources of volatility. It is based on characterizing the revisions to the expected short rate path under the risk neutral measure that are caused by different news events.

The take-aways are: (1) The conventional regression approach of separately estimating the impact of some surprise measure on the rate of each instrument is not the right apparatus to assess the impact of news on the term structure. (2) Monetary policy actions affect the entire term structure, with the strongest impact at medium maturities. (3) Different policy actions vary greatly in their impact on interest rates, with these differences intuitively resulting from the independent pieces of information that markets receive. When measuring policy surprises, we thus need to take into account the relevant horizon. (4) Macroeconomic announcements differ in their impact on short rate expectations, but most lead to a strongly hump-shaped response and a significant long-run revision. (5) The evidence is clearly in favor of policy inertia: Market participants revise their expectations of the short rate in accordance with the Fed sluggishly adjusting its policy rate. (6) The hypothesis that far-ahead forward rates do not move in response to macro announcements is rejected for almost all data releases.

A valuable extension to this paper would be the use of intraday data in order to improve the precision of the estimates. In particular for monetary policy surprises we would like to make sure that the revision we estimate is the one caused by the policy action, and that there are no other confounding impacts. Considering tight windows around the policy announcements would corroborate our results about the effects of monetary policy on the term structure.

Another important task is to disentangle changes in short rate expectations from changes in term premia. This provides answers to other policy-relevant questions: How much of the volatility of observed rate changes is due to changes in short rate expectations? In response to specific news events, how did market participants revise their expectations of monetary policy? Do risk premia systematically respond to macro news, and if yes in which way? In my job market paper (Bauer, 2009) I perform this exercise, and I find that at high frequencies changes in forward rates are mainly due to changing short rate expectations. This substantiates that the observed rate changes in response to news events in fact do predominantly signal changes in the expected path of the policy rate.

References

Backus, David K., Chris I. Telmer, and Liuren Wu, “Design and Estimation of Affine Yield Models,” GSIA Working Papers 5, Carnegie Mellon University, Tepper School of Business November 1999.

Balduzzi, Pierluigi, E. J. Elton, and T. C. Green, "Economic News and Bond Prices: Evidence from the U.S. Treasury Market," *Journal of Financial and Quantitative Analysis*, December 2001, *36* (4), 523–544.

_ **, Sanjiv Ranjan Das, and Silverio Foresi**, "The Central Tendency: A Second Factor In Bond Yields," *The Review of Economics and Statistics*, February 1998, *80* (1), 62–72.

_ **,** _ **,** _ **, and Rangarajan Sundaram**, "A Simple Approach to Three-Factor Affine Term Structure Models," *Journal of Fixed Income*, December 1996, pp. 43–53.

Bansal, Ravi and Hao Zhou, "Term Structure of Interest Rates with Regime Shifts," *Journal of Finance*, October 2002, *57* (5), 1997–2043.

Bauer, Michael D., "Term Premia and the News," job market paper, University of California, San Diego Oct 2009.

Brockwell, Peter J. and Richard A. Davis, *Time Series: Theory and Methods*, second ed., Springer, 2006.

Christensen, Jens H.E., Francis X. Diebold, and Glenn D. Rudebusch, "The Affine Arbitrage-Free Class of Nelson-Siegel Term Structure Models," Working Paper Series 2007-20, Federal Reserve Bank of San Francisco 2007.

Duffee, Gregory R., "Forecasting with the Term Structure: the Role of No-Arbitrage," Working Paper 2009.

_ **and Richard H. Stanton**, "Evidence on Simulation Inference for Near Unit-Root Processes with Implications for Term Structure Estimation," *Journal of Financial Econometrics*, Winter 2008, *6* (1), 108–142.

Faust, Jon, John H. Rogers, Shing-Yi B. Wang, and Jonathan H. Wright, "The high-frequency response of exchange rates and interest rates to macroeconomic announcements," *Journal of Monetary Economics*, May 2007, *54* (4), 1051–1068.

Fleming, Michael J. and Eli M. Remolona, "What moves the bond market?," *Economic Policy Review*, 1997, (Dec), 31–50.

_ **and Eli M Remolona**, "The term structure of announcement effects," BIS Working Papers 71, Bank for International Settlements June 1999.

Gürkaynak, Refet S., Brian P. Sack, and Eric T. Swanson, "Do Actions Speak Louder Than Words? The Response of Asset Prices to Monetary Policy Actions and Statements," *International Journal of Central Banking*, May 2005, *1* (1), 55–93.

_ , _ , and _ , "The Sensitivity of Long-Term Interest Rates to Economic News: Evidence and Implications for Macroeconomic Models," *American Economic Review*, March 2005, *95* (1), 425–436.

_ , Brian Sack, and Jonathan H. Wright, "The U.S. Treasury yield curve: 1961 to the present," Finance and Economics Discussion Series 2006-28, Board of Governors of the Federal Reserve System (U.S.) 2006.

Hamilton, James D., "Daily Changes in Fed Funds Futures Prices," NBER Working Papers 13112, National Bureau of Economic Research, Inc May 2007.

_ , "Assessing monetary policy effects using daily federal funds futures contracts," *Federal Reserve Bank of St. Louis Review*, 2008, (Jul), 377–394.

_ , Seth Pruitt, and Scott C. Borger, "The Market-Perceived Monetary Policy Rule," working paper, University of California, San Diego Aug 2009.

Kim, Don H. and Athanasios Orphanides, "Term structure estimation with survey data on interest rate forecasts," Finance and Economics Discussion Series 2005-48, Board of Governors of the Federal Reserve System (U.S.) 2005.

Kuttner, Kenneth N., "Monetary Policy Surprises and Interest Rates: Evidence from the Fed Funds Futures Market," *Journal of Monetary Economics*, 2001, *47*, 523–544.

