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A shadow rate without a lower bound constraint *

Rafael B. De Rezende† Annukka Ristiniemi‡

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Abstract

We propose a shadow rate that measures the expansionary (contractionary) interest rate effects of unconventional monetary policies that are present when the lower bound is not binding. Using daily yield curve data we estimate shadow rates for the US, Sweden, the euro-area and the UK, and find that they fall (rise) when market participants expect monetary policy to become more expansionary (contractionary), and price this information into the yield curve. This ability of the shadow rate to track the stance of monetary policy is identified on announcements of policy rate cuts (hikes), balance sheet expansions (contractions) and forward guidance, with shadow rates responding timely, and in line with government bond yields. We show two applications for our shadow rate. First, we decompose shadow rate responses to monetary policy announcements into conventional and unconventional monetary policy surprises, and assess the pass-through of each type of policy to exchange rates. We find that exchange rates respond more to conventional than to unconventional monetary policy. Lastly, a counterfactual experiment in a DSGE model suggests that inflation in Sweden would have been around 0.47 percentage points lower had the Riksbank not used unconventional monetary policy since February 2015.

Keywords: unconventional monetary policy; monetary policy stance; term structure of interest rates; short-rate expectations; term premium.

JEL Classification: E43, E44, E58, E52.

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†Corresponding author. Monetary Policy Department, Sveriges Riksbank (Central Bank of Sweden), Brunkebergstorg 11, 103 37 Stockholm, Sweden. Email: rafael.rezende@riksbank.se.

‡Monetary Policy Department, Sveriges Riksbank (Central Bank of Sweden), Brunkebergstorg 11, 103 37 Stockholm, Sweden. Email: annukka.ristiniemi@riksbank.se.

1 Introduction

During the financial crisis of 2008 and the following years, a number of central banks reduced their policy rates as far as deemed possible, and undertook very expansionary unconventional policies as a means to provide additional monetary stimulus. In the face of improving economic conditions and increasing inflation, central banks have recently entered a phase of reverse engineering these policies, a process that has been called "monetary policy normalization".

One central issue is that measuring the stance of monetary policy in this unconventional policy environment has been particularly tricky. As central banks have relied on a number of monetary policy tools to affect short- and long-maturity interest rates, such as target interest rate policy, forward guidance and balance sheet policy, it has become particularly difficult to attribute this role to one single measure. Moreover, the literature emphasizes that there are various channels through which unconventional policies are transmitted to interest rates, with effects varying considerably across maturities, meaning that single interest rates are only partially informative.[1]

In this paper, we provide an intuitive indicator that summarizes the stance of monetary policy in non-standard times. More specifically, we estimate a shadow rate that is directly comparable to the observed policy rate, and that can inform about the expansionary and contractionary interest rate effects of unconventional policies since the start of their implementation by central banks. One particular feature of our shadow rate is that its specification does not impose any lower bound constraint on nominal interest rates. This means that, in contrast with other specifications (Black 1995; Krippner 2012, 2014; Wu and Xia 2016; Bauer and Rudebusch 2016; Wu and Xia 2017), our shadow rate does not necessarily equal the observed short-rate when the lower-bound is not binding, allowing it to measure the interest rate effects of unconventional policies that have been actively used by central banks during the whole unconventional policy period. This is particularly important in the current policy environment, as most central banks are "normalizing" monetary policy by raising their policy rates before unwinding their quantitative easing portfolios, and have continued to use forward guidance and communication to inform about their future plans regarding target interest rate and balance sheet policies. In this context, the Federal Reserve is a classic example, as it is the central bank that has been leading the "monetary policy normalization" process by first exiting the lower-bound, and by initiating its procedures for balance sheet contraction afterwards, while continuing to manage monetary policy expectations through forward guidance. In addition,

[1] The literature has emphasized that different monetary policy intruments affect different segments of the yield curve (see De Rezende 2017 and Swanson 2017). Moreover, due to the existence of frictions and market segmentation, there exist various channels through which quantitative easing is transmitted to interest rates, such as the portfolio balance channel (Vayanos and Vila 2009), the reserve-induced portfolio balance channel (Christensen and Krogstrup 2016), the signaling channel (Bauer and Rudebusch 2014), the collateral channel (D'Amico et al. 2013) and the liquidity channel. These tend to affect interest rates differently across maturities (see Krishnamurthy and Vissing-Jorgensen 2011, Christensen and Rudebusch 2012, D'Amico and King 2013, De Rezende 2017).

it is important to emphasize that some central banks, such as the ECB and Sveriges Riksbank, have conducted conventional and unconventional monetary policies concurrently without explicitly setting a lower bound for their policy rates, which has lowered the constraints that an effective lower bond may impose on interest rates across maturities.[2] This is also particularly important in our context, as there is no need to make assumptions or to estimate the lower bound in order to measure the expansionary and contractionary interest rate effects of unconventional policies using our shadow rate. All these salient characteristics make our shadow rate an attractive and informative market-based measure of the monetary policy stance in non-standard times.

In our specification, the shadow rate is a function of factors extracted directly from the government bond yield curve and its short-rate expectations component, depending on the days on which unconventional monetary policies have been present and are announced. On days when unconventional measures are announced, the shadow rate responds to both the short-rate expectations and term premium components that are embedded in yield curve factors, since unconventional policies tend to affect both components on announcement days.[3] On non-announcement days, we consider that the shadow-rate is driven by short-rate expectations only, as term premium tends to carry substantial information that is not directly related to monetary policy (Kim and Orphanides 2007; Wright 2011), such as investors' perceptions of various macroeconomic risks, investors' degree of risk-aversion, as well as "flight to quality" effects at times of extreme volatility in financial markets, which may all add noise to the monetary policy stance measurement. On the other hand, short-rate expectations tend to adjust to events that affect investors' expectations of future monetary policy on any day, such as macroeconomic news, monetary policy announcements, speeches and so on. For our purposes, we set the day in which the central bank first announced its unconventional policies after the financial crisis of 2007/2008 as the date marking the beginning of the unconventional period, when the shadow rate may start diverging from the short-rate.

The computation of the shadow rate involves two steps. First, we decompose the yield curve into its short-rate expectations and term premium components using term structure models. Second, we obtain the estimates needed for the computation of the shadow rate using event study regressions and inverse prediction. More specifically, in the second step, we identify the estimates determining the relationship between the short-rate, short-rate expectations and the yield curve, by regressing short-rate surprises (Kuttner 2001; Gürkaynak, Sack and Swanson 2005) onto changes in short-rate expectations, as well as yield factors around small windows, and use inverse prediction (Graybill 1976; Osborne 1991; Graybill and Iyer 1994; Brown 1994, among others) to translate movements in those factors into an unobserved shadow rate that is computed for the unconventional monetary

[2] Sweden is perhaps the most extreme example, as policy rate expectations seemed to be partcularly unconstrained for a large part of its bond purchase program (see De Rezende 2017).

[3] This may happen through at least four channels: the portfolio balance channel, the signaling channel, the reserve induced portfolio balance channel and the collateral channel.

policy period.

We estimate shadow rates for the US, Sweden, the euro-area and the UK, and find that they lie well below the respective policy rates during the unconventional monetary policy period in each economy. This suggests that the unconventional measures implemented by central banks have eased financial conditions more than otherwise. Moreover, the shadow rates fall (rise) when market participants expect monetary policy to become more expansionary (contractionary), and price this information into the yield curve.

This ability of the shadow rate to track the stance of monetary policy is better identified on monetary policy announcements. Our estimates are able to precisely track episodes of policy rate cuts and hikes, balance sheet expansions and contractions, forward guidance, as well as speeches, in line with the responses of government bond yields. For instance, we find that the US shadow rate fell by 82.5 basis points on March 18, 2009, when the Fed announced the extension of QE1, as the five- and ten-year bond yields declined by 47.1 and 51.9 basis points. On August 9, 2011, the day of the announcement of explicit calendar-based forward guidance, the US shadow rate fell by 27 basis points. In addition, the US shadow rate reacted positively on the tapering of QE3, a policy perceived as contractionary by market participants. In Sweden, we find that our shadow rate declined by 26.9 basis points on the day the Riksbank launched its bond purchase program in February 2015, as the five- and ten-year bond yields declined by 15.6 and 11.1 basis points. In the UK, the shadow rate declined by 28.1 basis points on the announcement of the monetary stimulus package after Brexit. In the euro-area, the shadow rate increased by 21.1 basis points when the ECB disappointed market participants by not announcing an extension in the size of its bond purchase program on December 3, 2015. Sizable effects are also found for other important events.

Besides its use as a market-based policy stance indicator, we show two other applications for our shadow rate. In the first application, we exploit the information contained in shadow rate changes around announcements to try to better understand the pass-through of conventional and unconventional monetary policies to exchange rates across economies. For this exercise we use event study regressions with two measures of monetary policy surprises, (i) shadow rate changes and (ii) their decomposition into conventional and unconventional policy surprises, which can be used to assess the effectiveness of each type of policy, i.e. conventional and unconventional, to affect exchange rates on announcement dates. We find largely significant coefficient estimates. Using pooled regressions, our results suggest that, on average, a 10 basis point drop in the shadow rate depreciates the domestic currencies by 0.41 percent vis-à-vis foreign currencies. Additionally, we find that exchange rates respond more strongly to conventional monetary policy. Our results suggest that a 10 basis point drop in the conventional surprise measure leads the domestic currencies to depreciate by 1.08 percent vis-à-vis foreign currencies. The estimated impact of unconventional monetary policy is lower, about 0.35 percent. The higher effectiveness of conventional policy is confirmed when we estimate event study regressions using announcements by each central bank.

In our second application, we measure the macroeconomic effects of unconventional monetary policy. We replace the repo rate in the Riksbank's DSGE model Ramses II by the Swedish shadow rates and construct a counterfactual analysis for inflation and unemployment rate using the impulse responses to a repo rate shock from Ramses II (see Adolfson et al. 2013). Our results suggest that the unconventional policies implemented by the Riksbank since February 2015 further stimulated the Swedish economy, with CPIF inflation and unemployment being around 0.47 percentage points higher and 0.73 percentage points lower than otherwise by October 2017. This type of application is particularly appealing for monetary policy analysis, as DSGE models used by central banks typically lack a financial side that can fully model the transmission of unconventional monetary policy through the term structure of interest rates. Furthermore, scenarios estimating the effects of additional unconventional measures such as further bond purchases can be easily constructed.

The remainder of this paper is organized as follows. The next section introduces our shadow rate specification, its estimation method and how it compares to the other existing specifications in the literature. Section three describes the data used in the study. Section four and five describe the main results of the paper, and the sixth section concludes.

2 Shadow rate

In this section, we first describe the term structure model specification that will be used in the study, our shadow-rate specification, and the estimation method based on event-study regressions. Lastly, we describe how our shadow rate specification is compared to other existing specifications in the literature.

2.1 Term structure model

Our shadow rate specification requires a model that is able to decompose bond yields into short-rate expectations and term premia. In principle, this could be done by any model designed for this purpose (see And and Piazzesi 2003; Kim and Wright 2005; Joslin, Singleton and Zhu 2011; Joslin, Le and Singleton 2013; Adrian, Crump and Möench 2013; Wu and Xia 2016; Wu and Xia 2017, among others). In this paper, we use discrete-time Gaussian Dynamic Affine Term Structure Models (DATSMs), which assume that zero-coupon bonds are affine functions of pricing factors. More specifically, we assume that the $p \times 1$ vector of pricing factors X_t that drives movements in the whole term structure of interest rates follows a VAR(1) process under the objective probability measure $\mathbb{P}$,

$$X_{t+1} = \mu + \Phi X_t + \Sigma \varepsilon_{t+1} \tag{1}$$

where $\varepsilon_t \sim iid\, N(0, I_p)$ and Σ is an $p \times p$ lower triangular matrix. The stochastic discount factor (SDF) that prices all assets under the absence of arbitrage is assumed to be conditionally lognormal

$$M_{t+1} = exp\left(-r_t - \frac{1}{2}\lambda_t'\lambda_t - \lambda_t'\varepsilon_{t+1}\right) \tag{2}$$

where $\lambda_t = \lambda_0 + \lambda_1 X_t$ is a $p \times 1$ vector of risk prices that drive risk premia. We allow the short rate to vary freely, without imposing any constraints or asymmetries in the conditional distributions of short-rate expectations. The short-term interest rate is then affine in the pricing factors, $r_t = \delta_0 + \delta_1' X_t$. Under the risk-neutral measure $\mathbb{Q}$ the vector of pricing factors follows the dynamics,

$$X_{t+1} = \mu^{\mathbb{Q}} + \Phi^{\mathbb{Q}} X_t + \Sigma\varepsilon_{t+1} \tag{3}$$

where $\mu^{\mathbb{Q}} = \mu - \Sigma\lambda_0$ and $\Phi^{\mathbb{Q}} = \Phi - \Sigma\lambda_1$.

Under no-arbitrage bond prices are then exponential affine functions of the state variables, $P_t^n = exp(A_n + B_n' X_t)$, where A_n is a scalar and B_n is an $p \times 1$ vector that satisfy the recursions

$$\begin{aligned} A_{n+1} &= -\delta_0 + A_n + \mu^{\mathbb{Q}\prime} B_n + \tfrac{1}{2} B_n' \Sigma\Sigma' B_n \\ B_{n+1} &= \Phi^{\mathbb{Q}\prime} B_n - \delta_1 \end{aligned} \tag{4}$$

which start from $A_1 = -\delta_0$ and $B_1 = -\delta_1$. Model implied yields are computed as $y_t^n = -n^{-1} log\, P_t^n = -n^{-1}(A_n + B_n' X_t)$.

The functions A_n and B_n that enter the pricing equation above are computed under the risk-neutral measure $\mathbb{Q}$ and not under the objective probability measure $\mathbb{P}$. The difference is determined by the term premium, which is defined as the return difference demanded by investors to invest and hold an n-year bond until maturity instead of rolling over the short-term interest rate,

$$TP_t^n = y_t^n - \frac{1}{n}\sum_{i=0}^{n-1} E_t^{\mathbb{P}}(r_{t+i}) \tag{5}$$

The specification described above is quite general and is suitable for a large number of models in the class of discrete-time Gaussian DATSMs. A key modeling choice is which pricing factors to include in the vector X_t. In this paper, we follow the finance literature and estimate yields-only models, where X_t reflects only information in the yield curve. We use the canonical form of Joslin et al. (2011) (JSZ henceforth), which has as its main distinctive feature the inherent separation between the parameters of the $\mathbb{P}$ and $\mathbb{Q}$ distributions and the use of observable yield portfolios as pricing factors, $X = WY$, where W is a $p \times N$ matrix of portfolio weights and Y is a $N \times T$ matrix of observable yields. Following JSZ, we use the first p principal components of yields as pricing factors. In addition, we assume that bonds are priced without error, i.e. $X = WY = W\hat{Y}$. As noted by JSZ, these features facilitate the estimation of the model enormously with a near-instantaneous convergence to the global optimum of the likelihood function.

2.2 Shadow rate

Similar to the short-rate equation described above, our shadow rate specification is also a function of interest-rate factors. During the conventional monetary policy period, the shadow rate is equal to the short-term interest rate specified above, i.e. r_t. During the unconventional period, the shadow rate is a function of factors that drive the government bond yield curve and its short-rate expectations component specified in (5), depending on the days on which unconventional monetary policies are present, and are announced. More specifically, our specification assumes the following form,

$$\triangle s_t = \begin{cases} \triangle r_t \quad if \quad t < t_0 \\ \delta_{11}' \triangle X_t^{sr} \quad if \quad t \geq t_0 \;\; s.t. \;\; t \neq t^{\star} \\ \delta_{12}' \triangle X_t \quad if \quad t \geq t_0 \;\; s.t. \;\; t = t^{\star} \end{cases} \tag{6}$$

where t_0 is the day of first unconventional monetary policy announcement, $t^{\star}$ is a day of unconventional monetary policy announcement, X_t is a $q \times 1$ vector of yield factors, X_t^{sr} is a $q \times 1$ vector of factors that summarize the short-rate expectations component of yields, and s_t is the shadow rate.[4]

As can be seen from (6), the shadow rate is equal to the short-term interest rate when unconventional policies have not yet been implemented. During the unconventional period, however, the type of factors driving s_t depends on the days on which unconventional policies are announced. On announcement days, we consider that the shadow rate is driven by both the short-rate expectations and term premium components that are embedded in X_t, since unconventional policies tend to affect both components when $t = t^{\star}$.[5] On non-announcement days, however, s_t is driven by short-rate expectations only, as the term premium tends to carry substantial information that is not directly related to monetary policy (Kim and Orphanides 2007; Wright 2011). One important piece of that information is investors' perceptions of various macroeconomic risks such as unexpected rises in inflation that erodes the value of a nominal investment. Another aspect is the degree of investors' risk aversion, which tends to vary with the business cycle (Campbell and Cochrane 1999; Wachter 2006), leading term premia to evolve in a countercyclical fashion (Ludvigson and Ng 2009; Bauer et al. 2014). Additionally, during periods of financial turmoil such as the global financial crisis and the

[4]Notice that the short-rate expectation component of yields is an affine function of the pricing factors X. By setting $p = N$, we can then obtain X^{sr} through a simple rotation of X. More specifically, we define a $N \times N$ orthogonal matrix U^{sr} such that $W^{sr} = U^{sr}W$, and then obtain X^{sr} through $X^{sr} = W^{sr}Y^{sr}$. We use the matrix U^{sr} such that X^{sr} equals the principal components of the $N \times T$ matrix Y^{sr}. We can then use the first q rows of X^{sr} as driving factors for s_t.

