How ECB's monetary policy affects Norwegian asset prices*

Saskia ter Ellen, Edvard Jansen, Nina Larsson Midthjell†

September 2017

Abstract

In this paper we study how monetary policy shocks of the European Central Bank affect Norwegian financial variables. Using high-frequency data, we examine intraday changes in European interest rates to identify the monetary policy shocks. We use principal component analysis to identify two factors of monetary policy shocks interpreted as a conventional and an unconventional monetary policy surprise. The findings suggest that both factors have strong and significant effects on the exchange rate and Norwegian asset prices, yield curves and equity prices.

Keywords: monetary policy, forward guidance, interest rates, asset prices, small open economies

JEL classification codes: E43; E44; E52; E58; G12

*The views expressed in this paper are those of the authors and do not necessarily reflect the views of Norges Bank. This is work in progress, please do not share or cite without permission of the authors. We are grateful to Eric Swanson for sharing his code and for comments in the early stage of the project. We would like to thank Hong Xu and Kjetil Stiansen for indispensable help with data collection. We further thank participants of the Nordic Symposium on Macroeconomics (Normac) and seminar participants at Norges Bank for their comments.

†Saskia ter Ellen and Nina L. Midthjell work at Norges Bank, Saskia.ter-Ellen@Norges-Bank.no. and Nina-Larsson.Midthjell@Norges-Bank.no, and Edvard Jansen works at Formuesforvaltning, Edvard.Jansen@gmail.com.

1 Introduction

> For the past few decades, international macroeconomics has postulated the "trilemma": with free capital mobility, independent monetary policies are feasible if and only if exchange rates are floating. The global financial cycle transforms the trilemma into a "dilemma" or an "irreconcilable duo": independent monetary policies are possible if and only if the capital account is managed. - *Helene Rey, Jackson Hole Symposium 2013*

Over the recent years, it has become clear that monetary policy conducted by large central banks can have serious spillover effects on other countries, and that global financial integration can make monetary policy less independent in general. Rey (2015) argues that (lending) conditions of global financial institutions, as well as credit growth and capital flows, are largely driven by the global financial cycle, which in turn is mostly determined by monetary policy of the major central banks. This leads her to argue that rather than the classical *tri*lemma (exchange rate control, free capital mobility, and independent monetary policy) we are dealing with a *di*lemma (independent monetary policy is only possibly with some capital controls). Abstracting from whether this means that monetary policy has become less independent globally, we can safely say that this implies serious spillover effects from monetary policy. Moreover, the unconventional monetary policies that have been conducted over the past years have lead to a strong interest in the effects of such policies, both domestically and abroad.

In this paper we investigate what the effects of conventional and unconventional monetary policy from the ECB are on small open economies that are close to, but not part of, the European Monetary Union (EMU). In particular, we use high frequency identification to identify a monetary policy shock (an unexpected change in the key policy rate) and an unconventional monetary policy shock (an unexpected change in interest rates due to forward guidance or LSAP announcements), and analyse the effects of these shocks on asset prices and yields in Norway.[1]

In contrast to economic variables, financial variables respond instantly to changes in monetary policy. Hence, they are typically seen as a starting point of the transmission mechanism initiated by a monetary policy decision and as indicators of the effect on

[1] We are currently working on an extension that includes other small open economies, but the results are too preliminary to report as of yet

economic variables. The transmission mechanism is complex and not unique. Changes in expected future key policy rates affect both short- and longer-term market interest rates. Asset prices and the general economy are affected by the entire path of expected future interest rates. Praet (2013) describes this expectation channel as a two-step procedure. First, the economic agents interpret the strategy of central bank actions in response to the economic development. Second, they form expectations based on their understanding of the central bank's strategy and communicated outlook for economic variables. If the agents are forward looking, the central bank can influence expectations, with consequences for the economy today. In order to do so, a more open and transparent communication of future policy (forward guidance) may be effective.

In recent years, due to key policy rates near the effective lower bound, monetary policy has not been able to stimulate the economy solely by conventional measures. Many central banks have therefore extended their policy to include a more extensive use of forward guidance as well as liquidity improving actions in the form of quantitative easing. For the US, multiple papers find that monetary policy may still be efficient even if the federal funds rate is low or zero because the Federal Reserve (Fed) has the ability to influence financial market expectations (see e.g. Reifschneider and Williams 2000, Eggertsson and Woodford 2003, Gürkaynak, Sack, and Swanson 2005 and Swanson 2017. By communicating its intention to keep the key policy rate low for an extended period of time (in addition to large scale asset purchases), a central bank may effectively lower longer-term interest rates and stimulate economic growth. This result is supported by Brand, Buncic, and Turunen (2010) who find that during the press conference following a key policy rate decision by the ECB, market expectations for the path of monetary policy, illustrated by significant changes in European interest rates at medium and longer term maturities, change considerably.

The US and euro area account for around 40 percent of world GDP. In this respect, policy actions and statements by the Fed and the ECB are likely to cause spillovers to other countries, and may even impair the ability of central banks in small open economies (SOEs) to have an autonomous monetary policy. The literature on how economic, and especially financial variables of SOEs are affected by foreign monetary policy is dominated by studies looking at spillovers from the Fed to emerging market economies (e.g. Takats and Vela 2014, Chen, Mancini-Griffoli, and Sahay 2014, Tillmann 2016) and be-

tween advanced economies (e.g. Ehrmann, Fratzscher, and Rigobon 2011, Rogers, Scotti, and Wright 2016, Bauer and Neely 2014, Neely 2015).[2] An exception is Falagiagrda, McQuade, and Tirpak (2015), who show that spillovers occur from ECB's unconventional monetary policy to yields in non-euro area EU countries from Central and Eastern Europe. Furthermore, Bjørnland, Thorsrud, and Zahiri (2016) show that forward guidance in SOEs may be less effective if foreign variables are not taken into account because foreign variables help to forecast the central bank's revisions of interest rate projections, and market participants partly anticipate this. Likewise, Syrstad and Rime (2014) and Svensson (2015) find that large gaps between the market's and the central bank's rate paths can be explained by the gap between the central bank's path and foreign rates. There is also some evidence that money market integration may lead to the impairment of certain transmission channels. Cao and Dinger (2016) show that the Norwegian lending channel is less effective in times of deviations from interest rate parity because Norwegian banks can lend abroad.

In this paper, we investigate the effect of ECB's monetary policy on Norwegian yields and asset prices. This is particularly interesting as many of Norway's main trading partners are member countries of the European Monetary Union (EMU). We distinguish between conventional monetary policy, i.e. key policy rate decisions, and unconventional monetary policy, which encompasses both forward guidance and large scale asset purchases (LSAP), and identify shocks using high frequency identification (HFI) techniques.[3] In order to identify the policy rate shock, we take advantage of the fact that the ECB key policy rates decision is published 45 minutes prior to the press conference. This first part of monetary policy information is one-dimensional in the sense that it is not accompanied by forward guidance. Using high frequency (intraday) data we identify the shock by measuring immediate responses in short-term European Overnight Index Swap (OIS) rates. The findings suggest that a surprise to the ECB's key policy rates decision has strong and significant effects on Norwegian asset prices and yield curves immediately after the press release. The results show strongest effects for the short- and medium-term

[2]There is also a number of studies that evaluate spillovers from the US to a large number of countries, often focusing on equity markets. See, for example Ehrmann and Fratzscher (2009), Hausman and Wongswan (2011), Dedola, Rivolta, and Stracca (2017).

[3]Several papers have assessed responses to monetary policy shocks in a HFI framework, see e.g. Campbell et al. (2012), Gürkaynak, Sack, and Swanson (2005), Hamilton (2008), Hanson and Stein (2012), and Swanson (2017).

interest rate instruments. In addition, the exchange rate and equity prices also respond to the surprise.

Next, we adopt a methodology very similar to that of Gürkaynak, Sack, and Swanson (2005) and Swanson (2017) who use factor analysis on several U.S. money market instruments to identify two factors of the FOMC's monetary policy and estimate the impacts of these factors on U.S. equity prices and interest rates.[4] The first factor is interpreted as a shock to the federal funds rate and the second factor is interpreted as a shock to the future path of policy (forward guidance). From a set of interest rate surprises that together explain the actions and statements of the ECB's monetary policy, we extract two similar factors. At least prior to the ECB's introduction of asset purchases, these two factors can be interpreted as a policy rate surprise and a forward guidance surprise. After the ECB started with its asset purchasing program, however, the second factor represents a combination of forward guidance and asset purchases. The findings suggest that both factors have strong and significant effects on Norwegian financial variables, with the second factor having a characteristic hump-shape impact on the yield curve.[5]

The remainder of the paper is organized as follows: Section 2 presents the data. Section 3 provides an overview of the applied identification methods. The empirical analysis and results are presented in section 4. Section 5 concludes.