Litterman, Robert and J. Scheinkman, "Common Factors Affecting Bond Returns," *The Journal of Fixed Income*, June 1991, *1* (1), 54–61.

Marmol, Francesc, "The Stationarity Conditions for an AR(2) Process and Schur's Theorem," *Econometric Theory*, dec 1995, *11* (5), 1180–1182.

Monfort, Alain and Fulvio Pegoraro, "Switching VARMA Term Structure Models," *Journal of Financial Econometrics*, 2007, *5* (1), 105–153.

Peres-Neto, Pedro R., Donald A. Jackson, and Keith M. Somers, "How many principal components? stopping rules for determining the number of non-trivial axes revisited," *Computational Statistics & Data Analysis*, June 2005, *49* (4), 974–997.

Piazzesi, Monika, "An Econometric Model of the Yield Curve with Macroeconomic Jump Effects," NBER Working Papers 8246, National Bureau of Economic Research, Inc April 2001.

_ , "Bond Yields and the Federal Reserve," *Journal of Political Economy*, April 2005, *113* (2), 311–344.

_ , "Affine Term Structure Models," in Yacine Ait-Sahalia and Lars Hansen, eds., *Handbook of Financial Econometrics*, Vol. 1, Elsevier, 2009, chapter 12.

_ **and Eric T. Swanson**, "Futures prices as risk-adjusted forecasts of monetary policy," *Journal of Monetary Economics*, May 2008, *55* (4), 677–691.

Poole, William and Robert H. Rasche, "Perfecting the Market's Knowledge of Monetary Policy," *Journal of Financial Services Research*, 2000, *18* (2/3), 255–298.

Rigobon, Roberto and Brian Sack, "The impact of monetary policy on asset prices," *Journal of Monetary Economics*, November 2004, *51* (8), 1553–1575.

_ **and** _ , "Noisy Macroeconomic Announcements, Monetary Policy, and Asset Prices," NBER Working Papers 12420, National Bureau of Economic Research, Inc August 2006.

Rudebusch, Glenn D., "Monetary Policy Inertia: Fact or Fiction?," *International Journal of Central Banking*, December 2006, *2* (4).

Startz, Richard and Kwok Ping Tsang, "The Yield Curve through Time and Across Maturities," Working Papers UWEC-2007-05, University of Washington, Department of Economics March 2007.

White, Halbert, "Maximum Likelihood Estimation of Misspecified Models," *Econometrica*, January 1982, *50* (1), 1–25.

A Revision to short rate expectations

We need to find $(E_t^{\mathbb{Q}} - E_{t-1}^{\mathbb{Q}})r_{t+n} = (E_t^{\mathbb{Q}} - E_{t-1}^{\mathbb{Q}})(X_{1,t+n} + X_{2,t+n} + X_{3,t+n})$. For the level factor, which follows a random walk without drift, we simply have

$$(E_t^{\mathbb{Q}} - E_{t-1}^{\mathbb{Q}})X_{1,t+n} = \varepsilon_{1t}^{\mathbb{Q}}.$$

For the slope factor, which follows an AR(1) process, the moving-average (MA) representation is $X_{2t} = \sum_{j=0}^{\infty} \rho^j \varepsilon_{2,t-j}^{\mathbb{Q}}$, hence we have

$$(E_t^{\mathbb{Q}} - E_{t-1}^{\mathbb{Q}})X_{2,t+n} = \rho^n \varepsilon_{2t}^{\mathbb{Q}}.$$

The curvature factor follows an AR(2) process, $X_{3t} = \theta_1 X_{3,t-1} + \theta_2 X_{3,t-2} + \varepsilon_{3t}^{\mathbb{Q}}$, which we rewrite as $(1 - \phi_1 L)(1 - \phi_2 L)X_{3t} = \varepsilon_{3t}^{\mathbb{Q}}$, where L is the Lag-operator. Denote by ϕ_1 and ϕ_2 the roots of the characteristic equation $y^2 - \theta_1 y - \theta_2 = 0$, which are related to the parameters by $\theta_1 = \phi_1 + \phi_2$ and $\theta_2 = -\phi_1\phi_2$. We want to find the MA-representation of X_{3t},

$$X_{3t} = \sum_{j=0}^{\infty} \psi_j \varepsilon_{3,t-j}^{\mathbb{Q}},$$

and for the Wold-coefficients ψ_j we have the difference equation $\psi_j = \theta_1 \psi_{j-1} + \theta_2 \psi_{j-2}$ with initial conditions $\psi_1 = \theta_1$ and $\psi_2 = \theta_1^2 + \theta_2$ (see Brockwell and Davis, 2006, p. 92). For the case that we have distinct real roots ϕ_1 and ϕ_2 the solution to this initial value problem is given by $\psi_j = (\phi_1^{n+1} - \phi_2^{n+1})/(\phi_1 - \phi_2)$ so that we obtain

$$(E_t^{\mathbb{Q}} - E_{t-1}^{\mathbb{Q}})X_{3,t+n} = \frac{\phi_1^{n+1} - \phi_2^{n+1}}{\phi_1 - \phi_2} \varepsilon_{3t}^{\mathbb{Q}}.$$

In the case that the roots are real and equal we get $\psi_j = (1+n)\phi_1^n$ and thus

$$(E_t^{\mathbb{Q}} - E_{t-1}^{\mathbb{Q}})X_{3,t+n} = (1+n)\phi_1^n \varepsilon_{3t}^{\mathbb{Q}}.$$

B Loadings of futures rate changes on factor shocks

Consider the loadings on the physical innovations ε_t of the rate change in the i-month-ahead fed funds futures contract, denoted by $h_{FFi,t} = (h_{FFi,t}^1, h_{FFi,t}^2, h_{FFi,t}^3)'$. The loading on the level shock is of course unity, i.e. $h^1_{FFi,t} = 1$. The loading on the slope shock is

$$\begin{aligned} h^2_{FFi,t} &= M^{-1} \sum_{n=iM-m(t)+1}^{(i+1)M-m(t)} \rho^n \\ &= \frac{\rho^{iM-m(t)+1}(1-\rho^M)}{M(1-\rho)}. \end{aligned}$$