[5]This may happen through at least four channels: the portfolio balance channel, the signaling channel, the reserve induced portfolio balance channel and the collateral channel.

European debt crisis, term premia associated with government bonds of major economies are often compressed by safe-haven demands of investors, who place special value on the safety and liquidity of these assets. All these tend to add noise to the measurement of s_t. On the other hand, X_t^{sr} should adjust to events that may affect investors' expectations of future monetary policy intentions in any day, such as domestic and foreign macroeconomic news, monetary policy announcements, speeches and so on.

The shadow rate in levels is obtained by setting an initial value for s_t, such as the short-rate at $t = 1$, and by iterating equation (6) forward until the last sample observation, T. More specifically,

$$s_t = r_1 + \sum_{t=2}^{t_0-1} \triangle r_t + \sum_{t=t_0}^{T,t\neq t^\star} \delta_{11}' \triangle X_t^{sr} + \sum_{t=t_0}^{T,t=t^\star} \delta_{12}' \triangle X_t \tag{7}$$

Note that, even though the shadow rate in (6) is provided in first differences, the level of s_t is well defined, given that $r_1 = \delta_0 + \delta_1' X_1$. Note also that s_t may start diverging from r_t from $t = t_0$, which we set to be equal to the day on which the central bank first announced unconventional policies after the start of the global financial crisis of 2007/2008. The integral $\int_{t_0}^{t} s_t - r_t.dt$ may indicate how expansionary unconventional monetary policy has been compared to conventional monetary policy during the unconventional period, while s_t informs about the level of the stance of monetary policy at time t.

2.3 Estimation

The parameters of the short-rate equation $r_t = \delta_0 + \delta_1' X_t$ are estimated by maximum likelihood, within the term structure model specified in Section 2.1. The other parameters in (6) are estimated separately. In this paper, we use event study regressions, as a way of identifying the relationship between the short-rate and the yield curve (see Gürkaynak and Wright 2013), and to obtain estimates for our parameters of interest.

More specifically, we consider that each of the vectors X_t^{sr} and X_t in (6) have dimension equal to one, i.e. $q = 1$, and estimate event study regressions as in Kuttner (2001), Gürkaynak, Sack and Swanson (2005) and other related studies,

$$\triangle X_{t^\diamond}^{sr} = \beta \triangle r_{t^\diamond}^{u} + \varepsilon_{t^\diamond} \tag{8}$$

$$\triangle X_{t^\diamond} = \alpha \triangle r_{t^\diamond}^{u} + \varepsilon_{t^\diamond} \tag{9}$$

where $\triangle r_{t^\diamond}^{u}$ is the unexpected change in the policy rate observed in a day of conventional monetary policy announcement, $t^\diamond$. Regressions (8) and (9) are estimated over the sample in which only conventional monetary policy was being implemented, i.e. when $t < t_0$, as β and α should identify the link between the short-rate, yields and its short-rate expectations component that are embedded in X_t and X_t^{sr}, when conventional monetary policy was the only instrument of monetary policy available.[6]

We then translate movements in $\triangle X_t^{sr}$ and $\triangle X_t$ into estimates for the shadow rate change during the unconventional policy period through inverse prediction, or statistical calibration, which involves the use of an observed response variable to predict the corresponding unknown explanatory variable.[7] From (6), (8) and (9) we then have the following,

$$\widehat{\triangle s_t} = \begin{cases} \triangle r_t & if \quad t < t_0 \\ \frac{1}{\hat{\beta}} \triangle X_t^{sr} & if \quad t \geq t_0 \;\; s.t. \;\; t \neq t^\star \\ \frac{1}{\hat{\alpha}} \triangle X_t & if \quad t \geq t_0 \;\; s.t. \;\; t = t^\star \end{cases} \tag{10}$$

where $\frac{1}{\hat{\beta}}$ and $\frac{1}{\hat{\alpha}}$ are used as estimates for δ_{11} and δ_{12}.

Notice that on a day of unconventional monetary policy announcement, our estimate for the change in the shadow rate equals the sum of two terms: (i) the conventional monetary policy surprise observed on that day, and (ii) a prediction error, which can be associated with the surprise component of the unconventional monetary policies announced on that particular day, as well as other news that may affect bond yields, scaled by $\frac{1}{\hat{\alpha}}$. On a non-announcement day, the shadow rate change is equal to (i) the conventional monetary policy surprise observed on that day, which can be assumed to be zero, and (ii) a prediction error, which can be associated with any news that may affect short-rate expectations on that particular day, scaled by $\frac{1}{\hat{\beta}}$.

The estimated shadow rate in levels, $\widehat{s_t}$, is obtained by accumulating $\widehat{\triangle s_t}$ over the whole sample as in (7). As noted above, we use the respective first principal components of the yield curve and its short-rate expectations component as factors, i.e. $q = 1$. Even though we abstract from the information contained in other higher dimensional factors, we show in sections 4.1 and 4.2 that our shadow rate is able to capture quite well the observed daily movements in the yield curve. The event study methodology also helps substantially in that matter, as it is a powerful way of identifying the relationship between the short-rate and the yield curve.

2.4 Comparison with other shadow rate specifications

Based on the work by Black (1995), a number of recent studies have proposed different formulations for the shadow rate, which by construction respects a constant or time-varying lower bound constraint

[6] We abstract from the constants in (8) and (9), as the constant value in monetary policy surprise regressions is typically very small and statistically non-significant.

[7] For more details on regression inversion and statistical calibration please see Graybill (1976), Osborne (1991), Graybill and Iyer (1994), Brown (1994), among others.

for bond yields (Krippner 2013; Wu and Xia 2016; Bauer and Rudebusch 2016; Lemke and Vladu 2016; Wu and Xia 2017, Kortela 2016). Their formulations posit the existence of a shadow interest rate that is linear in Gaussian factors, with the actual short-term interest rate being the maximum of the shadow rate, s_t, and the lower bound, $\underline{r}$ $\left(\underline{r_t}\right)$. More specifically, one may have,

$$r_t = max\left(\underline{r}, s_t\right) \quad or \quad r_t = max\left(\underline{r_t}, s_t\right) \qquad s_t = \delta_0 + \delta_1' X_t \tag{11}$$

Note that when the short-rate is close enough to the lower bound and bond yields are sufficiently constrained, the shadow rate tends to diverge from the observed short-rate, being commonly interpreted as a better measure of the stance of monetary policy than the short-rate itself (Krippner 2012, 2014; Wu and Xia 2016; Wu and Xia 2017).

Although specification (11) shows similarities to ours, such as that both are driven by yield curve information, it also shows some fundamental differences. The first fundamental difference is that specification (6) does not rely on the $max(\circ)$ operator or $\underline{r}$ or $\underline{r_t}$, meaning that s_t does not necessarily equal the short-rate when the lower bound is not binding. We consider this to be particularly appealing for measuring the monetary policy stance in unconventional times, as the expansionary and contractionary interest rate effects of unconventional policies that have been actively used by the central bank during their whole unconventional policy periods, such as balance sheet policy, forward guidance and communication, can still be taken into account by (6), but not by specification (11). This is particularly important in the current policy environment as most central banks are "normalizing" monetary policy by first raising their policy rates before unwinding their quantitative easing portfolios. Moreover, they have continued to use forward guidance and communication to inform about their future plans regarding target interest rate and balance sheet policies.[8] Another difference is that, there is no need to specify or to estimate the value of the interest rate lower bound in our formulation. This is particularly convenient as some studies have shown that the shadow rate estimates in (11) are very sensitive to the value assigned to $\underline{r}$ (see Bauer and Rudebusch 2016). In addition, this also implies that the shadow rate in (6) is very flexible and can be applied to different cases of lower bounds that impose constraints on interest rates across maturities, such as constant lower bound, time-varying lower bound, and no lower-bound constraint. Another aspect is that formulation (6) does not take term premium information into the measurement of the shadow rate in all time t. As noted above, except from unconventional announcement days, we consider that term premium carries substantial information that is not particularly related to the stance of monetary policy, which may add noise to the shadow rate measurement.

[8] We discuss this in more details in section 4.2.

3 Data and term structure model estimation

We estimate shadow rates for four economies, i.e. the US, Sweden, the euro-area and the UK. These economies represent well the different cases of lower bound restrictions that may impose constrains on expected short-rates and the government bond yield curve, i.e. constant lower bound (US), time-varying lower bound (UK and euro-area), and no lower-bound constraint (Sweden), becoming natural cases of study. Below we describe the data and the unconventional policy announcements used in the study.

3.1 Zero-coupon government bond yield data

For the US, we use the daily zero-coupon government bond yields provided by Gürkaynak, Sack and Wright (2007). These are constructed using a smooth discount function based on the Svensson (1995) parameterization and are provided by the Federal Reserve Board.[9] In addition, nine maturities are used for estimation - one, three and six-months, and one, two, three, five, seven and ten-years - together with a sample that ranges from January 2, 1987 to October 31, 2017. This sample is consistent with other studies in the literature (Wright 2011; Bauer, Rudebusch and Wu 2012; Adrian, Crump and Moench 2013), and coincides with the Great Moderation period and a shift in the conduction of monetary policy by the Fed after the presidency of Paul Volcker (Clarida, Galí and Gertler 2000; Galí, Lopez-Salido and Valles 2003; Kim and Nelson 2006, among others).[10]

Swedish zero-coupon government bond yields are constructed using the Svensson (1995) parameterization. For the estimation of the term structure model we use zero-coupon bond yields for nine maturities - one, three and six-months, and one, two, three, five, seven and ten-years, and a sample that ranges from January 2, 1996 to October 31, 2017, which is consistent with the introduction of the inflation targeting regime by the Riksbank in 1995.

For the euro-area, we estimate the model using zero-coupon overnight index swap (OIS) rates based on Eonia. As reliable longer-maturity zero-coupon OIS rates are only available from August 2005, we follow Lemke and Vladu (2016) and extend the dataset backwards by merging the OIS data with spread-adjusted zero-coupon rates based on Euribor swaps.[11] Our dataset then consists of zero-coupon OIS rates for maturities of one, three and six-months (one, two, three, five, seven and ten-years) from January 4, 1999 (August 15, 2005) to October 31, 2017, and spread-adjusted

[9] The Svensson (1995) yield curve parameterization assumes the following functional form, $y_t^n = \beta_{0,t} + \beta_{1,t}\left(\frac{1-e^{-\lambda_{1,t}n}}{\lambda_{1,t}n}\right) + \beta_{2,t}\left(\frac{1-e^{-\lambda_{1,t}n}}{\lambda_{1,t}n} - e^{-\lambda_{1,t}n}\right) + \beta_{3,t}\left(\frac{1-e^{-\lambda_{2,t}n}}{\lambda_{2,t}\tau} - e^{-\lambda_{2,t}n}\right)$.

[10] The model is estimated using end-of-month data and parameter estimates are used to fit the daily data.

[11] Since swap contracts are traded at par, zero-coupon swap rates are constructed by bootstraping the original data. For merging the two datasets we follow Lemke and Vladu (2016) and first compute the average spreads between OIS and Euribor zero-coupon swap rates over the period from July 2005 to June 2007. We then subtract these average spreads from the Euribor zero-coupon swap rates from January 1999 to June 2005. We use these rates to replace the non-existent OIS zero-coupon interest rates over this period.

Euribor zero-coupon swap rates for maturities of one, two, three, five, seven and ten-years from January 4, 1999 to August 12, 2005. As discussed by the ECB (2014), these swap interest rates have been considered as adequate proxies for risk-free rates in the euro-area, in particular after the onset of the global financial crisis in 2008.

For the UK, we use the zero-coupon yields provided by the Bank of England for maturities of six-months, one, two, three, five, seven and ten-years, in addition to the Bank Rate. We use a sample comprising the period from October 1, 1992 to October 31, 2017, which is motivated by the adoption of the inflation targeting framework in the UK (see Malik and Meldrum 2016).

The term structure models are estimated using two and three pricing factors, $p = 2, 3$, following the shadow rate literature (Krippner 2012; Wu and Xia 2016; Bauer and Rudebusch 2016). The decompositions of the five-year yields for the four economies are shown in Figures 1 and 2. As can be seen, term premia for all economies have reached low and even negative levels in recent periods (see also Wright 2011). Possible explanations for such phenomenon include: (i) the low inflation environment in the US, Sweden, Europe and the UK observed since late 2013, which has led bondholders to be willing to accept less compensation for bearing inflation risk; (ii) the low uncertainty about the near-term outlook for policy rates in these economies, which is a result of low inflation and, consequently, low policy rates around the world; (iii) the zero-lower bound in the US and other major economies, which has also contributed to lower uncertainty about future policy rates in several economies; (iv) the bond purchases in the US, Sweden, the euro-area and the UK, which have helped to compress long-term term premia; and lastly (v) the facts that government bonds typically work as a hedge against different types of risk that may hurt returns on riskier assets, and that they are especially demanded by certain institutional investors due to liquidity and regulatory reasons, which together may induce investors to be willing to accept low or even negative compensation for holding them.

3.2 Policy rate surprises

As noted in Section 2.3, in order to estimate the shadow rates for the four economies, we need to specify measures of policy rate surprises. For the US, we follow Kuttner (2001) and Gürkaynak, Sack and Swanson (2005), and construct these using interest rate changes for the front contract of the one-month federal funds future. These are measured using a window of ten minutes before and twenty minutes after each monetary policy announcement. In addition, these changes are scaled to account for the timing of FOMC meetings within the month in which the contract is valid.

Policy rate surprises for Sweden are measured using changes in the one-month STINA (Stockholm Tomorrow Next Interbank Average) interest rate. STINA is an overnight index swap contract that has the T/N STIBOR (Tomorrow Next Stockholm Interbank Offered Rate) interest rate as the underlying rate. Since the STIBOR contract is commonly traded in the interbank market with an interest rate spread of ten basis points above the repo rate, the STINA interest rate becomes a natural candidate for measuring conventional monetary policy surprises. We use a window of fifteen minutes before and two hours and forty five minutes after each monetary policy announcement, in addition to adjustment terms that take into account the timing of the implementation of the repo rate within the month of the contract.

Policy rate surprises for the euro-area are measured using interest rates for the front contract of the three-month Euribor future, which is considered to be a reliable predictor for policy rates in the euro-area (Bernoth and von Hagen 2004). In this paper, we follow Bredin et al. (2009) and Haitsma et. al. (2016) and use daily interest rates changes.

For the UK we use one-day interest rate changes for the front contract of the three-month short-sterling future, as a long-history of overnight swap or Bank Rate future rates are not available (see Miranda-Agrippino 2017). These contracts settle based on the three-month interbank (GBP) Libor rate rather than on overnight rates, but are much more liquid and available for a much longer history. Furthermore, as suggested by Joyce, Relleen and Sorensen (2008), their forecasting performance is only slightly inferior to the performance of overnight swap rates.[12]

3.3 Monetary policy announcements

For computing the US shadow rate, we use the key expansionary and contractionary monetary policy announcements made by the Fed since the launch of its QE program in November 25, 2008. These are listed in Table 1, and include announcements that involved balance sheet expansions, forward guidance, tapering as well as balance sheet contractions. In addition, we include the last announcements that involved increases in the fed funds target rate, as these may contain information about the balance sheet contractions that were announced later on.

For estimating the Swedish shadow rate we use all the monetary policy announcements made by the Riksbank since its bond purchase program was launched in February 2015. As can be seen from Table 1, in addition to its conventional monetary policy tool, the repo rate, the Riksbank has been using at least three unconventional policy instruments: government bond purchases, communication, and forward guidance, which has been provided mainly through its repo rate path.[13] As can be seen, the Riksbank has announced conventional and unconventional monetary policies concurrently. In Section 5, we decompose the shadow rate into conventional and unconventional surprises, which helps to disentangle the effects of the two types of policy.

[12]The appendix show details on how the policy rate surprise measures for the four economies are computed. The window sizes differ due to availability of data.

[13]Norges Bank and the Reserve Bank of New Zealand are among the other central banks that use policy rate paths to manage policy rate expectations.

The ECB has provided unconventional stimulus through a number of measures (see Table 2). These involved liquidity provisions to improve the functioning of the interbank market and intermediation, and asset purchases that were designed to lower the borrowing costs of banks, firms and governments in the euro-area (CBPP1, CBPP2, LTROs, OMT, SMP), and to provide further monetary easing in a lower bound environment (EAPP). In addition, we include the announcements that involved a reduction in the pace of the ECB asset purchase program, starting from late 2016.

A large part of the unconventional measures in the UK was provided through the purchase of assets such as government and corporate bonds. For estimating the shadow rate for the UK we then use all the monetary policy announcements that involved asset purchases. In addition, we include the announcement of the result in the Brexit referendum, which may have led market participants to price in additional monetary accommodation by the Bank of England, which in fact happened in August 2016. We also include a couple of other announcements that were assicuated to large movements in government bond yields (see Table 2).

