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Abstract

This paper proposes a new econometric approach to disentangle two distinct response patterns of the yield curve to monetary policy announcements. Based on cojumps in intraday tick-data of a short and long term interest rate, we develop a day-wise test that detects the occurrence of a significant policy surprise and identifies the market perceived source of the surprise. The new test is applied to 133 policy announcements of the European Central Bank (ECB) in the period from 2001-2012. Our main findings indicate a good predictability of ECB policy decisions and remarkably stable perceptions about the ECB's policy preferences.

Keywords: Central bank communication; yield curve; spectral cojump estimator; high frequency tick-data.

JEL classification: E58, C14, C58

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1 Introduction

Understanding market responses to monetary policy announcements is of great interest for policy makers, financial market participants and academia alike. As central banks typically steer a very short term interest rate, a focal point of research has been on the transmission of monetary policy from the key policy rate to longer-term market interest rates.

The predominant approach to investigate the response pattern of the yield curve traces back to Cook and Hahn (1989) and Kuttner (2001), who regress changes in interest rates of single maturities on a monetary policy surprise variable.¹ While such regressions have established that the shorter-end of the yield curve consistently moves in the direction of the policy surprise, regression results for the longer-end of the yield curve are rather mixed and elusive. For the example of a ten year maturity of different countries or sample periods, empirical studies report inverse (e.g. Goldberg and Leonard, 2003), non-significant (e.g. Beechey and Wright, 2009) and positive (e.g. Gürkaynak et al., 2005) responses to the policy surprise variable.

The mixed regression results suggest that the response pattern of the yield curve is more sophisticated than a conventional surprise variable is able to explain. In fact, the theoretical models of Ellingsen and Söderström (2001) and Rudebusch and Wu (2008) show that it is not the occurrence and size of a policy surprise but the market perceived *source* of the surprise that determines the response pattern of the yield curve. Referring to a Taylor (1993) monetary policy reaction function, the models show that a policy surprise induced by news about economic conditions shifts all interest rate maturities in the same direction (*level shift* of the yield curve). In contrast, a policy surprise triggered by changes in central bank policy preferences drive the short and long end of the yield curve in opposite directions (*rotation* of the yield curve). These findings suggest to isolate the effect of a single policy announcement rather than studying average response patterns of the yield curve across years of monetary policy. However, econometric approaches are lacking to independently test single policy announcements for the occurrence of significant shifts and rotations of the yield curve.

The present paper aims at closing that gap. Our main contributions are both methodological and empirical. First, we propose a statistical test based on simultaneous jumps (cojumps) in intraday tick-data of a short and long term interest rate to discriminate between significant *level shifts* and *rotations* of the yield curve. The cojumps measure the news flow in the markets, see e.g. Dungey et al. (2009) and Lahaye et al. (2011). Distin-

¹The surprise is usually the unexpected changes in the key rate. Popular measures of monetary policy surprises include spreads in derivative prices (Kuttner, 2001), survey expectations (Ehrmann and Fratzscher, 2003) and jumps in short term interest rates (Winkelmann, 2013).

guishing between shifts and rotations allows to determine the underlying source of a policy surprise. We detect level shifts through unidirectional jumps and rotations by cojumps where the short and long end of the yield curve jump in opposite directions. The day-wise test for level shifts and rotations is based on estimation of a bivariate semimartingale. We adapt the spectral cojump estimator of Bibinger and Winkelmann (2013) which – in contrast to the approaches of Jacod and Todorov (2009) and Mancini and Gobbi (2012) – explicitly accounts for market microstructure frictions and non-synchronous observations of the tick-data.² Due to the high frequency perspective and the localizing features of the spectral approach, the test isolates the instantaneous response to a single policy announcement and establishes statistical independence of adjacent days. This is in sharp contrast to previous techniques like the classification of shifts and rotations via a factor model of the term structure with daily data by Claus and Dungey (2012).

Second, we apply the test for level shifts and rotations to tick-data of German short and long term interest rate futures. Using data on policy announcement days of the European Central Bank (ECB), offers a unique way of studying the individual response pattern of the yield curve to monetary policy announcements. Evidence is provided for 133 ECB policy announcements from 2001 to 2012. As demonstrated by Ehrmann and Fratzscher (2009), ECB announcements not only affect markets through a press release on the actual decision on the key interest rate, but also move markets through a subsequent press conference that provides important information about the reasons behind the policy decision. Our approach separates the impact of the two communication channels. We use the detected cojumps in response to the press releases and press conferences to set up regressions that justify the focus on cojumps to detect policy surprises and to support the empirical validity of the structural implications of the Ellingsen and Söderström (2001) and Rudebusch and Wu (2008) models.

Our empirical results indicate that 15% of ECB policy announcements are interpreted by market participants to provide news about the current state of the economy. In contrast, less than 1% can be considered to be driven by perceived adjustments in ECB policy preferences. In particular, we find that perceptions about policy preferences have become more accurate after the ECB’s clarification of its monetary policy strategy in 2003. Our results confirm the general ability of central banks to guide market expectations. While there are a few adjustments in the yield curve as a result of the market being surprised by the policy rate announcement itself, the majority of significant yield curve reactions occur during the ECB’s communication in the subsequent press conference. We show that providing information about current and future economic developments through press conferences

²See Aït-Sahalia et al. (2005) and Zhang (2011) for arguments to account for these stylized facts of high frequency data.

has gained in importance during the recent global financial and European sovereign debt crisis, compare the discussion by Woodford (2012). All in all, the results reflect a credible monetary policy conduct and clear communication. It appears that markets have well understood the ECB's policy reaction function with regard to the achievement of its policy objective.

The present paper is arranged in six upcoming sections. Section 2 reviews the link between monetary policy surprises and level shifts and rotations of the yield curve. The new test for level shifts and rotations is introduced in Section 3. Section 4 provides information about the high frequency tick-data of the yield curve. Empirical results are presented in Section 5. Section 6 concludes.