For the loading on the curvature shock – we consider here only the case of equal roots – the average we need to calculate is

$$h^3_{FFi,t} = M^{-1} \sum_{n=iM-m(t)+1}^{(i+1)M-m(t)} (1+n)\rho^n$$

In order to find this average first consider the well-known summation formula for the geometric progression,

$$\sum_{k=m}^{n} r^k = \frac{r^m - r^{n+1}}{1-r},$$

and take the first derivative with respect to r to obtain

$$\sum_{k=m}^{n} k r^{k-1} = \frac{m r^{m-1} - (n+1)r^n}{1-r} + \frac{r^m - r^{n+1}}{(1-r)^2}.$$

This can be applied to our summation to yield

$$h^3_{FFi,t} = \frac{(iM - m(t) + 2)\rho^{iM-m(t)+1} - [(i+1)M - m(t) + 2]\rho^{(i+1)M-m(t)+1}}{M(1-\rho)} + \frac{\rho^{iM-m(t)+2}(1-\rho^M)}{M(1-\rho)^2}$$

The loadings for Eurodollar futures follow by analogy – simply replace M by Q, replace $m(t)$ by $q(t)$, and take the first and last period of the relevant horizon for the summations to be one day earlier than in the case for fed funds futures (see footnote 14).

C Additional evidence for policy inertia

One of the pieces of evidence presented in Rudebusch (2006) against the hypothesis of policy inertia is based on the following approach: Rudebusch calculates the ratio of 3-by-3-month forward rate to 3-month yield, based on intraday data on U.S. Treasury securities, for days with either a new employment report or new CPI data. In the case of policy inertia, the forward rate should move more strongly than the yield, and hence the ratio should usually be above one. Since the median and mean of this ratio are essentially equal to one in his sample, he concludes that "the case of little or no inertia is the relevant one" (p.29).

News	$\Delta ED_t^{(2)}/\Delta ED_t^{(1)}$			$\Delta ED_t^{(3)}/\Delta ED_t^{(1)}$			$\Delta ED_t^{(4)}/\Delta ED_t^{(1)}$			
	median	mean	(s.e.)	median	mean	(s.e.)	median	mean	(s.e.)	obs.
Empl. report	1.83	2.30	(0.20)	2.25	3.08	(0.30)	2.32	3.35	(0.38)	136
CPI/PPI	1.63	1.98	(0.16)	2.00	2.74	(0.27)	2.33	3.30	(0.33)	185
Retail sales	2.11	2.46	(0.22)	3.33	3.80	(0.45)	3.75	4.33	(0.57)	61
Pooled	1.78	2.17	(0.11)	2.26	3.03	(0.19)	2.50	3.48	(0.23)	382

Medians, means, and standard errors for the means for relative rate changes. means Sample: 10-1988 to 06-2007. I include only observations for which the denominator rate change is non-zero (using unity for the ratio when the denominator is zero still results in medians and means far above one).

The above table presents comparable evidence, using the rate changes in the Eurodollar futures contracts ED2 to ED4 relative to the change in the contract ED1. The median and mean of this ratio is in all subsamples far above one. Hence for the futures rate changes in my sample, the evidence is strongly in favor of policy inertia also using Rudebusch's approach, indicating that policy inertia is a fact rather than fiction.

How can the differences in our evidence be explained? Adjusting the sample window to the one used by Rudebusch does not change the qualitative results. The use of intraday data as opposed to my daily data is no likely candidate explanation, since the rate variation on the days under consideration is certainly caused to a large extent by the news event. The features of the yield data is the most likely explanation: Possibly 3-month and 6-month U.S. treasury securities move much more in lock-step than indicated by the expectations hypothesis, because of phenomena such as flight-to-security or hedging motives. The use of money market futures appears more likely to deliver reliable results.

D Regression coefficients and R^2 implied by the model

The population parameters for regressions of rate changes in Eurodollar futures contracts on rate changes in the FF3 contract are equal to the covariance between the two variables, divided by the variance of the fed funds futures rate changes. The coefficient of determination is simply the squared correlation. The model parameters imply both variances and covariances, and hence predict the regression coefficients and R^2. Importantly, these depend on the news regime through the factor covariance matrix V_r. In regime r, the model-implied regression coefficients and coefficients of determination for a regression of Eurodollar futures contract i on the contract FF3 are

$$\begin{aligned}\beta_i &= \frac{Cov(\Delta ED_t^{(i)}, \Delta FF_t^{(3)})}{Var(\Delta FF_t^{(3)})} = \frac{Cov(h'_{EDi}\varepsilon_t, h'_{FF3}\varepsilon_t)}{Var(h'_{FF3}\varepsilon_t + \eta_t^{FF3})} = \frac{h'_{EDi}V_r h_{FF3}}{h'_{FF3}V_r h_{FF3} + \sigma^2_{\eta,FF3}}, \text{ and} \\ R_i^2 &= \frac{(Cov(\Delta ED_t^{(i)}, \Delta FF_t^{(3)}))^2}{Var(\Delta ED_t^{(i)})Var(\Delta FF_t^{(3)})} = \frac{(h_{EDi}{}'V_r h_{FF3})^2}{(h_{FF3}{}'V_r h_{FF3} + \sigma^2_{\eta,FF3})(h_{EDi}{}'V_r h_{EDi} + \sigma^2_{\eta,EDi})}.\end{aligned}$$

Here $i = 1, \ldots, 16$, and η_t^{FF3} stands for the pricing error of FF3, which has a variance of $\sigma^2_{\eta,FF3}$, the square of the third diagonal element of R. The pricing error variances for the Eurodollar futures $\sigma^2_{\eta,EDi}$ correspond to the squares of the 7th to 22nd diagonal elements of R.