2 International transmission channels of monetary policy

There are several channels through which monetary policy, both conventional and unconventional, in one country might spill over to other countries (see, among others, Ammer et al. 2016; Falagiagrda, McQuade, and Tirpak 2015). In this section we discuss the most important spillover channels, and we show what the implications of the various channels are for the effects of ECB's monetary policy on small open economies.

First of all, the ECB's monetary policy can affect economic conditions in other countries through the *exchange rate channel*. For example, when ECB is easing monetary policy, the Euro will depreciate against other currencies, and so these currencies will experience a relative currency appreciation. This harms the competitiveness of these

[4]Brubakk, Ter Ellen, and Xu (2017) apply this methodology to Norwegian data. We follow their methodology and variable selection very closely.

[5]This hump-shape is also found by Gürkaynak, Sack, and Swanson (2005) and interpreted as the impact of forward guidance.

countries, which may shift demand from those countries to the more competitive Eurozone countries. A drop in (expected) output and inflation might lead these countries to subsequently lower their interest rates as well.

Whereas the exchange rate channel shifts demand away from (to) the affected countries, the *domestic (/global) demand channel* increases (decreases) global demand, and as such also demand for goods in other countries. Higher interest rates will decrease domestic demand. For a large economy such as the euro area, this is a large fraction of global demand. So a shift in domestic demand, will shift global demand, and therewith demand for foreign products. This lowers the net present value of domestic companies, and as such lowers the equity index in these countries. Moreover, lower domestic demand increases the probability that the local central bank will stimulate output by lowering interest rates.

The *financial* or *portfolio rebalancing channel* implies that when yields go down in Europe, due to target rate surprises, forward guidance, or asset purchases from the ECB, investors need to rebalance their portfolio to reach an appropriate risk-return ratio again. They might rebalance their portfolios towards non-Euro area countries, which drives demand for those assets up, increasing prices and lowering yields on those assets. This channel can be much stronger when the ECB conducts large scale asset purchases, as this also affects the overall availability of (safe) European assets. Moreover, the ECB's monetary policy might directly affect lending conditions of foreign, financially integrated, banks.

The *signalling channel* works through expectations of future short term interest rates. When the ECB purchases assets or communicates that it will keep rates low for long (i.e. forward guidance), this lowers expectations about future short term interest rates. Long term yields are effectively the aggregation of expected short term interests over the term of the bond, plus a term premium. Therefore, the signalling channel lowers long term interest rates. Subsequent spillovers then occur through aforementioned channels.

Monetary policy actions and communications do not only affect expectations, but have also been found to affect investor confidence (Bekaert and Hoerova 2013). With this *investor confidence channel* (Falagiagrda, McQuade, and Tirpak 2015) monetary policy can be seen as a tool to reduce uncertainty and to increase investor confidence. It may also have an effect on the risk appetite of investors, as Bekaert and Hoerova (2013)

have shown. However, Piazzesi and Swanson (2008) show that risk appetite doesn't respond to monetary policy shocks directly, but varies over the much lower frequency of business cycles. A lower level of uncertainty lowers risk premia, and will therefore lower (particularly long term) yields and asset prices.

As all these channels are most likely all at work at the same time, we will only be able to identify which channels are dominating the effects. Finally, it is also important to note that in the way we identify the unexpected part of monetary policy, we do not distinguish between a monetary policy surprise resulting from the ECB deviating from their structural response (so a classic monetary policy *shock*), and a monetary policy surprise caused by communication revealing that the economic outlook is better or worse than market participants expected.

3 Data

We analyze intraday data on a variety of Norwegian and European financial variables over the sample period 2001Q1 to 2015Q4. We chose not to start in 1999 as Rosa and Verga (2008) show that it took market participants until 2001 to learn about the credibility of the ECB.[6] All variables are presented in Tables 1 and 2 and are 15-minutes frequency observations obtained from Thomson Reuters and Bloomberg. The data are aggregated from tick-by-tick data, which means that the observation at the time of the ECB policy decision press release, at 1:45 p.m., is the latest tick before that exact time (e.g. a tick quote from a dealer at 1:44:58 p.m.). The choice of event windows is described in Section 4.1.

In the factor analysis in section 4.2, we use one-month and three-month European OIS rates, the seventh (21-month) EURIBOR futures contract, and the two-, five-, and ten-year German Treasury Bonds.[7] For Euribor futures contracts, we calculate mid-quotes as the average of bid and ask quotations. While the data for German treasuries are

[6]For the factor analysis in section 4.2 where we identify forward guidance surprises, we start the sample in 2002Q1 because the ECB only held press conferences for every second rate decision in 2001.

[7]European OIS contracts are fixed-for-floating interest rate swaps where the Euro overnight index average (EONIA) is the floating leg interbank rate, i.e. the weighted average of the interest rates on overnight unsecured transactions for the panel banks (http://www.emmi-benchmarks.eu/euribor-eonia-org/about-eonia.html). European forward rate agreements (FRAs) and futures contracts have EURIBOR as the underlying (floating) interest rate. EURIBOR futures are standardized contracts traded on an exchange.

Table 1: Descriptive statistics - announcement window

	1:45 p.m. - 2:30 p.m.				
	Mean	Std. Dev.	Min.	Max.	Obs.
2w OIS - E	0.0077	0.0349	-0.1270	0.1800	139
FRA 1 - N	0.0010	0.0148	-0.0800	0.0700	187
FRA 2 - N	-0.0004	0.0174	-0.1100	0.1000	187
FRA 3 - N	-0.0006	0.0211	-0.1100	0.0800	187
FRA 4 - N	-0.0011	0.0223	-0.1100	0.1050	187
FRA 5 - N	0.0016	0.0242	-0.1100	0.1200	96
FRA 6 - N	0.0005	0.0206	-0.1200	0.0700	96
FRA 7 - N	-0.0031	0.0199	-0.1200	0.0300	75
FRA 8 - N	-0.0024	0.0201	-0.1350	0.0200	75
2y swap - N	-0.0005	0.0177	-0.0900	0.0450	187
5y swap - N	0.0000	0.0149	-0.0900	0.0700	187
10y swap - N	0.0010	0.0136	-0.0600	0.0400	187
OSEBX - N	-0.0007	0.0035	-0.0298	0.0065	177
EURNOK	-0.0002	0.0013	-0.0067	0.0030	187

Note: Descriptive statistics are shown for (log) changes in interest rates (asset prices) over the time-window from 1:45 p.m. to 2:30 p.m., around ECB's policy rate announcements, used for estimating Equation 2. "N" denotes a Norwegian variable, "E" denotes a European variable.

Table 2: Descriptive statistics - full window

	1:30 p.m. - 3:45 p.m.				
	Mean	Std. Dev.	Min.	Max.	Obs.
1m OIS - E	0.0032	0.0343	-0.1800	0.1700	187
3m OIS - E	0.0007	0.0333	-0.1850	0.1350	187
7th Euribor - E	-0.0011	0.0391	-0.1375	0.1325	184
2y Bund - E	0.000	0.0534	-0.2710	0.2315	187
5y bund - E	0.0014	0.0471	-0.1925	0.1595	187
10y Bund - E	0.0013	0.0331	-0.1295	0.1548	187
FRA 1 - N	0.0010	0.02412	-0.0900	0.1200	187
FRA 2 - N	-0.0011	0.0277	-0.1200	0.1150	187
FRA 3 - N	-0.0018	0.0345	-0.1900	0.1500	187
FRA 4 - N	-0.0029	0.0378	-0.1800	0.1350	187
FRA 5 - N	-0.0014	0.0417	-0.1300	0.1450	96
FRA 6 - N	0.0000	0.0469	-0.1200	0.2150	96
FRA 7 - N	-0.0013	0.0373	-0.1100	0.0850	75
FRA 8 - N	-0.0025	0.0395	-0.1300	0.0850	75
2y swap - N	-0.0025	0.0298	-0.1300	0.1300	187
5y swap - N	-0.0027	0.0322	-0.1100	0.1300	187
10y swap - N	-0.0005	0.0284	-0.1000	0.0800	187
OSEBX - N	-0.0010	0.0052	-0.02391	0.0118	176
EURNOK	-0.0003	0.002519	-0.0097	0.0123	187

Note: Descriptive statistics are shown for (log) changes in interest rates (asset prices) over the time-window from 1:30 p.m. to 3:45 p.m., around ECB's policy rate announcements, used for estimating Equation 3. "N" denotes a Norwegian variable, "E" denotes a European variable.

complete, the data for OIS-contracts and Euribor futures contain some missing values (see section B in the appendix for further description of how to deal with missing values).