4 Shadow rate estimates

4.1 Shadow rate estimates and their responses to monetary policy announcements

In this section, we describe the estimated shadow rates for the four economies. Table 2 provides the parameter estimates for regressions (8) and (9). As can be seen, the first factor of the yield curve and its short-rate expectations component respond significantly to policy rate surprises in all economies, with R2 values ranging from 0.20 to 0.74. These determine the link between the policy rate, the yield curve and its short-rate expectations component, and are used to compute the shadow rates, as described in section 2.3.

4.1.1 United States

The estimated shadow rates using the two and three-factor models for the US are shown in Figure 3. As can be seen, the two estimates lie below the federal funds target rate for most of the unconventional period, suggesting that the unconventional measures implemented by the Fed eased financial conditions in the US. The shadow rates fall as market participants price in new information about the expansionary policies implemented by the Fed, such as QE1, QE2, QE3 and forward guidance, and rise when market participants expect monetary policy to become more contractionary, as in the period around the tapering of QE3.

In order to better identify how the stance of monetary policy has changed with these policies, we look at how the shadow rates responded to the unconventional policy announcements that are listed in Table 1. These are shown in Table 4. As can be seen, the US shadow rates responded strongly to the first four announcements related to QE1. Since policy rate surprises were small - except on December 16, 2008 - these movements can be almost fully attributed to the QE announcements. The subsequent announcements of QE2 and QE3, however, had less of an impact on the US shadow rates.

Other important events with significant impacts on Treasury yields are Ben Bernanke's speech at the Jackson Hole conference on August 27, 2010 and the two forward-guidance announcements made on December 14, 2010 and August 9, 2011. As can be seen from Table 4, following government bond yields, the shadow rates increased following Bernanke's speech and the first forward-guidance announcement, but dropped by 27 basis points after the Fed announced that it would keep the fed funds target rate at zero until mid-2013. As shown in Figure 3, the US shadow rates remained low and stable after that event, suggesting that the Fed was successful in keeping policy rate expectations low for some time.

The stance of monetary policy in the US started changing after May 22, 2013, when Bernanke announced the potential tapering of QE3, which led long-term yields to rise during the "taper tantrum" episode in mid-2013. After that date, it is possible to identify a number of contractionary announcements by the Fed: (i) QE3 tapering, (ii) interest rate hikes, and (iii) the announcements involving balance sheet contractions in mid-2017; which mostly led the shadow rates to rise.

It is also interesting to compare our estimates with the ones by Wu and Xia (2016) and Krippner (2014). Besides the fact that our measure is provided with daily frequency, we see other major differences. First, our shadow rates responded immediately to the first four expansionary announcements made by the Fed, and lowered by 37.7, 33.3, 32.1 and 82.5 basis points. Second, our estimates do not equal the short-rate when the Fed first hiked its policy rate in late 2015, meaning that it can still capture the interest rate effects of contractionary policies that were announced later on, such as balance sheet contractions and forward guidance. As discussed in Section 2.4, this is mainly because our specification does not rely on the $max(\circ)$ operator, and on a set value for the interest rate lower bound. Furthermore, as can be seen from Figure 3 and Table 4, our shadow rates are able to track quite well all the announcements of tapering of QE3, increasing on most of those dates. The Wu and Xia (2016) shadow rate, however, show a sharp decline during this period. Interestingly, our three factor shadow rate and the Wu and Xia (2016) shadow rate show very similar estimates for the period from January 2011 to January 2014. The shadow rate estimated by Krippner (2014) does indeed start increasing as soon as Bernanke announced the potential tapering of QE3 on May 22, 2013. However, as mentioned above, its main restriction is that it also equates with the short-rate as soon as the lower-bound is no longer binding.

4.1.2 Sweden

The shadow rate estimates for Sweden are shown in Figure 3. As can be seen from the shadow rates, the unconventional policies by the Riksbank have provided additional monetary stimulus compared to the repo rate since February 2015. For instance, our estimates reach the levels of -1.23 (two-factor model) and -1.24 (three-factor model) percent in October 31, 2017, suggesting that market participants perceived unconventional monetary policy in Sweden to be around 0.75 percentage points more expansionary than conventional monetary policy on that particular day.

We can also study the expansionary interest rate effects of the unconventional policies in Sweden by looking at how the shadow rates respond to monetary policy announcements. In order to do so, we focus here on the responses to announcements that involved bond purchases only, with numbers being provided in Table 5.

We start our analyses by looking at the announcement of February 12, 2015, which marks the start of the Riksbank's bond purchase program. The repo rate was lowered to -0.10 percent on that day, informing market participants that the Riksbank could set negative interest rates and make conventional monetary policy more expansionary. We see a fairly large response of shadow rates, which declined by 26.9 basis points. This is only partially explained by the interest rate cut. The repo rate surprise measure marks -5.9 basis points, with the rest being largely attributed to the bond purchase announcement, as market newsletters collected before the decision suggest that the announcement of SEK 10 billion was a full surprise.[14] However, we understand that an additional effect came from the Riksbank setting a negative repo rate for the first time in history. Our interpretation is that trespassing the zero lower bound worked as an additional tool of unconventional monetary policy, with repo rate expectations becoming particularly unconstrained after that date.

Other important expansionary announcements were made on March 18, 2015, July 2, 2015, October 28, 2015 and April 27, 2017, when market participants were surprised by repo rate cuts and/or bond purchases. The first two announcements had strong impacts on government bond yields, leading the shadow rates to decline by 22.7 and 21.1 basis points. The other two announcements affected mostly the long-end of the Swedish yield curve, with shadow rates declining by 6.7 and 7.8 basis points, respectively. Notice also that the declines in shadow rates were larger than the surprises in the repo rate, suggesting that bond purchases and forward guidance were successful in lowering the stance of monetary policy in Sweden.

Contractionary announcements can be seen on April 29, 2015 and April 21, 2016, with positive responses of shadow rates. This can be mainly attributed to market participants being disappointed

[14] Information about QE expectations is collected from market newletters before every monetary policy announcement. Market participants providing such information include Nordea, Handelsbanken, SEB, Swedbank, Citibank, Danske Bank, JP Morgan, Nykredit, RBS and Goldman Sachs. We construct a measure of QE surprise by subtracting the average of QE expectations from the announced amount of bond purchases.

by the Riksbank not cutting the repo rate - $\triangle r_t^u = 7.3$ basis points on April 29, 2015 - and by announcing increments in bond purchases that were lower than expected, as on April 21, 2016.

Interestingly, we can also use the shadow rate estimates to provide an estimate of the interest rate effect of an unanticipated announcement of SEK 10 billion purchase in government bonds, in terms of the repo rate. We use five announcements that involved bond purchases, so that we can clearly identify their unanticipated component: March 18, 2015, July 2, 2015, October 28, 2015, April 21, 2016 and April 27, 2017. With the help of repo rate and bond purchase surprise measures we calculate the shadow rate responses minus the repo rate surprises, $\triangle s_{t^\star} - \triangle r_{t^\star}^u$, and scale them in terms of a suprise of SEK 10 billion in purchases. We find: -2.7, -2.8, -3.7, -2.2 and -4.8 basis points, which give an average response of -3.3 basis points in repo rate terms.

4.1.3 Euro-area

Since the ECB unconventional policies involved a series of measures, it becomes particularly difficult to precisely set an initial date to start estimating our shadow rates. We decided to choose the date on which the ECB launched its first unconventional measure, May 7, 2009, which is also quite close to the day on which the deposit facility rate was lowered to 0.25 percent, April 8, 2009. The estimated shadow rates for the euro-area are shown in Figure 4. As can be seen, there is a clear downward trend in the estimates, which is only interrupted by the interest rate hikes from late 2010 to late 2011, and more recently, by the recent increases starting around mid-2016. Moreover, the shadow rates lie well below the one-month OIS interest rate for most of the period, suggesting that the various unconventional measures implemented by the ECB eased financial conditions in the euro-area.

In Table 6, we see the shadow rate responses to a series of unconventional announcements by the ECB. The European swap rates moved little following most announcements, with the shadow rates also moving accordingly. The announcements made on May 7, 2009, May 10, 2010, October 6, 2011, September 4, 2014, December 3, 2015 and March 10, 2016 were the only ones that had sizeable effects, although yields and shadow rates responded mostly positively. Interestingly, on October 6, 2011 the shadow rates increased by 17.1 basis points. This can be largely attributed to the surprise in the policy rate, which strongly affected the short-end of the yield curve with the two-year yield increasing by 20.4 basis points.

The first extension of the Expanded Asset Purchase Program (EAPP) announced in December 2015 also frustrated market participants, who expected a larger expansion of the program. As indicated in Table 6, the European shadow rates increased by 21.1 basis points on that particular day, which can be mostly attributed to the unconventional policy announcement since the policy rate surprise increased by 7.5 basis points only.

4.1.4 United Kingdom

The estimated shadow rates for the UK are shown in Figure 4. As for other economies, the UK shadow rate shows a downward trend, following the highly expansionary measures provided by the Bank of England since March 2009. These reach the values of -1.01 (two-factor model) and -0.98 (three-factor model) percent in October 31, 2017.

We can also better identify the movements in the UK shadow rates by measuring their reactions to the monetary policy announcements made by the Bank of England during the unconventional period. As can be seen from Table 7, there were four announcements that can be considered strongly expansionary - February 11, 2009, March 5, 2009, June 24, 2016 and August 4, 2016 - and four that can be considered strongly contractionary - July 9, 2009, June 13, 2014, July 15, 2017 and September 14, 2017.

On February 11, 2009 the Bank of England suggested that it could buy assets in the near-future. This led yields on Gilts to fall sharply, with the UK shadow rates responding accordingly, and lowering by 45.9 basis points. After that, on March 5, 2009, the Bank of England announced its first round of QE together with a cut of 0.5 percent in Bank Rate. According to our estimates, the Bank Rate cut was largely expected by market participants, meaning that the decline in the UK shadow rates by 35.7 basis points can be largely attributed to the QE announcement. Interestingly, the announcement of "Brexit" on June 24, 2016 also caused the shadow rates to decline strongly by 42.7 basis points, following government bond yields. Also the expansionary package announced on August 4, 2016 led the shadow rates to decline by 28.1 basis points. The announcements of March 10, 2011, June 30, 2016 and August 3, 2017, together with other QE announcements, were slightly expansionary, with the UK shadow rates declining by 11.3, 10.3 and 11.4 basis points, respectively.

The most important contractionary announcements, which happened on July 9, 2009, June 13, 2014, July 15, 2017 and September 14, 2017, led the shadow rates in UK to rise sharply. On the first date, the shadow rates increased by 19.6, with market participants being disappointed when the Bank of England did not announce additional monetary easing. On June 13, 2014 the shadow rates increased by 17.5 basis points, after Mark Carney stated that Bank Rate would be increased sooner than expected by market participants. The last two announcements are characterized by the Bank of England signaling that Bank Rate could be increased soon, which led market participants to quickly price this information into the yield curve, causing the shadow rates to increase by 16.6 and 15.4 basis points, respectively.

4.2 Monetary policy normalization across economies: discussion

As described above, the shadow rate in equation (7) seems to increase as market participants perceive current and future monetary policy to become less expansionary - or more contractionary - and price this information into the yield curve. In this context, it is useful to compare the shadow rates estimated for the four economies to shed light on the interest rate effects of monetary policy normalization. One important aspect of this analysis is the differences in communication and use of the set of policy tools by the different central banks.

The Fed has been the first central bank to start normalizing monetary policy. Its strategy followed a sequence of events, with (i) the announcement of tapering of its open-ended QE policy, (ii) communication of the reinvestment of the principal payments from its asset holdings, with the aim of using asset holdings as a passive monetary policy instrument, (iii) policy rate increases, and (iv) announcement of its plans for balance sheet contraction. The interest rate effects of this strategy can be seen in Figure 5, with the announcement by Bernanke made on May 22, 2013 marking its beginning. Although market participants became aware of the potential tapering of QE3, the US shadow rate did not rise significantly. In fact, we observe a sharp increase in long-term Treasury term premia right after, resulting from the higher uncertainty regarding the upcoming policy (see Figure 1). This uncertainty was only resolved after December 2013, when a series of tapering announcements came in, calming investors, and bringing term premia back to lower levels. As a result, the US shadow rate responded promptly, rising continuously from the end of 2013. Interestingly, we see a sharp rise around October 28, 2015, when the Fed communicated that the first policy rate hike could happen in December 2015, and after September 2015, when the balance sheet contraction was announced.

The normalization process in other economies was initiated later, with their respective central banks providing less information about their normalization strategies than the Fed. For instance, the ECB has only communicated until when its asset purchases are expected to last, and that its key interest rates will remain at their present levels for an extended period of time, well past the horizon of its net asset purchases. The interest rate effects of the ECB's strategy can be seen in Figure 5, with the shadow rate for the euro-area starting to increase around October 2016, when market participants speculated that the ECB would provide extensions of its EAPP, but with a gradual reduction in the pace of purchases.[15] When these speculations started to materialize in December 2016, with a series of less expansionary announcements by the ECB, we see a continuing increase of the shadow rate, with investors potentially pricing in a more contractionary policy by the ECB further out in the future.

The same profile has not yet been seen in Sweden, although the Riksbank has communicated its future target interest rate policy intentions through its repo rate path. In the UK, due to surging inflation and improved economic conditions, the Bank of England started communicating on June 15, 2017 that it could raise interest rates soon. The UK shadow rate responded, starting to rise after that date.

[15] See for instance, https://www.ft.com/content/4867052a-d5f6-334c-901e-b5d3010ab02d.

5 Applications

This section presents two applications for the shadow rate. In the first application, we exploit the information about the stance of monetary policy contained in the shadow rate responses around announcements and try to better understand the pass-through of conventional and unconventional monetary policies to exchange rates across economies. In the second application, we measure the macroeconomic effects of unconventional monetary policy by replacing the repo rate in the Riksbank's DSGE model Ramses II by the Swedish shadow rates shown in Figure 3, and by running a counterfactual experiment to evaluate the effects of unconventional monetary policy on inflation and unemployment.

5.1 Monetary policy stance surprises and exchange rates

In this section, we exploit the information contained in the shadow rates on announcement days and measure the pass-through of monetary policy to exchange rates. For the analysis we use event study regressions. More specifically, we regress exchange rate changes around announcements on measures of monetary policy surprises, and assess their responses.

We use shadow rate changes observed on days of monetary policy announcements as our first measure of monetary policy suprise, as the shadow rate summarizes movements in the whole term structure of interest rates, capturing the interest rate effects of conventional and unconventional monetary policies together.[16] We also decompose these shadow rate changes into two additional surprise measures, i.e. conventional and unconventional. More specifically, we subtract the policy rate surprise measure, $\triangle r^u_{t^\star}$, from shadow rate changes and obtain a measure of unconventional monetary policy surprise, $\triangle ump^u_{t^\star} = \triangle s_{t^\star} - \triangle r^u_{t^\star}$, which may include information about monetary policy that affects the whole term structure of interest rates, except policy rate surprises. [17] This decomposition, which is shown in Figures 6 and 7, can be used to assess the pass-through of each type of monetary policy, i.e. conventional and unconventional, to exchange rates, with effects being directly comparable, as the two variables are policy rate equivalent. We then estimate event study regressions as the following,

$$\triangle e_{t^\star} = \nu + \phi \triangle s_{t^\star,d} + \theta \triangle s_{t^\star,f} + \varepsilon_{t^\star} \qquad (12)$$

[16]Other studies using changes in government bond interest rates around announcements as measures of monetary policy surprises are Wright (2012), Rogers, Scotti and Wright (2014), Glick and Leduc (2015).

[17]As noted in Section 2.3, from regression (9), shadow rate changes on unconventional announcement days can be decomposed into two terms: (i) the conventional monetary policy surprise observed on that day, and (ii) a prediction error, which can be associated with the surprise component of the unconventional monetary policies announced on that particular day, as well as other news that may affect bond yields, scaled by $\frac{1}{\hat{\alpha}}$.

$$\triangle e_{t^\star} = \eta + \gamma \triangle r^u_{t^\star,d} + \vartheta \triangle ump^u_{t^\star,d} + \omega \triangle s_{t^\star,f} + \varepsilon_{t^\star} \tag{13}$$

where $\triangle e_{t^\star}$ is the percentage change in the nominal exchange rate between the domestic currency and the foreign currency, $\triangle s_{t^\star,d}$ is the domestic shadow rate change, and $\triangle r^u_{t^\star,d}$ and $\triangle ump^u_{t^\star,d}$ are the measures of conventional and unconventional surprises for the domestic economy. In addition, we add the foreign shadow rate change, $\triangle s_{t^\star,f}$, in order to control for changes in foreign interest rates that may happen on the same day and that may also affect $\triangle e_{t^\star}$. We expect coefficients on $\triangle s_{t^\star,d}$, $\triangle r^u_{t^\star,d}$ and $\triangle ump^u_{t^\star,d}$ to be negative, that is, expansionary monetary policy announcements lead to a depreciation of the domestic currency vis-à-vis the foreign currency.