The above notation ignores that the loadings of the futures depend on the day of the month and the day of the quarter, and hence the regression coefficient is a different one for each combination of these. To obtain an unconditional regression coefficient, I simply average out the day of the month/quarter.

E Inference about latent shocks and the revisions

Given estimates of the model parameters the values of the latent shocks and thus the entire revision can be inferred from observed rate changes. Optimal inference about the latent shocks implies finding the conditional expectation of the shock vector given the data on day t, $E(\varepsilon_t|Y_t)$. Because of the normality assumption it can be calculated from a linear projection:

$$\begin{aligned}\hat{\varepsilon}_t = E(\varepsilon_t|Y_t) &= Cov(\varepsilon_t, Y_t)[Var(Y_t)]^{-1}(Y_t - \hat{\mu}) \\ &= V_{r(t)}H_t(H_t'V_{r(t)}H_t + R)^{-1}(Y_t - \hat{\mu}) \qquad (6)\end{aligned}$$

The fitted values for the futures rate changes are $\hat{\mu} + H_t'\hat{\varepsilon}_t$. The estimated revision to the $\mathbb{Q}$-expected short rate path is given by equation 1, where we substitute the estimated shocks for the unobserved errors. Note that we also have an estimate for the long-run revision $\lim_{n\to\infty}(E_t^{\mathbb{Q}} - E_{t-1}^{\mathbb{Q}})r_{t+n} = \varepsilon_{1t}$, which is simply equal to the level shock.

Table 1: Estimation results for benchmark model

Parameter	policy days	empl. report	CPI/PPI	retail sales
$\sigma_{\varepsilon,1}$	6.5434	10.0468	6.3384	8.2916
	(0.4992)	(0.6740)	(0.3060)	(0.9709)
$\sigma_{\varepsilon,2}$	9.9291	11.3830	7.2834	9.9564
	(1.3795)	(0.9379)	(0.3755)	(1.3312)
$\sigma_{\varepsilon,3}$	0.0415	0.0648	0.0379	0.0419
	(0.0038)	(0.0056)	(0.0028)	(0.0050)
$corr(\varepsilon_{1t}, \varepsilon_{2t})$	-0.6390	-0.8437	-0.8877	-0.9394
	(0.0962)	(0.0301)	(0.0223)	(0.0201)
$corr(\varepsilon_{1t}, \varepsilon_{3t})$	+0.2676	+0.5035	+0.2358	+0.2505
	(0.0883)	(0.0651)	(0.0565)	(0.0856)
$corr(\varepsilon_{2t}, \varepsilon_{3t})$	-0.3662	-0.5426	-0.4273	-0.3312
	(0.0662)	(0.0752)	(0.0596)	(0.0949)
Energy content				
1st PC	85.37%	92.32%	94.50%	97.07%
2nd PC	14.63%	7.68%	5.50%	2.93%
3rd PC	< 0.01%	< 0.01%	< 0.01%	< 0.01%
ρ	0.9973			
	(0.0001)			
Log-likelihood	-31,422			
Other models				
different roots	-31,422			
equal V_r's	-31,609			
equal means	-31,447			
zero means	-31,451			

I use fed funds futures contracts FF1 to FF6 and Eurodollar futures contracts ED1 to ED16 to estimate the model. The sample consists of days with news events from Oct-1988 to Jun-2007. The number of days is 799, with 148, 215, 316, and 120 days in each of the four news regimes. Numbers in parentheses are robust standard errors. Also reported is the energy content of each principal components for each of the shock covariance matrices V^1 to V^4, as well as the log-likelihood for the benchmark version of the model and for more and less restricted versions. For details please refer to text.

Table 2: Regressions of rate changes on different measures of monetary policy surprises.

	Target factor			**Target and path factors**				**Horizon-specific surprise**		
	const.	target	R^2	const.	target	path	R^2	const.	shock	R^2
Futures										
FF1	0.17	1.00*	0.93	0.17	1.00*	0.00	0.93			
	(0.15)	(0.03)		(0.14)	(0.03)	(0.01)				
ED4	-0.64	0.59*	0.18	-0.09	0.59*	0.59*	0.98			
	(0.60)	(0.16)		(0.09)	(0.02)	(0.01)				
yields										
two years	-0.21	0.46*	0.21	0.15	0.46*	0.38*	0.86	-0.12	0.83*	0.84
	(0.47)	(0.12)		(0.20)	(0.05)	(0.02)		(0.21)	(0.03)	
five years	-0.27	0.26	0.07	0.11	0.26*	0.40*	0.76	-0.06	0.83*	0.75
	(0.51)	(0.15)		(0.25)	(0.08)	(0.03)		(0.28)	(0.04)	
ten years	-0.33	0.13	0.02	-0.03	0.13	0.32*	0.60	-0.14	0.70*	0.59
	(0.46)	(0.12)		(0.29)	(0.07)	(0.03)		(0.31)	(0.06)	
forward rates (6mo)										
two years	-0.18	0.30	0.06	0.27	0.30*	0.48*	0.80	0.08	0.83*	0.79
	(0.60)	(0.16)		(0.28)	(0.07)	(0.03)		(0.29)	(0.04)	
five years	-0.36	0.07	< 0.01	-0.03	0.07	0.35*	0.50	-0.12	0.77*	0.48
	(0.49)	(0.14)		(0.34)	(0.10)	(0.05)		(0.39)	(0.06)	
ten years	-0.45	-0.04	< 0.01	-0.28	-0.04	0.18*	0.20	-0.24	0.40*	0.17
	(0.47)	(0.07)		(0.42)	(0.06)	(0.04)		(0.42)	(0.08)	