2 Sources of policy surprises and the yield curve

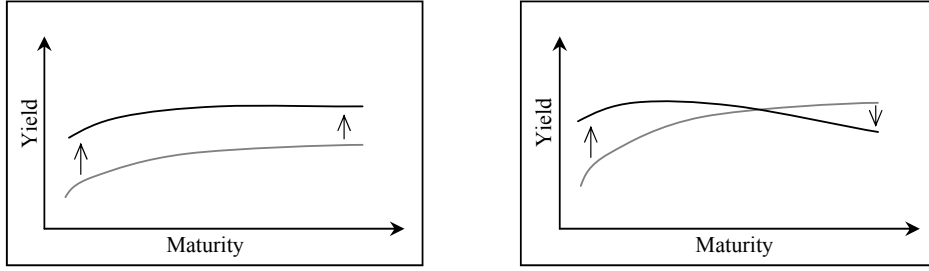
Following the pathbreaking work of Taylor (1993), Clarida et al. (1998) and Clarida et al. (1999), an extensive theoretical and empirical literature has studied interest rate settings by central banks. A brought consensus has emerged that monetary policy can be described by a simple rule that connects changes in a central bank's key interest rate Δr_t with changes in main economic variables, i.e. in inflation $\Delta \pi_t$ and output Δy_t :

$$\Delta r_t = \lambda \Delta \pi_t + (1 - \lambda) \Delta y_t, \quad \lambda \in [0, 1]. \quad (1)$$

The rule simply implies that central banks increase (decrease) their key rate when inflation rises (falls) or when output expands (weakens), in order to reduce (induce) future inflationary pressure. In accordance with Taylor (1993), rules like (1) are called Taylor-rules. Although Taylor-rules rules are remarkably adept at describing central banks' interest rate decisions empirically, the implementation of reaction functions is not officially confirmed by central banks. Therefore, interest rate rules remain rather implicit and markets' expectations about future policy decisions depend on individual assessments about the future economic variables as well as the central banks' preference parameter λ , see e.g. Schmidt and Nautz (2012). In this context, monetary policy surprises can be triggered by two distinct sources: First, news about π_t and y_t , such that markets readjust expectations about current and future economic conditions. Second, changes in the preference parameter λ , such that markets change the weighting of the economic variables in their individual interest rate rules. In both cases markets update their expectations about future key rates and price the changes into the yield curve.³

³Note that the market perceived inflation target is assumed to be constant. In that framework changes in perceived policy preferences are fully captured by the parameter λ .

Figure 1: Upward level shift (left) and a rotation (right) of a yield curve.



The stylized macroeconomic model of Ellingsen and Söderström (2001) suggests the identification of the market perceived sources of policy surprises through the particular response pattern of the yield curve.⁴ They extend a dynamic version of a simple aggregate supply-aggregate demand model by the expectations hypothesis of interest rates. An interest rate rule like (1) determines the optimal strategy of monetary policy in that framework. Inducing information asymmetries between market participants and the monetary policy authority, they find two distinct response patterns of the yield curve that disentangle the two sources of monetary policy surprises. First, in the case where markets interpret the policy surprise to provide news about current and future economic conditions, changes in expected future key rates shift all yields of the maturity structure in the same direction (level shift). Second, if markets perceive the policy surprise to reflect changes in policy preferences, revisions of expected future key rates drive the short and long end of the yield curve in opposite directions (rotation).

In economic terms, level shifts and rotations can mainly be explained by the connection of interest rates and markets' inflation expectations, compare Ehrmann et al. (2011). While changes in shorter-term rates are mostly driven by the current key rate, responses of longer-term interest rates are determined by policy effects on future inflation. Due to relatively strong inflation persistence, documented in e.g. Hassler and Wolters (1995) and Meller and Nautz (2012), news that significantly affect the current rate of inflation translate to revisions of inflation expectations along *all* maturity horizons, see also the discussion in Gürkaynak et al. (2007).⁵ Therefore, a positive (negative) policy surprise that reflects significant news about an increase (decrease) in current inflation and output increases (decreases) inflation expectations at every expectation horizon. As illustrated by

⁴We focus here on Ellingsen and Söderström (2001). However, similar conclusions can be drawn from a standard DSGE model (Ellingsen and Söderström, 2006) and, with a slightly different terminology, from a macro-finance model (Rudebusch and Wu 2008).

⁵Note that the joint movements appear as a necessary condition of level shifts and rotations. Consequently, the analysis excludes policy surprises that induce idiosyncratic movements at either the short or long end of the term structure.

the left hand plot of Figure 1, in this case, the yield curve shifts upwards (downwards). In contrast, a positive (negative) policy surprise observed to increase (decrease) the weight on inflation, decreases (increases) inflation persistence. Consequently, shocks to inflation decay faster (slower) and longer-term inflation expectations drop (move up).⁶ The right hand plot of Figure 1 displays an example of a resulting rotation of the yield curve.

In the following, we provide a test for level shifts and rotations of the yield curve. We refer to high-frequency tick-data of interest rates on monetary policy announcement days, to distinguish between the two response patterns of the yield curve.

3 A testing framework for level shifts and rotations of the yield curve

In this section we introduce the test for level shifts and rotations of the yield curve. The approach is based on cojumps in intraday tick-data of a short and long term interest rate. First, we describe the standard setting of continuous time processes to model high frequently recorded asset prices. We refer to discrete noisy and non-synchronous observations and highlight the estimation problem. Second, we review the spectral estimator of cojumps of Bibinger and Winkelmann (2013) in the bivariate case. Third, based on the spectral estimator, we adapt a wild bootstrap type of test for cojumps and define a test for level shifts and rotations of the yield curve.

3.1 Non-parametric volatility model

Due to the imperfections of trading processes, tick-data is widely known to be very noisy, see Hautsch (2012) for a comprehensive discussion. The noise comes from a vast array of issues collectively known as market microstructure, including price discreteness, infrequent trading and bid-ask bounce effects. A common modeling framework for noise perturbation in high-frequency data is to treat the microstructure as observation error, see e.g. Aït-Sahalia et al. (2005). In the following, the notation $t \in [0, 1]$ refers to the trading time of a single day. Thus, we aim at presenting cojump statistics for each day separately.

Let $Y^{(q)} = (Y_i^{(q)})_{i=0, \dots, T^{(q)}}$ denote the log of discretely observed high-frequency prices with $q = 1$ the short end and $q = 2$ the long end of the maturity structure. The index $i = 0, \dots, T^{(q)}$ counts respective intraday observations. The observed processes are then expressed as the latent, true log-price processes $X^{(q)} = \left(X_{t_i^{(q)}}^{(q)} \right)_{t_i^{(q)} \in [0, 1]}$ plus market

⁶This argument requires the increase (decrease) of the weight on inflation to be taken during times where inflation is above (underneath) a target or steady state value.

microstructure noise $\varepsilon_i^{(q)}$.

$$Y_i^{(q)} = X_{t_i^{(q)}}^{(q)} + \varepsilon_i^{(q)}, \quad q = 1, 2, \quad t_i^{(q)} \in [0, 1], \quad i = 0, 1, \dots, T^{(q)} \quad (2)$$

The microstructure noise is a mean zero, i.i.d. sequence with standard deviation $\eta^{(q)}$ and independent of $X^{(q)}$. The time index of $X^{(q)}$ allows the modeling of non-synchronous observations of the two processes, with $t_i^{(1)} \neq t_i^{(2)}$ for $i = 0, \dots, T^{(q)}$. In accordance with term structure models of e.g. Duffie and Kan (1996) and Dai and Singleton (2000), we utilize the class of semimartingales to model the true bond price processes $X^{(q)}$. The short and long end of the maturity structure evolves as

$$dX_t^{(q)} = \mu_t^{(q)} dt + \sigma_t^{(q)} dW_t^{(q)} + dJ_t^{(q)}, \quad q = 1, 2, \quad t \in [0, 1], \quad (3)$$

where $\mu_t^{(q)}$ is a drift, $\sigma_t^{(q)}$ the spot volatility, $W_t^{(1)}$ and $W_t^{(2)}$ correlated standard Brownian motions with $d[W^{(1)}, W^{(2)}]_s = \rho_s ds$ and $J_t^{(1)}, J_t^{(2)}$ possibly correlated pure jump processes.

