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# The Norges Bank's key rate projections and the news element of monetary policy: a wavelet based jump detection approach

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# The Norges Bank's key rate projections and the news element of monetary policy: a wavelet based jump detection approach

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## Abstract

This paper investigates the information content of the Norges Bank's key rate projections. Wavelet spectrum estimates provide the basis for estimating jump probabilities of short- and long-term interest rates on monetary policy announcement days *before* and *after* the introduction of key rate projections. The behavior of short-term interest rates reveals that key rate projections have only little effects on market's forecasting ability of current target rate changes. In contrast, longer-term interest rates indicate that the announcement of key rate projections has significantly reduced market participants' revisions of the expected future policy path. Therefore, the announcement of key rate projections further improves central bank communication.

Keywords: Central bank communication, interest rate projections, wavelets, jump probabilities.

JEL classification: E52, E58, C14

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# 1 Introduction

Guiding and influencing expectations about future policy decisions has become a standard practice of central banks around the world. Beside setting a very short-term interest rate, i.e. the key rate, the expectation management about future key rate settings is a crucial ingredient of monetary policy, see Woodford (2005). However, specific techniques to manage expectations are remarkably different, see Blinder et al. (2008). While most central banks, including the Federal Reserve and the European Central Bank, give only qualitative signals on the short-term development, a small but increasing number of central banks started to publish numerical projections of its key rate up to three years into the future.<sup>1</sup> The difference in the implementation practice reflects the uncertainty about the particular effect of numerical projections on markets' expectations, see e.g. Mishkin (2004) and Rudebusch and Williams (2008). While a rich empirical literature on central banks' communication concentrates on the effect of qualitative guidance through talks and interviews of monetary policy committee members (e.g. Ehrmann and Fratzscher 2007), the empirical literature on key rate projections is scant; notable exceptions include Moessner and Nelson (2008), Holmsen et al. (2008), Andersson and Hofmann (2009) and Ferrero and Secchi (2009).

This paper follows Holmsen et al. (2008) by focussing on the Norwegian example. It explores whether key rate projections improve central banks' communication about current and future key rates. To that aim, this paper investigates the news element of monetary policy announcements and how it has changed since the Norges Bank publishes its key rate projections.

In order to identify the news element of monetary policy announcements the empirical methodology builds on the recently emerged literature on jumps in financial return series. According to Dungey et. al (2009), jumps in financial time series occur most likely in response to macroeconomic news announcements. In particular, Das (2002), Piazzesi (2005) and Andersson (2010) find that policy decisions of the Federal Reserve generate jumps in US treasury returns.

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<sup>1</sup>There are currently five banks that publish their interest rate projections: the Reserve Bank of New Zealand (since 1997), the Norges Bank (since 2005), the Swedish Riksbank (since 2007), the Czech National Bank (since 2008), and the Sedlabanki Islands (since 2007).

In contrast to traditional methods applied in empirical studies on central banks' communication, i.e. parametric modeling in the framework of Kuttner (2001) -style event studies, jump modeling identifies extreme events in a non-parametric setting. Inherently, jumps locate the unexpected component of monetary policy and hence avoids handling survey based or futures rates expectation measures.

Since intraday trading in Norwegian treasury bonds is fairly infrequent,<sup>2</sup> the popular jump measure derived from an estimate of the integrated volatility, i.e. the bi-power model of Barndorff-Nielsen and Shaphard (2004), is infeasible. Therefore, the empirical analysis of this paper uses daily data and a very general representation paralleling classical spectral methods. In the spirit of Wang (1995), Antoniadis and Gijbels (2002) and Fan and Wang (2007), wavelet periodograms' highest frequencies provide the basis of the empirical analysis. Since wavelets are localized in both, the time and frequency domain, they provide a natural tool in detecting high frequent characteristics like jumps in interest rates.<sup>3</sup>

In accordance with Gürkaynak et al. (2005), short- and long-term interest rates are used to distinguish between monetary policy target and path surprises. Whether key rate projections have an impact on target and path surprises is evaluated in two steps. First, jump probabilities of interest rates on monetary policy announcement days are compared with jump probabilities observed on non-announcement days. Second, the different jump probabilities on announcement and non-announcement days are compared before and after the introduction of key rate projections.

While most empirical studies emphasize the impact of the projections on the day of its publication (Moessner and Nelson 2008, Andersson and Hofmann 2009, Ferrero and Secchi 2009), there is only little empirical evidence on changes in target and path surprises due to the introduction of key rate projections. Holmsen et al. (2008) find evidence that the publishing of key rate projections reduces the volatility of short-term interest rates, implying a smaller target surprise. In contrast, Andersson and Hofmann (2009) apply a descriptive approach to different countries with

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<sup>2</sup>In the observed timespan for some maturities often not more than six trades per day occur (source: Bloomberg).

<sup>3</sup>Wavelet methods are increasingly used in different fields of economic studies such as core inflation (Baqae 2010) and inflation persistence (Zagaglia 2009) as well as the modeling and forecasting of stock market returns (Fryzlewicz 2005) and its comovements (Rua and Nunes 2009).

different guidance strategies and conclude that target surprises are equally likely irrespective of whether forward guidance involves publication of an own interest rate path or not. Effects of the introduction of key rate projections on changes in the path surprise have not been studied so far. However, since the longer-term guidance horizon is one distinguishing feature of key rate projections, it is of particular interest whether the projections decrease market's uncertainty about central banks' longer-term assessments.

This paper achieves two main findings. First, jump probabilities of the three month money market rate on monetary policy announcement days in the regime of qualitative guidance are not statistically different from jump probabilities in the regime of quantitative guidance. Therefore, the publication of key rate projections has not further improved market's forecasting ability of current key rate decisions. Second, jump probabilities of the six month up to ten year rates have decreased significantly since key rate projections have been published. At the same time a decrease in jump probabilities on non-announcement days can not be found. This suggests that the announcement of key rate projections reduces market participants' revisions of the expected future policy path and, therefore, improves central bank communication significantly.

The rest of the paper is structured as follows: Section 2 describes some aspects of the Norges Bank's projections and further clarifies the testing idea. A brief introduction to wavelet spectrum estimates and the jump measure are presented in Section 3, while Section 4 describes the data. Results and interpretations are presented in Section 5. Section 6 concludes.