5.1.1 Results

We first assess the transmission of monetary policy to exchange rates using regression (12), with results being provided in Table 8. We measure the percentage change in exchange rates using intraday data, with a window of 30 minutes before and 30 minutes after each announcement. On announcements by the ECB we use a window from 11:30 to 14:00 (GMT 0), which includes both the monetary policy decision and the press conference. As can be seen, we find highly statistically significant coefficient estimates for all economies, and high regression R2s. For instance, for Sweden, we find R2s around 80 percent, suggesting that the Riksbank has been successful in affecting foreign exchange rates, which is in line with its policy of avoiding a quick appreciation of the Swedish krona since the start of its bond purchase program in 2015. In terms of coefficient estimates, we find higher values using announcements by the ECB, with numbers ranging from -0.086 to -0.145. Lower estimates are found using announcements by the Fed, with values ranging from -0.024 to -0.044.[18]

Results using conventional and unconventional surprises are shown in Table 9. Interestingly, coefficient estimates on both measures are also highly significant and negative, indicating that exchange rates have responded to both monetary policies. However, we find larger responses to conventional monetary policy, with coefficient estimates ranging from -0.084 to -0.207. In turn, estimates for the unconventional surprise measure range from -0.022 to -0.125, depending on which central bank we look at.

In order to obtain a more general estimate of the exchange rate effects of conventional and unconventional policies we also estimate pooled event study regressions, where we put together the percentage changes of the eleven exchange rates that are available, i.e. three for the US, Sweden and the euro-area, and two for the UK, and run one single OLS regression using all the announcements

[18]We do not report regression results with announcements by the Bank of England and GBP per SEK, since we only have intraday data for this bilateral from 2015 onwards.

listed in Tables 1 and 2.[19] As for the single event study regressions, results shown in Table 10 suggest that conventional policy has been more effective in affecting the foreign exchange market than unconventional policy. On average, a 10 basis point drop in the conventional surprise measure depreciates the domestic currencies by 1.08 percent vis-à-vis foreign currencies. The estimated impact of unconventional monetary policy is lower, about 0.35 percent for a decrease of 10 basis points in the unconventional measure.

Another question that arises is whether effects are the same on announcements in which market participants perceive the stance of monetary policy to be more expansionary or contractionary. This can be tested by splitting the sample according to positive and negative changes in the shadow rates, and by estimating the same type of event study regressions using data for each subsample. Results suggest that exchange rates rise by about 0.36 percent when the shadow rates are lowered by 10 basis points, and decrease by 0.24 percent when the shadow rates rise by 10 basis points. Coefficient estimates for expansionary announcements are also higher than for contractionary announcements when we decompose the shadow rate changes into conventional and unconventional surprises. These results suggest that exchange rates seem to respond somewhat more strongly to expansionary than to contractionary monetary policy.

5.2 The macroeconomic effects of unconventional monetary policy

As a second application we measure the macroeconomic effects of unconventional monetary policy. We construct a counterfactual analysis by replacing the repo rate in the Riksbank's DSGE model Ramses II with the Swedish shadow rates, and by computing the what the inflation and unemployment rates would have been had the Riksbank not conducted unconventional monetary policy since February 2015.[20] In practice, negative monetary policy shocks are fitted to the difference between the repo rate and the shadow rates shown in Figure 3. For the analysis we use the impulse responses from Ramses II, estimated with data from the first quarter of 1995 to the fourth quarter of 2014. These are shown in Figure 8, and have a typical hump-shaped form. As the economy responds with a lag, the initial effect of a 0.25 percentage points repo rate shock on inflation and unemployment rate is approximately -0.03 percentage points and zero, respectively. The maximum effect is reached after 3–5 quarters, with a decline of 0.08 percentage points in inflation, and an increase of 0.08 percentage points in the unemployment rate.

[19] We also estimated panel regressions with fixed and random effects. Coefficient estimates are very similar to those using pooled OLS.

[20] Ramses II is a medium-scale open economy DSGE model that is currently used by the Riksbank to produce macroeconomic forecasts, to construct alternative scenarios, and for monetary policy analysis in general. For a detailed description of the model, see Adolfson et al. (2013).

5.2.1 Results

Results are shown in Figure 8, with dashed lines showing the counterfactuals for a scenario with no unconventional monetary policy. As suggested by our estimates, had the Riksbank relied on the repo rate only to stimulate the economy since February 2015, CPIF inflation would have been 0.42 (0.51) percentage points lower in October 2017, according to the two-factor (three-factor) model shadow rate. Unemployment, in turn, is estimated to have been 0.65 (0.81) percentage points higher in October 2017, according to the two-factor (three-factor) model shadow rate. These results suggest that the unconventional policies implemented by the Riksbank since 2015, including its bond purchase program, have further stimulated the Swedish economy.

6 Concluding remarks

In this paper, we propose a shadow rate that measures the expansionary and contractionary interest rate effects of unconventional monetary policy, without imposing a lower bound constraint on interest rates. This is particularly important in the process of "monetary policy normalization", as most central banks are raising their policy rates before unwinding their quantitative easing portfolios, and have continued to use forward guidance and communication to inform about their future plans regarding target interest rate and balance sheet policies. Moreover, some central banks, such as the ECB and Sveriges Riksbank, have conducted conventional and unconventional monetary policies concurrently without explicitly setting a lower bound for their policy rates. Since there is no need to make any assumptions or to estimate the lower bound in our specification, our shadow rate can accommodate cases in which interest rates are constrained by a fixed or time-varying lower-bounds, or in which there are no lower-bound constraints. These salient characteristics make our shadow rate an attractive and informative market-based measure of the monetary policy stance in non-standard times.

Using daily yield curve data, we estimate shadow rates for the US, Sweden, the euro-area, and the UK, and find that they fall (rise) when market participants expect monetary policy to become more expansionary (contractionary), and price this information into the yield curve. Our estimates are able to precisely track episodes of policy rate cuts and hikes, balance sheet expansions and contractions, forward guidance, as well as speeches. These events identify the ability of the shadow rate to track the stance of monetary policy.

Additionally, we show two applications for the shadow rate. In the first application, we measure the pass-through of monetary policy to exchange rates using event study regressions with a decomposition of shadow rate changes around announcements into conventional and unconventional monetary policy surprises. Using pooled and single exchange rate regressions, we find larger responses to conventional monetary policy. Our estimates suggest that a 10 basis points decrease in the conventional surprise measure depreciates the domestic currencies by 1.08 percent vis-à-vis foreign currencies. We find the estimated impact of unconventional policy to be lower, about 0.35 percent. Furthermore, we find some evidence of non-linear effects, with exchange rates responding more strongly to expansionary announcements.

In our second application, we measure the macroeconomic effects of unconventional monetary policy in Sweden by replacing the repo rate in the Riksbank's DSGE model Ramses II with the Swedish shadow rates, and by running a counterfactual experiment. Our estimates suggest that the unconventional policies conducted by the Riksbank since 2015 have further stimulated the Swedish economy, with CPIF inflation and unemployment being around 0.47 percentage points higher and 0.73 percentage points lower than otherwise by October 2017, respectively. This type of application is particularly appealing to monetary policy analysis as DSGE models used by central banks typically lack a financial side that can model the transmission of unconventional policies through the term structure of interest rates. Furthermore, scenarios estimating the effects of further unconventional policies such as bond purchases can be easily constructed.

Appendix. Conventional monetary policy surprise measures

A.1. US

Letting ff_t^h denote the price of the federal funds future contract expiring on day h of a given month with D days, then

$$ff_t^h = \frac{1}{D}\sum_{i=1}^{N} E_t\left(r_{t+i}\right) + \xi_t^h \tag{14}$$

where r_t is the effective federal funds rate and ξ_t^h is a corresponding time-varying term premium. Kuttner (2001) and Gürkaynak et al. (2005) construct monetary policy surprises using quotes of the front contract of the one-month federal funds future, ff_t^1, which are based on the average of the federal funds rate calculated over the current month. Considering that a FOMC meeting will happen within this period, we can then write:

$$ff_{t-\triangle t}^1 = \frac{d}{D} r_0 + \frac{D-d}{D} E_{t-\triangle t}\left(r_1\right) + \xi_{t-\triangle t}^1 \tag{15}$$

where d denotes the day of the FOMC meeting, r_0 is the federal funds rate that has prevailed so far in the month, r_0 is the federal funds rate that has prevailed so far in the month, r_1 is the rate that is expected to prevail for the reminder of the month and $\xi_{t-\triangle t}^1$ is the corresponding term premium. We use a window $\triangle t$ of ten minutes before and twenty minutes after each monetary policy announcement. By leading this equation to time t and differencing, the surprise component of the change in the federal funds target rate is given by,

$$\triangle r_t^u = \left(ff_t^1 - ff_{t-\triangle t}^1\right)\frac{D}{D-d} \tag{16}$$

A.2. Sweden

The surprise component of the change in the repo rate, $\triangle r_t^u$, is given by

$$\triangle r_t^u = \frac{\left(stina_t^1 - stina_{t-\triangle t}^1\right)(d1+d2)}{d2} \tag{17}$$

where $\left(stina_t^1 - stina_{t-\triangle t}^1\right)$ is the change in the 1-month STINA interest rate around a window of fifteen minutes before and two hours and forty five minutes after each monetary policy announcement, $d1$ is the number of days between the day the STINA contract takes effect and the repo rate implementation day, and $d2$ is the number of days within the repo rate implementation day and the day in which the contract ends. STINA is an overnight index swap contract that has the T/N

STIBOR (Tomorrow Next Stockholm Interbank Offered Rate) interest rate as the underlying rate.

A.3. Euro-area

For constructing policy rate surprises for the Euro-area we use one-day interest rate changes for the front contract of the three-month Euribor future, which are based on the three-month Euribor interest rate. We do not use any scaling that takes into account the days of ECB announcements. $\triangle r_t^u$ is then given by,

$$\triangle r_t^u = ef_t^3 - ef_{t-1}^3 \tag{18}$$

A.4. UK

For constructing policy rate surprises for the UK we use one-day interest rate changes for the front contract of the three-month short-sterling future, which are based on the three-month interbank (GBP) Libor rate. More specifically,

$$\triangle r_t^u = sf_t^3 - sf_{t-1}^3 \tag{19}$$

References

[1] Adolfson, M., Laséen, S., Christiano, L., Trabandt, M. and Walentin, K. (2013). “Ramses II - Model Description”. Sveriges Riksbank Occasional Paper Series n. 12.

[2] Adrian, T., Crump, R. K. and Moench, E. (2013). “Pricing the term structure with linear regressions”. Journal of Financial Economics, v. 110, p. 110-138.

[3] Ang, A. and Piazzesi, M. (2003). “A No-Arbitrage Vector Autoregression of Term Structure Dynamics with Macroeconomic and Latent Variables”. Journal of Monetary Economics, v. 50, p. 745-787.

[4] Bauer, M. D. and Rudebusch, G. D. (2014). “The Signaling Channel for Federal Reserve Bond Purchases”. International Journal of Central Banking, 10(3), p. 233-289.

[5] Bauer, M. D., Rudebusch, G. D. and Wu, C. (2014). “Term Premia and Inflation Uncertainty: Empirical Evidence from an International Panel Dataset: Comment”. American Economic Review, v. 104(1), p. 323-337.

[6] Bauer, M. D. and Rudebusch, G. D. (2016). “Monetary Policy Expectations at the Zero Lower Bound”. Journal of Money, Credit and Banking, v. 48(7), p. 1439-1465.

[7] Bernoth, K. and Von Hagen, J. (2004). “Euribor futures market: efficiency and the impact of ECB policy announcements”. International Finance, v. 7(1), p. 1-24.

[8] Black, F. (1995) “Interest Rates as Options”. Journal of Finance, v. 50, p. 1371–1376.

[9] Bredin, D., Hyde, S., Nitzsche D., O’Reilly G. (2009). “European monetary policy surprises: the aggregate and sectoral stock market response”. International Journal of Finance and Economics, v. 14(2), p. 156- 171.

[10] Brown (1994). “Measurement, Regression, and Calibration”. Oxford Statistical Science Series.

[11] Campbell, J. Y. and J. H. Cochrane. (1999). “By Force of Habit: A Consumption-Based Explanation of Aggregate Stock Market Behavior”. Journal of Political Economy, v. 107, p. 205–251.

[12] Christensen, J. and Rudebusch, G. (2012). "The Response of Interest Rates to US and UK Quantitative Easing". Economic Journal, 122(564), p. F385-F414.

[13] Christensen, J. (2015). “A Regime-Switching Model of the Yield Curve at the Zero Bound”. Federal Reserve Bank of San Francisco Working Paper Series, No 2013-34.

[14] Christensen, J. and Krogstrup, S. (2016). "Transmission of Quantitative Easing: The Role of Central Bank Reserves". Federal Reserve Bank of San Francisco Working Paper 2014-18.

[15] Clarida, R., Galí, J. and Gertler, M. (2000). “Monetary Policy Rules And Macroeconomic Stability: Evidence And Some Theory". The Quarterly Journal of Economics, v. 115(1), p. 147-180.

[16] D’Amico, S. and King, T. (2013) “Flow and Stock Effects of Large-Scale Treasury Purchases: Evidence on the Importance of Local Supply”. Federal Reserve Bank of Chicago, WP 2013-22.

[17] D’Amico, S., Fan, R. and Kitsul, Y. (2013) “The scarcity value of Treasury collateral: repo market effects of security-specific supply and demand factors”. Journal of Financial Economics, v. 108, p. 425–448.

[18] De Rezende, R. B. (2017). “The interest rate effects of government bond purchases away from the lower bound”. Journal of International Money and Finance, v. 74, p. 165-186.

[19] ECB (2014). “Euro area risk-free interest rates: Measurement issues, recent developments and relevance to monetary policy”. In Monthly Bulletin July 2014, p. 63-77.

[20] Foerster, A. and Cao G. (2013). “Expectations of large-scale asset purchases”, Federal Reserve Bank of Kansas City, Economic Review 98, p. 5-29.

[21] Gagnon, J., Raskin, M., Remache, J. and Sack, B. (2011). “The financial market effects of the Federal Reserve’s large-scale asset purchases”. International Journal of Central Banking, v. 7, p. 3–43.

[22] Galí, J., Lopez-Salido, J. D., and Valles, J. (2003). “Technology shocks and monetary policy: assessing the Fed’s performance”. Journal of Monetary Economics, v. 50(4), p. 723-743.

[23] Glick, R. and Leduc, S. (2015). “Unconventional Monetary Policy and the Dollar: Conventional Signs, Unconventional Magnitudes”. Federal Reserve Bank of San Francisco Working Paper 2015-18.

[24] Graybill, F. A. (1976). “Theory and Application of the Linear Model”. Duxbury Classic Series. Duxbury, Pacific Grove, CA.

[25] Graybill, F. and H. Iyer. (1994). “Regression Anaysis”. First Edition, Duxbury Press, p. 427-431.

[26] Gürkaynak, R., Sack, B. and Swanson, E. (2005). “Do Actions Speak Louder Than Words? The Response of Asset Prices to Monetary Policy Actions and Statements”. International Journal of Central Banking, v. 1(1), p. 55-93.

[27] Gürkaynak, R., Sack, B. and Wright, J. H. (2007). “The U.S. Treasury Yield Curve: 1961 to the Present”. Journal of Monetary Economics, v. 54, p. 2291–2304.

[28] Gürkaynak, R. and Wright, J. H. (2013). “Identification and Inference Using Event Studies”, Manchester School, v. 81, p. 48-65.

[29] Haitsma, R., Unalmis, D. and de Haan, J. (2016). “The impact of the ECB’s conventional and unconventional monetary policies on stock markets”. Journal of Macroeconomics, v. 48, p. 101-116.

[30] Joslin, S., Singleton, K. and Zhu, H. (2011). “A new perspective on Gaussian dynamic term structure models”. Review of Financial Studies, 24, p. 926-970.

[31] Joyce, M., Relleen, J. and Sorensen, S. (2008). “Measuring Monetary Policy Expectations from Financial Market Instruments”, Working Paper Series 0978, European Central Bank.

[32] Kim, C-L., and Nelson, C. R. (2006). “Estimation of a Forward-Looking Monetary Policy Rule: A Time-Varying Parameter Model using Ex-Post Data”. Journal of Monetary Economics, v. 53(8), p. 1949-1966.

[33] Kim, Dom, and Orphanides, A. (2007). “The bond market term premium: what is it, and how can we measure it?”. BIS Quarterly Review, 2007.

[34] Kortela, T. (2016). “A shadow-rate model with time-varying lower bound of interest rates”. Bank of Finland Research Discussion Paper 19 2016.

[35] Krippner, L. (2012). “Measuring the stance of monetary policy in zero lower bound environments", Economics Letters 118, 135–138. Also RBNZ Discussion Paper 2012/04

[36] Krippner, L. (2013). “A tractable framework for zero lower bound Gaussian term structure models”. Discussion Paper, Reserve Bank of New Zealand, 2013/02.

[37] Krippner, L. (2014). “Measuring the stance of monetary policy in conventional and unconventional environments”. CAMA Working Papers, Centre for Applied Macroeconomic Analysis, Crawford School of Public Policy, The Australian National University.

[38] Krishnamurthy, A. and Vissing-Jorgensen, A. (2011). “The effects of quantitative easing on long-term interest rates”, Brookings Papers on Economic Activity, p. 215–265.