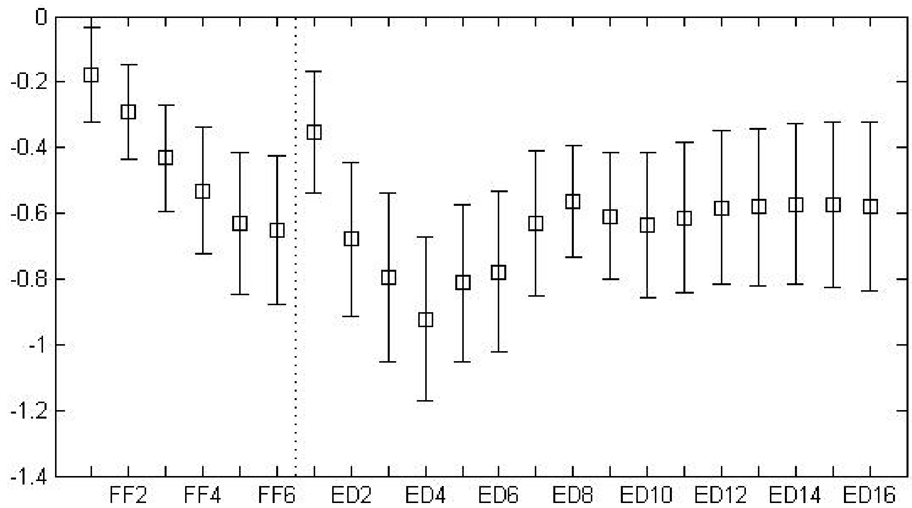
The number of observations is 148. Numbers in parentheses are White standard errors. * denotes statistical significance at the 1% level. Forward rates are for six-month loans ending at the specified maturities. For explanation of target and path factors refer to text and Gürkaynak et al. (2005a). Horizon-specific policy surprise measure is calculated as average estimated revision over relevant horizons (details see text). Policy surprise measures are inferred from information set including fed funds futures contracts FF1 to FF6 and Eurodollar futures contracts ED1 to ED4.

Table 3: Effects of macroeconomic announcements

News release	FF2	ED4	2y yield	$\hat{\varepsilon}_{1t}$	$\hat{\varepsilon}_{2t}$	$\hat{\varepsilon}_{3t}$
Non-farm payroll employment	3.09**	8.11**	5.82**	3.76**	-3.48**	0.04**
	(0.35)	(0.88)	(0.59)	(0.67)	(1.00)	(0.01)
Unemployment rate	-1.30**	-1.91*	-1.44**	-0.33	-0.89	-0.01
	(0.33)	(0.74)	(0.51)	(0.62)	(0.80)	(0.00)
Hourly earnings	0.85**	2.42**	1.86**	1.34	-1.64	0.01**
	(0.26)	(0.81)	(0.58)	(0.73)	(0.95)	(0.00)
Core CPI	1.02**	2.58**	2.08**	1.83**	-1.51**	0.01**
	(0.23)	(0.63)	(0.48)	(0.52)	(0.57)	(0.00)
Core PPI	0.45*	1.06	0.54	1.27**	-0.86	-0.00
	(0.19)	(0.59)	(0.48)	(0.47)	(0.56)	(0.00)
Retail sales	0.84**	3.14**	2.38**	1.62**	-2.14**	0.02**
	(0.23)	(0.65)	(0.50)	(0.55)	(0.62)	(0.00)

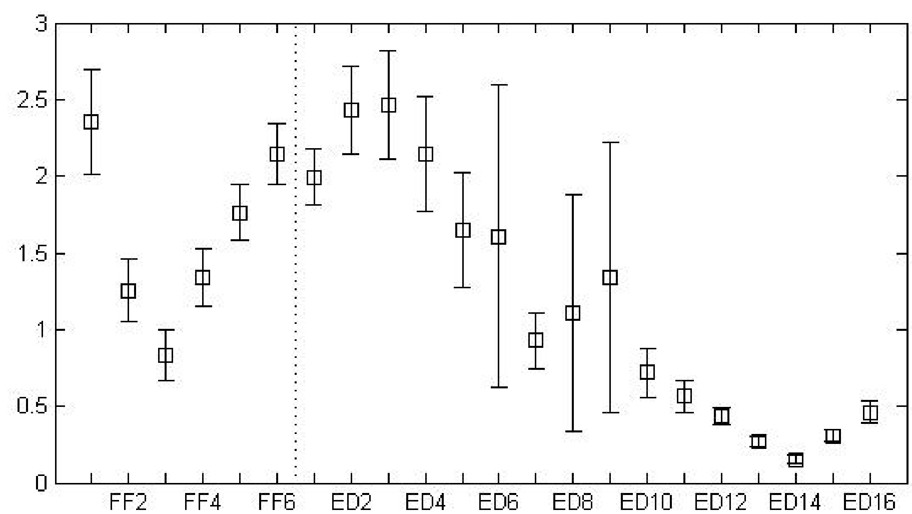
Responses of instrument rates and term structure shocks to a one-standard-deviation surprise in six different macroeconomic data releases. Sample: Days with at least one macroeconomic announcement but without policy action, Oct-1988 to Jun-2007, $N = 647$. Numbers in parentheses are White standard errors. * and ** denote significance at 5% and 1% level, respectively.