The Norwegian interest rates represent a wide variety of financial derivatives contracts that reflect both short, medium and long term interest rates. These are money market rates up to two years (FRAs), and interest rate swaps with maturities of two, five and ten years. We use Norwegian swap rates rather than Norwegian government bond yields due to the low volume and poor liquidity of that bond market. The FRA market is regarded as the most liquid part of the Norwegian money market. The Norwegian FRA contracts reflect the short to medium end of the yield curve, while the swap contracts reflect the expected average short-term interest rates over the two-, five-, and ten-year horizons.[8] We include the first to eighth quarter FRA contracts. These contracts capture the three-month interest rate in one to eight quarters out. We further include data for the spot EURNOK exchange rate. For Norwegian equity prices, we use data for the OSEBX equity index (Oslo Børs).

The ECB key policy rates

The ECB has three key policy interest rates: the marginal lending facility, the main refinancing operation rate (fixed rate), and the marginal deposit facility. Figure 1 shows the key policy rates for 2001-2015.

Over the sample period, the ECB has had 187 scheduled meetings with key policy rates decisions.[9]

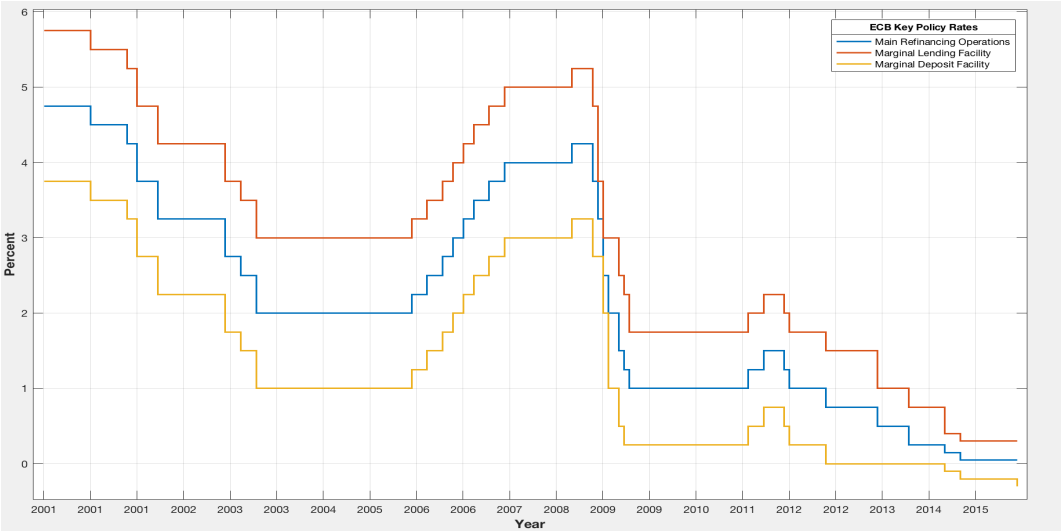
4 Identification

Interest rates over several horizons are affected by two types of monetary policy shocks: Surprises to the short term interest rate, i.e. to the key policy rate, and surprises to long term interest rates, i.e. to expectations of future short term interest rates or to the use

[8]Norwegian forward rate agreements are over the counter (OTC) cash settled agreements of the difference between the fixed interest rate and reference rate (NIBOR) on a notional amount of NOK 1 million. An interest rate swap is an agreement between two parties to swap interest rate payments where the buyer pays a fixed rate (swap rate) and the seller pays the floating for a pre-determined period.

[9]Two policy meetings were unscheduled. The response to economic uncertainty caused by the 9/11 attacks was announced at 5:30 p.m. on September 17, 2001, and the response to financial distress after the Lehman Brothers collapse was announced at 1 p.m. on October 8, 2008. These two rate decisions are considered as outliers and eliminated from all data sets for the empirical analysis. All dates for the ECB's monetary policy decisions are collected from the ECB webpage: www.ecb.europa.eu.

Figure 1: ECB Key Policy Rates: 2001Q1 to 2015Q4



Source: ECB, www.ecb.europa.eu

of asset purchasing programs. We apply two methods for identfication of ECB monetary policy shocks. First, we use high frequency data to identify the conventional policy rate surprises. Next, we apply factor analysis using principal components to jointly identify the conventional and unconventional monetary policy surprises.

4.1 High frequency identification

In line with Gürkaynak, Sack, and Swanson (2005) and Kuttner (2001) among others, we identify the key policy rate surprise by using an interest rate instrument that covers expectations about the short-term monetary policy stance. Potential instruments consist of overnight index swaps (OIS) and various futures rates, all with maturities shorter than the frequency of the ECB's monetary policy meetings. As there is no futures market for the ECB key policy rate, we use the two-week OIS rate. Then, at the day of the ECB monetary policy meeting, if t is some time after the policy rate announcement and $t-j$ is right before the announcement, $\Delta i_t^{OIS} = i_t^{OIS} - i_{t-j}^{OIS}$ is assumed to be the unexpected part of the ECB's policy rate decision. As most money market instruments contain a risk-premium term, the crucial assumption for the interest rate instrument described above to adequately reflect the policy rate surprise is that the risk-premium is constant over the time window used. As Piazzesi and Swanson (2008) show that nrisk premia mostly vary over lower frequency (business cycles) we believe this is a fair assumption.

Since 2001, the ECB key policy rates decision has been announced at 1:45 p.m., followed by a press conference 45 minutes later, at 2:30 p.m..[10] We define the *full announcement window* as the time window from 1:30 p.m. to 3:45 p.m., containing both the press release and the press conference. Thus, our full data set consists of observations for this time window for all ECB monetary policy meeting dates over the sample period.

The full announcement window includes not only information about the key policy rate decision, but also the ECB's forward guidance provided at the press conference. To isolate the policy rate surprise, we therefore employ a shorter 45-minutes time window, from the time of the press release (1:45 p.m.) to the start of the press conference (2:30 p.m.).[11]

Figure 2 yields the change in the two-week European OIS rate over the time window from 1:45 p.m. to 2:30 p.m. at the day of the ECB monetary policy meeting. If the change is zero, markets perfectly anticipated the policy rate decision. The figure shows that although the majority of rate decisions to some extent surprised the markets, the large surprises are few.[12]

4.2 Factor analysis using principal components

Following Gürkaynak, Sack, and Swanson (2005), we use principal component analysis to extract unobserved factors that can be interpreted as the conventional and unconventional monetary policy surprises. The hypothesis is that the ECB monetary policy announcement may not only contain a policy rate surprise component, but that other dimension(s) of monetary policy may also influence European financial variables (with potential spill-over effects on Norwegian interest rates and asset prices). Since we are now interested in all dimensions of the monetary policy shocks, we employ the full announcement window (i.e. the time window from 1:30 p.m. to 3:45 p.m.). In order to extract the factors, we use data on interest rates of maturities up to 10 years. This can be represented by:

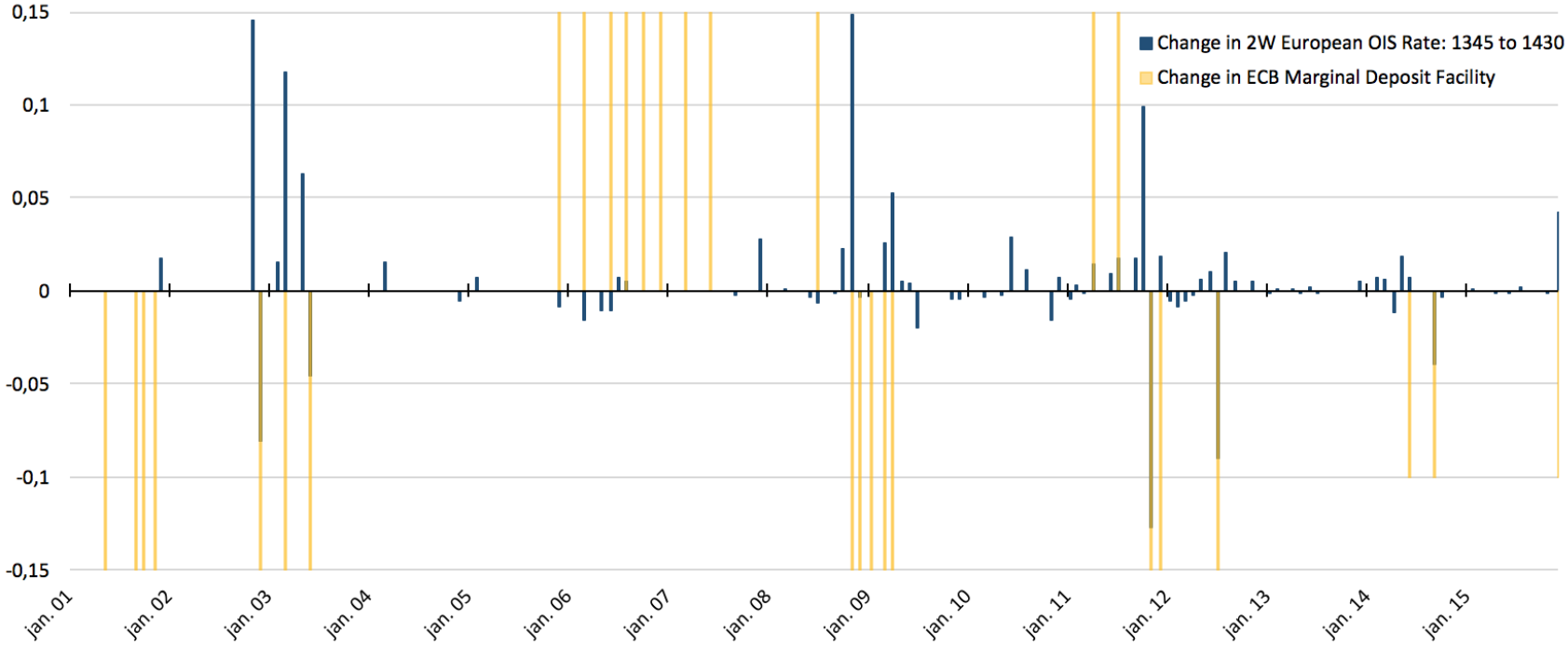
$$X = F\Lambda + \eta \tag{1}$$

[10]The press conference includes an introductory statement with a subsequent session of Q&A. Before 2002, a press conference followed only after the first meeting of the month.

[11]To extract the separate components of the ECB's monetary policy surprise during the full announcement window, we make use of factor analysis, see section 4.2.

[12]For an example of how changes in OIS rates are able to identify policy rate surprises, see section A in the appendix.

Figure 2: Change in two-week OIS from 1:45 p.m. to 2:30 p.m. on ECB policy rate announcement dates. 2001 to 2015.



Note: If changes in the European OIS rate is zero, markets perfectly anticipated the ECB's policy rate decision. The changes in the key policy rate are 25 basis points (bp) with the following exceptions: A 10 bp reduction in June and September 2014 and December 2015; a 50 bp reduction in September and November 2001, December 2002, June 2003 and March 2009; a 75 bp reduction in December 2008 and a 100 bp reduction in January 2009. *Source:* ECB's webpage and Thomson Reuters

where X is a $T \times n$ matrix of $T = 187$ scheduled ECB key policy rate announcements and $n = 6$ European financial variables: the one-month and three-month European OIS rates; the 21-month Euribor future; and the two-year, five-year and ten-year German Treasury Bond (GT).[13] F denotes a $T \times k$ matrix of the unobserved factors with $k < n$, and Λ is a $k \times n$ matrix of factor loadings. η represents white noise error terms. Each element of X is the change in one of the n variables for the full announcement window.

Using principal component analysis on X, we extract the unobserved factors F. In this way, we can represent the joint variability of the correlated observed n European interest rates in terms of a smaller set of independent unobserved factors. The set of orthogonal factors F_i with $i = 1, ..., k$ are decomposed from X in such a way that F_1 accounts for as much of the variability as possible of X. F_2 is the factor that has maximum explanatory power for the residuals of X after estimating F_1, and so on.

For the full sample, the Cragg-Donald test rejects the hypothesis of more than two factors at the 5% level.[14] Hence, the test implies that in addition to the policy rate surprise, one factor is enough to explain variation in European interest rates within the full announcement window. We further examine whether there is a potential third factor due to large scale asset purchases (LSAP) in the period from May 10, 2010 to the end of the sample. The test strongly rejects more than two factors also for this LSAP sample.[15]

The two extracted factors are only a statistical decomposition from X. To provide a more structural interpretation of the factors, we further follow Gürkaynak, Sack, and Swanson (2005) and rotate the two extracted factors F_1 and F_2 into a new set of rotated factors denoted Z_1 and Z_2.[16] The most important identifying restriction is that a policy

[13] OIS contracts provide a good estimate of the market expectation of the ECB's key policy rates for the closest upcoming Governing Council meetings. The 21-month Euribor future and the two-year GT provide information about the market expectations for the key policy rate over the medium to long term. Five-year and ten-year GTs account for the European interest rate expectations for very long maturities. For details on the data, see section 3.

[14] Cragg and Donald (1997). Since the column dimension of X is quite small, the Cragg-Donald test is to be preferred over other tests relying on the columns and rows of the X matrix to go to infinity (see e.g. Brand, Buncic, and Turunen (2010) and Bai and Ng (2002)). The null hypothesis of the test is that X is described by k_0 factors against the alternative hypothesis of $k > k_0$ factors (by measuring the minimum distance between the covariance of X and the covariance matrices of all possible factor models with k_0 factors). After normalizing, this distance has a limiting χ^2 distribution with $(n - k_0)(n - k_0 - 1)/(2 - n)$ degrees of freedom. For further details, see the appendix of Gürkaynak, Sack, and Swanson (2005).

[15] Surprisingly, there is weak evidence of a third factor in the pre-LSAP. However, with principal component methods, the first factors do not change when one allows or does not allow for an additional factor. We are therefore confident that we extract enough information with the first two factors.

[16] The computational details of this factor rotation, can be found in the appendix of Gürkaynak, Sack, and Swanson (2005).

rate surprise should only be related to the surprise in the key policy rate setting, whereas a forward guidance surprise should move interest rates with maturities beyond the current policy meeting, but should not at all be related to the policy rate surprise in current policy. In other words, only the first rotated factor, Z_1, should load onto the interest rate with the shortest maturity (i.e. the one-month OIS rate, which is the first coloumn of X), denoted as the *target factor*, whereas the second rotated factor, Z_2, should not have any relation with the one-month European OIS. Consequently, Z_1, may be interpreted as the policy rate surprise of the ECB's announcement and Z_2 may be interpreted as all other information in the ECB's announcements that changes financial market expectations about the future path of key policy rates (Swanson 2017). In short, we denote the factor as the *path factor*, which, for the LSAP sample, is likely to be a representation of both forward guidance and LSAP effects.

Finally, to facilitate the interpretation of the rotated factors, Z_1 is rescaled such that it moves one-for-one with the surprise component of the key policy rate setting (measured as the change in one-month OIS). In addition, Z_2 is rescaled so that both factors have the same effect on the third column of X (i.e. the 21-month Euribor Future). By such a normalization, we have a reference point for the size of the second factor: assuming the same effect on the mdeium term European rates, we can see how strong the relative effects are on Norwegian short, medium, and long term rates.

Table 3 reports the results for the rotated loadings of the extracted factors for the full sample, as well as for a pre-LSAP and LSAP sample.[17] The results for the various interest rates are shown as basis points change following a one standard deviation increase in factor Z_i and imply that the overall effects of a policy rate surprise is strongest for the shortest maturities and dies out for longer maturities, consistent with theory (key policy rates affect the short end of the yield curve).[18] Moreover, the path factor, Z_2, has a characteristic hump-shape with strongest effects on European interest rates with maturities of about two years.[19] Furthermore, the factor loading of the 10-year German Treasury yield is clearly higher for the LSAP sample than for the pre-LSAP sample. This may indicate that Z_2 picks up a combination of forward guidance and LSAP in the LSAP period.

[17] We separately extract and rotate two factors for the different sample periods.

[18] Note that comparing relative sizes of impacts on the European interest rates can only be done for the same factor.