## **2 Key rate projections**

### **2.1 Theoretical considerations**

In order to reach the goal of price stability, inflation targeting central banks need to affect macroeconomic variables like output and employment. Referring to standard forward looking macroeconomic models, the main channel through which a central bank stabilizes these macro variables are long term interest rates, see Woodford (2005). In light of the expectation hypothesis of the term structure, steering

the very short end of the term structure has only minor effects on long-term rates. Instead, theory highlights the importance of expectations about future short rates that cumulate to longer-term market rates. According to Rudebusch and Williams (2008), by publishing projections of future key rates, central banks are intended to affect these expectations about future short rates.

However, as put forward by Mishkin (2004) and Issing (2005), simply publishing a future policy path comprises the risk that markets misinterpret the projections as an unconditional commitment to future key rate settings. Morris and Shin (2002), Kool et al. (2007) and Rudebusch and Williams (2008) show that central banks' projections may crowd out private forecasts which results in even worse outcomes relative to the case of no central bank communication. Thus, a crucial ingredient of the published projections is its implementation in a coherent communication strategy that highlights the conditionality of the projections and provides detailed descriptions and background information.

Given such information, market participants are endowed with a better knowledge about the central bank's reaction pattern. Consequently, in response to macroeconomic shocks arising between monetary policy announcement days, markets are able to adjust their expectations about future key rate settings appropriately, see Svensson (2006). According to King (2000) this reduces the need of adjustments on monetary policy announcement days and enhances the efficiency of monetary policy.

## **2.2 The Norges Bank's guidance strategy**

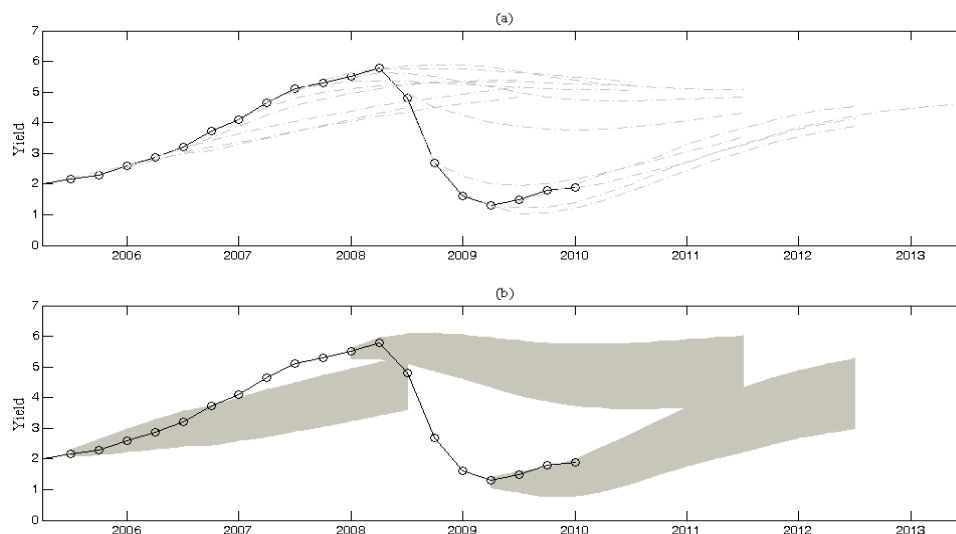
During the 2001 to 2005 period the Norges Bank provides forward guidance in a qualitative fashion, see Ferrero and Secchi (2009). Qualitative guidance is intended to steer market expectations on a short term horizon by indicating whether the key rate is more likely to increase, decrease or to stay on a constant level.<sup>4</sup>

Since November 2005 the Norges Bank publishes at every third monetary policy announcement day its key rate projections. Projections are published in Monetary Policy Reports as a path of quarterly averages up to three years into the future; for the underlying model and additional criteria for the projections see Brubakk et al.

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<sup>4</sup>During the observed period from 2001 to 2010 the key rate is set every sixth week on monetary policy announcement days. The key rate is the overnight deposit rate, see Norges Bank (2009).

Figure 1: The Norges Bank's key rate and its projections.



*Notes:* The upper figure shows projections published by the Norges Bank (gray, dashed) in conjunction with the realized average of the key rate (black, solid). The lower figure shows the same key rate but in comparison with 90% confidence bands published in Nov. 05, Mar. 08 and June 09.

(2006) and Qvigstad (2006, 2008).

Figure 1a gives an example of the realized key rate (black, solid line) along with projections (gray, dashed lines) published between November 2005 and July 2010. Each projection reflects the Norges Bank's forecast given the information on the particular day of its disclosure.

In order to prevent market participants from putting too much weight on particular numerical projections, Norges Bank publishes confidence intervals, i.e. the fan charts as depicted in Figure 1b. Fan charts are used to emphasize that the path of key rates is not a promise but a forecast which is conditional on an information set which itself is subject to uncertainty, e.g. forecasts of the output-gap and inflation. Moreover, it illustrates that the Norges Bank adjusts the key rate projections in response to economic shocks. Essentially, this is what the variability of the gray dashed lines at certain time points in Figure 1a reflect. Revisions in absolute values between two adjacent projections over the three year horizon are on average 47 basis points. The revisions reflect the difficulty central banks face when forecasting their own future behavior in a shock driven economic environment. Revisions are mainly

triggered by a stronger than expected increase in the 2006 to 2008 period and the unforeseen downturn due to the global financial crisis.<sup>5</sup>

A further feature of the Norges Bank's key rate projections is that the bank provides information about alternative scenarios of interest rate response to macroeconomic shocks. The different scenarios not only highlight the conditional nature of the projections but provide important information about the Norges Bank's preferences within its monetary policy reaction function.

In addition to presenting policy reactions to various economic developments, Monetary Policy Reports include an account of disturbances that have led to changes in the key rate projections from the previous report. The account illustrates how changes in the assessments of international and domestic variables have affected the projections, see Holmsen et al. (2008).<sup>6</sup>

The Norges Bank is clear about the purposes of its guidance strategy. As documented in Norges Bank (2009, p. 63), the key rate projections aim to strengthen transparency on the decision making process of monetary policy.

In order to assess whether the improved communication about current and future interest rates is well understood by market participants the news element of monetary policy before and after the introduction of key rate projections is analyzed.

### **2.3 Jumps and the news element of monetary policy**

The analysis of the news element of monetary policy announcements is considered in the target and path surprise framework. Following Gürkaynak et al. (2005) a target surprise is defined as an unexpected key rate change. Since the key rate is a major component of short-term market rates, the empirical analysis performed below takes jumps in short-term money market rates on monetary policy announcement days as an indicator of unexpected policy decisions. Although short-term qualitative guidance in Norway before 2005 has already been on a high level, one would expect that published projections of future key rates further improve the forecast ability of market participants, thus lowers the probability of jumps in short-term interest

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<sup>5</sup>See the Appendix A for further statistics on the projections.

