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# Staff memo

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# Monetary Policy and the Exchange Rate in Norway

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**Abstract**

I estimate how monetary policy affects the exchange rate in Norway using a local projection instrumental variables (LP-IV) framework with high-frequency monetary policy surprises as instruments. I find that a surprise increase in the Norwegian policy interest rate leads to an immediate appreciation of the currency followed by a gradual depreciation. The effects are short-lived, with the exchange rate returning to its pre-shock level within three months. Surprise changes in monetary policy in the Euro zone has a similar, but opposite effect on the Euro/NOK exchange rate. Increases in the projected interest rate path published by Norges Bank also appreciates the currency, and the effects are stronger for changes at longer projection horizons.

**Keywords:** Monetary Policy Transmission, Exchange Rate, Interest Rates, High Frequency
**JEL Classification:** C26, E43, E44, E52, E58, F31, F42

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# 1 Introduction

In small, open economies, the exchange rate channel is an important channel of monetary policy transmission. Typically, an unexpected tightening of domestic policy leads to an appreciation of the domestic currency, which helps reduce imported inflation and can lower demand by improving net export. Understanding the strength of this channel is therefore essential for grasping how monetary policy operates.

In most New Keynesian macroeconomic models of small, open economies, the relationship between monetary policy and the exchange rate is governed by a condition of uncovered interest rate parity. According to this condition, when there are no constraints on capital mobility between a domestic and a foreign economy, the expected depreciation of the domestic currency equals the risk-adjusted interest rate differential between the domestic and the foreign economy. Combined with an assumption on the long-run equilibrium real exchange rate, the UIP condition implies that the nominal exchange rate responds instantaneously to news about current and future monetary policy. The domestic currency appreciates in response to higher expectations of the real interest rate differential between the domestic and foreign economies, adjusted for risk. Following the initial appreciation, and in the absence of new shocks, the exchange rate gradually reverts back to its pre-shock level. Foreign monetary policy surprises have a symmetric effect on the bilateral exchange rate if they move the expected real interest rate differential in the same way.

In this Staff Memo, I examine empirically how unexpected changes in monetary policy affect the exchange rate in Norway. Using a local projection approach, I estimate the dynamic, high-frequency response of the exchange rate to changes in the short-run policy rate. Since my focus is on the effect of innovations to the policy rate that were unexpected by market participants, I instrument monetary policy by movements in market interest rate expectations in a short window around monetary policy announcements.

Using daily data over the period 2001 – 2024, I find that a one percentage point unexpected increase in Norges Bank's policy rate leads to an immediate appreciation of the krone by approximately 2 percent against major trading partners' currencies.[1] However, this appreciation is transitory; within about three months, the exchange rate reverts to its pre-shock level. These dynamics are consistent across bilateral exchange rates against the Euro, the US dollar, and the Swedish krona. Notably, following an unexpected tightening of monetary policy, the exchange

[1] The size of this effect is in line with the effect of a monetary policy shock on the exchange rate in Norges Bank's policy model NEMO (Kravik and Mimir, 2019).

rate reverts back to its pre-shock level considerably quicker than does the policy rate itself. When examining foreign monetary policy shocks – particularly those originating in the Euro area – I find that the exchange rate responds in a similar manner to domestic shocks, both in timing and magnitude; a tightening of monetary policy abroad leads to a temporary depreciation of the krone.

I also explore how unexpected revisions to Norges Bank's published monetary policy projections affect the exchange rate. The published policy rate projections contain potentially valuable information for market participants about the future path of interest rates, and I find that revisions to these projections does affect the exchange rate. Notably, changes in longer-horizon projections tend to produce stronger effects, suggesting that market participants interpret such revisions as signals of a more durable shift in the monetary policy stance.