[39] Kuttner, K. (2001). “Monetary Policy Surprises and Interest Rates: Evidence from the Fed Funds Futures Market”. Journal of Monetary Economics, v. 47(3), p. 523-44.

[40] Lemke, W. and Vladu, A. (2016). “Below the zero lower bound – a shadow-rate term structure model for the euro area”, Deutsche Bundesbank, Discussion Paper 32-2016.

[41] Ludvigson, S.C. and Ng, S. (2009). “Macro factors in bond risk premia". Review of Financial Studies, v. 22, p. 5027-5067.

[42] Malik, S. and Meldrum, A. (2016). “Evaluating the robustness of UK term structure decompositions using linear regression methods”. Journal of Banking and Finance, v. 67, p. 85-102.

[43] Miranda-Agrippino, S. (2017). “Unsurprising Shocks: Information, Premia, and the Monetary Transmission”. mimeo.

[44] Osborne (1991). “Statistical Calibration: A Review”. International Statistical Review, v. 59, p. 309-336.

[45] Svensson, L. E. O. (1994). “Estimating and Interpreting Forward Interest Rates: Sweden 1992–1994”. NBER Working Paper Series No. 4871.

[46] Vayanos, D. and Vila, Jean-Luc. (2009) “A Preferred-Habitat Model of the Term Structure of Interest Rates”. Working Paper, London School of Economics.

[47] Wachter, J. (2006). “A Consumption Based Model of the Term Structure of Interest Rates”. Journal of Financial Economics, v. 79, p. 365–399.

[48] Wright, J. H. (2011). “Term Premia and Inflation Uncertainty: Empirical Evidence from an International Panel Dataset”. American Economic Review, v. 101, p. 1514-1534.

[49] Wright, J. H. (2012). “What does Monetary Policy do to Long-term Interest Rates at the Zero Lower Bound?”. Economic Journal, v. 122, p. F447-F466.

[50] Wu, J. C. and Xia, F. D. (2016). “Measuring the Macroeconomic Impact of Monetary Policy at the Zero Lower Bound”. Journal of Money, Credit, and Banking, v. 48(2-3), p. 253-291.

[51] Wu, J. C. and Xia, F. D. (2017). “Negative interest rate policy and yield curve”. Chicago Booth Research Paper No. 17-34.

Table 1: Monetary policy announcements by the Fed and the Riksbank

Notes: This table describes the key monetary policy announcements by the Fed and the Riksbank since the launch of their unconventional monetary policy measures.

Date	Announcement description
US	
Nov 25, 2008	QE1 announcement: Fed to purchase up to $500 billion in MBS and $100 billion in GSE debt
Dec 1, 2008	Announcement indicating potential purchases of Treasury securities
Dec 16, 2008	Fed sets the range of 0 to 0.25% for the federal funds rate, and mentions that it could purchase long-term Treasury securities
Mar 18, 2009	QE1 extension. Fed to purchase $300 billion in Treasuries, additional $750 billion in MBS and $100 billion in agency debt
Aug 10, 2010	Fed to continue rolling over its holdings of Treasury securities as they mature
Aug 27, 2010	Bernanke foreshadows QE2 at Jackson Hole
Sep 21, 2010	Fed to continue rolling over its holdings of Treasury securities as they mature and is prepared to provide additional stimulus
Oct 15, 2010	Bernanke indicates that monetary easing will continue
Nov 3, 2010	Announcement of QE2. Purchase of $600 billion in longer dated treasuries, at $75 billion per month
Dec 14, 2010	Fed to retain the fed funds target rate near 0 percent "for an extended period"
Aug 9, 2011	Fed announces first explicit calendar forward guidance (mid-2013)
Sep 21, 2011	Announcement of the "Operation-Twist"
Jan 25, 2012	Extension of calendar-based forward guidance to late-2014
Aug 31, 2012	Bernanke announces intention for further action at Jackson Hole
Sep 13, 2012	Extension of calendar-based forward guidance to mid-2015. Announcement of QE3. $40 billion per month in MBS
Dec 12, 2012	QE3 extension. Fed to purchase additional $45 billion per month of Treasury securities
May 22, 2013	Bernanke foreshadows the potential tapering of QE3
Dec 18, 2013	Fed announces first tapering of QE3 and reduces purchases by $10 billion per month
Jan 29, 2014	Fed announces tapering of QE3 and reduces purchases by $10 billion per month
Mar 19, 2014	Fed announces tapering of QE3 and reduces purchases by $10 billion per month
Apr 30, 2014	Fed announces tapering of QE3 and reduces purchases by $10 billion per month
Jun 18, 2014	Fed announces tapering of QE3 and reduces purchases by $10 billion per month
Jul 30, 2014	Fed announces tapering of QE3 and reduces purchases by $10 billion per month
Sep 17, 2014	Fed announces tapering of QE3 and reduces purchases by $10 billion per month
Oct 29, 2014	Fed announces last tapering of QE3 and reduces purchases by $15 billion per month
Oct 28, 2015	Fed leaves fed funds target rate unchanged and hints at possible hike in December 2015
Dec 16, 2015	Fed increases the fed funds target rate by 0.25% to the range of 0.25% to 0.5%
Dec 14, 2016	Fed increases the fed funds target rate by 0.25% to the range of 0.5% to 0.75%
Mar 15, 2017	Fed increases the fed funds target rate by 0.25% to the range of 0.75% to 1.0%
Apr 5, 2017	Minutes indicating that balance sheet contraction may start in late 2017
May 3, 2017	Fed keeps the fed funds target rate in the range of 0.75% to 1.0%
Jun 14, 2017	Fed increases the fed funds target rate by 0.25% to the range of 1.0% to 1.25% and reveals plans to contract its balance sheet
Jul 26, 2017	Fed keeps the fed funds target rate in the range of 1.0% to 1.25%
Sep 20, 2017	Fed keeps the fed funds target rate in the range of 1.0% to 1.25% and announces balance sheet contraction
Sweden	
Feb 12, 2015	Riksbank cuts repo rate to −0.10 percent, buys government bonds for SEK 10 billion and is prepared to do more at short notice
Mar 18, 2015	Riksbank cuts repo rate to −0.25 percent and buys government bonds for SEK 30 billion
Apr 29, 2015	Riksbank buys government bonds for SEK 40-50 billion and lowers the repo-rate path significantly
Jul 2, 2015	Repo rate cut to −0.35 percent and purchases of government bonds extended by SEK 45 billion
Sep 3, 2015	Repo rate unchanged at −0.35 percent
Oct 28, 2015	Riksbank purchases government bonds for a further SEK 65 billion and keeps the repo rate at −0.35 percent for a longer time
Dec 15, 2015	Repo rate unchanged at –0.35 percent and the Riksbank is still highly prepared to act
Feb 11, 2016	Repo rate cut to −0.50 percent
Apr 21, 2016	Riksbank to purchase government bonds for a further SEK 45 billion and repo rate held unchanged at -0.50 percent
Jul 6, 2016	Repo rate unchanged at -0.50 percent, future rate increases postponed
Sep 7, 2016	Repo rate unchanged at −0.50 percent
Oct 27, 2016	Low repo rate for longer, Executive Board ready to extend government bond purchases in December
Dec 21, 2016	Further purchases of government bonds for SEK 30 billion, repo rate unchanged at -0.50 percent
Feb 15, 2017	Repo rate unchanged at −0.50 percent
Apr 27, 2017	Government bond purchases extended by SEK 15 billion, repo rate unchanged at -0.50 percent, rate increases postponed
Jul 4, 2017	Repo rate unchanged at −0.50 percent and bond purchases according to plan
Sep 7, 2017	Repo rate unchanged at −0.50 percent and bond purchases according to plan
Oct 26, 2017	Repo rate unchanged at −0.50 percent

Table 2: Monetary policy announcements by the ECB and the Bank of England

Notes: This table describes the key monetary policy announcements made by the ECB and the Bank of England since the launch of their unconventional monetary policy measures.

Date	Announcement description
Euro-area	
May 7, 2009	ECP lowers policy rates and announces its first Covered Bond Purchase Program (CBPP)
May 10, 2010	Securities Markets Program (SMP)
Oct 6, 2011	Second Covered Bond Purchase Program (CBPP2)
Sep 6, 2012	Outright Monetary Transactions (OMT) program
Jun 5, 2014	ECP lowers policy rates and announces its Asset-Backed Securities Purchase Program (ABSPP)
Sep 4, 2014	ECP lowers policy rates and announces its second Covered Bond Purchase Program (CBPP3)
Dec 4, 2014	ECB does not announce its Expanded Asset Purchase Program (EAPP) and frustrates market participants
Jan 2, 2015	Draghi hints that ECB is in technical preparations to adjust the size, speed and composition of its stimulus program
Jan 22, 2015	EAPP is announced. ECB to buy €60 billion per month until September 2016
Sep 3, 2015	Draghi hints at further purchases if necessary
Oct 22, 2015	Draghi hints at further measures to be announced in December 2015
Dec 3, 2015	ECB lowers its deposit facility rate and extends EAPP to March 2017
Jan 21, 2016	ECB signals more easing to come as early as March 2016
Feb 18, 2016	ECB minutes indicate further actions to be announced in March 2016
Mar 10, 2016	ECP lowers policy rates and expands EAPP to €80 billion per month, which is expected to last until March 2017
Apr 21, 2016	Corporate Bond Purchase Program (CBPP)
Sep 8, 2016	ECB disappoints by not announcing EAPP extension
Oct 20, 2016	ECB hints at EAPP extension to be announced in December 2016
Dec 8, 2016	EAPP extended to December 2017, but purchases reduced to €60 billion per month
Jun 27, 2017	Draghi's speech in Sintra reveals that ECB is considering scaling back its EAPP
Sep 7, 2017	ECB leaves rates on hold and paves its way to tapering its stimulus program
Oct 26, 2017	EAPP extended to September 2018, but purchases reduced to €30 billion per month
UK	
Feb 11, 2009	Press conference and inflation report indicating that asset purchases were likely
Mar 5, 2009	Bank of England cuts Bank Rate to 0.5 percent and announces asset purchases of £75 billion within the next three months
May 7, 2009	Bank of England to buy additional £50 billion in assets. Total of £125 billion to be completed within the next three months
Jul 9, 2009	Bank of England keeps Bank Rate at 0.5 percent and maintains the stock of purchased assets at £125 billion
Aug 6, 2009	Bank of England to purchase additional £50 billion in assets within the next three months
Nov 5, 2009	Bank of England to purchase additional £25 billion in assets within the next three months
Sep 9, 2010	Bank of England keeps Bank Rate at 0.5 percent and maintains the stock of purchased assets at £200 billion
Mar 10, 2011	Bank of England keeps Bank Rate at 0.5 percent and maintains the stock of purchased assets at £200 billion
Oct 6, 2011	Bank of England to purchase additional £75 billion in assets
Dec 8, 2011	Bank of England keeps Bank Rate at 0.5 percent and maintains the stock of purchased assets at £275 billion
Feb 9, 2012	Bank of England to purchase additional £50 billion in assets
Jul 5, 2012	Bank of England to purchase additional £50 billion in assets
Aug 2, 2012	Bank of England keeps Bank Rate at 0.5 percent and maintains the stock of purchased assets at £375 billion
Nov 7, 2013	Bank of England keeps Bank Rate at 0.5 percent and maintains the stock of purchased assets at £375 billion
Feb 6, 2014	Bank of England keeps Bank Rate at 0.5 percent and maintains the stock of purchased assets at £375 billion
Jun 13, 2014	Carney states that "bank rate may be increased sooner than expected by markets"
Jun 4, 2015	Bank of England keeps Bank Rate at 0.5 percent and maintains the stock of purchased assets at £375 billion
Jun 24, 2016	Brexit followed by the resignation of Prime Minister David Cameron
Jun 30, 2016	Carney states that "some monetary easing will likely be required over the summer"
Aug 4, 2016	Bank of England cuts Bank Rate to 0.25 percent, introduces a Term Funding Scheme, and
	announces it will purchase up to £10 billion of corporate bonds and an additional of £60 billion of government bonds
Jun 15, 2017	Bank of England keeps Bank Rate at 0.25 percent, but three MPC members call for an increase to 0.5 percent
Aug 3, 2017	Bank of England keeps Bank Rate at 0.25 percent
Sep 14, 2017	Bank of England keeps Bank Rate at 0.25 percent, but hints at rate rise in the coming months

Table 3: Regression results

Notes: This table shows estimation results for the regressions $\triangle X_{t^\diamond} = \alpha \triangle r^u_{t^\diamond} + \varepsilon_{t^\diamond}$ and $\triangle X^{sr}_{t^\diamond} = \beta \triangle r^u_{t^\diamond} + \varepsilon_{t^\diamond}$, where $\triangle X_{t^\diamond}$ and $\triangle X^{sr}_{t^\diamond}$ are the changes in the first principal components of the yield curve and its short-rate expectations component. $\triangle r^u_{t^\diamond}$ is the unexpected change in the policy rate, or policy rate surprise. The regressions are estimated for the US, Sweden, the euro-area and the UK, with data observed on days of conventional monetary policy announcements only. The estimation samples are: February 08, 1990 to October 29, 2008 in a total of 175 observations (US); February 07, 2003 to December 16, 2014 in a total of 76 observations (Sweden); November 08, 2001 to July 3, 2008 in a total of 81 observations (euro-area); January 11, 2001 to Ferbuary 5, 2009 in a total of 99 observations (UK). Huber-White heteroskedasticity consistent standard errors are provided in parenthesis.

	α	$R2$	β $(p=2)$	$R2$	β $(p=3)$	$R2$
US	1.018***	0.20	1.282***	0.31	1.241***	0.31
	(0.270)		(0.276)		(0.232)	
Sweden	1.354***	0.67	1.945***	0.79	1.549***	0.74
	(0.286)		(0.192)		(0.104)	
Euro-area	1.665***	0.32	1.829***	0.55	1.988***	0.36
	(0.346)		(0.287)		(0.482)	
UK	1.282***	0.35	1.525***	0.29	1.182***	0.46
	(0.374)		(0.570)		(0.185)	

Table 4: Shadow rate responses to monetary policy announcements by the Fed

Notes: This table shows shadow rate responses to the key unconventional monetary policy announcements made by the Fed, and that are described in Table 1. It also shows the responses of government bond yields as well as the values for the policy rate surprise measure. Interest rate changes are provided in basis points.

Monetary policy announcement	Policy rate	Policy rate surprise ($\triangle r^{u}_{t^{\star}}$)	2-year yield	5-year yield	10-year yield	Shadow rate ($p=2,3$)
Nov 25, 2008	0.0	-1.0	-14.3	-22.5	-21.4	-37.7
Dec 1, 2008	0.0	-1.0	-11.9	-21.4	-21.5	-33.3
Dec 16, 2008	-75.0	-16.0	-10.7	-16.3	-17.5	-32.1
Mar 18, 2009	0.0	0.0	-26.4	-47.1	-51.9	-82.5
Aug 10, 2010	0.0	0.4	-2.7	-7.1	-6.9	-8.3
Aug 27, 2010	0.0	0.0	5.4	12.3	16.6	18.8
Sep 21, 2010	0.0	0.0	-3.7	-9.6	-10.7	-11.2
Oct 15, 2010	0.0	0.0	-1.2	2.6	8.6	4.6
Nov 3, 2010	0.0	0.8	-1.5	-4.0	4.1	-2.1
Dec 14, 2010	0.0	0.0	4.9	16.8	20.2	21.9
Aug 9, 2011	0.0	-0.7	-8.6	-19.1	-20.5	-27.0
Sep 21, 2011	0.0	0.8	6.5	1.8	-8.4	0.4
Jan 25, 2012	0.0	-0.5	-3.8	-9.4	-8.0	-8.6
Aug 31, 2012	0.0	0.0	-3.7	-6.4	-7.0	-10.4
Sep 13, 2012	0.0	0.9	-0.9	-3.7	-2.9	-4.5
Dec 12, 2012	0.0	0.4	0.0	2.3	5.7	3.3
May 22, 2013	0.0	0.0	1.3	6.8	9.6	6.2
Dec 18, 2013	0.0	0.0	-1.5	2.6	4.6	6.5
Jan 29, 2014	0.0	0.0	-2.0	-5.9	-7.7	-8.4
Mar 19, 2014	0.0	0.0	10.6	18.4	9.8	24.2
Apr 30, 2014	0.0	0.0	-2.4	-4.8	-3.5	-7.8
Jun 18, 2014	0.0	0.0	-1.3	-4.9	-4.7	-5.0
Jul 30, 2014	0.0	-0.5	2.7	7.5	10.2	18.3
Sep 17, 2014	0.0	0.0	3.2	3.6	2.0	8.1
Oct 29, 2014	0.0	0.5	6.7	8.8	3.0	11.2
Oct 28, 2015	0.0	-0.5	8.5	9.2	5.3	13.0
Dec 16, 2015	25.0	2.2	4.3	5.0	2.9	4.7
Dec 14, 2016	25.0	0.0	9.9	10.1	5.4	15.3
Mar 15, 2017	25.0	0.5	-6.3	-10.6	-9.5	-17.2
Apr 5, 2017	0.0	0.0	-1.7	-3.2	-1.9	0.6
May 3, 2017	0.0	0.0	3.9	4.9	3.8	10.8
Jun 14, 2017	25.0	0.9	-1.5	-4.5	-6.5	-6.8
Jul 26, 2017	0.0	0.0	-4.3	-6.2	-4.1	-8.5
Sep 20, 2017	0.0	0.0	4.9	5.0	3.7	5.6

Table 5: Shadow rate responses to monetary policy announcements by the Riksbank

Notes: This table shows shadow rate responses to unconventional monetary policy announcements made by the Riksbank, and that are described in Table 1. It also shows the responses of government bond yields as well as the values for the policy rate surprise and the QE surprise measures. QE surprises are measured in SEK billions (bn) and are obtained from market newsletters by subtracting the expected amount from the announced amount of purchases. Interest rate changes are provided in basis points.