<sup>6</sup>Economic variables are e.g. inflation and demand in Norway, interest rates and growth abroad, risk premiums in the money market.



rates on monetary policy announcement days.

In contrast to the target surprise, the path surprise measures the degree to which market participants revise their future expected monetary policy path following the actual decision or the disclosure of projected key rates. The path surprise, as documented in Gürkaynak et al. (2005), can be assumed to have a pronounced impact on longer-term rates. In the analysis below jumps in medium- to long-term rates on monetary policy announcement days are interpreted as evidence about revisions in market's expectations about future policy decisions. Since the projections are intended to provide a clearer view on central bank's longer-term assessments, projections should lower market's uncertainty about future key rate settings, leading to lower jump probabilities in longer-term rates on monetary policy days.

Whether key rate projections have an impact on target and path surprises is evaluated in two steps. First, the qualitative (2001-2005) and quantitative (2005-2010) guidance periods are examined separately. It is tested whether jump probabilities of interest rates on monetary policy announcement days are different to jump probabilities observed on non-announcement days. These tests provide information on the news effect of monetary policy and allows for giving statements whether target or path surprises are more likely. Second, the qualitative guidance period is compared with the quantitative guidance period. It is evaluated whether the news element of monetary policy, i.e. the target and path surprise, has decreased since key rate projections are published. As a control for an overall decrease of jump probabilities it is tested whether this decrease can be observed for the non-announcement days as well.

In Section 4 wavelet spectrum estimates are employed as a tool to locate jumps in long- and short-term interest rates. They provide the basis for estimating the jump probabilities on monetary policy announcement and non-announcement days before and after the publishing of key rate projections.

## 3 Wavelet periodogram and jump measure

### 3.1 The locally stationary wavelet periodogram

To obtain detailed insights into the periodicity and persistence of mean zero, second order stationary processes, classical spectral analysis provides a standard method to decompose a process into its frequency components.<sup>7</sup> However, stationarity of the second order structure is a fairly strong assumption when attached to financial return series and their well known stylized facts, e.g. the volatility clustering and excess kurtosis. Referring to Fryzlewicz (2005), in this case a time varying autocovariance and jump points make it important to model a periodogram that is not just a function of frequency but also provides detailed time resolution. The wavelet transform is one efficient way that such local frequency information can be obtained, see Vidakovic (1999).

Following Nason et al. (2000), the wavelet periodogram is defined by expanding the time series  $(x_t)_{t=1,\dots,n}$  on the wavelet system

$$\left\{ \left( 2^{-j/2} \psi \left( \frac{t-k}{2^j} \right) \right)_{t=1,\dots,n} : j = 1, \dots, J, k = 1, 2, \dots, n \right\}, \quad (1)$$

with  $\psi(t)$  the so called mother wavelet,  $j$  its scale or dilation index and  $k$  the time or translation index.<sup>8</sup> To be admissible as a mother wavelet  $\psi(t)$  needs to be localized in both the time and frequency domain. The time localization makes wavelets zero outside a compact interval around  $t$ . Inside the interval wavelets oscillate at a certain frequency and integrate to zero, i.e. resemble little waves.<sup>9</sup> The wavelet periodogram is given by:

$$I_{t,n}^{(j)} = 2^{-j} \left| \sum_{k=1}^n x_{k,n} \psi \left( \frac{t-k}{2^j} \right) \right|^2, \quad j = 1, \dots, J. \quad (2)$$

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<sup>7</sup>For the convenience of readers in Appendix B essentials of the classical spectral analysis and the differences between the Fourier and the wavelet basis are reviewed.

<sup>8</sup>Small scales correspond to high frequencies, large scales to low frequencies. The wavelet system (1) belongs to the translation invariant transform of Nason and Silverman (1995). As stated in van Bellegem and von Sachs (2008), taking the translation invariant transform is crucial to ensure that the relation between the local autocovariance function and the wavelet spectrum holds. The treatment of boundary conditions is discussed in Percival and Walden (2000 p. 136).

<sup>9</sup>See Daubechies (1992 Chap. 1) and Vidakovic (1999 p. 44) for the formalized properties and the Appendix B for the example of the Haar wavelet.

The wavelet periodogram relaxes the assumptions made on the process  $\{x_t\}$  in the case of the classical periodogram. The wavelet periodogram (2) requires  $\{x_t\}$  to be stationary in a local sense only, i.e. the process is allowed to have a time varying autocovariance and jumps in time, see van Bellegem and von Sachs (2008). Since (2) is calculated for each time point  $t$  and scale  $j$  high frequent features of the time series can be easily detected.

Asymptotic properties of the wavelet periodogram (2) have been studied for instance by Nason et al. (2000) and Fryzlewicz and Nason (2006). They show that the wavelet periodogram is not an asymptotically unbiased estimator. Furthermore, as for classical periodograms, the wavelet periodogram has an asymptotically non-vanishing variance and needs to be smoothed to obtain consistency.

To achieve asymptotic unbiasedness Nason et al. (2000) suggest an appropriate correction of (2). The correction is accomplished by pre multiplying the periodogram with elements of the inverted, inner product matrix (A) of the autocorrelation wavelets:<sup>10</sup>

$$L_{t,n}^{(j)} = \sum_{l=1}^J 2^{-l} A_{j,l}^{-1} \left| \sum_{k=1}^n x_{k,n} \psi \left( \frac{t-k}{2^l} \right) \right|^2, \quad j = 1, \dots, J. \quad (3)$$

While  $L_{t,n}^{(j)}$  is an asymptotically unbiased estimator of the wavelet spectrum, it needs to be smoothed to obtain consistency. A comparison of different smoothing techniques can be found in Fryzlewicz and Nason (2006). The consistent estimate of the wavelet spectrum is denoted  $\tilde{L}_{t,n}^{(j)}$ .