Figure 1: Estimated means of futures rate changes



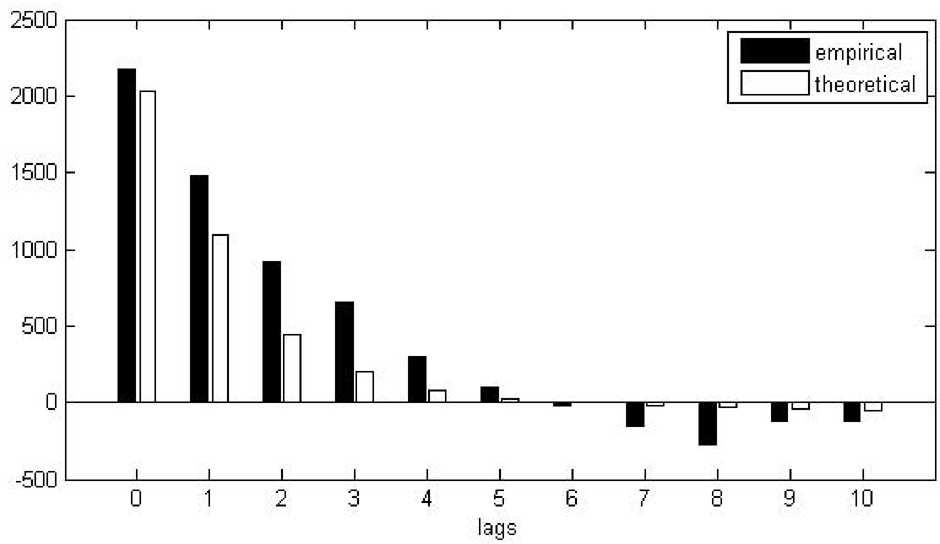
Estimated means of rate changes of money market futures, together with 95%-confidence intervals based on Quasi-Maximum-Likelihood standard errors, for benchmark specification of the model.

Figure 2: Estimated volatilities of pricing errors



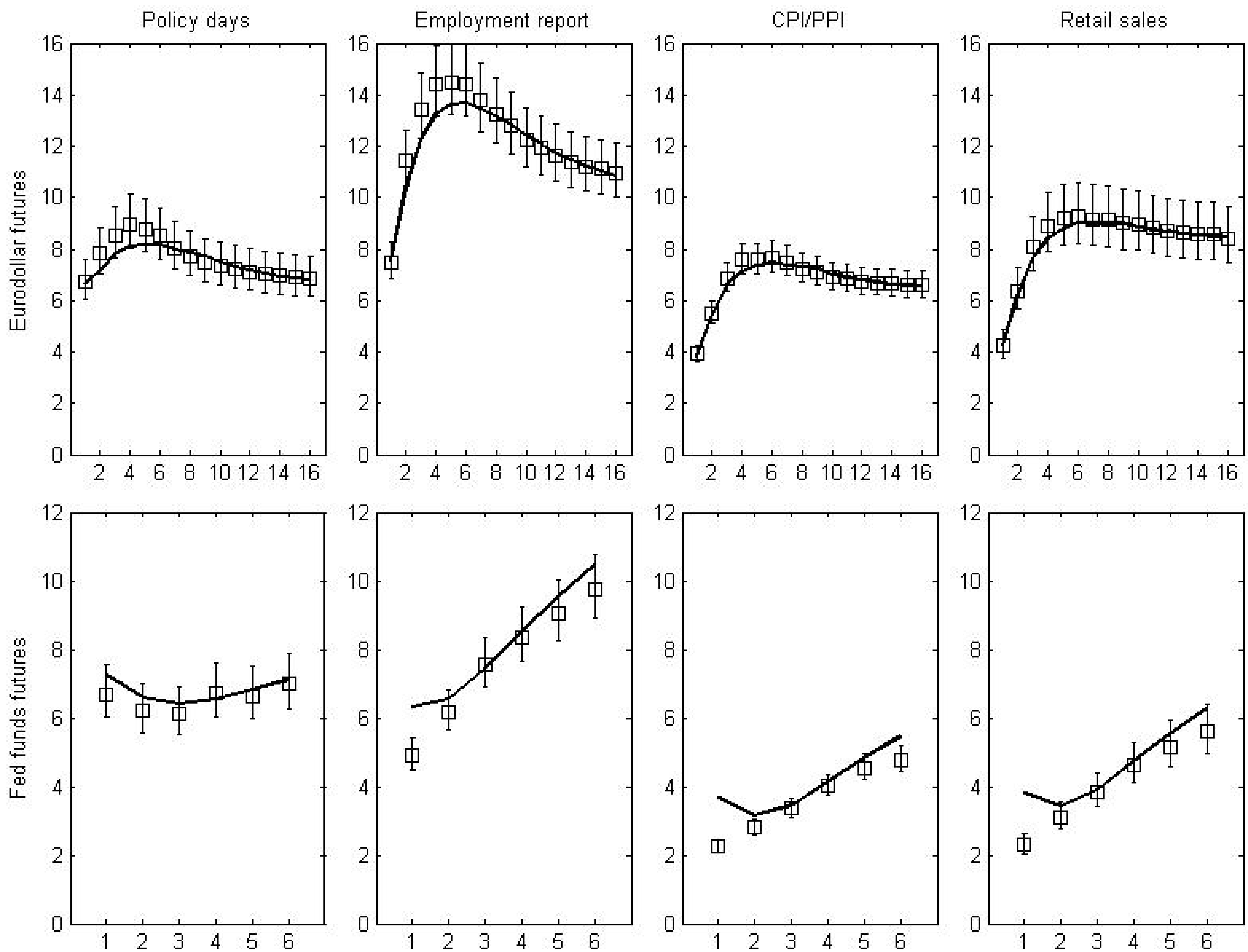
Estimated volatilities of pricing errors together with 95%-confidence intervals based on Quasi-Maximum-Likelihood standard errors, for benchmark specification of the model.