[19] Recall that, by construction, Z_2 has no effect on the one-month OIS.

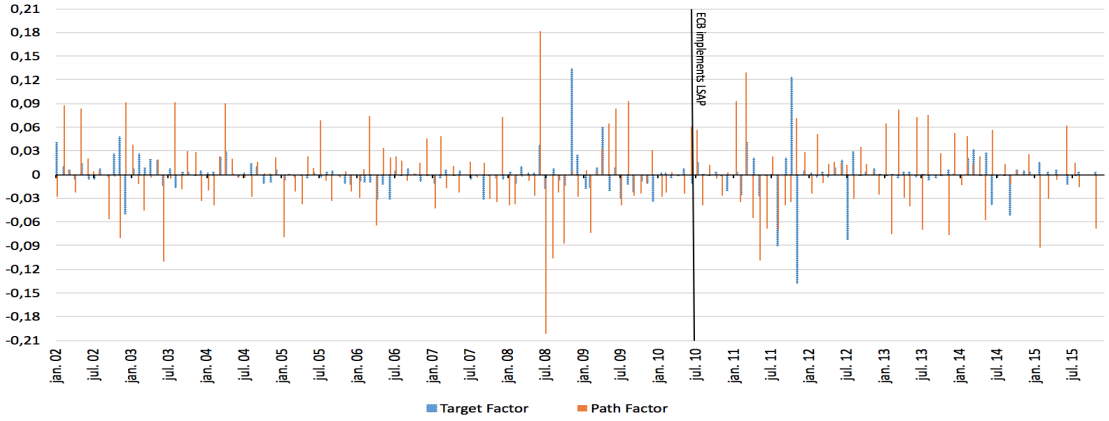
Table 3: Rotated loadings of X: Estimated effects of conventional and unconventional monetary policy announcements by the ECB*

		1M OIS	*3M OIS*	*7th EF*	*2y G. Tr.*	*5y G. Tr.*	*10y G. Tr.*
2002-2015	Z_1	2.5746	2.6792	1.1520	2.3258	1.4812	0.2822
	Z_2	0.0000	1.0225	2.2408	4.4171	4.2907	2.8792
Pre-LSAP	Z_1	2.1761	2.2199	0.7061	2.0809	1.4937	0.5463
	Z_2	0.0000	1.0362	2.4115	4.9371	4.3871	2.5665
LSAP	Z_1	3,1242	3,2730	1.5640	2.6953	1.5820	0.0308
	Z_2	0.0000	1.0595	2.1163	3,5623	4,1070	3,3679

Note: Z_1 is the target factor, which may be interpreted as the policy rate surprise. Z_2 is the path factor, which may be interpreted as the Forward Guidance surprise in the pre-LSAP period (i.e. from 2002 to May 10, 2010) and a combination of Forward Guidance and LSAP in the LSAP period (i.e. from May 10, 2010 to the end of the sample). 7th EF is the 21-month Euribor Future, see section 3 for more details.

Figure 3 plots the two rotated factors over the sample period. An interesting aspect is that the factor realizations not necessarily have the same direction, which implies that different surprise components of the ECB's announcement may influence interest rates in opposite directions.

Figure 3: Two dimensions of ECB shocks: A target factor and a path factor. 2002-2015



Source: ECB and Thomson Reuters

5 Empirical analysis and results

In order to study the effects of unexpected changes in ECB monetary policy on Norwegian interest rates and asset prices, we run the following two regressions:

$$\Delta R_{t,i} = \alpha + \beta \Delta OIS_t + \epsilon_t \tag{2}$$

$$\Delta R_{t,i} = \alpha + \beta_1 Z_{1,t} + \beta_2 Z_{2,t} + \epsilon_t \tag{3}$$

where equation 2 examines the effect of a one-dimensional monetary policy shock, consisting of an interest rate surprise, and equation 3 examines the effect of a two-dimensional monetary policy shock, consisting of both an interest rate surprise and a forward guidance/LSAP surprise. To isolate the effect of the interest rate surprise, equation 2 is run over the short time window from the time of the press release (at 1:45 p.m.) to the start of the press conference (at 2:30 p.m.). Equation 3 captures the entire monetary policy announcement and is therefore run over the full announcement window (i.e. from 1:45 p.m. to 3:45 p.m.). $\Delta R_{t,i}$ is the observed change in the Norwegian interest rate or asset price of interest for the time window considered, ΔOIS_t is the surprise change in the two-weeks European OIS rate, $Z_{1,t}$ is the rescaled rotated target factor, representing the policy rate surprise, and $Z_{2,t}$ is the rescaled rotated path factor, representing the forward guidance/LSAP surprise. The regressions are run for three different samples: the whole sample (from 2001Q1-2015Q4 for the one-dimensional shock and from 2002Q1-2015Q4 for the two-dimensional shock), the pre-LSAP period (from 2002 to May 10, 2010), and the LSAP period (from May 10, 2010 to the end of the sample).

The results are presented in Tables 4-7. The first column in the tables yields the dependent variable. For the policy rate surprise, the estimated coefficients can be interpreted as the percentage point change in the Norwegian interest rates and the 100*β percent change in the Norwegian asset prices (OSEBX and EURNOK) from a one-percentage point policy rate surprise.

Table 4, which yields the results for the one-dimensional monetary policy shock, suggests that Norwegian financial markets are affected by unexpected changes in the ECB's policy rate setting, and the re-pricing seems to happen quite fast after the new informa-

tion has been received. This is in line with the findings in Gürkaynak, Sack, and Swanson (2005), Brubakk, Ter Ellen, and Xu (2017), and Brand, Buncic, and Turunen (2010).[20] As expected, the short and medium end of the Norwegian yield curve respond stronger to the policy rate surprise than the longer-term interest rate instruments. The results further suggest that Norwegian equity prices (OSEBX) are strongly affected by a policy rate surprise. The sign is as expected: interest rates are used to discount future cash flows, higher interest rates implying a higher discounting rate, and hence higher rates lead to lower equity prices. Explicitly, following an unexpected policy rate increase of one percentage point, the index is estimated to fall 3.37%. The foreign exchange (FX) market also responds to a policy rate surprise: an unexpected one percentage point policy rate increase will appreciate the Euro by around 1% to the Norwegian krone.

The effects are stronger on interest rates during the LSAP period than during the pre-LSAP period, see Table 5. It is not obvious whether we should interpret this as a time-effect or as something specific to monetary policy in a time with key policy rates near their effective lower bound and substantial use of unconventional monetary policy. The parameter instability between the sub-samples may come from other factors than LSAP. Stock markets do not react stronger in the LSAP sample, but there is some evidence that the exchange rate channel has become stronger, judging from the size and significance of the EURNOK response to the shock. In the LSAP sample, the policy rate surprise explains approximately 27% of the variation in the exchange rate in the 45-minute time window following the ECB press release.[21]

Next, Table 6 yields the results for the two-dimensional monetary policy shock. Although the estimates cannot be directly compared with the results found in Table 4 because different time windows and OIS rates[22] are applied in the analysis, the results support the previous finding that a policy rate surprise, here represented by the *target* factor, has strong effects on short and medium-term Norwegian interest rates, while the impact on longer maturities is smaller.

The results further indicate that the *path* factor has strongest effects for the medium

[20]Notably, these papers differ in the way that they are not estimating cross border effects.

[21]It is worth mentioning that the LSAP estimates may be more precise because the data set for European OIS contracts is fairly complete for the LSAP sample period, while missing a substantial amount of observations in the pre-LSAP period.

[22]The one-dimensional monetary policy shock is identified using two-week OIS contracts, whereas the target factor is based on the one-month OIS and hence includes the current policy rate surprise as well as updates in expectations of potential other meetings in the coming month.

Table 4: Effects of an ECB policy rate surprise on Norwegian financial variables. 2001-2015

	MP Surprise (std.err)	R^2	*Obs*
FRA1	0.2068** (0.0895)	0.22	139
FRA2	0.3017*** (0.0991)	0.34	139
FRA3	0.2706*** (0.0957)	0.20	139
FRA4	0.2673** (0.1110)	0.17	139
FRA5	0.5072*** (0.1185)	0.34	91
FRA6	0.3872*** (0.0581)	0.27	91
FRA7	0.3616*** (0.0815)	0.19	74
FRA8	0.3260*** (0.0653)	0.15	74
2Y SWAP	0.1884** (0.0818)	0.13	139
5Y SWAP	0.0857 (0.0648)	0.04	139
10Y SWAP	0.0536 (0.0412)	0.02	139
OSEBX	-0.0337** (0.0159)	0.08	134
EURNOK	0.0117** (0.0045)	0.08	139

Note: Results are obtained using ordinary least squares with HAC standard errors (in parentheses). Constant terms are excluded for presentation convenience. ***=1% **=5% *=10% significance level. Time window: From 1:45 p.m. to 2:30 p.m.