### 3.2 Jump detection based on the wavelet periodogram

Starting with the seminal paper of Wang (1995), the wavelet literature on jump detection is closely related to wavelet based non-parametric function estimation, i.e. wavelet shrinkage as introduced by Donoho and Johnstone (1994). The jump detection approach applies a part of wavelet shrinkage, namely transforming the time series in the wavelet domain and locating noise-free coefficients. Since jumps are

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<sup>10</sup>See the Appendix C for details on the calculation of  $A$ , van Bellegem and von Sachs (2008) for details why this correction results in an asymptotically unbiased estimator and Nason's (2008, p. 184) remarks on how  $A$  is defined in the special case of the Haar wavelet.

a high frequent characteristic Wang's (1995) approach focusses on the finest scale, i.e. the highest frequency of the transform. The method is based on contributions reviewed in Daubechies (1992, Chap. 2.9), that at fine scales near by jump points absolute wavelet coefficients are considerable larger than at points where no jump occurs. Therefore, jumps in time series can be identified by locating peaks over a threshold. The method has been successfully utilized in e.g. Antoniadis and Gijbels (2002) and Fan and Wang (2007).

In comparison to Wang (1995) four modifications are made. First, the method is translated such that the thresholding can be applied on the wavelet spectrum estimate instead of applying it to the absolute wavelet coefficients. Jump detection via the wavelet spectrum estimate has the advantage that the threshold can directly be linked to the consistent estimate of the spectrum's finest scale, i.e. the squared coefficients as suggested in von Sachs and MacGibbon (2000). Second, as Antoniadis and Gijbels (2002) argue, the translation invariant transform provides a better time resolution and thus detects jumps more easily than the dyadic transform applied in Wang (1995). Third, the universal threshold in Wang (1995) is replaced by the more efficient (in the mean square sense) minimax threshold.<sup>11</sup> The minimax threshold has been proposed by Donoho and Johnstone (1994) as an improvement to the universal threshold which sets the threshold conservatively high, thus asymptotically underestimates the number of jumps. Fourth, as suggested by von Sachs and MacGibbon (2000) the minimax threshold  $\lambda$  is chosen to be time varying to allow for heteroscedastic noise in the underlying time series. The threshold is given by:

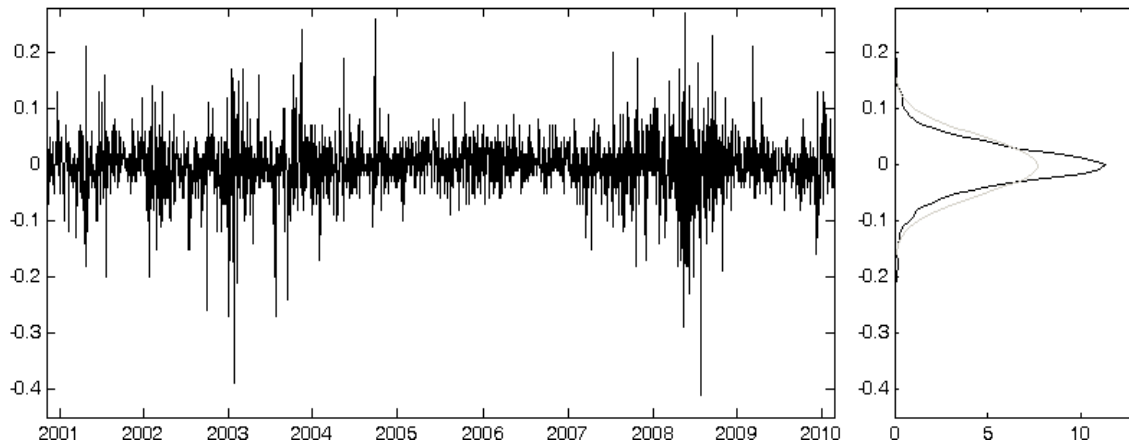
$$\lambda_t = \sum_{l=-m}^m \frac{\tilde{L}_{t+l,n}^{(1)}}{(2m+1)} \delta^2(m), \quad (4)$$

where  $\tilde{L}_{t,n}^{(1)}$  is the spectrum estimate of the observed process  $\{x_t\}$  at the finest scale, at time point  $t$ . Averages of the spectrum estimate serve as an estimator of the local variance. Values of the squared function  $\delta(m)$  achieving the minimax rate for different window width ( $m$ ) are tabulated in Bruce and Gao (1996). Given the

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<sup>11</sup>See Vidakovic (1999 p. 185) for a general introduction to the minimax paradigm in relation to wavelet shrinkage and Bruce and Gao (1996) for the derivation of formulae for the exact bias and variance of the estimates in finite sample situations.

Figure 2: Three year interest rate and its density.



*Notes:* Daily changes of the three year government bond series are measured in percentage points. The right hand plot shows the estimated probability density and a corresponding normal density (gray). The estimate is based on a Gaussian kernel with bandwidth chosen by Silverman's (1986, p.48) rule.

thresholds in (4), the thresholding rule

$$\theta_t = \begin{cases} 1 & \tilde{L}_{t,n}^{(1)} \geq \lambda_t & \text{(jump)} \\ 0 & \tilde{L}_{t,n}^{(1)} < \lambda_t & \text{(no-jump)} \end{cases} \quad (5)$$

locates jumps in the underlying time series. Since  $\theta_t$  is Bernoulli distributed, jump probabilities  $\hat{p}_h$  of sets of size  $h$  are approximately normal with mean  $p$  and variance  $p(1-p)/h$ .

## 4 Data

The interest rate data consist of constant maturity zero coupon rates that are provided by Bloomberg.<sup>12</sup> Rates are derived from the Norwegian yield curve. In order to shed light on the effects of the Norges Bank's key rate projections on target and path surprises, it is revealing to analyze reactions of different maturities. Accordingly, maturities of three and six month as well as one, three and ten years are considered.

Although it seems to be appealing to use intraday data, infrequent trading in Norwe-

<sup>12</sup>Identifikation code: NKG03S <INDEX>.

Table 1: Interest rate statistics for different maturities.

	Mean	Std. Dev.	Skew.	Kurt.	JB
3 month	-0.002	0.12	-1.11	70.6	0.00
6 month	-0.002	0.11	-0.75	44.9	0.00
1 year	-0.002	0.10	-0.54	37.9	0.00
3 year	-0.002	0.05	-0.61	9.91	0.00
10 year	-0.001	0.05	0.45	9.50	0.00

*Notes:* Mean and the standard deviation of daily changes in interest rates are given in percentage points. Skewness and kurtosis denote the third and fourth standardized moments. JB indicates the p-value of the Jaque-Bera test with the null of normality.

gian government bonds makes it necessary to choose daily data representing closing day rates. First differences are taken to receive daily changes measured in percentage points. The data captures the timespan from the introduction of inflation targeting in March 2001 until July 2010. The sample of 2337 data points is suitable for testing purposes because the overall monetary policy strategy has been kept constant except for the change in the guidance strategy in November 2005. Of course, the global financial crisis (2008-2010) may disturb the empirical analysis which potentially increases jump probabilities in the quantitative guidance sample. However, the comparison of announcement and non-announcement days remain unaffected since it can be assumed that the crisis affect both jump probabilities to the same extent. Since jump probabilities are higher during the financial crisis, it becomes more difficult to find significantly smaller jump probabilities in the quantitative guidance sample. Consequently, evidence on a significant decrease of jump probabilities reflects a strong result.