The main goal of the econometric approach is to provide an estimator of simultaneous jumps under (2). The general idea to achieve this goal stems on the non-noisy case and considers occasions where the product of jump sizes $\Delta J_t^{(1)} \Delta J_t^{(2)}$ is different from zero, compare Mancini and Gobbi (2012). Therefore, the cojump estimation is usually based on the quadratic covariation between the true log-prices:

$$[X^{(1)}, X^{(2)}] = \int_0^1 \rho_t \sigma_t^{(1)} \sigma_t^{(2)} dt + \sum_{0 \leq t \leq 1} \Delta J_t^{(1)} \Delta J_t^{(2)}, \quad t \in [0, 1]. \quad (4)$$

The covariation comprises two parts, the integrated covolatility and the cojumps. The integrated covolatility is made up of the spot volatilities $\sigma_t^{(q)}$ and the correlation ρ_t between the two Brownian semimartingale parts. The cojumps are given by the sum of cross products between simultaneous jumps. To estimate the two parts in (4) under noisy and non-synchronous observations, we utilize the spectral cojump estimator of Bibinger and Winkelmann (2013).

3.2 Spectral estimator of cojumps

The spectral estimator of cojumps by Bibinger and Winkelmann (2013) is build on Reiß (2011) and Bibinger and Reiß (2013). It provides an efficient cojump estimator via thresholding increments of the estimated quadratic covariation. Estimation in the spectral domain benefits from the orthogonality of the transform, hence, reduces the estimator's variance. To localize the cojumps and account for the noise perturbation, the trading time $t \in [0, 1]$ is split into h^{-1} partitions. Thus, up to the time length h of a block, we are

able to detect the cojumps.

The block-wise map of observed returns $\Delta_i Y^{(q)} = Y_i^{(q)} - Y_{i-1}^{(q)}$, $i = 1, \dots, T^{(q)}$, $q = 1, 2$, in the frequency domain is accomplished via the sine basis. The spectral statistic for block $k = 0, \dots, h^{-1} - 1$ and frequency $j = 1, \dots, J$ is given by

$$S_{jk}^{(q)} = \frac{\sqrt{2h}}{j\pi} \sum_{i=2}^{T^{(q)}} \Delta_i Y^{(q)} \sin \left(j\pi h^{-1} (t_i^{(q)} - kh) \right) \mathbb{1}_{[kh, (k+1)h]}(t_i^{(q)}), \quad (5)$$

where the indicator function $\mathbb{1}$ evaluates the transform on block k . The map in the frequency domain results in independent statistics $S_{jk}^{(q)}$, $j \geq 1$. Information from non-synchronous intraday returns within each block k is translated to the synchronous spectral statistics $S_{jk}^{(1)}, S_{jk}^{(2)}$, $k = 0, \dots, h^{-1} - 1$. The expansion (5) can be considered a linear combination of weighted (with the sine) pre-averages of the return series that smooth out the microstructure.⁷ Higher frequencies contain diminishing information about the process (3), thus, we discard frequencies above a spectral cut-off J .

Block-wise increments in the quadratic covariation (4) between the short and long term interest rate are provided by the **SP**ectral **E**stimator of the **Co**Variation

$$\Delta_k \mathbf{SPECV}(Y^{(1)}, Y^{(2)}) = h \sum_{j=1}^J w_{jk} \frac{\pi^2 j^2}{h^2} S_{jk}^{(1)} S_{jk}^{(2)}, \quad k = 0, \dots, h^{-1} - 1, \quad (6)$$

such that on $t \in [0, 1]$ for $T^{(q)} \rightarrow \infty$

$$\sum_{k=0}^{h^{-1}-1} \Delta_k \mathbf{SPECV}(Y^{(1)}, Y^{(2)}) \xrightarrow{\mathbb{P}} [X^{(1)}, X^{(2)}].$$

The quadratic covariation between the true price processes $X^{(q)}$ is consistently estimated by appropriately scaled cross products of spectral statistics of the observed processes $Y^{(q)}$, $q = 1, 2$. The optimal weights w_{jk} , with $\sum_j w_{jk} = 1$, are proportional to local Fisher information and minimize the estimator's mean square error, see Bibinger and Winkelmann (2013) for their explicit form. Under vanishing microstructure noise all frequencies are weighted equally and the estimator reduces to the realized covolatility, the natural choice in this situation.

From (4) it follows that the absolute value of increments of quadratic covariation (6) are much larger on blocks k where the product of jump sizes is different from zero. Therefore, cojumps can be detected and estimated via thresholding the increments of the quadratic covariation. The daily **SP**ectral **E**stimator of **Co**Jumps in interest rates based on a locally

⁷Or equivalently a pre-average of the price process with the cosine, see Bibinger and Reiß (2013).

adaptive threshold u_k is given by

$$\mathbf{SPECJ}(Y^{(1)}, Y^{(2)}, u_k) = \sum_{k=0}^{h^{-1}-1} \Delta_k \mathbf{SPECV}(Y^{(1)}, Y^{(2)}) \mathbb{1}_{\{|\Delta_k \mathbf{SPECV}(Y^{(1)}, Y^{(2)})| > u_k\}}, \quad (7)$$

with $T^{(q)} \rightarrow \infty$ on $t \in [0, 1]$ satisfying

$$\mathbf{SPECJ}(Y^{(1)}, Y^{(2)}, u_k) \xrightarrow{\mathbb{P}} \sum_{0 \leq t \leq 1} \Delta J_t^{(1)} \Delta J_t^{(2)}.$$

If an increment in quadratic covariation estimates on a given block k is below the threshold u_k , it contributes to the integrated covolatility. In contrast, increments above the threshold localize and consistently sum up to cojumps. Since increments of the Brownian components in (3) are normally distributed, extreme value theory provides a supremum of block-wise increments of the integrated covolatility. Thus, the universal threshold $\hat{u}_k = 2 \log(h^{-1}) h \sigma_k^{(1,2)}$, with $k = 0, \dots, h^{-1} - 1$ and $\sigma_k^{(1,2)}$ a pilot estimator of the spot covolatility, separates the integrated covolatility and cojumps. To obtain a feasible pilot estimator, we refer to local averages of (6) in the neighborhood of k with equally weighted spectral statistics.

The sign of the spectral estimator of cojumps (7) can be interpreted like the sign of a correlation coefficient. It reflects whether the relation between the short and long end of the term structure is positive or negative. Thus, up to the blocklength h we can detect cojumps and also verify whether they are unidirectional or point in different directions. Next, we propose a test to detect level shifts and rotations of the yield curve.