Monetary policy announcement	Policy rate	Policy rate surprise $(\triangle r^u_{t^*})$	QE surprise	2-year yield	5-year yield	10-year yield	Shadow rate $(p = 2, 3)$
Feb 12, 2015	-10.0	-5.9	10 bn	-12.0	-15.6	-11.1	-26.9
Mar 18, 2015	-15.0	-14.5	30 bn	-10.4	-11.8	-14.8	-22.7
Apr 29, 2015	0.0	7.3	10-20 bn	5.5	6.7	6.9	11.0
Jul 2, 2015	-10.0	-8.5	45 bn	-11.2	-13.1	-8.9	-21.1
Sep 3, 2015	0.0	5.3	0 bn	2.6	-2.2	-3.6	-0.4
Oct 28, 2015	0.0	4.5	30 bn	-2.2	-7.5	-8.2	-6.7
Dec 15, 2015	0.0	-0.4	0 bn	3.1	6.4	8.4	7.7
Feb 11, 2016	-15.0	-7.9	0 bn	-4.1	-4.0	-4.1	-7.5
Apr 21, 2016	0.0	1.0	-15 bn	-0.3	3.8	8.3	4.3
Jul 6, 2016	0.0	1.2	0 bn	0.4	1.5	-0.2	-0.6
Sep 7, 2016	0.0	0.0	0 bn	0.3	1.7	0.8	1.2
Oct 27, 2016	0.0	0.2	0 bn	-2.6	0.8	6.0	0.5
Dec 21, 2016	0.0	0.0	0 bn	3.3	-0.7	-2.3	0.4
Feb 15, 2017	0.0	0.0	0 bn	-2.5	-2.0	-1.8	-1.6
Apr 27, 2017	0.0	-0.6	15 bn	-3.4	-6.4	-7.3	-7.8
Jul 4, 2017	0.0	1.0	0 bn	-4.1	-4.3	-3.6	-5.8
Sep 7, 2017	0.0	0.0	0 bn	-2.6	-4.4	-3.6	-5.3
Oct 26, 2017	0.0	-0.8	0 bn	-3.2	-3.7	-3.8	-5.1

Table 6: Shadow rate responses to monetary policy announcements by the ECB

Notes: This table shows shadow rate responses to key unconventional monetary policy announcements made by the ECB, and that are described in Table 2. It also shows the responses of government bond yields as well as the values for the policy rate surprise measure. Interest rate changes are provided in basis points.

Monetary policy announcement	Policy rate (MRO)	Policy rate surprise ($\triangle r^u_{t^\star}$)	2-year yield	5-year yield	10-year yield	Shadow rate ($p = 2, 3$)
May 7, 2009	-25.0	-5.0	-1.0	10.2	16.0	7.8
May 10, 2010	0.0	-15.5	5.0	8.5	13.2	7.8
Oct 6, 2011	0.0	10.5	20.4	7.7	5.6	17.1
Sep 6, 2012	0.0	1.0	3.3	2.9	7.6	5.8
Jun 5, 2014	-10.0	-2.0	0.5	-4.2	-3.1	-3.8
Sep 4, 2014	-10.0	-4.0	-6.3	-4.6	1.0	-8.5
Dec 4, 2014	0.0	0.5	1.5	1.1	2.4	0.3
Jan 2, 2015	0.0	-1.0	-1.2	-2.2	-6.0	-3.5
Jan 22, 2015	0.0	0.0	-0.8	-1.9	-1.3	-1.3
Sep 3, 2015	0.0	0.0	-0.9	-3.7	-5.5	-3.9
Oct 22, 2015	0.0	-3.5	-4.3	-5.2	-4.9	-6.6
Dec 3, 2015	0.0	7.5	12.7	18.1	16.6	21.1
Jan 21, 2016	0.0	-2.5	-3.2	-5.1	-3.2	-5.6
Feb 18, 2016	0.0	-1.0	-2.1	-2.9	-5.8	-4.5
Mar 10, 2016	-5.0	1.5	6.5	5.3	3.7	7.7
Apr 21, 2016	0.0	0.0	1.0	3.9	6.3	3.7
Sep 8, 2016	0.0	1.0	2.5	4.0	6.9	5.0
Oct 20, 2016	0.0	-0.5	0.7	0.1	-1.6	0.0
Dec 8, 2016	0.0	-0.5	-2.4	-0.5	2.1	-1.1
Jun 27, 2017	0.0	0.0	3.4	8.5	9.5	7.7
Sep 7, 2017	0.0	-0.5	-4.3	-2.4	-2.1	-2.7
Oct 26, 2017	0.0	-0.5	-1.8	-4.1	-5.0	-3.5

Table 7: Shadow rate responses to monetary policy announcements by the BoE

Notes: This table shows shadow rate responses to the key monetary policy announcements made by the Bank of England, and that are described in Table 2. It also shows the responses of government bond yields as well as the values for the policy rate surprise measure. Interest rate changes are provided in basis points.

Monetary policy announcement	Policy rate	Policy rate surprise $(\triangle r^{u}_{t^{\star}})$	2-year yield	5-year yield	10-year yield	Shadow rate $(p = 2, 3)$
Feb 11, 2009	0.0	-7.0	-29.8	-25.2	-20.4	-45.9
Mar 5, 2009	-50.0	5.0	-2.0	-18.0	-31.7	-35.7
May 7, 2009	0.0	-4.0	1.3	4.6	5.7	5.6
Jul 9, 2009	0.0	2.0	8.9	14.6	17.1	19.6
Aug 6, 2009	0.0	-6.0	-3.4	-11.1	-7.3	-9.6
Nov 5, 2009	0.0	2.0	0.6	4.5	6.9	5.0
Sep 9, 2010	0.0	-1.0	3.1	4.7	6.7	7.0
Mar 10, 2011	0.0	-3.0	-5.8	-8.1	-8.2	-11.3
Oct 6, 2011	0.0	0.0	4.1	3.2	4.5	6.3
Dec 8, 2011	0.0	0.0	-1.8	-8.4	-10.2	-9.1
Feb 9, 2012	0.0	1.0	0.9	-1.4	5.4	1.2
Jul 5, 2012	0.0	-2.0	-7.2	-9.5	-6.0	-11.6
Aug 2, 2012	0.0	4.0	-4.0	-6.9	-7.9	-8.5
Nov 7, 2013	0.0	-1.0	-5.1	-5.8	-3.9	-7.6
Feb 6, 2014	0.0	0.0	2.5	4.7	5.9	5.4
Jun 13, 2014	0.0	3.0	12.6	8.5	2.8	17.5
Jun 4, 2015	0.0	1.0	-3.6	-5.7	-6.0	-7.3
Jun 24, 2016	0.0	-10.0	-23.8	-29.5	-26.4	-42.7
Jun 30, 2016	0.0	-6.0	-5.5	-5.2	-3.7	-10.3
Aug 4, 2016	-25.0	-2.0	-8.3	-15.8	-16.8	-28.1
Jun 15, 2017	0.0	0.0	8.1	11.0	10.2	16.6
Aug 3, 2017	0.0	0.0	-4.9	-6.8	-8.2	-11.4
Sep 14, 2017	0.0	0.0	8.2	8.8	7.1	15.4

Table 8: Exchange rate effects of monetary policy stance surprises - individual currencies

Notes: This table shows the exchange rate effects of monetary policy stance surprises for each individual currency. Percentage changes in exchange rates are regressed onto shadow rate changes for the domestic and foreign economies, i.e. $\triangle s_{t^\star,d}$ and $\triangle s_{t^\star,f}$. Regressions are estimated using data observed on days of unconventional monetary policy announcements by each central bank, which are listed in Tables 1 and 2. Huber-White heteroskedasticity-consistent standard errors are provided in parenthesis.

	Federal Reserve			Riksbank		
	USD/SEK	USD/EUR	USD/GBP	SEK/USD	SEK/EUR	SEK/GBP
const.	0.051	0.303	0.197	$-0.129^{\star}$	$-0.188^{\star}$	$-0.244^{\star\star\star}$
	(0.102)	(0.090)	(0.167)	(0.066)	(0.082)	(0.076)
$\triangle s_{t^\star,d}$	$-0.044^{\star\star\star}$	$-0.036^{\star\star\star}$	$-0.024^{\star\star\star}$	$-0.057^{\star\star\star}$	$-0.065^{\star\star\star}$	$-0.070^{\star\star\star}$
	(0.005)	(0.005)	(0.006)	(0.006)	(0.010)	(0.010)
$\triangle s_{t^\star,f}$	0.013	0.017	0.022	$0.016^{\star\star}$	0.015	0.015
	(0.024)	(0.036)	(0.017)	(0.007)	(0.032)	(0.010)
$\overline{R2}$	0.67	0.63	0.23	0.83	0.77	0.81
	ECB			**Bank of England**		
	EUR/USD	EUR/SEK	EUR/GBP	GBP/USD	GBP/SEK	GBP/EUR
const.	0.156	$0.194^{\star}$	0.216	0.190	–	0.060
	(0.174)	(0.093)	(0.121)	(0.124)		(0.102)
$\triangle s_{t^\star,d}$	$-0.145^{\star\star\star}$	$-0.086^{\star\star\star}$	$-0.104^{\star\star\star}$	$-0.040^{\star\star\star}$	–	$-0.065^{\star\star\star}$
	(0.034)	(0.021)	(0.017)	(0.012)		(0.012)
$\triangle s_{t^\star,f}$	0.021	0.037	0.014	0.033	–	$0.081^{\star\star\star}$
	(0.025)	(0.033)	(0.025)	(0.035)		(0.020)
$\overline{R2}$	0.56	0.44	0.53	0.49	–	0.66

Table 9: Exchange rate effects of conventional and unconventional monetary policy surprises - individual currencies

Notes: This table shows the exchange rate effects of conventional and unconventional monetary policy announcements for each individual currency. Percentage changes in exchange rates are regressed onto the decomposition of shadow rate changes into conventional $\left(\triangle r^{u}_{t^{\star},d}\right)$ and unconventional $\left(\triangle ump^{u}_{t^{\star},d}\right)$ monetary policy surprises, as well as onto shadow rate changes for the foreign economy $(\triangle s_{t^{\star},f})$. Regressions are estimated using data observed on days of unconventional monetary policy announcements by each central bank, which are listed in Tables 1 and 2. Huber-White heteroskedasticity-consistent standard errors are provided in parenthesis.

	Federal Reserve			Riksbank		
	USD/SEK	USD/EUR	USD/GBP	SEK/USD	SEK/EUR	SEK/GBP
$const.$	0.059	0.027	0.017	−0.094	−0.142⋆	−0.215⋆⋆⋆
	(0.107)	(0.091)	(0.162)	(0.054)	(0.067)	(0.062)
$\triangle r^{u}_{t^{\star},d}$	−0.117⋆⋆⋆	−0.084⋆⋆⋆	−0.093⋆⋆⋆	−0.096⋆⋆⋆	−0.099⋆⋆⋆	−0.095⋆⋆⋆
	(0.036)	(0.023)	(0.018)	(0.022)	(0.015)	(0.016)
$\triangle ump^{u}_{t^{\star},d}$	−0.044⋆⋆⋆	−0.036⋆⋆⋆	−0.022⋆⋆⋆	−0.042⋆⋆⋆	−0.044⋆⋆⋆	−0.057⋆⋆⋆
	(0.005)	(0.005)	(0.006)	(0.010)	(0.014)	(0.011)
$\triangle s_{t^{\star},f}$	0.029	0.033	0.027	0.003	0.022	0.019⋆
	(0.025)	(0.034)	(0.018)	(0.011)	(0.027)	(0.009)
$\overline{R2}$	0.68	0.64	0.25	0.85	0.83	0.83
	ECB			Bank of England		
	EUR/USD	EUR/SEK	EUR/GBP	GBP/USD	GBP/SEK	GBP/EUR
$const.$	0.141	0.171	0.178	0.100	–	−0.035
	(0.183)	(0.102)	(0.128)	(0.124)		(0.097)
$\triangle r^{u}_{t^{\star},d}$	−0.173⋆⋆⋆	−0.095⋆⋆⋆	−0.139⋆⋆⋆	−0.207⋆⋆⋆	–	−0.121⋆⋆
	(0.054)	(0.024)	(0.033)	(0.062)		(0.052)
$\triangle ump^{u}_{t^{\star},d}$	−0.125⋆⋆⋆	−0.060⋆⋆	−0.077⋆⋆	−0.012	–	−0.057⋆⋆⋆
	(0.034)	(0.030)	(0.030)	(0.014)		(0.009)
$\triangle s_{t^{\star},f}$	0.010	0.014	0.004	−0.054⋆	–	0.072⋆⋆⋆
	(0.023)	(0.035)	(0.026)	(0.030)		(0.020)
$\overline{R2}$	0.56	0.43	0.58	0.69	–	0.68

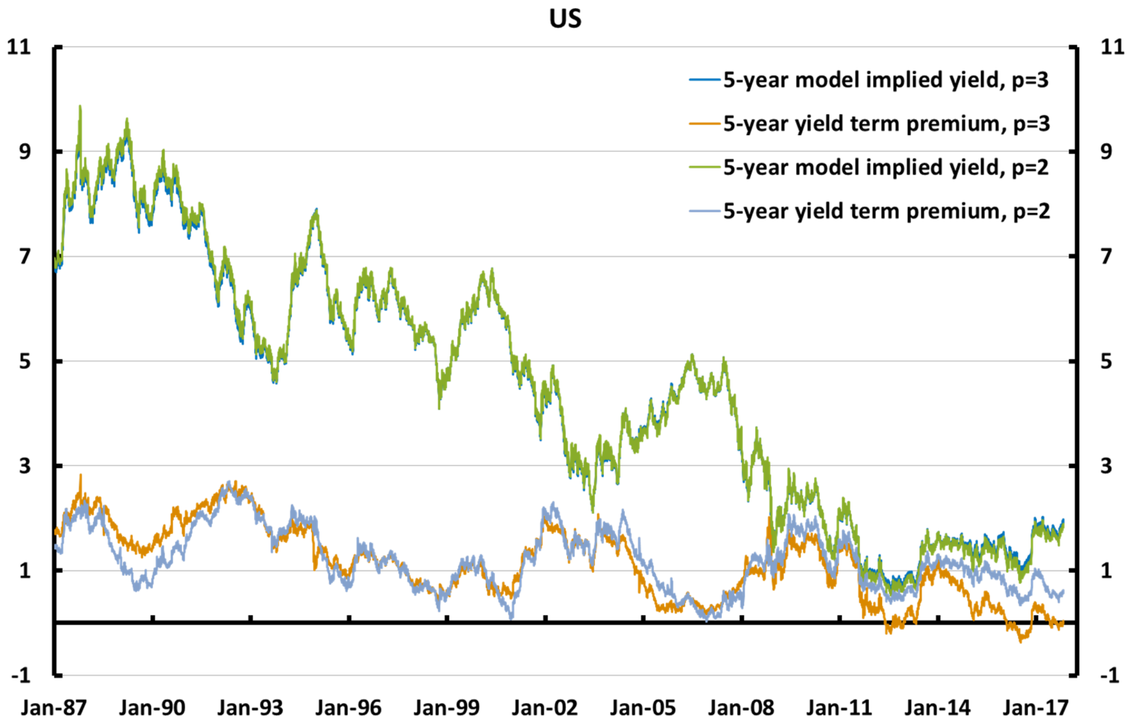
Table 10: Exchange rate effects of conventional and unconventional monetary policy surprises - all currencies

Notes: This table shows the exchange rate effects of conventional and unconventional monetary policy announcements using pooled OLS regressions. Percentage changes in exchange rates are regressed onto shadow rate changes for the domestic economy $(\triangle s_{t^\star,d})$, their decomposition into conventional $\left(\triangle r^u_{t^\star,d}\right)$ and unconventional $\left(\triangle ump^u_{t^\star,d}\right)$ monetary policy surprises, as well as shadow rate changes for the foreign economy $(\triangle s_{t^\star,f})$. Regressions are estimated using data observed on days of unconventional monetary policy announcements by the Fed, Riksbank, ECB and Bank of England, which are listed in Tables 1 and 2. Huber-White heteroskedasticity-consistent standard errors are provided in parenthesis.