Descriptive statistics of the interest rate series reveal the well known and often cited stylized facts of financial return series. Figure 2 shows an example of the three year rate indicating: i) that the sample mean is close to zero; ii) the marginal distribution is roughly symmetric or slightly skewed, has a peak at zero, and is heavy tailed; iii) volatility is clustered, i.e. days of either large or small movements are followed by days of similar characteristics. As indicated in Table 1, tests on normality are rejected. In particular the distribution's positive excess kurtosis highlights the presence of jumps.

## 5 Jumps in Norwegian interest rates

### 5.1 Wavelet spectrum estimates

The inputs to the wavelet periodograms are the changes in the respective interest rate series. Estimates of the wavelet spectrum are based on the Haar mother wavelet.<sup>13</sup> Following Nason et al. (2000), the computational steps are as follows: first, the periodogram is calculated; second, each scale is smoothed by applying the non-linear thresholding procedure introduced by Donoho and Johnstone (1994);<sup>14</sup> third, the smoothed periodogram is bias corrected as demonstrated in equation (3). Given the consistent estimate of the wavelet spectrum, for each series the jump point measure is derived from the finest scale which reflects a period of two days. The critical values of the thresholding procedure are based on local variance estimates in a six month interval symmetrically surrounding each time point  $t$ , see equation (4).<sup>15</sup> Spectrum estimates that exceed the threshold are identified as jumps in the underlying interest rate series, see Section 3.3.

To get a first impression, Figure 3 shows the evolution of the highest frequency of the wavelet spectrum estimates (gray, solid line) of the time series under investigation. The plots highlight monetary policy announcement days (black, empty circles). The black, solid lines indicate the time dependent thresholds.

The overall characteristics of the jump measure are fairly similar across maturities and can roughly be divided into four segments. While in the first half of the samples jumps accrue relatively often, the number of values above the thresholds sharply decrease in 2005 and stood at a low level until the end of 2007. In this mid period only few jump points can be observed. Shocks of the financial crisis increase the jump activity again until late 2009. Until the most recent days the number of jumps is back on a low level although maturities of one and more years show a tendency to a renewed upswing.

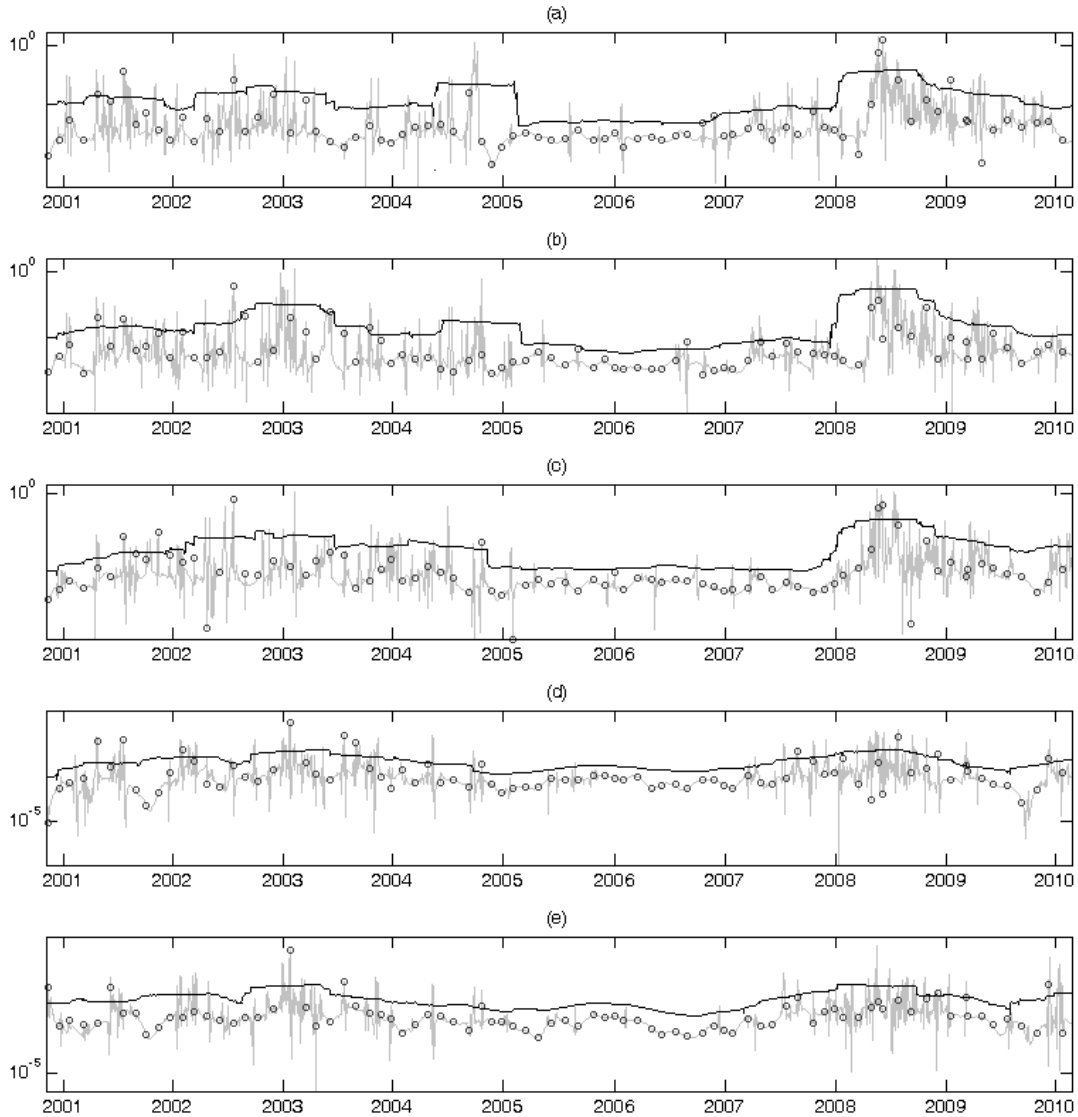
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<sup>13</sup>To check for the robustness of the results against different wavelet bases, other wavelets like the symmlet family (see Vidacovic 1999, p. 86) have been applied to the data. Although the detected number of jumps are smaller for the symmlets than for the Haar wavelets, the tests applied in the next subsection produces the same qualitative results, see Appendix D.