3.3 The test for level shifts and rotations

Based on the spectral estimator of cojumps (7) for noisy and non-synchronous tick-data of a short and long term interest rate, we provide a test for level shifts and rotations of the term structure. For a single trading day, the test evaluates the direction of simultaneous jumps. We formalize the hypotheses as follows:

Level shift hypothesis: $H_1^L := \left(\sum_{0 \leq t \leq 1} \Delta J_t^{(1)} \Delta J_t^{(2)} \right) > 0$

- The short end ($q = 1$) and long end ($q = 2$) of the yield curve jump in the same direction. Significant cojumps lead to a parallel shift of the term structure.

Rotation hypothesis: $H_1^R := \left(\sum_{0 \leq t \leq 1} \Delta J_t^{(1)} \Delta J_t^{(2)} \right) < 0$

- The short end ($q = 1$) and long end ($q = 2$) of the yield curve jump in opposite directions. Significant cojumps tilt the term structure.

The null hypothesis stresses that no cojump occurs, i.e. $H_0 := \left(\sum_{0 \leq t \leq 1} \Delta J_t^{(1)} \Delta J_t^{(2)}\right) = 0$. To test the hypotheses, we utilize one-sided alternatives of the wild bootstrap type of test proposed by Bibinger and Winkelmann (2013). The wild bootstrap principle avoids that the test statistic degenerates under H_0 by disturbing its block-wise increments in the case of no cojumps. Similar to the cojumps estimator (7), the test statistic is based on the increments in quadratic covariation (6):

$$\mathcal{T}(Y) = T_{\min}^{\frac{1}{4}} \sum_{k=0}^{h^{-1}-1} \Delta_k \mathbf{SPECV}(Y^{(1)}, Y^{(2)}) \left(1 - \zeta_k \mathbb{1}_{\{|\Delta_k \mathbf{SPECV}(Y^{(1)}, Y^{(2)})| \leq u_k\}}\right), \quad (8)$$

where $\mathbb{1}$ is the indicator function and ζ_k the i.i.d. noise term on each intraday block k . With ζ_k a Binomial process, satisfying $\mathbb{P}(\zeta_k = 0.9) = 0.5 = \mathbb{P}(\zeta_k = 1.1)$, and an appropriately scaled test statistic $\tilde{\mathcal{T}}(Y)$, Bibinger and Winkelmann (2013) establish a central limit theorem under the null of no cojumps. Thus, the standard normal distribution and its critical values can be used to distinguish between the hypotheses. Since cojumps dominate the value of the test statistic, the sign of $\tilde{\mathcal{T}}(Y)$ enables the discrimination between the Level shift and Rotation hypothesis. The test for shifts and rotations is summarized by the following diagram.

$$\begin{cases} H_1^L := \left(\sum_{0 \leq t \leq 1} \Delta J_t^{(1)} \Delta J_t^{(2)}\right) > 0 & \text{if } \tilde{\mathcal{T}}(Y) > c_{1-\alpha} & \Leftrightarrow & \text{level shift} \\ H_1^R := \left(\sum_{0 \leq t \leq 1} \Delta J_t^{(1)} \Delta J_t^{(2)}\right) < 0 & \text{if } \tilde{\mathcal{T}}(Y) < c_\alpha & \Leftrightarrow & \text{rotation} \\ H_0 := \left(\sum_{0 \leq t \leq 1} \Delta J_t^{(1)} \Delta J_t^{(2)}\right) = 0 & \text{if } |\tilde{\mathcal{T}}(Y)| \leq c_{1-\alpha} & \Leftrightarrow & \text{no cojump} \end{cases}$$

The test can be seen as a mixture of two one-sided tests. Since both are based on the same test statistic and differ by their sign only, we take them as a single test. The practical implementation works as follows: We choose a significance level α and compute the test statistic. If $\tilde{\mathcal{T}}(Y)$ is positive, we compare the test statistic with the upper critical value $c_{1-\alpha}$. In the case where the test statistic is larger than $c_{1-\alpha}$, we detect a level shift of the yield curve. If $\tilde{\mathcal{T}}(Y)$ is negative, we take the lower critical value c_α . A test statistic smaller than c_α , detects a rotation. If both critical values are not exceeded, we find no significant shift or rotation of the yield curve.⁸

We now introduce the high-frequency interest rate data to test ECB announcement days for shifts and rotations of the yield curve.

⁸Note that the null hypothesis includes disjoint jumps at either the short or long end of the term structure.

4 Yield curve data

To study the individual response pattern of the yield curve to monetary policy announcements of the ECB, we refer to tick-data on German government bonds. Instead of picking actually traded bonds, we utilize futures data from the derivative exchange EUREX.⁹ Compared to bonds, futures usually have the advantages to be traded more frequently and to represent constant maturity prices. As evidenced by Dungey and Hvozdyk (2012), high frequency prices of government bond futures share closely related dynamics with the underlying bond market, especially the occurrence of jumps are strongly correlated.

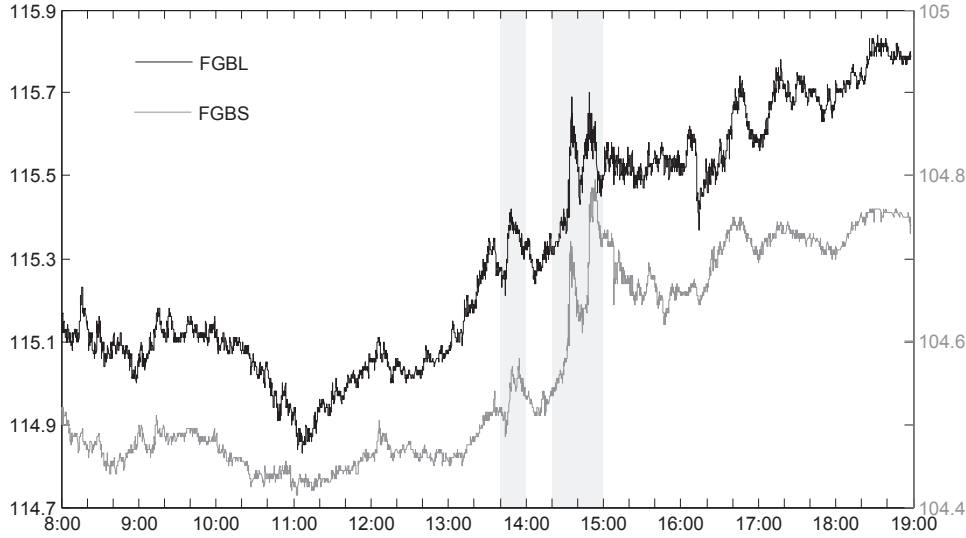
The short end of the term structure is represented by the Euro-Schatz Futures (FGBS), whose underlying is a fictive German government bond maturing in about 2 years having a coupon of six percent. The FGBS closely captures the medium term policy horizon of the ECB. While the 2 year maturity is sufficiently long to prevent a close control via monetary policy, it is sufficiently short to be consistent with the direction of money market responses to monetary policy announcements.¹⁰ The long end of the term structure is captured by the Euro-Bund Futures (FGBL), which calls for the delivery of a fictive 10 year German government bond with a coupon of six percent. The 10 year horizon of FGBL is important for investment and saving decisions, however, not explicitly triggered by monetary policy.