Figure 3: Reality check: Empirical vs. model-implied autocovariances of the short rate



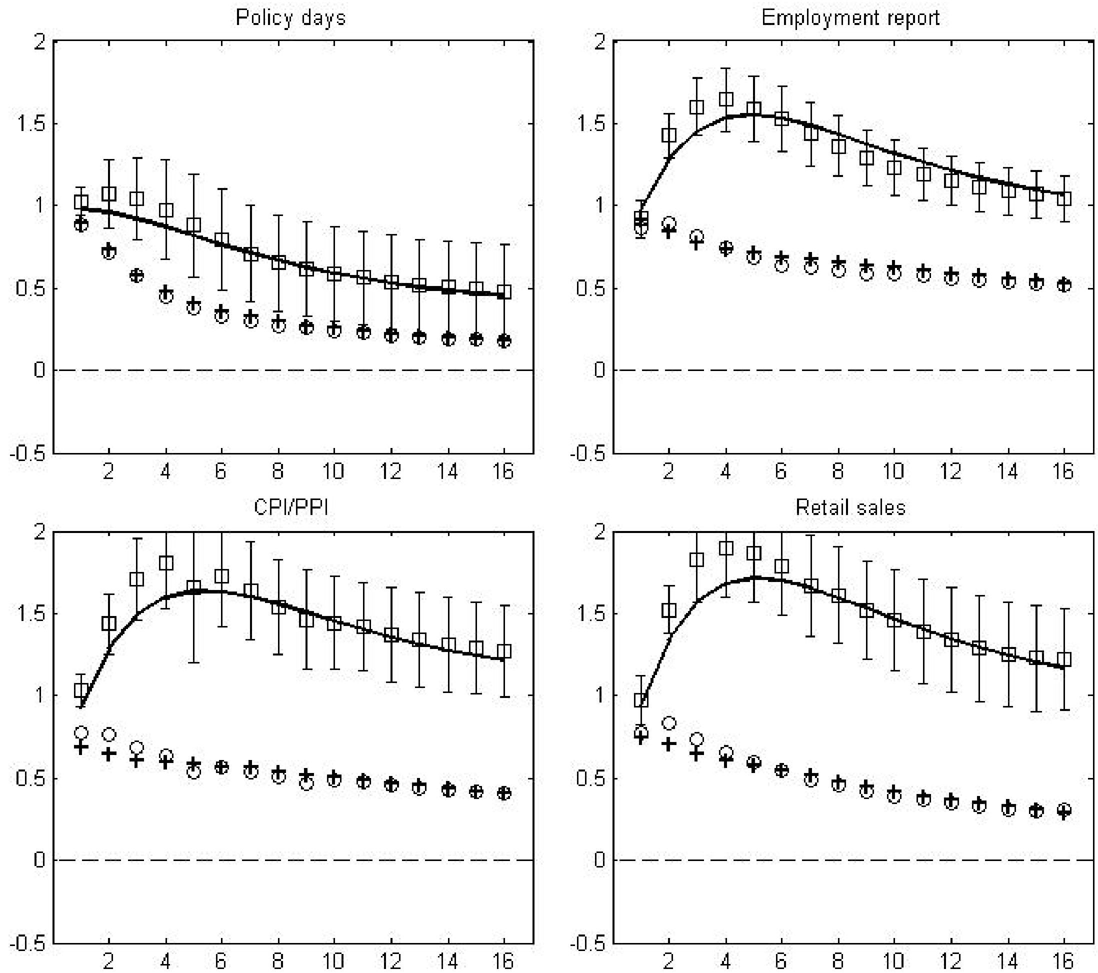
Autocovariances of changes in the average quarterly short rate. Empirical autocovariances are for the effective federal funds rate from Oct-1988 to Jun-2007. Theoretical autocovariances are based on the model-implied short rate process.

Figure 4: Vol curves of money market futures in the four different news regimes



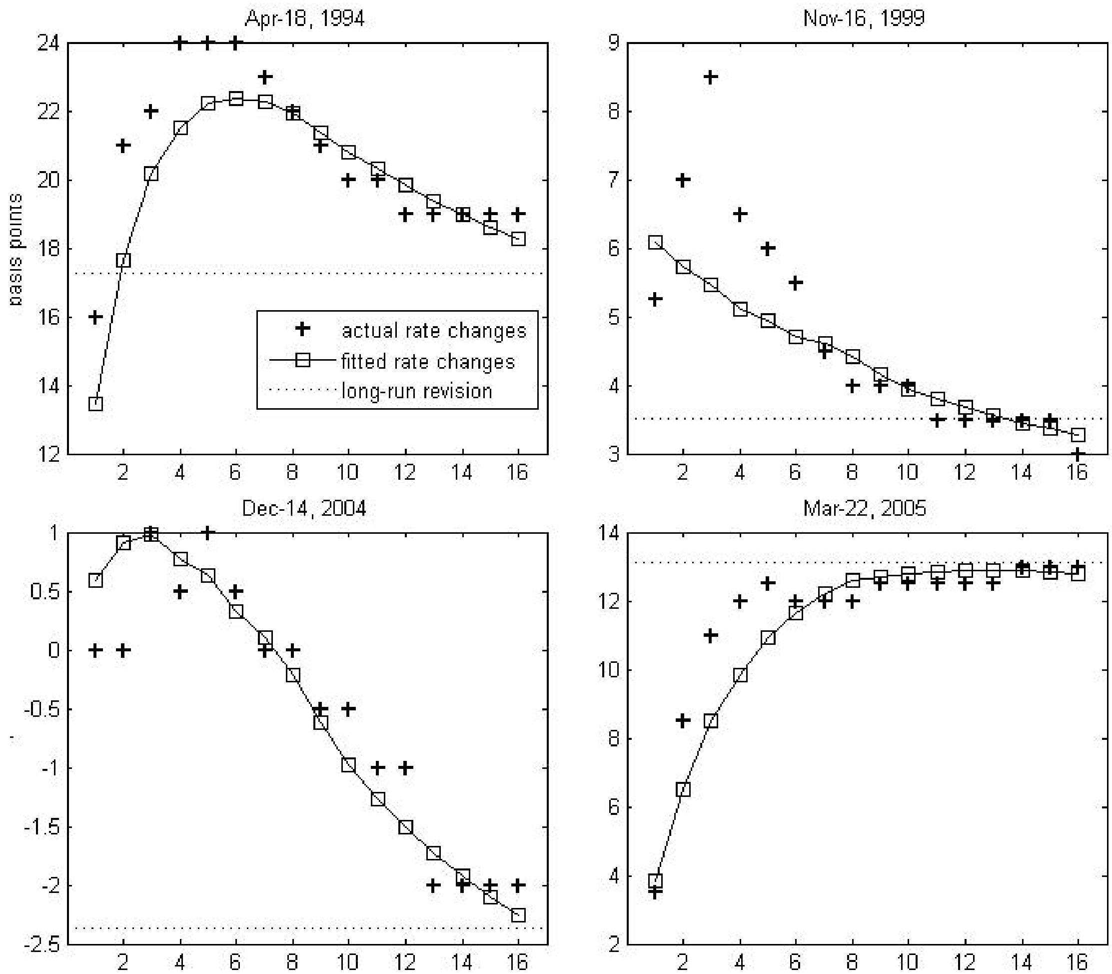
Empirical volatilities (sample standard deviations) with 95%-confidence intervals as well as model-implied volatilities for daily changes in Eurodollar futures rates and fed funds futures rates (in basis points) in each of the four news regimes.