	$\triangle e_{t^\star}$		
	All announcem.	Expansionary announcem.	Contractionary announcem.
$const.$	$0.073^\star$	$0.225^{\star\star\star}$	$-0.212^{\star\star}$
	(0.044)	(0.083)	(0.107)
$\triangle s_{t^\star,d}$	$-0.041^{\star\star\star}$	$-0.036^{\star\star\star}$	$-0.024^{\star\star}$
	(0.004)	(0.005)	(0.011)
$\triangle s_{t^\star,f}$	0.005	0.003	0.006
	(0.011)	(0.017)	(0.018)
$\overline{R2}$	0.47	0.40	0.03
$const.$	0.042	$0.258^{\star\star\star}$	-0.170
	(0.040)	(0.094)	(0.105)
$\triangle r^u_{t^\star,d}$	$-0.108^{\star\star\star}$	$-0.098^{\star\star\star}$	$-0.090^{\star\star\star}$
	(0.010)	(0.016)	(0.024)
$\triangle ump^u_{t^\star,d}$	$-0.035^{\star\star\star}$	$-0.030^{\star\star\star}$	$-0.021^{\star\star\star}$
	(0.003)	(0.004)	(0.008)
$\triangle s_{t^\star,f}$	0.001	0.008	0.006
	(0.009)	(0.021)	(0.018)
$\overline{R2}$	0.54	0.45	0.16

Figure 1: Decomposition of five-year government bond yield for the US and Sweden

Notes: This figure shows the decompositions of the five-year zero-coupon government bond yield into short-rate expectations and term premium for the US and Sweden. The Swedish sample ranges from January 2, 1996 to October 31, 2017. The US sample ranges from January 2, 1987 to October 31, 2017. The decompositions are obtained using the Joslin, Singleton and Zhu (2011) model with two $(p = 2)$ and three $(p = 3)$ pricing factors.



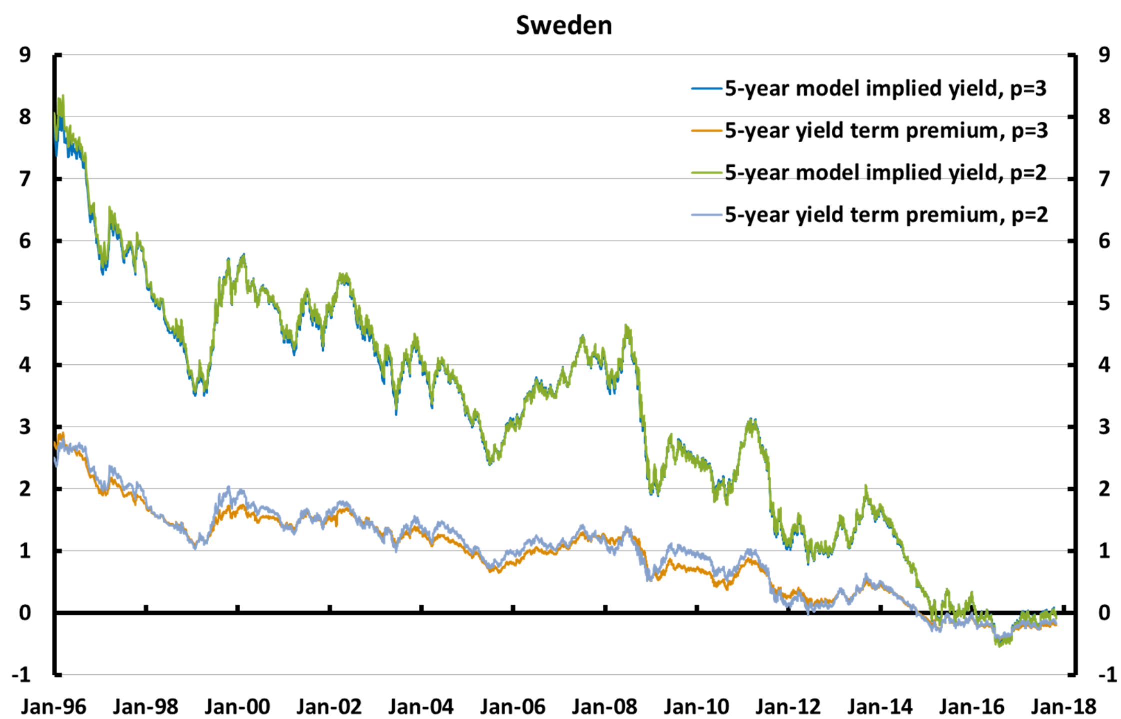
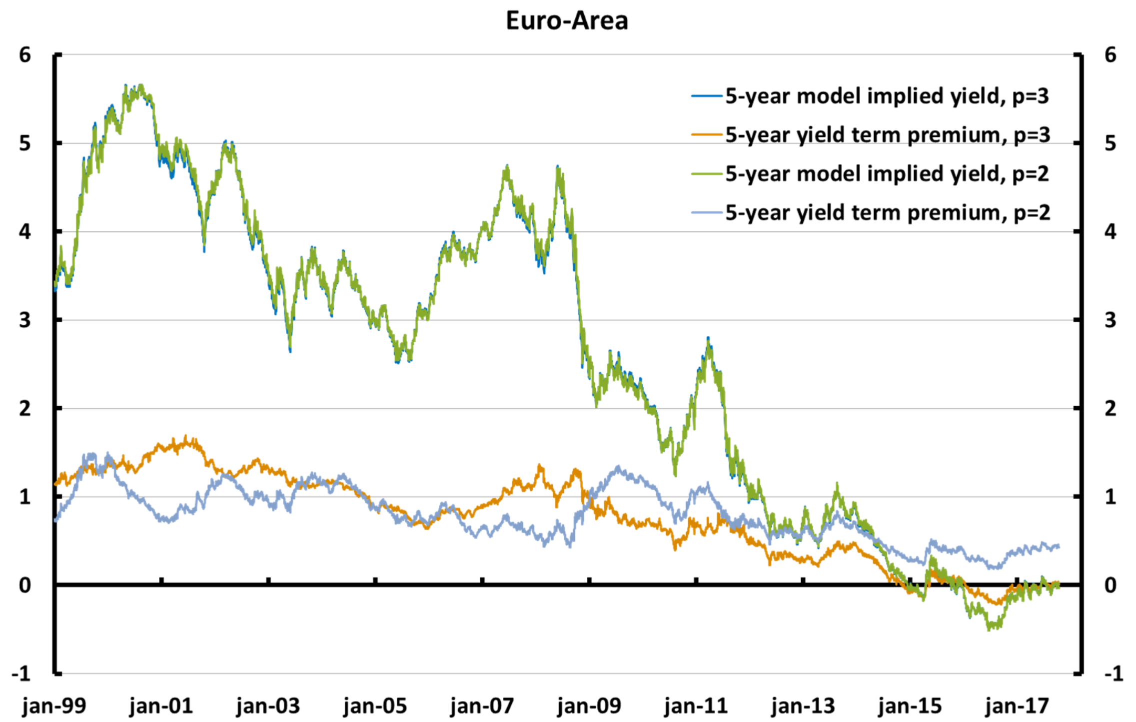


Figure 2: Decomposition of five-year government bond yield for the euro-area and the UK

Notes: This figure shows the decompositions of the five-year zero-coupon government bond yield into short-rate expectations and term premium for the euro-area and the UK. The euro-area sample ranges from January 19, 1999 to October 31, 2017. The UK sample ranges from October 1, 1992 to October 31, 2017. The decompositions are obtained using the Joslin, Singleton and Zhu (2011) model with two ($p = 2$) and three ($p = 3$) pricing factors.



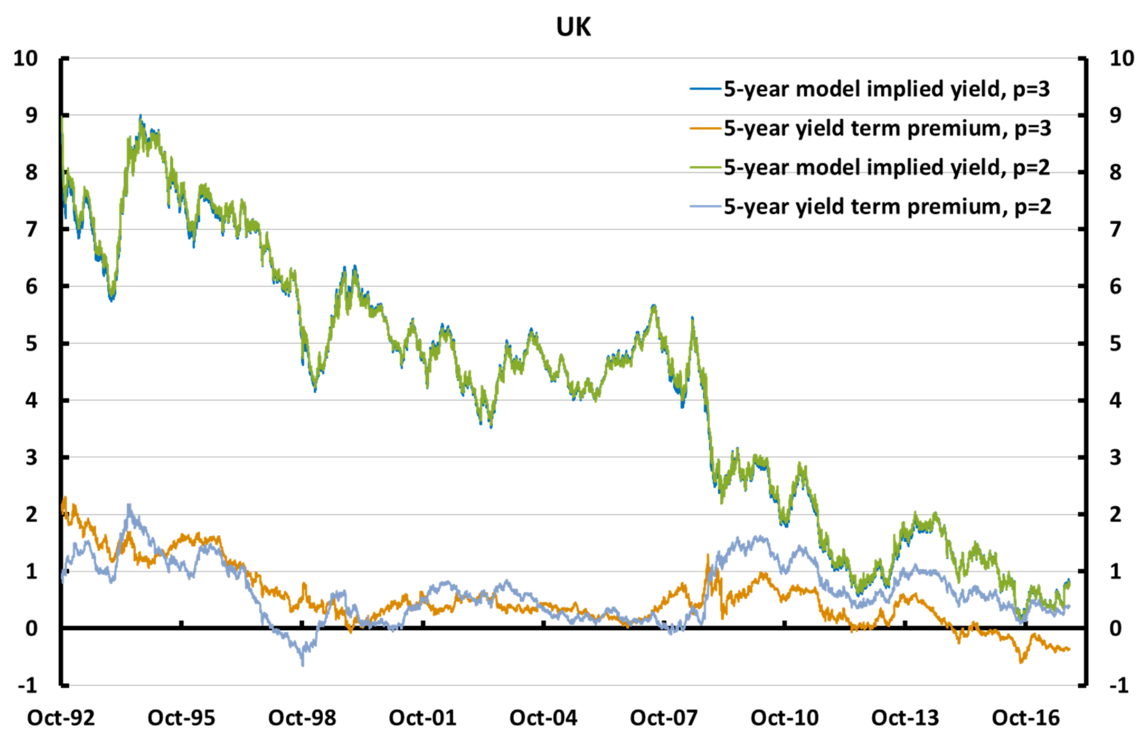


Figure 3: Shadow rate estimates for the US and Sweden

Notes: This figure shows shadow rate estimates for the US and Sweden. Dashed vertical lines indicate the unconventional monetary policy announcements described in Table 1.

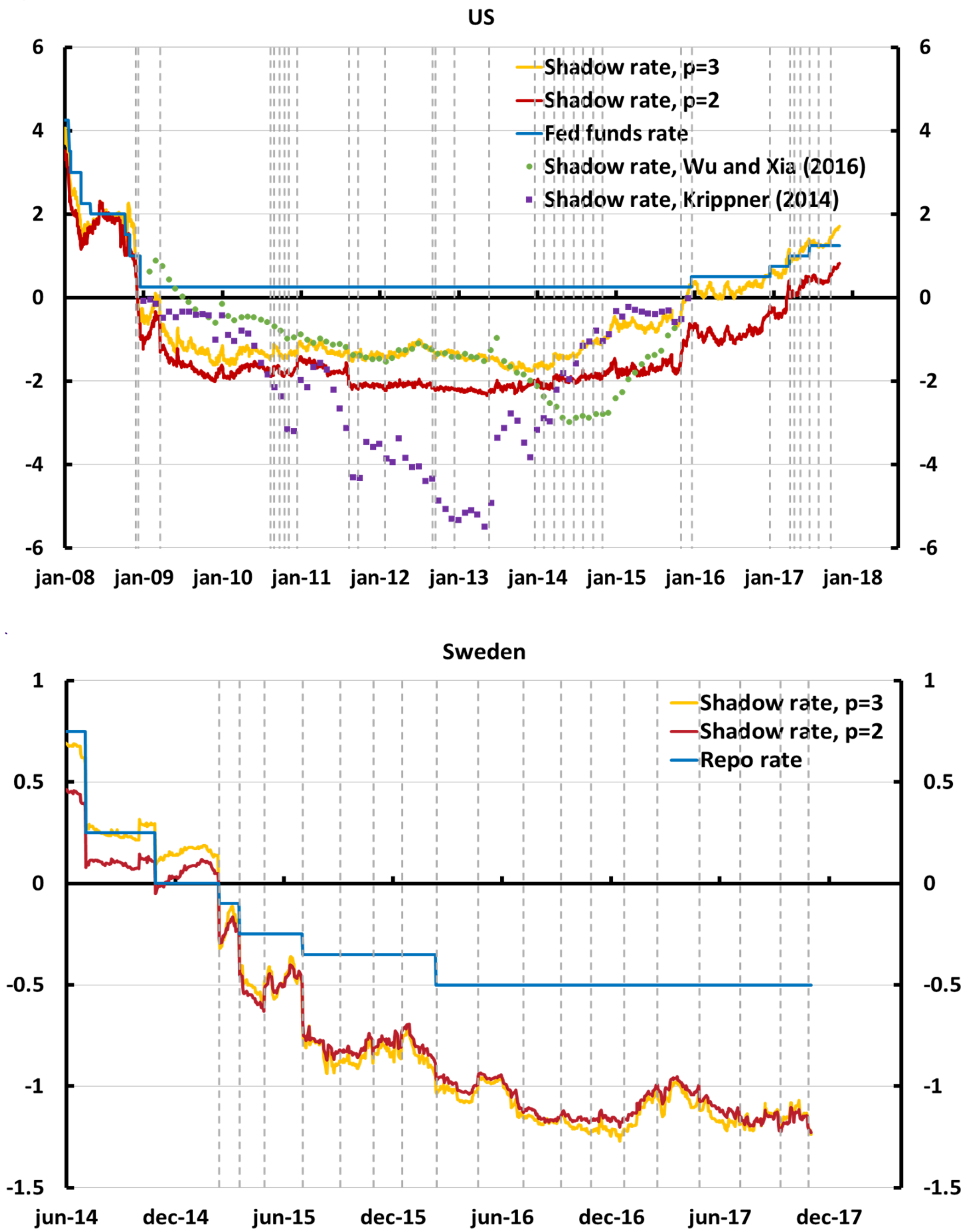


Figure 4: Shadow rate estimates for the Euro-area and the UK

Notes: This figure shows shadow rate estimates for the euro-area and the UK. Dashed vertical lines indicate the unconventional monetary policy announcements described in Table 2.

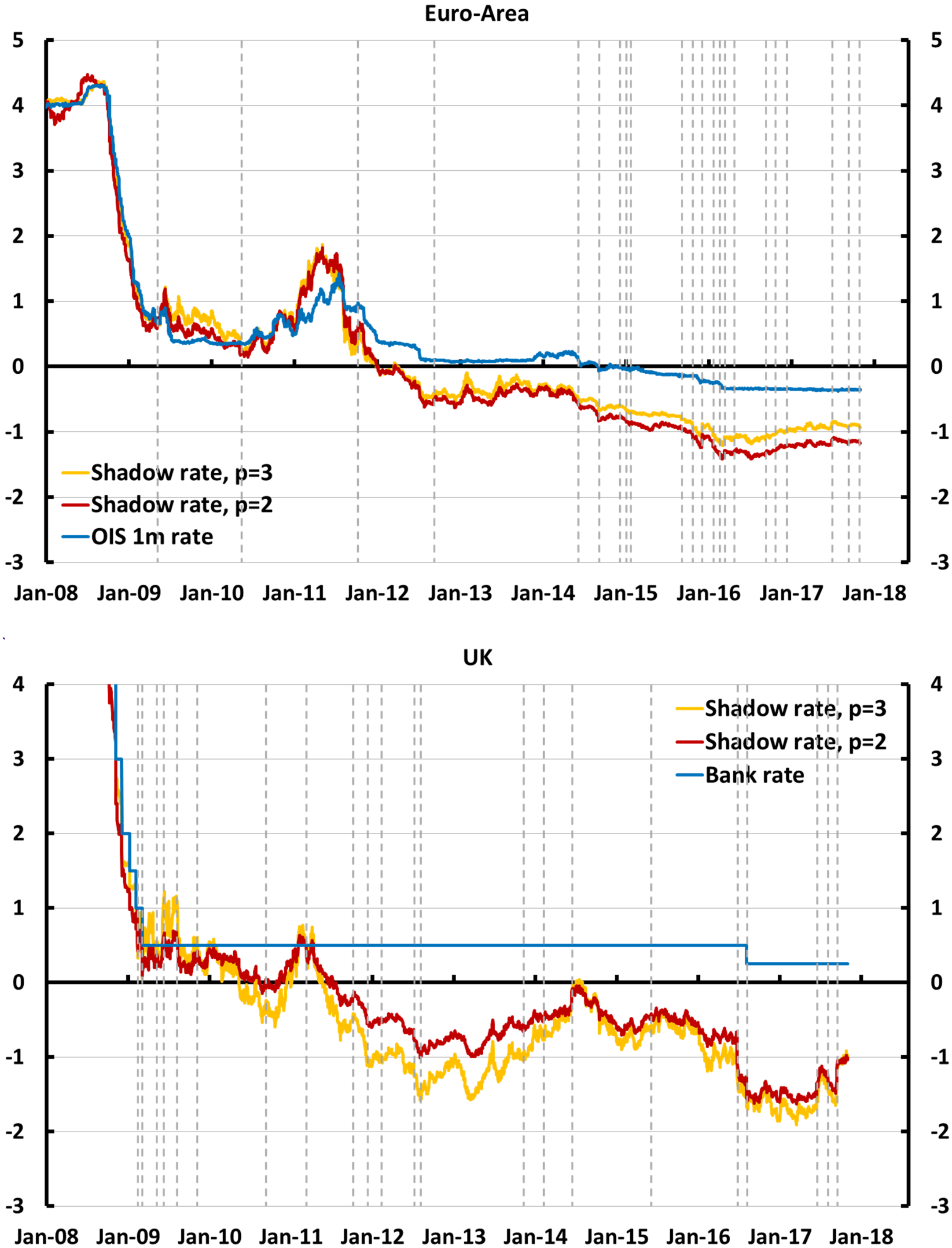


Figure 5: Monetary policy normalization across economies

Notes: This figure shows the three-factor (p=3) shadow rate estimates for the US, Sweden, the euro-area and the UK. Dashed vertical lines indicate the contractionary monetary policy announcements described in Tables 1 and 2. These start from May 22, 2013 for the US, from October 20, 2016 for the Euro-area and from September 14, 2017 for the UK.