<sup>14</sup>The smoothing is chosen to be non-linear to account for jumps in the underlying time series. Results are robust to different smoothing setups.

<sup>15</sup>Although the smoothness of the thresholds depends on the chosen window width, a smaller (3 month) as well as a longer (1 year) width does not change general findings, see Appendix D.

Figure 3: Jump detection in interest rates.



*Notes:* (a) the 3 month, (b) 6 month (c) 1 year, (d) 3 year, (e) 10 year spectrum estimates (gray solid lines). Spectra are estimated by the Haar wavelet and non-linearly smoothed. The depicted scale is equal to a period of two days. Black, empty circles indicate monetary policy announcement days. The minimax thresholds (black solid lines) are computed as described in Section 3.3. The y-axis is scaled in logged units.



Table 2: Jump probabilities and the announcement - non-announcement tests.

		Obs.	3 month	6 month	1 year	3 year	10 year
<i>Qualitative guidance (2001-2005)</i>	Announc.	40	7.50 (4.16)	12.50 (5.23)	12.50 (5.23)	20.00 (6.32)	12.50 (5.23)
	Non-announc.	1106	5.88 (0.71)	6.06 (0.72)	5.24 (0.67)	5.97 (0.71)	4.79 (0.64)
	P-val.		0.72	0.17	0.08	0.00	0.05
<i>Quantitative guidance (2005-2010)</i>	Announc.	43	9.30 (4.43)	2.33 (2.30)	4.65 (3.21)	9.30 (4.43)	4.65 (3.21)
	Non-announc.	1148	5.84 (0.69)	4.79 (0.63)	4.44 (0.61)	5.23 (0.66)	4.27 (0.60)
	P-val.		0.44	0.50	0.95	0.32	0.91

*Notes:* Jump probabilities in interest rates of different maturities are given in percent. Numbers in brackets show standard deviations of the jump probabilities. P-values indicate whether the null hypothesis of equal jump probabilities on monetary policy announcement and non-announcement days can be rejected.

## 5.2 Jump probabilities and monetary policy days

The wavelet based jump detection approach allows for estimating jump probabilities of different subsets of the data. In order to test whether the news element of monetary policy has changed since Norges Bank publishes its key rate projections, the different subsets are meant to measure jump probabilities on monetary policy announcement and non-announcement days. Furthermore, to test the impact of the enhanced communication, the sets are separated in a sample representing qualitative guidance (2001-2005) as well as quantitative guidance (2005-2010). Tests are performed in two steps: First, the existence of significant news effects on monetary policy announcement days during the qualitative and quantitative guidance period is tested. Second, the question is answered whether key rate projections decrease the news effect of monetary policy, i.e. lower target and path surprises.

Table 2 comprises the results of the testing procedure's first step. In line with standard findings for the US, i.e. Kuttner (2001), Das (2002), Piazzesi (2005), the Norwegian interest rates show a pronounced response to monetary policy announcements.

The upper part of Table 2 presents the results of the *qualitative guidance* sample. For example, the three year rate jumps on announcement days with a probability of 20%, i.e. eight jumps out of 40 announcements. The standard deviation of 6.32% highlights that the jump probability is significantly different from zero. The jump

probability on non-announcement days is 5.97%, i.e. 66 jumps out of 1106 days, with a standard deviation of 0.71%. As indicated by the p-value, the probability that a jump occurs on non-announcement days is significantly smaller than on announcement days. This suggests a significant news effect of monetary policy.

The shortest money market rate has with 7.5% the lowest jump probability among the tested interest rates. It indicates that in the period before key rate projections have been published unexpected key rate changes, i.e. target surprises, occur with a total number of three times. Thus, market's forecasting ability of current key rate changes in the regime of qualitative guidance can be thought of as being on a high level.

On average, jumps in Norwegian interest rates on monetary policy announcement days are more than twice as likely as on all other days. While this difference is statistically significant for maturities of one year and longer, for money market rates, i.e. the three and six month rates, the null hypothesis of no difference can not be rejected. Interestingly, jumps on announcement days in longer term rates occur more often than in short term rates. This suggests that revisions in market's expected future policy paths, i.e. path surprises, are more likely than adjustments to the current key rate level. The finding reflects the shorter term perspective of qualitative guidance and may serve as an argument for increasing communication about longer term assessments.

In the *quantitative guidance* period jump probabilities are for the majority of the yields still higher on announcement days than on non-announcement days. However, as shown in the lower part of Table 2, the difference in the jump probabilities on announcement and non-announcement days are (with the exception of the three month rate) much smaller than in the sample without key rate projections. The statistical significant difference found in the qualitative guidance sample holds no longer to be true. Consequently, no significant news effect of monetary policy can be found since the Norges Bank publishes its key rate projections.

The decrease of the difference in the jump probabilities on announcement and non-announcement days is mainly caused by the decline of jumps on monetary policy days. For the example of the three year rate the jump probability on announcement days has decreased by 10.7 percentage points. With a total number of 43 policy days this implies halving the absolute number of jumps in comparison to the qualitative guidance sample. At the same time jumps on non-announcement days stood with a jump probability of 5.23% at a fairly constant level.

Table 3: Jump probabilities and the Qualitative - quantitative guidance tests.

		Obs.	3 month	6 month	1 year	3 year	10 year
<i>Monetary pol. announcement</i>	Qual.	40	7.50 (4.16)	12.50 (5.23)	12.50 (5.23)	20.00 (6.32)	12.50 (5.23)
	Quant.	43	9.30 (4.43)	2.33 (2.30)	4.65 (3.21)	9.30 (4.43)	4.65 (3.21)
	P-val.		0.88	0.03	0.09	0.11	0.09
<i>Non-announcement</i>	Qual.	1106	5.88 (0.71)	6.06 (0.72)	5.24 (0.67)	5.97 (0.71)	4.79 (0.64)
	Quant.	1148	5.84 (0.69)	4.79 (0.63)	4.44 (0.61)	5.23 (0.66)	4.27 (0.60)
	P-val.		0.49	0.37	0.41	0.43	0.44

*Notes:* Jump probabilities in interest rates of different maturities are given in percent. Numbers in brackets show standard deviations of the jump probabilities. P-values indicate whether the null hypothesis of equal jump probabilities in the qualitative (2001-2005) and quantitative (2005-2010) guidance sample can be rejected.