An additional contribution of this Staff Memo is to produce a new series of monetary policy shocks for Norway. These shocks can be interpreted as the surprise component of revisions to the policy rate at each meeting of the Monetary Policy Committee. I show that three periods contained the bulk of large monetary policy surprises: the years immediately following the formalization of inflation targeting in Norway in 2001; the period of the Great Financial Crisis of 2008 – 2009; and the period of high inflation in 2022 – 2023.

## 1.1 Related literature

A broad literature is devoted to estimating the effects of monetary policy on macroeconomic variables, including the exchange rate. This paper is related in particular to four strands of this literature. First, we follow Gürkaynak et al. (2005), Gertler and Karadi (2015), and Jarociński and Karadi (2020), among others, in using high-frequency changes in market expectations on announcement days to identify exogenous variation in monetary policy. My contribution to this literature is to construct a new series of monetary policy shocks for Norway since the formal start of inflation targeting. The method for constructing monetary policy shocks has previously been used on Norwegian data for a shorter period of time by Ahn et al. (2024).

Second, several papers use high-frequency identification in either structural vector autoregression (VAR) models or in local projections to estimate the exchange rate response to monetary policy (Alessi and Kerssenfischer, 2019; Hausman and Wongswan, 2011; Kearns and Manners, 2006; Faust et al., 2003; Bauer and Swanson, 2023; Bolhuis et al., 2024). While the size of the effects differ across countries, my results are generally in line with the literature. Notably, Bolhuis et al. (2024) find that a one percentage point unexpected increase in the interest rate on average across 12 advanced economies appreciates the local currency by 2.1 percent on impact, with a peak response of 6.1 percent after 20 trading days. Kearns and Manners (2006) find similar responses on the announcement day for four advanced economies.

Third, several papers estimate how the value of the Norwegian krone reacts to monetary policy shocks. Using both long-run sign restrictions in an SVAR and high-frequency identification in an event study, Bjørnland (2008) finds that for the period 1993 – 2004, the Euro/NOK exchange rate appreciated by 0.8 – 3.4 percent in the short run in response to a 1 percentage point higher interest rate. Using narrative monetary policy shocks in a local projection on monthly data, Holm et al. (2021) find that the USD/NOK exchange rate appreciates by 1 – 2 percent within the first few months in response to a similar increase in the policy rate. While the short-run responses are similar to the results in this Staff Memo, these authors find a somewhat longer-lived exchange rate response.

Fourth, a strand of the literature on the effect of monetary policy examines the effect of forward communication, either by isolating changes in market expectations at long maturities (following Gürkaynak et al. (2005)) or by constructing a direct measure of revisions of Central Bank guidance about future policy rates relative to the market's expectations. In the Norwegian context, the former approach is used by Brubakk et al. (2022) and the latter by Brubakk et al. (2021). My contribution to this literature is to develop a new method to instrument for changes in future Central Bank communication, as well as to estimate the effects of this communication on the exchange rate.

## 2 Theory: Uncovered Interest Parity

In most New Keynesian models used to analyze the macroeconomic effects of monetary policy in small, open economies, the relationship between monetary policy and the exchange rate is governed by an uncovered interest parity condition. According to this condition, returns denominated in two different currencies must be equal once risk is accounted for. Formally, we have that

$$E_t s_{t+1} - s_t = (r_t - r_t^*) - z_t, \tag{1}$$

where $s_t$ is the logarithm of the nominal exchange rate, while $r_t$ and $r_t^*$ are the nominal risk-free return in domestic and foreign currency, respectively, between period $t$ and $t+1$, and $z_t$ is a risk premium. As shown in Appendix A, this equation follows from the assumption that in expectations, and adjusted for risk, it should not be possible to make a profit by converting domestic currency into a foreign currency. The condition stems from a standard optimization requirement for investors: they invest in each asset until it is no longer profitable to purchase more. This implies that relative risk-adjusted returns are equal in expectation.[2]

It follows from Equation 1 that if the interest rate differential between the domestic and foreign markets is positive, or if the risk premium is negative, the exchange rate is expected to depreciate. A higher expected risk-adjusted return on domestic investments increases the value of holding domestic currency. Investors will buy that currency until they expect a sufficiently large depreciation of the krone so that it is no longer profitable to keep investing.[3]