Table 5: Effects of an ECB policy rate surprise on Norwegian financial variables. Pre LSAP & LSAP. 2001-2015

	Pre-LSAP			**LSAP**		
	2001 - May 10, 2010			**May 10, 2010 - 2015**		
	MP Surp.	R^2	*Obs*	*MP Surp.*	R^2	*Obs*
	(Std.err.)			*(Std.err.)*		
FRA1	0.1139	0.08	76	0.4678***	0.72	63
	(0.0824)			(0.0805)		
FRA2	0.2019**	0.22	76	0.5646***	0.71	63
	(0.0965)			(0.1089)		
FRA3	0.1781*	0.11	76	0.4991***	0.57	63
	(0.0938)			(0.1163)		
FRA4	0.1658	0.08	76	0.5282***	0.56	63
	(0.1227)			(0.0661)		
FRA5				0.3777***	0.48	63
				(0.0716)		
FRA6				0.3879***	0.45	63
				(0.0780)		
FRA7				0.3646***	0.38	63
				(0.0816)		
FRA8				0.3285***	0.36	63
				(0.0649)		
2Y SWAP	0.0775	0.03	76	0.4845***	0.57	63
	(0.0694)			(0.0728)		
5Y SWAP	-0.0100	0.01	76	0.3628***	0.55	63
	(0.0502)			(0.0307)		
10Y SWAP	-0.0107	0.00	76	0.2340***	0.22	63
	(0.0354)			(0.0656)		
OSEBX	-0.0377*	0.08	71	-0.0208**	0.08	63
	(0.0224)			(0.0098)		
EURNOK	0.0060	0.04	76	0.0282***	0.27	63
	(0.0048)			(0.0067)		

Note: Results are obtained using ordinary least squares with HAC standard errors (in parentheses). Constant terms are excluded for presentation convenience. Data starts in 2007Q2 for FRA 5-6 and 2009Q3 for FRA 7-8, which means that for the 5th-8th Norwegian FRA, the sample size is too small for the pre-LSAP period, and regressions are eliminated. ***=1% **=5% *=10% significance level. Time window: From 1:45 p.m. to 2:30 p.m.

and longer-term interest rates, while the shortest end of the Norwegian yield curve is not affected to the same extent. The estimates indicate the characteristic hump-shape, with a peak around 18-24 months. These findings are in line with Gürkaynak, Sack, and Swanson (2005), Swanson (2017) and Brubakk, Ter Ellen, and Xu (2017). Adding the second dimension of monetary policy increases the explanatory power, which now ranges between 40 and 76 percent for the Norwegian interest rates. A striking result is the response in the 10-year swap rate: 62% of the variation in the two hours following the ECB press release can be explained by surprises in ECB's monetary policy.

Furthermore, the results suggest that the two factors have opposite signs for the effect on Norwegian equity prices. With higher interest rates increasing the discount factor of future dividends, the estimated coefficient on the policy rate surprise is negative. Hence, the discount effect is prevailing for the target factor. The estimated coefficient of the path factor, on the other hand, is positive. One interpretation could be that the ECB implicitly signal better economic conditions ahead when they (surprisingly) signal higher future interest rates.[23] Consistent with Gürkaynak, Sack, and Swanson (2005), as financial markets revise their forecasts of output upward in response to positive path factor surprises, expected future cash flows go up.

Moreover, the effects on the exchange rate are not statistically significant for the target factor. This is in contrast to the strongly significant estimates found for the narrower time window in the one-dimensional analysis. Hence, effects from a policy rate surprise seem to be quickly absorbed for the exchange rate. This may be caused by an off-setting effect of Norwegian rates reacting to the ECB's monetary policy shocks: an unexpected increase in European interest rates will appreciate the Euro, but also increase the Norwegian rates which dampens the total effect on the interest differential.

The results for the target factor are virtually the same for the pre-LSAP and LSAP periods, see Table 7. Also the path factor provides fairly similar estimates for the two sample periods for the short end of the Norwegian yield curve, although explanatory power is substantially higher during the LSAP period. As in the one-dimensional case, estimated effects on the longest maturities are much larger for the LSAP period. This indicates that a potential interpretation of the LSAP path factor may be a *combined unconventional policy component* on Norwegian interest rates.[24]

[23]This interpretation rests on the path factor being solely a forward guidance component.

[24]However, the underlying assumption that the relative impacts of the ECB's forward guidance are

The largest sub-sample differences can be seen for the exchange rate and stock market. First of all, the target factor appears to have a negative effect on the exchange rate in the pre-LSAP sample, i.e. an unexpected monetary tightening in the euro area appreciates the Norwegian krone. However, the explanatory power is very low as compared to the LSAP period. Furthermore, we can see that the positive relation between the path factor and the stock market is mostly driven by the pre-LSAP period. This is in line with the ECB only conducting *Delphic forward guidance* (Campbell et al. 2012) during that period. In the latter sample, asset purchases may have caused portfolio rebalancing towards Norwegian assets, offsetting the 'economic signalling' effect of other communication.

similar between the two sub-samples is rather strict. The ECB has in recent years changed its monetary policy communication strategy to include both more forward guidance, but also more transparent guidance.

Table 6: Effects of a target factor and a path factor on Norwegian financial variables. 2002-2015

	Constant *(std.err)*	*Target Factor* *(std.err)*	*Path Factor* *(std.err)*	*Adjusted* R^2	*Obs*
FRA1	0.0015	0.4496***	0.2046***	0.40	162
	(0.0013)	(0.1028)	(0.0398)		
FRA2	-0.0020	0.5449***	0.2531***	0.47	162
	(0.0019)	(0.0818)	(0.0565)		
FRA3	-0.0023	0.5589***	0.4055***	0.51	162
	(0.0020)	(0.0801)	(0.0502)		
FRA4	-0.0038*	0.5609***	0.4971***	0.57	163
	(0.0021)	(0.0807)	(0.0527)		
FRA5	-0.0007	0.5606***	0.5629***	0.76	95
	(0.0020)	(0.0606)	(0.0397)		
FRA6	0.0008	0.7358***	0.5744***	0.72	95
	(0.0029)	(0.1910)	(0.0384)		
FRA7	-0.0021	0.4835***	0.5984***	0.73	73
	(0.0022)	(0.0458)	(0.0566)		
FRA8	-0.0035	0.4582***	0.6323***	0.71	73
	(0.0024)	(0.0636)	(0.0656)		
2Y SWAP	-0.0013	0.3886***	0.4012***	0.57	162
	(0.0015)	(0.0532)	(0.0317)		
5Y SWAP	-0.0018	0.2872***	0.4371***	0.53	162
	(0.0017)	(0.0810)	(0.0354)		
10Y SWAP	-0.0006	0.1662***	0.4267***	0.62	162
	(0.0013)	(0.0490)	(0.0296)		
OSEBX	-0.0934**	-0.0296**	0.0241**	0.06	161
	(0.0449)	(0.0130)	(0.0097)		
EURNOK	-0.0367**	0.0066	0.0128***	0.06	162
	(0.0171)	(0.0113)	(0.0047)		

Note: Results are obtained using ordinary least squares with HAC standard errors (in parentheses). Data starts in 2007Q2 for FRA 5-6 and 2009Q3 for FRA 7-8. ***=1% **=5% *=10% significance level. Time window: From 1:30 p.m. to 3:45 p.m.