Figure 5: Empirical and model-implied results for the traditional regression approach



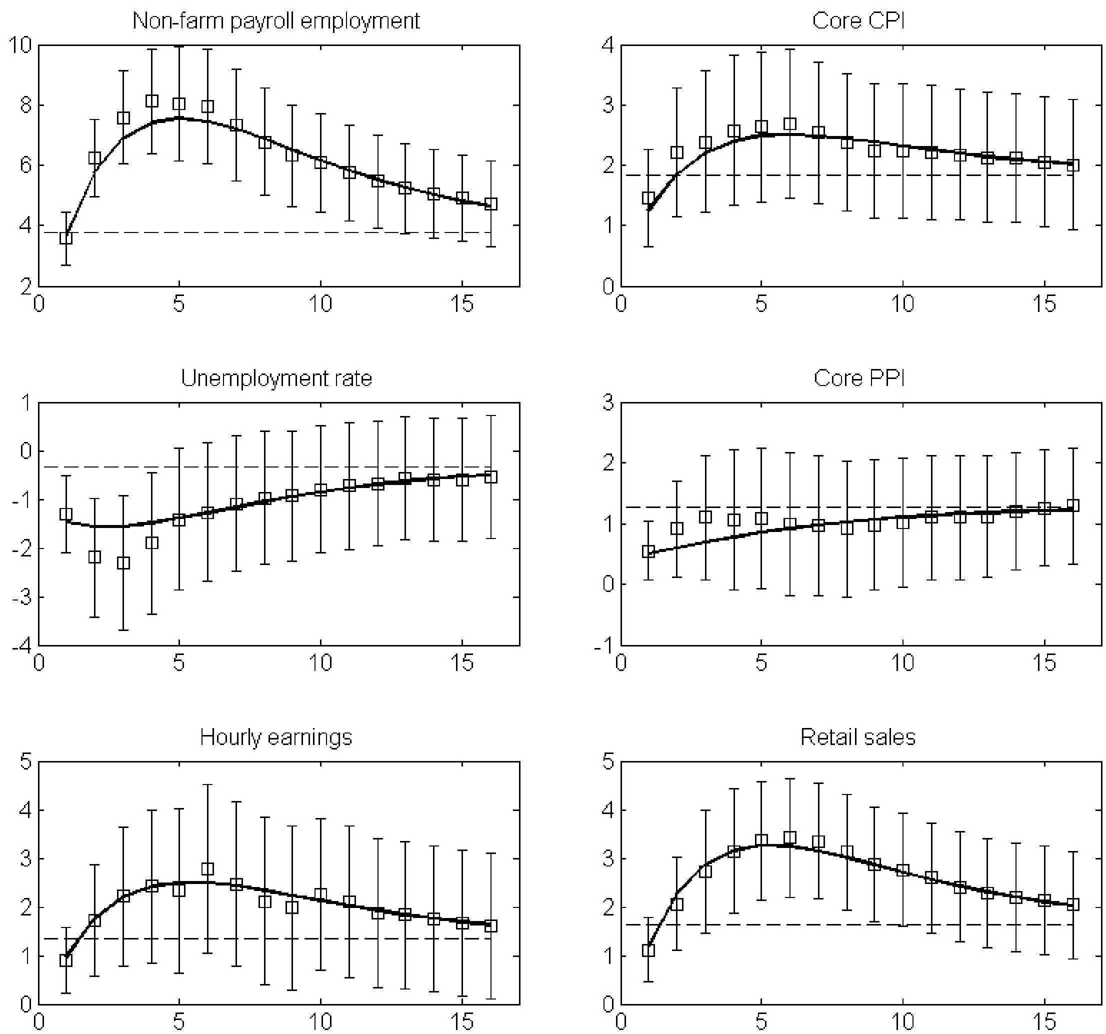
Regressions of changes in Eurodollar futures rates on changes in near-term federal funds futures rates (FF3) in different news regimes: Empirical response coefficients (squares) with 95% confidence intervals based on White standard errors, and model-implied response coefficients (thick line). Also shown are empirical coefficients of determination (circles) and the model-implied counterparts (crosses).

Figure 6: Policy surprises: Examples of revisions resulting form policy actions



Actual changes in Eurodollar futures rates (crosses) and fitted changes implied by revisions (squares) on four days with monetary policy actions. Also shown are the estimated long-run revisions (dotted lines). Note: The Fed increased the target by 25 bps on all of these days. On the dates shown in the top row, the FF1 rate increased by 10 and 8 bps respectively, whereas on the dates shown in the bottom row it did not change at all.

Figure 7: Term structure of announcement effects



Responses to a one-standard-deviation surprise in six different macroeconomic data releases: Empirical responses of futures rates with 95% confidence intervals (error-bars) and model-implied responses of futures rates (solid lines). Units are basis points.