Results of the testing procedure's second step can be found in Table 3. The upper part of Table 3 highlights the change on announcement days. While in the qualitative guidance sample the path surprise is more likely than the target surprise, this no longer holds since the Norges Bank publishes its key rate projections. In fact, since the publishing of key rate projections has been introduced, jump probabilities on announcement days of the six month up to ten year rate have decreased on average by 64% or 9.14 percentage points. Tests show that the decrease is (except for the three year rate) statistically significant on a 10% level. This indicates that in response to policy decisions market participants revise their expectations about future key rate settings less frequent. It reflects that path surprises became less likely since the Norges Bank publishes its key rate projections.

In contrast to the longer end of the term structure, jumps in the three month rate increase slightly by 1.8 percentage points. Consequently, significant improvements of market's forecast ability of current target rate changes can not be found. This suggests that target surprises are not effected by the publishing of key rate projections.

In order to test whether the decrease in the path surprise is driven by an overall decline in the jump probabilities, the lower part of Figure 3 tests for a decline in the jump probabilities on non-announcement days. On average jump probabilities of the six month rate and longer are 12% or 0.67 percentage points smaller since key rate projections are published. The decline is evaluated as not statistically significant. This strengthens the finding of a significant decline in jump probabilities

on announcement days.

To sum up, the published projections do not effect the target surprise but significantly decrease the path surprise.

## 6 Conclusion

The publishing of key rate projections is a new and debated tool in the expectation management of central banks. The Norges Bank is among the pioneers and publishes projections since 2005. To analyze how the news element of monetary policy announcements has been affected by the increased communication, jump probabilities of daily interest rates in the timespan 2001-2010 has been examined before and after the introduction of key rate projections. By focusing on jumps it was possible to identify the unexpected part of key rate changes as well as revisions in market's expected future policy paths due to monetary policy. It has been tested whether the key rate projections increase market's ability in forecasting current key rate changes and whether market participants became more capable in evaluating central bank's long term assessments.

In order to identify jumps in interest rates, Wang's (1995) wavelet based approach has been applied in the context of wavelet spectrum estimates. In particular, estimates of the spectrums highest frequency reflecting a two day period along with a thresholding rule were employed to estimate jump probabilities.

The paper reaches two main findings: first, since key rate projections have been published, jump probabilities on monetary policy announcement days of the short-term money market rate have changed on a small and insignificant level. Thus, the unexpected part of actual key rate changes has not decreased indicating no further improvement of market's forecasting ability of current key rate decisions. Second, jump probabilities in longer-term rates have decreased significantly since key rate projections have been published. At the same time a decrease in jump probabilities on non-announcement days can not be found.

This suggests that being transparent about longer term assessments in a quantitative fashion significantly decreases market's uncertainty about the central bank's long-term behavior and thus improves the Norges Bank's communication.

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# A Evaluations of the Norges Bank's key rate projections

Table 4: RMSE of the Norges Bank's projections and constant rate benchmark.

Horizon	1Q	2Q	3Q	4Q	8Q	12Q
whole sample	0.47	0.79	1.30	1.62	2.67	3.02
ex. financial crisis	0.09	0.12	0.39	0.42	1.57	-
const. rate	0.70	1.13	1.59	1.99	2.87	1.98

*Notes:* Errors are measured in percentage points. For comparison purpose effects of the financial crisis are excluded in the second row (the sample includes data up to Aug. 08 thus no data is available for the three year forecast). The constant or random walk forecast uses data of the whole sample.

- Root mean square errors of Norges Bank's key rate projections are (except for the three year horizon) smaller than a random walk benchmark and decrease significantly when the financial crisis is excluded.
- The actual key rate crosses the published 90% confidence bands on average after 5 quarters with a maximum of 10 quarters (the projections of November 2006) and a minimum of two quarters (June and October 2008).
- Revisions in absolute values over the three year horizon are on average 47 basis points for the whole sample and 25 basis points excluding the financial crisis.

# B Fourier and wavelet analysis

A time series  $(x_t)_{t=1,\dots,n}$  can be uniquely represented in terms of the Fourier basis  $\{\exp(-i\omega_j t)\}$  composed of different frequencies  $\omega_j = 2\pi j/n$ ,  $t, j = 1, \dots, n$ , and  $i^2 = -1$ . The periodogram is of main interest in the classical spectral analysis and can be estimated by

$$I(\omega_j) = (2\pi)^{-1} \left| \sum_{t=1}^n x_t \exp(-i\omega_j t) \right|^2. \tag{B1}$$

Because of Euler's formular  $\exp(-i\omega_j t) = \cos(\omega_j t) - i \sin(\omega_j t)$  Fourier series can be regarded as an expansion of the process  $\{x_t\}$  in terms of sine and cosine functions;

see Brockwell and Davis (1991, p. 116). Since sinusoids are perfectly localized in frequency and hence are non-localized in time, it becomes clear why the periodogram is a function of frequency only. This implies the requirement that statistical properties of  $\{x_t\}$  need to be time-invariant, i.e. stationary.<sup>16</sup>

While the Fourier expansion uses the orthonormal system

$$\{((2\pi)^{-1/2} \exp(-i\omega_j t))_{t=1,\dots,n} : j = 1, \dots, n\} \quad (\text{B2})$$

to map the time series into the frequency domain, the wavelet expansion in contrast expands the time series on the orthonormal basis

$$\left\{ \left( a_j^{-1/2} \psi \left( \frac{t - b_{j,k}}{a_j} \right) \right)_{t=1,\dots,n} : a_j = 2^j, b_{j,k} = k2^j, j = 1, \dots, J, k = 1, 2, \dots, n \right\}, \quad (\text{B3})$$

with  $\psi(t)$  the so called mother wavelet,  $a_j$  its scale or delation index and  $b_{j,k}$  the time or translation index.<sup>17</sup> The best known example of wavelets are Haar wavelets. They are given by the simple step functions:

$$\psi_{a_j, b_{j,k}}^H(t) = a_j^{-1/2} \{ \mathbb{1}(b_{j,k} \leq t < a_j/2 + b_{j,k}) - \mathbb{1}(a_j/2 + b_{j,k} \leq t \leq a_j + b_{j,k}) \}, \quad (\text{B4})$$

where  $\psi_{a_j, b_{j,k}}(t)$  is the shorthand notation for the basis (B3) and  $\mathbb{1}$  the indicator function.