Table 7: Effects of a target factor and a path factor on Norwegian financial variables. Pre LSAP & LSAP. 2002-2015

	Pre-LSAP: 2002 - May 10, 2010				**LSAP: May 10, 2010 - 2015**			
	Target Factor (std.err)	*Path Factor (std.err)*	*Adjusted R^2*	*Obs*	*Target Factor (std.err)*	*Path Factor (std.err)*	*Adjusted R^2*	*Obs*
FRA1	0.4491** (0.2041)	0.1714*** (0.0390)	0.34	100	0.4279*** (0.1108)	0.1627*** (0.0415)	0.55	62
FRA2	0.4905*** (0.0691)	0.2088*** (0.0530)	0.41	100	0.5667*** (0.1379)	0.2116*** (0.0526)	0.58	62
FRA3	0.5581*** (0.1293)	0.3262*** (0.0405)	0.47	100	0.5319*** (0.1059)	0.3565*** (0.0525)	0.69	62
FRA4	0.5334*** (0.0882)	0.3592*** (0.0604)	0.50	100	0.5716*** (0.0715)	0.5454*** (0.0529)	0.73	62
FRA5					0.5482*** (0.0737)	0.6147*** (0.0581)	0.77	62
FRA6					0.4970*** (0.0545)	0.6974*** (0.0544)	0.83	62
FRA7					0.4743*** 0.0470)	0.7151*** (0.0670)	0.77	62
FRA8					0.4589*** (0.0504)	0.7860*** (0.0709)	0.78	62
2Y SWAP	0.3503*** (0.0932)	0.2887*** (0.0318)	0.51	100	0.4168*** (0.0557)	0.4460*** (0.0448)	0.71	62
5Y SWAP	0.3103* (0.1699)	0.2880*** (0.0308)	0.45	100	0.2459*** (0.0622)	0.5635*** (0.0652)	0.69	62
10Y SWAP	0.2436*** (0.0882)	0.2777*** (0.0236)	0.56	100	0.1125* (0.0572)	0.5441*** (0.0535)	0.73	62
OSEBX	-0.0357 (0.0231)	0.0245** (0.0104)	0.09	100	-0.0280** (0.0114)	0.006810 (0.0110)	0.03	61
EURNOK	-0.0198** (0.0086)	0.003432 (0.002410)	0.04	100	0.024604 (0.0168)	0.034*** (0.0101)	0.29	62

Note: Results are obtained using ordinary least squares with HAC standard errors (in parentheses). Constant terms are excluded for presentation convenience. Data starts in 2007Q2 for FRA 5-6 and 2009Q3 for FRA 7-8, which means that for the 5th-8th Norwegian FRA, the sample size is too small for the pre-LSAP period, and regressions are eliminated. The two principal components are extracted separately for the two sub-samples. ***=1% **=5% *=10% significance level. Time window: From 1:30 p.m. to 3:45 p.m.

6 Concluding remarks

This paper employs the HFI approach to measure the immediate effects of the ECB's monetary policy surprises on Norwegian interest rates and asset prices. We find that ECB policy rate surprises have substantial effects on the short end of the Norwegian yield curve. In addition, policy rate surprises have strong significant effects on the Norwegian exchange rate and equity prices.

However, a policy rate surprise does not tell the whole story. The results provide evidence that (at least) one additional factor, above and beyond the policy rate surprise, is needed to adequately describe movements in European interest rates around the ECB's monetary policy announcements. Following Gürkaynak, Sack, and Swanson (2005), we extract two factors of the ECB's policy announcements: a target factor, which represents the policy rate surprise, and a path factor. The path factor contains information provided by the ECB beyond the policy rate decision. Specifically, it can be interpreted as forward guidance, indicating how markets react to the ECB's communication of the future monetary policy path. Our results suggest that the path factor has larger effects on the medium and longer-term Norwegian interest rates than the target factor. We discuss several transmission channels that can have been responsible for these movements.

We also find that Norwegian financial variables have been more affected by unexpected ECB monetary policy announcements after they introduced their large scale asset purchasing program in May 2010. However, our identification does not allow us to distinguish the effect from asset purchases from changes in communication or generally intensified financial integration between Norway and the euro area.

References

Ammer, John et al. (2016). "International spillovers of monetary policy". In: *International Financial Discussion Paper Notes*.

Bai, Jushan and Serena Ng (2002). "Determining the Number of Factors in Approximate Factor Models". In: *Econometrica* 70.1, pp. 191–221.

Bauer, Michael D. and Christopher J. Neely (2014). "International channels of the Fed's unconventional monetary policy". In: *Journal of International Money and Finance* 44, pp. 24–46.

Bekaert, Geert and Marie and Hoerova (2013). "Risk, uncertainty and monetary policy". In: *Journal of Monetary Economics* 60.7, pp. 771–788.

Bjørnland, Hilde C, Leif Anders Thorsrud, and Sepideh Khayati Zahiri (2016). "Do Central Banks Respond Timely to Developments in the Global Economy?" In: *Norges Bank Working Paper* 19/2016.

Brand, Claus, Daniel Buncic, and Jarkko Turunen (2010). "The Impact of ECB Monetary Policy Decisions and Communication on the Yield Curve". In: *Journal of the European Economic Association* 8.6, pp. 1266–1298. URL: `http://EconPapers.repec.org/RePEc:tpr:jeurec:v:8:y:2010:i:6:p:1266-1298`.

Brubakk, Leif, Saskia Ter Ellen, and Hong Xu (2017). "Forward guidance through interest rate projections: does it work?" In: *Norges Bank Working Paper 6/2017*.

Campbell, Jeffrey R et al. (2012). "Macroeconomic effects of Federal Reserve forward guidance". In: *Brookings Papers on Economic Activity* 2012.1, pp. 1–80.

Cao, Jin and Valeriya Dinger (2016). "Financial Globalization and Bank Lending: The Limits of Domestic Monetary Policy?" In: *Working Paper*.

Chen, Jiagian, Tommaso Mancini-Griffoli, and Ratna Sahay (2014). "Spillovers from United States monetary policy on emerging markets: different this time?" In: *IMF working paper 14/240*.

Cragg, John G and Stephen G Donald (1997). "Inferring the Rank of a Matrix". In: *Journal of Econometrics* 76, pp. 223–250.

Dedola, Luca, Giulia Rivolta, and Livio Stracca (2017). "If the Fed sneezes, who catches a cold?" In: *ECB working paper 2050*.

Eggertsson, Gauti and Michael Woodford (2003). "The Zero Lower Bound on Short-Term Interest Rates and Optimal Monetary Policy". In: *Brookings Papers on Economic Activity* 1, pp. 139–211.

Ehrmann, Michael and Marcel Fratzscher (2009). "Global financial transmission of monetary policy shocks". In: *Oxford Bulletin of Economics and Statistics* 71.6, pp. 739–759.

Ehrmann, Michael, Marcel Fratzscher, and Roberto Rigobon (2011). "Stocks, bonds, money markets and exchange rates: measuring international financial transmission". In: *Journal of Applied Econometrics* 26.6, pp. 948–974.

Falagiagrda, Matteo, Peter McQuade, and Marcel Tirpak (2015). "Spillovers from the ECB's non-standard monetary policies on non-euro area EU countries: evidence from an event-study analysis". In: *ECB Working Paper Series 1869*.

Gürkaynak, Refet S., Brian Sack, and Eric Swanson (2005). "Do Actions Speak Louder Than Words? The Response of Asset Prices to Monetary Policy Actions and Statements". In: *International Journal of Central Banking* 1.1, pp. 55–93.

Hamilton, James D. (2008). "Assessing Monetary Policy Effects Using Daily Federal Funds Futures Contracts". In: *Federal Reserve Bank of St. Louis Review* 90.4, pp. 377–93.

Hanson, Samuel and Jeremy C. Stein (2012). "Monetary policy and long-term real rates". In: *Finance and Economics Discussion Series (FEDS), Federal Reserve Board, Discussion Paper*.

Hausman, Joshua and Jon Wongswan (2011). "Global asset prices and FOMC announcements". In: *Journal of International Money and Finance* 30, pp. 547–571.

Kuttner, Kenneth N. (2001). "Monetary Policy Surprises and Interest Rates: Evidence from the Fed Funds Futures Markets". In: *Journal of Monetary Economics* 47.3, pp. 523–44.

Neely, Christopher J. (2015). "Unconventional monetary policy had large international effects". In: *Journal of Banking and Finance* 52, pp. 101–111.

Piazzesi, Monika and Eric Swanson (2008). "Futures prices as risk-adjusted forecasts of monetary policy". In: *Journal of Monetary Economics* 55.4, pp. 677–691.

Praet, Peter (2013). "Forward Guidance and the ECB". In: *Forward Guidance: Perspectives from Central Bankers, Scholars and Market Participants, Vox eBook*.

Reifschneider, David and John Williams (2000). "Three Lessons for Monetary Policy in a Low-Inflation Era". In: *Journal of Money, Credit and Banking* 32, pp. 936–66.

Rey, Helene (2015). "Dilemma not trilemma: the global financial cycle and monetary policy independence". In: *NBER working paper 21162*.