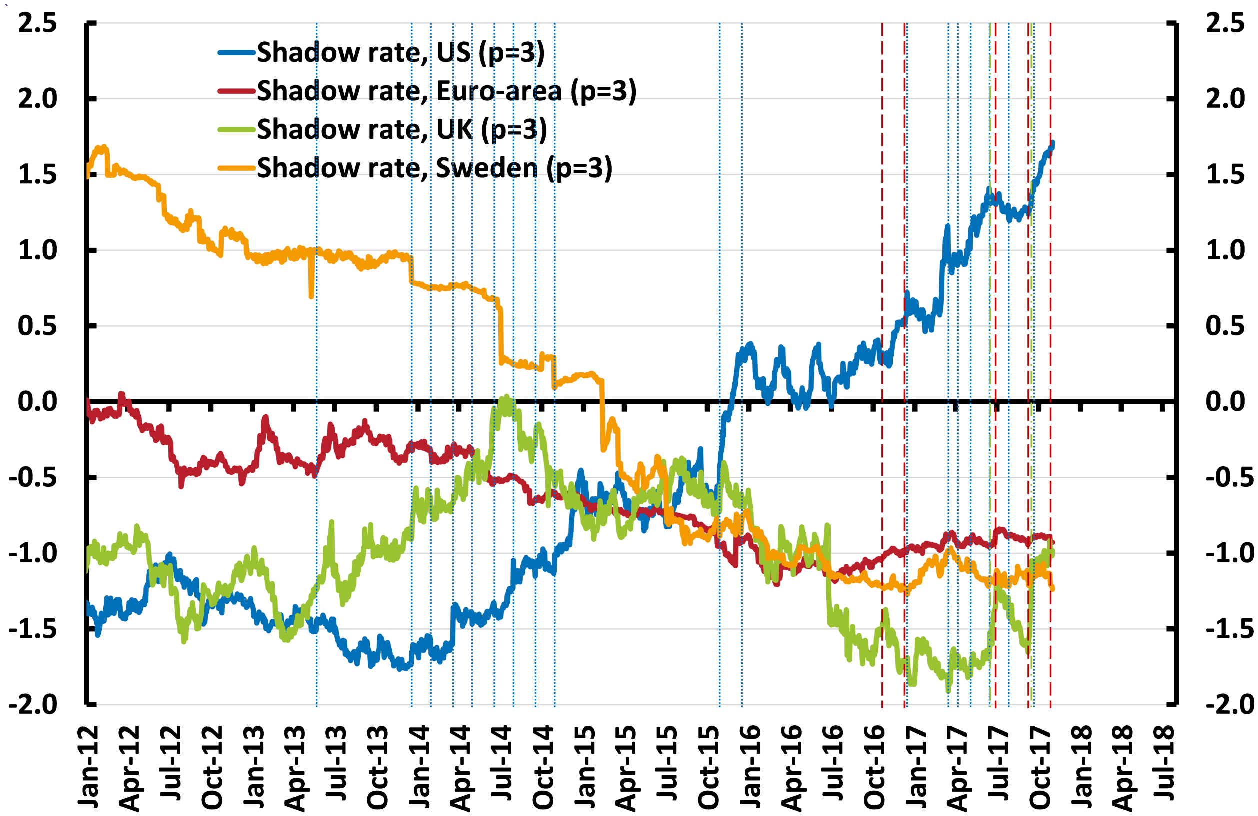


Figure 6: Decomposition of shadow rate changes around announcements for the US and Sweden

Notes: This figure shows the measures of conventional and unconventional monetary policy surprises for the US and Sweden. The measure of unconventional monetary policy surprise is defined as the difference between shadow rate changes and policy rate surprises, computed on unconventional announcement days, i.e. $\triangle ump^u_{t^\star} = \triangle s_{t^\star} - \triangle r^u_{t^\star}$. Values are provided in basis points.

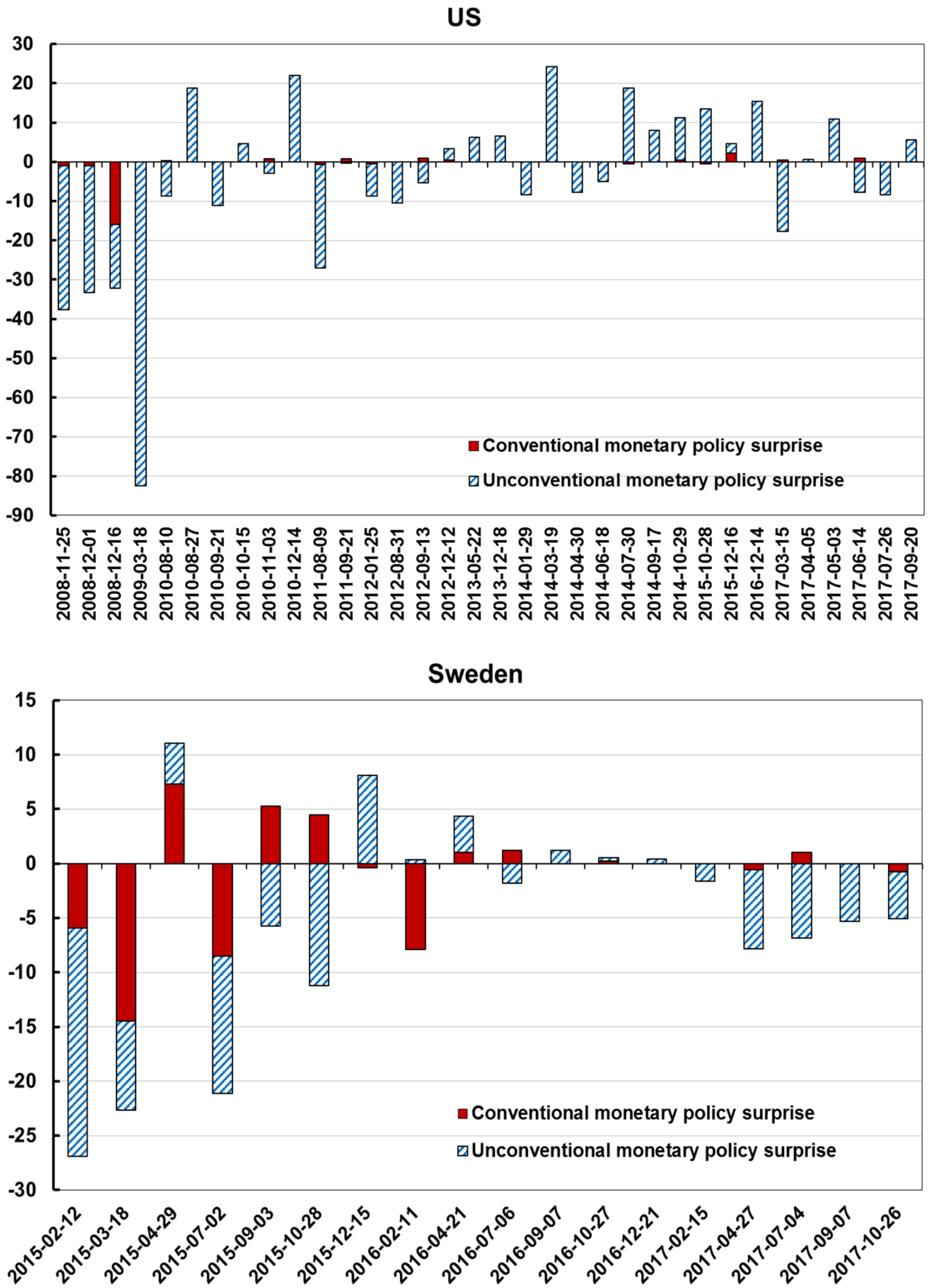


Figure 7: Decomposition of shadow rate changes around announcements for the euro-area and the UK

Notes: This figure shows the measures of conventional and unconventional monetary policy surprises for the euro-area and the UK. The measure of unconventional monetary policy surprise is defined as the difference between shadow rate changes and policy rate surprises, computed on unconventional announcement days, i.e. $\triangle ump^{u}_{t^{\star}} = \triangle s_{t^{\star}} - \triangle r^{u}_{t^{\star}}$. Values are provided in basis points.

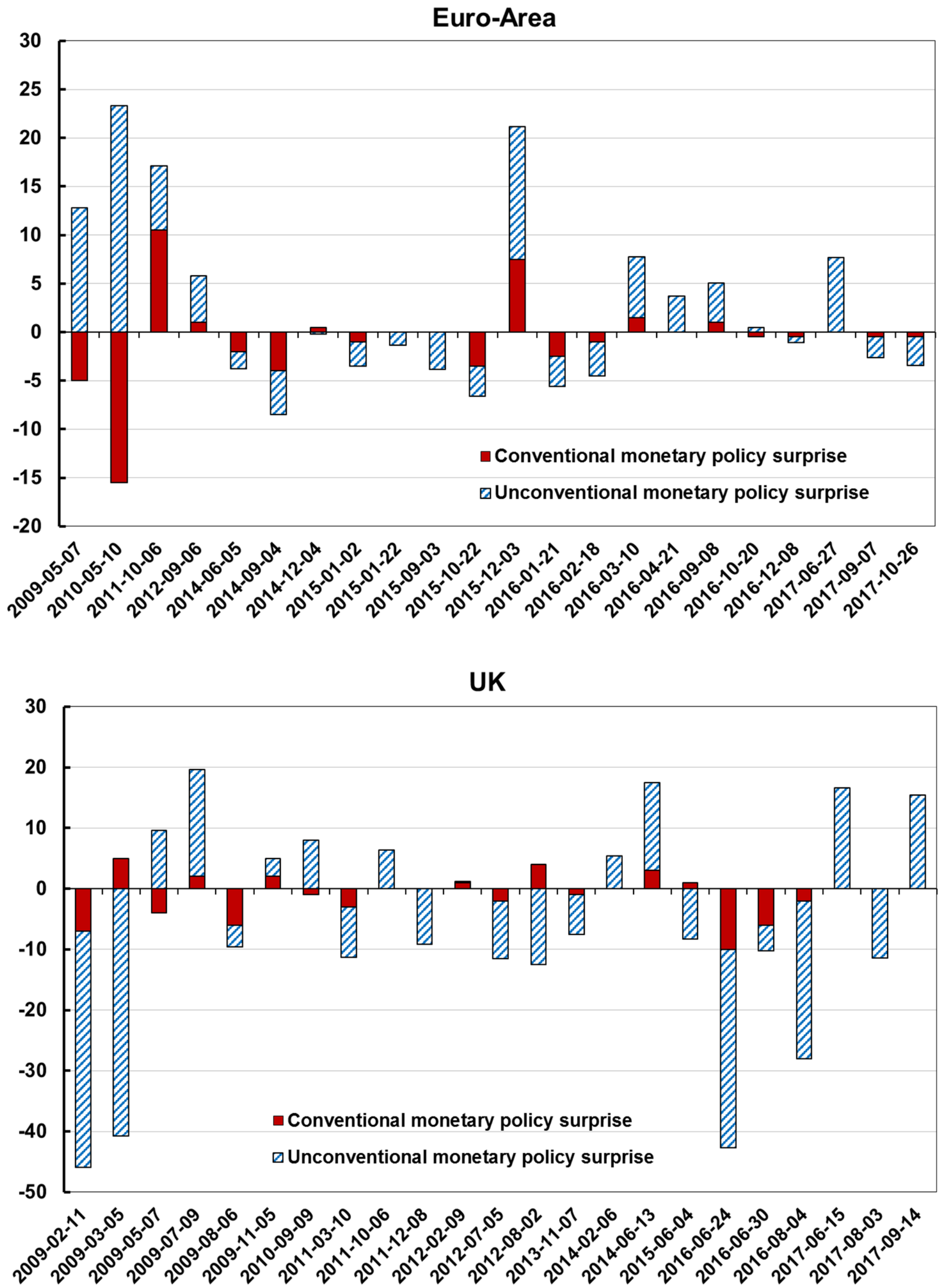
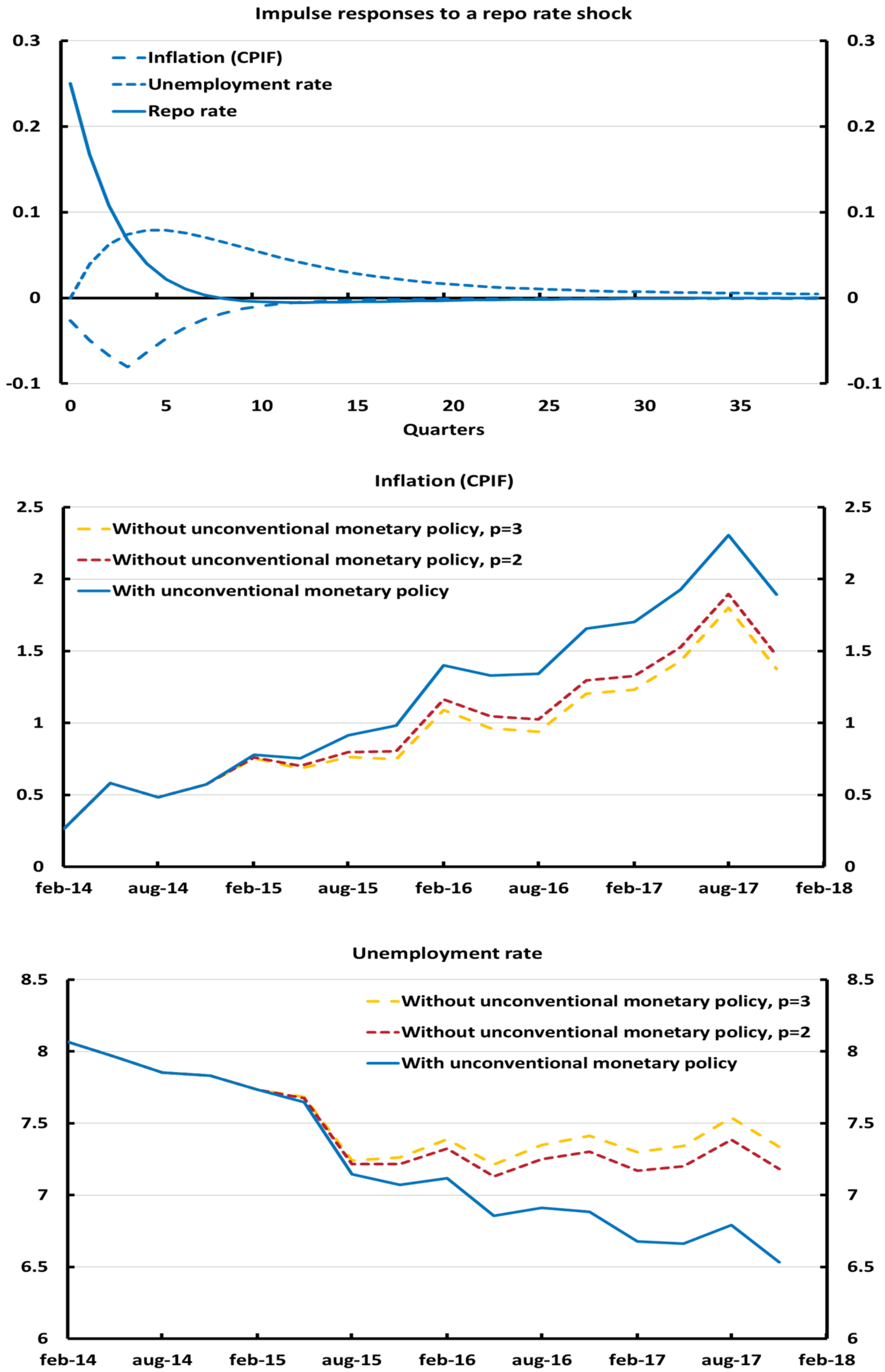


Figure 8: The macroeconomic effects of unconventional monetary policy

Notes: This figure shows the counterfactuals for inflation (CPIF) and the unemployment rate in Sweden, as well as the impulse response functions (IRFs) to a 25 basis points shock in the repo rate, which are used to construct the counterfactuals. The IRFs are obtained from Ramses II, estimated with data from the first quarter of 1995 to the fourth quarter of 2014. Values are provided in percentage points.



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Sveriges Riksbank
Visiting address: Brunkebergs torg 11
Mail address: se-103 37 Stockholm

Website: www.riksbank.se
Telephone: +46 8 787 00 00, Fax: +46 8 21 05 31
E-mail: registratorn@riksbank.se