The localization in the time domain makes the crucial difference between the Fourier and the wavelet basis. It implies that the Fourier domain is a two dimensional space, measuring contributions of different frequencies ( $\omega_j$ ), while the wavelet domain is three dimensional, comprising the contribution of different scales ( $a_j$ ) at different time points ( $t$ ). This ability makes it possible to identify localized, high frequent features like jumps in interest rate returns.

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<sup>16</sup>See for instance Brockwell and Davis (1991, p. 330ff) for a detailed introduction and the derivation of the statistical properties of the periodogram.

<sup>17</sup>Small scales correspond to high frequencies, large scales to low frequencies. The treatment of boundary problems is discussed in Percival and Walden (2000 p. 136).

## C Autocorrelation wavelets

$$\Psi_j(\tau) = \sum_{t=1}^n \psi\left(\frac{t}{2^j}\right) \psi\left(\frac{t-\tau}{2^j}\right) \quad (\text{C1})$$

is the autocorrelation wavelet function for the mother wavelet  $\psi$ , at scale  $j = 1, \dots, J$  and correlation order  $\tau = 1, 2, \dots$ . Contributions are zero outside the wavelets' support (taking the translation invariant approach). For the decimated transform and well chosen wavelets, e.g. the Haar wavelet, the transform is orthogonal, hence  $\Psi_j(\tau) = 0 \forall \tau$  and  $j$ .

The  $(j, l)$ th item of the invertible, inner product matrix of the autocorrelation wavelets (A) is then defined by

$$A_{j,l} = \sum_{\tau} \Psi_j(\tau) \Psi_l(\tau). \quad (\text{C2})$$

See Nason (2008, p. 183) for further details.

## D Jump point evaluation and robustness

- 1) Absolute jump sizes in Table 5 indicate how well the wavelet method detects jumps in the underlying time series.
- 2) Table 6 shows wavelet spectrum estimates applying symlets with six vanishing moments (instead of the Haar wavelet) and Haar based spectra but with thresholds of different window width, i.e. 3 month and 1 year.

Table 5: Jump sizes.

maturity	3 month	6 month	1 year	3 year	10 year
whole sample	0.05	0.05	0.05	0.03	0.03
meeting	0.31	0.11	0.30	0.17	0.11
no-meeting	0.23	0.25	0.23	0.09	0.09

*Notes:* The jump sizes are computed as the mean of the absolute change in the interest rate data on days that are identified as jump days. Sizes are given in percentage points.

Table 6: Jump probabilities of different maturities; robustness analysis.

maturity	sym6			window 3M			window 1Y			
	Meeting $[\hat{p}_i^{M}]$	No-meeting $[\hat{p}_i^{NM}]$	p-val. $[H_0:p_i^M=p_i^{NM}]$	Meeting $[\hat{p}_i^{M}]$	No-meeting $[\hat{p}_i^{NM}]$	p-val. $[H_0:p_i^M=p_i^{NM}]$	Meeting $[\hat{p}_i^{M}]$	No-meeting $[\hat{p}_i^{NM}]$	p-val. $[H_0:p_i^M=p_i^{NM}]$	
3 month	pre	7.50 (4.16)	4.52 (0.62)	0.41	7.50 (4.16)	6.33 (0.73)	0.80	7.50 (4.16)	4.52 (0.62)	0.41
	past	9.30 (4.43)	4.53 (0.61)	0.19	11.63 (4.89)	5.92 (0.70)	0.22	4.65 (3.21)	3.83 (0.57)	0.79
	p-val. $[H_0:\hat{p}_{pre}^j=\hat{p}_{past}^j]$	0.88	0.99		0.77	0.46		0.27	0.42	
6 month	pre	7.50 (4.16)	5.52 (0.69)	0.65	15.00 (5.65)	7.96 (0.80)	0.20	5.00 (3.45)	4.70 (0.64)	0.94
	past	2.33 (2.30)	3.14 (0.51)	0.75	9.30 (4.43)	5.14 (0.65)	0.31	2.33 (2.30)	3.05 (0.51)	0.77
	p-val. $[H_0:\hat{p}_{pre}^j=\hat{p}_{past}^j]$	0.09	0.24		0.24	0.30		0.18	0.30	
1 year	pre	12.50 (5.23)	4.43 (0.62)	0.03	12.50 (5.23)	7.59 (0.80)	0.38	12.50 (5.23)	3.98 (0.59)	0.01
	past	4.65 (3.21)	3.14 (0.51)	0.56	6.98 (3.89)	4.62 (0.62)	0.52	4.65 (3.21)	3.31 (0.53)	0.62
	p-val. $[H_0:\hat{p}_{pre}^j=\hat{p}_{past}^j]$	0.09	0.34		0.20	0.26		0.09	0.41	
3 year	pre	15.00 (5.65)	3.53 (0.55)	0.00	20.00 (6.32)	5.79 (0.70)	0.00	15.00 (5.65)	3.98 (0.59)	0.00
	past	4.65 (3.21)	2.26 (0.44)	0.23	9.30 (4.43)	4.01 (0.58)	0.11	6.98 (3.89)	3.57 (0.55)	0.25
	p-val. $[H_0:\hat{p}_{pre}^j=\hat{p}_{past}^j]$	0.06	0.30		0.12	0.32		0.14	0.45	
10 year	pre	7.50 (4.16)	2.98 (0.51)	0.08	10.00 (4.74)	4.16 (0.60)	0.09	10.00 (4.74)	3.07 (0.52)	0.01
	past	4.65 (3.21)	1.74 (0.39)	0.08	2.33 (2.30)	4.01 (0.58)	0.60	2.33 (2.30)	2.70 (0.48)	0.87
	p-val. $[H_0:\hat{p}_{pre}^j=\hat{p}_{past}^j]$	0.27	0.27		0.05	0.48		0.05	0.44	

Notes: Jump probabilities on monetary policy announcement (“meeting”) and non-announcement (“no-meeting”) days before the introduction of published key rate projections (“pre”) and afterwards (“past”) are given in percent. Numbers in brackets indicate standard deviations of the jump probabilities. Instead of using the Haar wavelet the results in the left block (“sym6”) are based on symlets with six vanishing moments. The middle block (“window 3M”) is computed using the Haar wavelet but thresholds where the window size is 3 month instead of six month. Right block (“window 1Y”) the same as “window 3M” but with a 12 month window.

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