Rogers, John H., Chiara Scotti, and Jonathan H. Wright (2016). "Unconventional Monetary Policy and International Risk Premia". In: *International Finance Discussion Papers* 1172.

Rosa, Carlo and Giovanni Verga (2008). "The impact of central bank announcements on asset prices in real time". In: *International Journal of Central Banking* 4.2, pp. 175–217.

Svensson, Lars E O (2015). "Forward Guidance". In: *International Journal of Central Banking* 11.S1, pp. 19–64. DOI: 10.3386/w20796.

Swanson, Eric T. (2017). "Measuring the Effects of Federal Reserve Forward Guidance and Asset Purchases on Financial Markets". In: *Working Paper* 21816.

Syrstad, Olav and Dagfinn Rime (2014). "Norges Bank's endogenous interest rate path and its impact on interest rate expectations". In: *Norges Bank Staff Memo* 6.

Takats, Elod and Abraham Vela (2014). "International monetary policy transmission". In: *BIS report*.

Tillmann, Peter (2016). "Unconventional monetary policy and the spillovers to emerging markets". In: *Journal of International Money and Finance* 66, pp. 136–156.

A Intraday trading in European OIS Contracts on three ECB policy decision dates

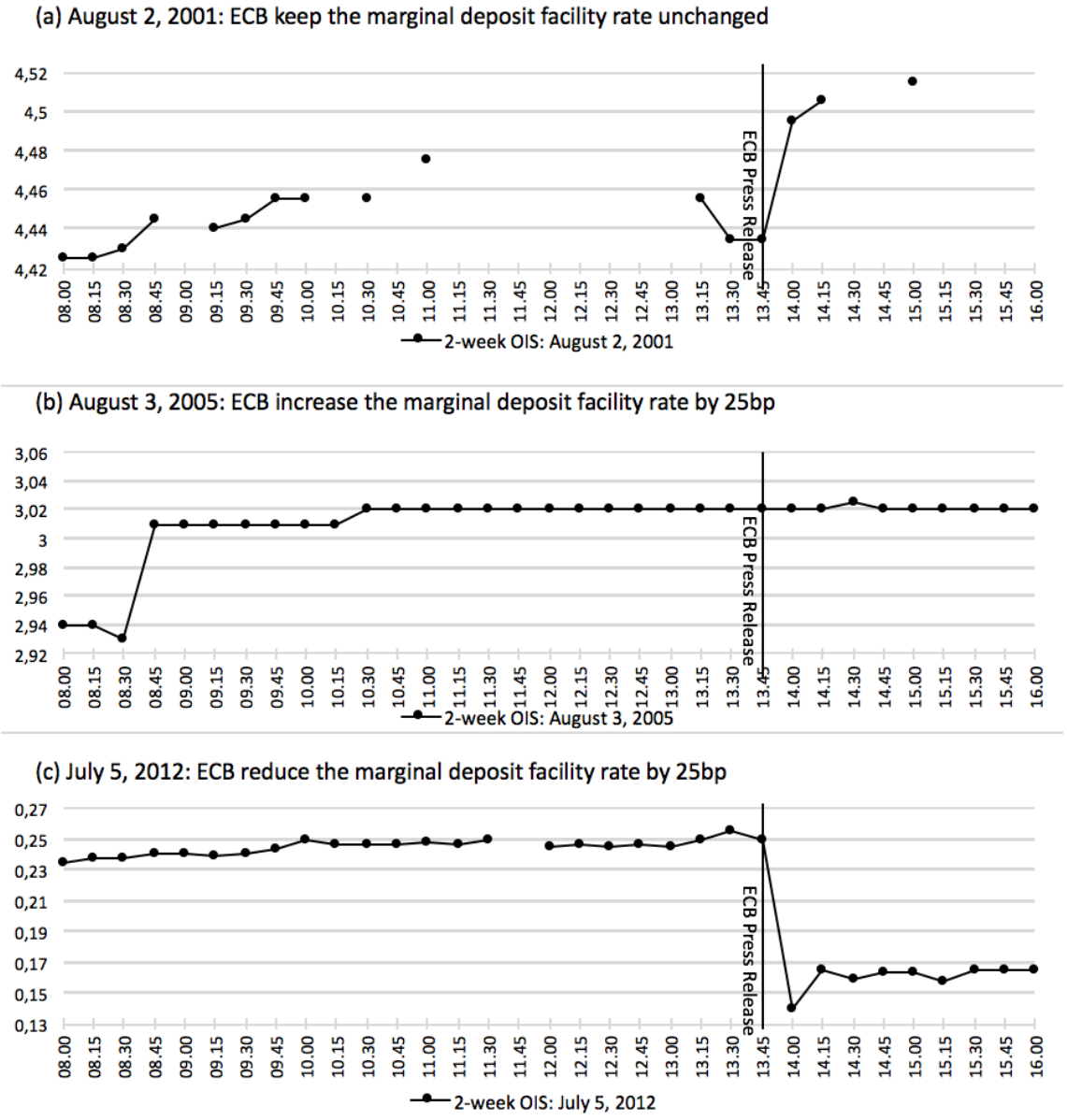
As an example of how changes in the two-week OIS rate are able to identify policy surprises, we plot intraday trading for three dates when the ECB announced that the key policy rates would remain unchanged, increase by 25 bp and be reduced by 25bp, respectively (see figure **??**). Panel (a) shows trading on August 2, 2001 when the ECB announced that key policy rates remained unchanged. At the time of the press release (i.e. at 1:45 p.m.), the OIS rate rose by 6 bp. Thus, markets had priced in a rate cut with some probability. Next, panel (b) shows trading on August 3, 2005, when the ECB announced a 25 bp increase in the key policy rates. The market response was insignificant, implying that the markets had expected the rate hike. Finally, panel (c) shows trading on July 5, 2012, when the ECB announced a 25 bp reduction in the key policy rates. The drop in the OIS rate by 11 bp suggests that the markets did not expect the cut.

B Dealing with missing values

In the identification, we use the two-week European OIS in the HFI framework and the one-month European OIS in the factor analysis. The choice is due to missing values: In the beginning of the sample period, the two-week OIS data have more missing values than the one-month OIS data. However, as there has been less than one month between the ECB's monetary policy decisions, the one-month OIS rate contains expectations about more than one key policy rate decision. Using the one-month OIS rate in our analysis may therefore be imprecise.[25] Consequently, we use the two-week OIS data for the HFI-identification of the conventional monetary policy shocks. For the factor analysis, on the other hand, we need as much data as we can to extract the factors. Hence, we use the one-month OIS data for that part of the analysis. This should not affect the total explanatory power of the two factors much – in the worst case, we slightly underestimate the effect of unconventional monetary policy, as a small part of that will be captured by the monetary policy shock.

[25]Clearly, there is a trade-off in the precision of the estimates to changed expectations to one key policy rate decision, and the number of observations. While the two-weeks OIS will isolate expectations about one policy decision, the data for one-month OIS are of better quality.

Figure 4: Intraday trading in European two-week OIS Contracts



Source: Thomson Reuters

Furthermore, the OIS-contracts and Euribor futures contain some missing values for the time-windows of interest. By assuming that such NaN observations mean that there is no change from the previous non-NaN observation, we reduce the number of missing values by looking for the closest tick as much as on hour prior, in 15 minutes intervals.[26] This yields a non-NaN observation for the majority of the NaN observations. If an observation is still not found with this modification, we look for the closest non-NaN observation one hour after, in 15 minutes intervals. If the observation is still missing, we look for the closest

[26]To illustrate with an example: If there is no tick for a 2:30 p.m. observation in the original data, the modified data set looks for the closest non-NaN tick at 2:15 p.m., 2 p.m., 1:45 p.m. and 1:30 p.m..

earlier/later non-NaN observation, but no earlier/later than 10 a.m./6 p.m. If this still does not yield an observation, the observation is assumed missing.[27] This modification method may induce measurement errors in the results. However, Gürkaynak, Sack, and Swanson (2005) and Brubakk, Ter Ellen, and Xu (2017) suggest that the results from using daily data are quite similar to using narrower time windows. Hence, such potential measurement errors are in any case small.

[27]The modifications also depend on which surprises we are studying. If the policy rate surprise is considered, the modification will not search for observations after 2:30 p.m. to avoid overlap with the ECB press conference. Similarly, for the forward guidance surprise, the modification will not search for observations prior to the start of the press conference.