Our sample includes tick-data of FGBS and FGBL from January 2001 to August 2012. For both futures we take the most frequently traded contract month, which is the three month expiring horizon. Allowing for recurring response patterns, we focus on 133 scheduled ECB policy announcements, which typically take place on the first Thursday of each month. On each announcement day the ECB follows a fixed communication scheme. The decision on the key rate is published via a press release at 13:45 CET and is further explained in a subsequent press conference starting at 14:30 CET. The press conference consists of two parts, the reading out of an introductory statement by the ECB's president followed by a question and answer session. Besides the announcement days, we take 458 Thursdays without ECB policy announcements to contrast the average response patterns. We fix the trading time from 8:00 CET to 19:00 CET. The average number of trades per day is around 10,000 for the FGBL series and around 5,000 for FGBS. The different numbers of observations in the short and long term futures markets indicate non-synchronous transactions. Furthermore, Appendix A demonstrates that the tick-data is affected by market microstructure noise. Our spectral estimation approach is designed for these typical characteristics of high frequency data.

⁹The data is provided by the "Research Data Center" of the CRC 649.

¹⁰E.g. Gürkaynak et al. (2005) and Brand et al. (2010) report a positive relation between monetary policy surprises and a 2 year rate. Appendix C provides evidence that the 2 year German bond futures jump in the direction of the policy surprise. Thus, using a shorter than 2 year (e.g. money market) maturity does not change the test results on level shifts and rotations.

Figure 2: Government bond futures on 2.10.2008.



Notes: Price notation. FGBS (grey) represents the 2 year maturity, FGBL (black) the 10 year maturity. Number of ticks: FGBL 7,710; FGBL 14,849. Intervals where the ECB communicates with markets are emphasized.

Figure 2 provides an example of the tick-data for October, 2. 2008. The figure reflects positively correlated dynamics of the 2 and 10 year prices. Particularly around the shaded time intervals where the ECB communicates with markets, both series appear to be tied together more closely than during the rest of the day. Due to decreasing yields (increasing prices) at either the short and long end of the term structure, this policy announcement day most likely induces a level shift. Particularly the strong movements around 14:20 to 15:00 CET may reflect the arrival of new information during the press conference.

In the next section, we apply the test for level shifts and rotations to each of the 133 policy announcement days. We evaluate whether the comovements are sufficiently strong to identify policy surprises.

5 Empirical evidence from ECB monetary policy announcements

This section provides empirical evidence about level shifts and rotations of the German yield curve on ECB policy announcement days. First, we apply the cojump estimation and testing procedure introduced in Section 3. The focus is on daily statistics, thus, we determine for each policy announcement day independently whether a level shift, a

rotation or no significant joint movement prevails. As discussed in Section 2, we utilize the response pattern of the yield curve to draw conclusions about the market perceived source of a policy surprise. Second, we evaluate the daily results of shifts and rotations. We localize cojumps on intraday time intervals to establish a direct link between the timing of cojumps and the policy communication via press releases and press conferences. We utilize the detected cojumps to set up regressions that justify the focus on cojumps to detect policy surprises and to support the conclusions about the market perceived sources of policy surprises.

5.1 Shifts and rotations on policy announcement days

In this subsection we present the main results of our test for level shifts and rotations of the term structure. Since the test is based on cojumps, we also report cojump estimates (7) for each of the 133 ECB announcements. For the daily estimates, we refer to the noisy and non-synchronous tick-data of government bond futures presented in Section 4. We set $h^{-1} = 33$, thus, detect cojumps on 20 minutes time intervals (33 blocks per day). Blocks of 20 minutes appear as a reasonable number to study the timing of shifts and rotations to the ECB's press releases (13:45 CET) and press conferences (starting 14:30 CET). We set the frequency cut-off $J = 35$ and refer to a 5% significance level. We find that our economic conclusions do not critically depend on the specific values of these parameters.

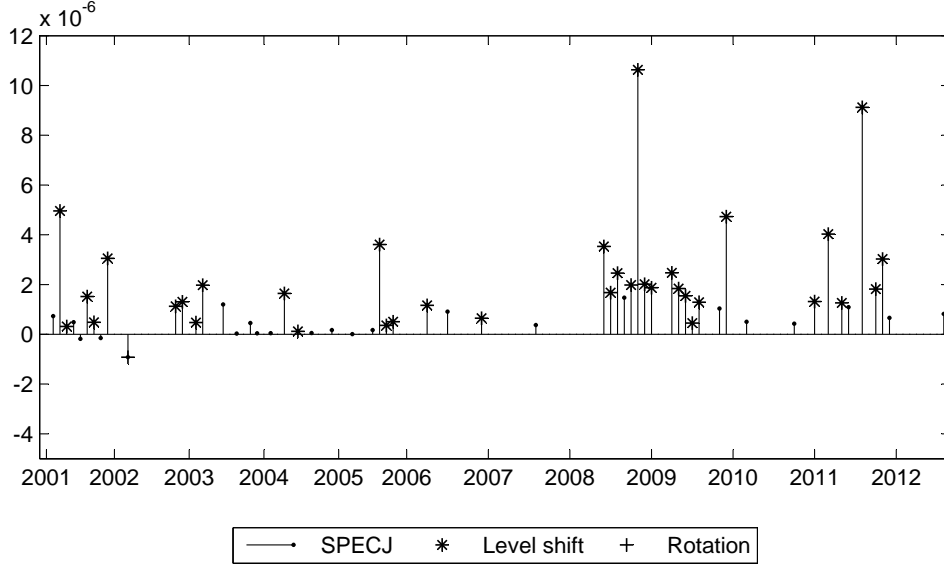
Figure 3 summarizes the main results. The bars display the value of the cojump estimator (7) at respective policy announcement days. Since the cojump estimator equals zero in the case where none of the intradaily increments in quadratic covariation exceed the threshold, the majority of the policy announcement days indicate no cojump activity. On 58 out of the 133 ECB announcements, the cojump estimator is different from zero. The larger the absolute size of the estimate, the stronger is the effect of the cojump on the yield curve.¹¹ However, if on a particular day the intradaily variation is very high, it is possible that even larger estimated cojumps are non-significant. In the same way, relatively small cojumps can be statistically significant if the intradaily variation is very low. The test for level shifts and rotations detects the significant cojumps.

First, we take the negative cojump estimates and verify whether they imply yield curve rotations. The test reveals that only one out of three negative cojump estimates rotates the yield curve. In Figure 3 the rotation is highlighted by a plus sign.¹² Interestingly, policy announcements associated with negative cojump estimates occur in the beginning

¹¹Quantifying the yield curve movement in terms of basis points from the covariance type of estimator is not possible. The largest tick increase in the 2Y futures is approx. 30 basis points and for the 10Y futures around 80 basis points.

¹²The rotation occurred on March, 7. 2002. More detailed information about the estimate and the economic background on that day is provided in Appendix B.

Figure 3: Shifts and rotations of the yield curve on ECB announcement days.



Notes: SPECJ is the cojump estimator (7). The detection of level shifts and rotations are based on the cojump test (Section 4) and a 5% significance level. Daily estimates and tests refer to tick-data of the short (2 year) and long (10 year) term interest rate.

of the sample around late 2001 and early 2002 only. In terms of identification, the negative cojumps suggest that markets tend to interpret the policy announcements to reflect revisions in ECB policy preferences during that time. The finding matches with the assessments of Schmidt and Nautz (2012). For a period before 2003, they find that markets were uncertain about the ECB's reaction function with respect to arising risks to price stability. This also corresponds to the period in which the ECB's Governing Council clarified the ECB's definition of price stability (inflation should be below but close to 2%), see ECB (2003). According to Schmidt and Nautz (2012), this clarification of the policy strategy was an important step towards a more transparent reaction function of the ECB. The test for level shifts and rotations confirms this finding. Since the policy clarification in 2003, cojump estimates on policy announcement days are exclusively positive. Thus, monetary policy surprises no longer reflect perceived changes in ECB's policy preferences. Our second focus is on the positive cojump estimates. Significant cojumps that shift the level of the term structure are marked by stars in Figure 3. In total, out of 55 positive cojump estimates 35 are evaluated as level shifts. Level shifts occur more regularly during the global financial crisis (starting around late 2008) and the European sovereign debt crisis (since 2011). As put forward in Section 2, level shifts identify policy surprises perceived to provide news about the current and future state of the economy. Since deep

financial turbulences usually reflect uncertain macroeconomic conditions, the state of the economy is more difficult to evaluate during times of financial stress. The more frequent and stronger level shifts around 2008 and 2011 appear as a natural consequence.

The test results suggest a stable and well-communicated policy implementation. In particular, the policy communication during the global financial and European sovereign debt crisis appears to be successful, since we observe no adjustments in markets' perceptions about policy preferences during the crisis periods. This provides evidence that financial markets do not perceive the non-standard or unconventional measures, summarized by Eser et al. (2012) and the reference therein, to change the ECB's policy preferences.¹³

5.2 Verification of the test results

In this subsection we provide evidence that the test for level shifts and rotations detects monetary policy surprises and identifies the market perceived source of a policy surprise. First, we locate the average intradaily timing of shifts and rotations. Second, we set up regressions that explain the intradaily occurrence of cojumps by standard survey measures of monetary policy surprises and wording indicators of the ECB's press conferences.

5.2.1 Intraday localization of cojumps

If level shifts and rotations of the yield curve are driven by monetary policy surprises, they should occur within time intervals where the ECB communicates with markets. To study this relation, we decompose the cojump estimator (7) and refer to average absolute increments in quadratic covariation estimates on the 20 minutes intraday blocks. According to the test statistic (8), large increments locate significant shifts and rotations of the yield curve.

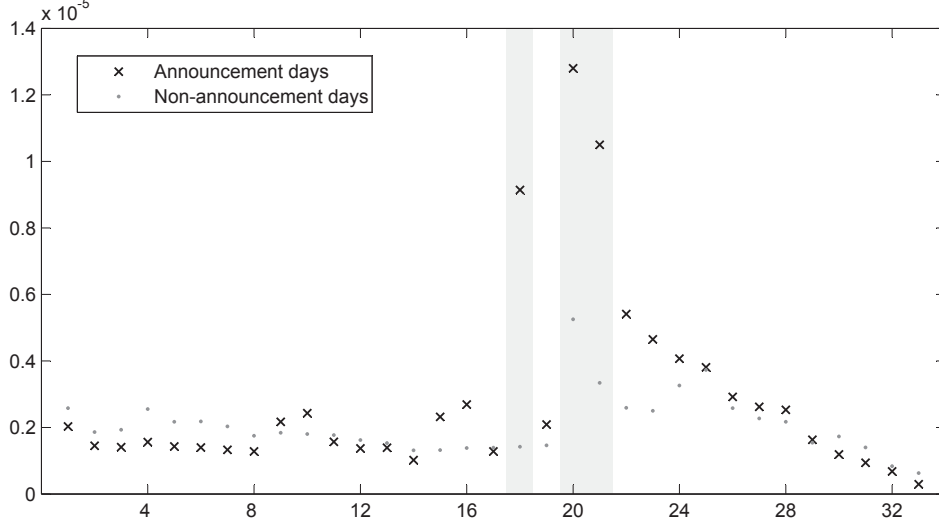
Figure 4 shows the average increment for each of the 33 intraday blocks. Increments on policy announcement days (cross) within the shaded intervals clearly indicate that press releases (block 18) and press conferences (block 20, 21) have on average a strong impact on the yield curve. In contrast, the intraday pattern on non-announcement days (gray dots) is rather flat.¹⁴ Thus, the detected level shifts and rotations occur instantaneously in response to the ECB's communication.

The relative size of increments in Figure 4 reflects that the press conferences have on average a larger effect on the maturity structure than the actual decision on the key rate. The

¹³Note that the majority of non-standard or unconventional measures were announced in press conferences on policy announcement days.

¹⁴The spike on non-announcement days on block 20 can be explained by the publication of weekly US jobless claims on Thursdays at 14:30 CET.

Figure 4: Block-wise averages of increments in quadratic covariation estimates.



Notes: The figure depicts average increments of SPECV on each intraday block for the 133 policy announcement and 458 non-announcement days from 2001 to 2012. The x-axis refers to the 33 20 minute intraday blocks. Blocks where the ECB communicates with markets are emphasized.

importance of the press conferences can also be highlighted by localizing the occurrence of significant cojumps on each single policy announcement day.¹⁵ For the whole sample period we detect three announcement days (2% of policy announcements) where yields exclusively cojump in response to the press release. On six days (5% of policy announcements) we find cojumps in response to both the press release and press conference. On twelve days (9% of policy announcements) it is only the press conference that triggers the joint movements in the yield curve. Nine out of these twelve occasions happen during crisis periods. In line with the regressions of EURIBOR futures by Ehrmann and Fratzscher (2009), this finding emphasizes the meaning of press conferences to communicate intentions of policy decisions and to guide markets. In the context of the structural explanations for level shifts and rotations (Section 2), press conferences help market participants to infer the source of policy surprises and to adjust expectations about future policy decisions appropriately.

5.2.2 Explaining the cojumps in regressions

If the theoretical considerations reviewed in Section 2 hold true and if the new test developed in Section 3 consistently detects level shifts and rotations of the yield curve, the

¹⁵Appendix B illustrates the localizing features of our cojump approach on single announcement days.

Table 1: Sources of detected level shifts.

Expl. variables $X_{k,t}$	Press release $P(y_{k=18,t} X_{k=18,t})$	Press conference $P(y_{k=20,t} X_{k=20,t})$
<u>Survey expectations:</u>		
· Target surprise	0.62 *** (0.12)	0.04 (0.27)
· Dispersion	4.80 *** (0.96)	1.54 (1.31)
<u>Wording indicators:</u>		
· Staff projections: Inflation		5.30 *** (1.98)
· Staff projections: GDP		3.97 ** (1.90)
· KOF index		2.12 * (1.37)
· Code word: 'Vigilance' dummy		-0.26 (0.61)
McFadden R^2	0.44	0.27

Notes: Probit regressions on intraday blocks ($k = 18, 20$). *, **, *** indicates significance at the 10%, 5% and 1% level, respectively. GLM standard errors are given in parenthesis. The binary dependent variable $y_{k,t}$ for each policy announcement day $t = 1, \dots, 133$ takes the values 0 (no level shift on block k) and 1 (significant level shift on block k). The (mean) surprise measure and dispersion are computed from Bloomberg surveys. The KOF index is the 'KOF Monetary Policy Communicator' which quantifies statements during the introductory statement concerning risks to price stability. GDP and HICP ECB-staff projections are announced quarterly during the introductory statement (revisions of mean projections for the following year). Regressions include a constant, (mean) surprises of US jobless claim announcements and a dummy for announcements of non-standard measures during the crisis period (all three not reported).

test results should be explainable in a regression study. Since the occurrence of rotations is too rare to display a repeating pattern, the focus of this analysis is on the detected level shifts. We explain cojumps that occur on the intraday time intervals of press releases (block $k = 18$) and press conferences (block $k = 20$) in two separate probit regressions. The two regressions incorporate explanatory variables that cover information given during the respective intraday blocks. We study the whole sample period of 133 policy announcement days from 2001 to 2012.

Table 1 reports the regression results. For the press release block, we find that conventional monetary policy surprise measures explain the occurrence of level shifts of the yield curve. The larger absolute deviations of survey expectations from the actual decision on the key interest rate (target surprise), the more likely is a level shift on the press release block. Furthermore, a more pronounced heterogeneity of the expectations about the decision on the key rate (dispersion) increases the probability of a level shift of the term structure. The results on the press release block provide a link to the standard linear regression literature of Cook and Hahn (1989) and Kuttner (2001). As documented in e.g. Ander-

sson et al. (2009) and Brand et al. (2009), responses of single maturities along the term structure to ECB policy surprises are uniformly positive. Our test for level shifts and rotations confirms that finding and suggests that the majority of yield curve responses are simultaneous adjustments at both the short and long end of the maturity structure.

Significant yield curve movements during the ECB's press conferences show no systematic readjustments to the surprise component of the actual decision on the key interest rate. Both survey expectations measures are non-significant. However, most wording indicators display a significant impact. Particularly the announcements of the ECB staff projections provided during every third press conference trigger level shifts of the term structure. The stronger the absolute revisions of mean projections compared to the previous quarter, the more likely the occurrence of a level shift. While the staff projections are a prime example where the central bank directly provides news about the economy, the other indicators are more indirect measures. The KOF wording indicator quantifies statements during the introductory statement concerning risks to price stability.¹⁶ The significant regression coefficient shows, stronger statements on inflation increase the probability of level shifts of the term structure. The 'vigilance' dummy is non-significant in our regression analysis. 'Vigilance' was perceived as a code word for a rate hike at the next meeting during the rate hike cycle of 2005-2007. Our finding suggests that the mentioning of the code word had a timing effect, relevant for short rates but not for the longer-end of the yield curve. The significant responses of the yield curve to the wording of the press conferences demonstrate the ECB's ability to directly steer market expectations. Our regression analysis indicates that the ECB provides relevant information about key economic variables like inflation and output. These information about the current and future state of the economy trigger level shifts of the yield curve.

All in all the regressions show that the test for level shifts and rotations consistently detects monetary policy surprises. Furthermore, we find supporting results for the theoretical relations discussed in Section 2. The test for level shifts and rotations identifies the market perceived source of a surprise.

6 Conclusion

This paper contributes to the literature on yield curve responses to monetary policy announcements. We propose an empirical test to distinguish between *level shifts* and *rotations* of the yield curve. The test is based on daily high-frequency statistics and discriminates the response patterns through cojumps of a short and long term interest rate. The

¹⁶We kindly thank Michael Lamla from the KOF Swiss Economic Institute for providing the KOF Monetary Policy Communicator.

cojump approach is consistent with the traditional regression studies of Cook and Hahn (1989) and Kuttner (2001), however, allows to zoom in to single monetary policy announcements and to study the response pattern of the yield curve for each announcement day independently.

The practical value of the new test is motivated by the theoretical work of Ellingsen and Söderström (2001) and Rudebush and Wu (2008). The response of the yield curve on a particular monetary policy announcement day detects the occurrence of a policy surprise and identifies markets' perceptions about the *source* of the surprise. Thus, the test enables central banks to monitor markets' understanding about monetary policy and to learn whether intentions of a policy decision are well-communicated.

The empirical example of ECB monetary policy announcements from 2001 to 2012 suggests stable and well-communicated policy preferences. Ever since the ECB's clarification of the monetary policy strategy in 2003, we find that markets' perceptions about policy preferences have been remarkably stable. Overall, our results lend to support the theory that central banks can effectively guide market expectations via its policy announcements and communication. In fact, major central banks around the world have recently moved into the direction of providing greater market guidance to steer expectations of future interest rates. Our results indicate that for the ECB, the press conference is indeed seen as providing valuable information about macroeconomic conditions and hence can significantly shift the yield curve. This gives some indication on the effectiveness of monetary policy communication in steering expectations about future interest rates.

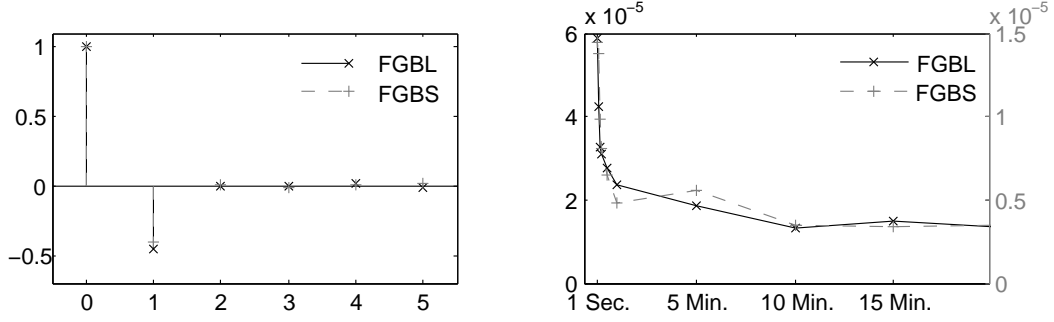
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Figure 5: Autocorrelation (left) and signature plot (right) on 2.10.2008.



Notes: The autocorrelation up to five lags is based on tick-data. The signature plot refers to the realized volatility (sum of squared returns) computed for each sampling frequency (x-axis) separately.

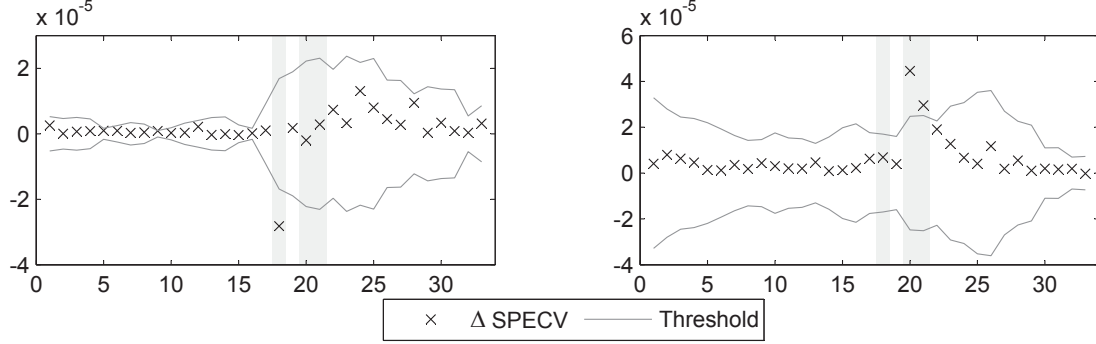
A The role of microstructure noise

In this paper we identify policy surprises via cojumps in tick-data of the FGBS and FGBL series. However, due to the imperfections of trading processes, tick-data is widely known to be very noisy, see Hautsch (2012) for a textbook exposition. The noise comes from a vast array of issues collectively known as market microstructure, including price discreteness, infrequent trading and bid-ask bounce effects. If microstructure frictions are present, single transaction prices no longer reflect the true price process. In this case, large observed returns do not consistently localize (co)jumps. Thus, it is of crucial importance that the econometric approach to estimate and test for cojumps explicitly accounts for the microstructure.

The observed processes in Figure 2 do not directly display a noise perturbation. As shown by Aït-Sahalia et al. (2005), the presence of microstructure frictions can be detected by a negative first order autocorrelation and an exponentially increasing realized volatility (sum of squared returns) the higher the sampling frequency. Therefore, Figure 5 depicts the autocorrelation structure and the signature plot of the observed processes. For both the FGBL and FGBS data a significant first order autocorrelation around -0.4 and a strongly increasing realized volatility, for sampling frequencies of tick size to 15 minute intervals, are evident.

To distinguish between level shifts and rotations of the yield curve in the context of the noisy interest rate futures, we utilize the spectral estimator and test for cojumps of Bibinger and Winkelmann (2013).

Figure 6: Detection of a rotation on 07.03.2002 (left) and level shifts on 02.10.2008 (right).



Notes: Cojump estimates are given by the sum of increments in SPECV (6) outside the threshold bands. The x-axis displays the 33 20 minute intraday blocks. Blocks where the ECB communicates with markets are emphasized.

B Examples of level shifts and rotations

This appendix illustrates how the day-wise estimation of cojumps works and provides news related arguments for particular shifts and rotations of the yield curve. We highlight two different examples of monetary policy announcement days. Based on the test results in Section 5.1, we pick the rotation of the yield curve on March, 7. 2002 and the level shift of the yield curve on October, 2. 2008. In Section 3.3 we define negative cojump estimates as rotations and positive estimates as level shifts of the yield curve. Figure 6 depicts increments in quadratic covariation estimates (6) and respective thresholds. The cojump estimator (7) shows that increments outside the threshold bands localize cojumps and sum up to the cojump estimate.

On March, 7. 2002, the negative cojump estimate is determined by the increment on block 18. Thus, the publication of the press release triggered a policy surprise on that day. With an unchanged key rate at 3.25%, some Bloomberg survey participants expected lower interest rates to boost the economic recovery after the 2000-2001 recession (average expectations were slightly below 3.25%). However, with annual inflation above 2%, the ECB emphasized with its interest rate decision the role of inflation more strongly than expected. Markets adjusted to that new information about policy preferences such that the yield curve rotated. The press conference (block 20 and 21) did not provide further significant surprises on that day.

In terms of policy response, the right hand plot of Figure 6 displays the exact opposite compared to the left hand plot. On October, 2. 2008 the positive cojump estimate is determined by the increments on block 20 and 21. According to the Bloomberg survey, on

Table 2: Upward and downward level shifts.

Block	Press release ($k = 18$)	
	pre crisis	crisis
Period		
Policy surprise	0.48 * (0.22)	0.61 * (0.27)
Pseudo R^2	0.30	0.27

Notes: Ordered probit regressions refer to a normal error distribution. Huber, White robust standard errors are given in parenthesis. * indicates significance at the 5% level. Results are based on 78 monetary policy announcement days in the pre-crisis period (2001-2007) and 55 in the crisis period (2008-2012).

that day the decision on the key rate (unchanged at 4.25%) was fully expected. However, strong pronouncements of downside risks due to the intensification of the global financial crisis during the press conference lead to revisions of markets' economic outlook. The news about the economic conditions triggered level shifts of the yield curve.¹⁷

C The direction of level shifts

If the test for level shifts and rotations consistently detects monetary policy surprises, the level shifts should move the term structure in the direction of the surprise variable. We focus on upward and downward level shifts that occur in response to the press release. Upward and downward level shifts are classified through the sign of average returns (evaluated by the sign of the spectral statistic's (5) lowest frequency component) on the respective intraday block. The difference between the actual decision on the key rate and mean expectations serves as a monetary policy surprise variable. Expectations are taken from the Bloomberg survey.

Regression results of the ordered variable on the survey measure are reported in Table 2. The significant coefficient estimates indicate that the test for level shifts and rotations consistently capture the direction of monetary policy surprises. If markets overestimate (underestimate) the decision on the key rate, the whole yield curve shifts downwards (upwards). This result also implies that taking a money market interest rate instead of the 2 year bond maturity to model the shorter end of the yield curve would not affect our results about shifts and rotations of the term structure reported in Section 5.

¹⁷The wording of the introductory statement and the question and answer session can be find on the ECB webpage: <http://www.ecb.int/press/pressconf/2008/html/index.en.html> .

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