While Equation 1 tells us what we should *expect* of future changes in the exchange rate, it does not directly tell us what the level of the exchange rate will be today. This period's exchange rate is determined by expected future interest rate differentials as well as by what the exchange rate is expected to be in the future. To pin down the current level, we need a terminal condition on what investors expect to receive when their domestic investments end and they convert back to foreign currency. Let us first define the *real* exchange rate as $e_t = s_t + p_t^* - p_t$. Substituting $s_t$ and $s_{t+1}$ into the UIP equation, we obtain

$$e_t = -\big[(r_t - E_t\pi_{t+1}) - (r_t^* - E_t\pi_{t+1}^*)\big] + z_t + E_t e_{t+1}. \tag{2}$$

Hence, the UIP condition also holds for the real exchange rate, but with real interest rates in the place of nominal interest rates. To determine today's real exchange rate $e_t$, we need to know the expected real exchange rate next period, $E_t e_{t+1}$. Using induction to solve this equation forward, we get

$$e_t = -E_t \sum_{k=0}^{\infty} \big[(r_{t+k} - \pi_{t+1+k}) - (r_{t+k}^* - \pi_{t+1+k}^*)\big] \; + \; E_t \sum_{k=0}^{\infty} z_{t+k} \; + \; \lim_{k\to\infty} E_t e_{t+k}.$$ [4]

Thus, today's real exchange rate depends on the current expectations of all future real interest

[2] An important additional assumption is that there are no barriers to capital flows across countries or financial instruments.

[3] In the simple yet general theoretical framework described in the appendix, the risk premium $z_t$ arises from two factors that increase the expected (average) return on domestic investments relative to foreign currency, for a given expected depreciation or appreciation of the exchange rate. First, investors require a higher relative return on NOK investments if the krone exchange rate typically fluctuates more than other currencies. Second, they demand a higher return if the krone tends to depreciate in bad times, because high returns are especially valuable in such periods. A large literature has identified other factors that can also influence risk premia in foreign exchange markets. Empirically, the term $z_t$ in the UIP equation represents everything that determines the exchange rate beyond the interest rate differential and the equilibrium exchange rate (discussed below).

[4] A requirement is that expectations are consistent such that the law of total expectation holds. For instance, this occurs under the assumption of rational expectations.

rate differentials and all future risk premia, in addition to the terminal value for the real exchange rate, given by the limit term $\lim_{k\to\infty} E_t e_{t+k}$. The latter can be interpreted as the real exchange rate an investor anticipates when eventually selling off domestic currency at a distant future date. In many cases, it is natural to assume that the real exchange rate will reach a long-term equilibrium value on average (in expectation). For instance, open economy macroeconomic models typically assume that the real exchange rate has a steady state value that it will converge to in the absence of shocks. Denoting the long-run real exchange rate by $\bar{e}$ and the expectation of this at time $t$ by $E_t\bar{e}$, the terminal condition becomes $\lim_{k\to\infty} E_t e_{t+k} = E_t\bar{e}$.

The long-run *nominal* exchange rate is determined by the long-run real exchange rate and the long-run difference in price levels. The price levels depend on historical inflation. Hence, there is no single *equilibrium level* for the nominal exchange rate. Instead, it is determined by the equilibrium real exchange rate, the current price level differential between countries, and future inflation differentials. More precisely, the current nominal exchange rate is given by

$$\begin{aligned} s_t = {} & E_t\bar{e} + p_t - p_t^* \\ & - \; E_t \sum_{k=0}^{\infty}\big[(r_{t+k} - \pi_{t+1+k}) - (r_{t+k}^* - \pi_{t+1+k}^*)\big] \; + \; E_t \sum_{k=0}^{\infty} z_{t+k}, \end{aligned} \tag{3}$$

where $p_t$ is the price level.

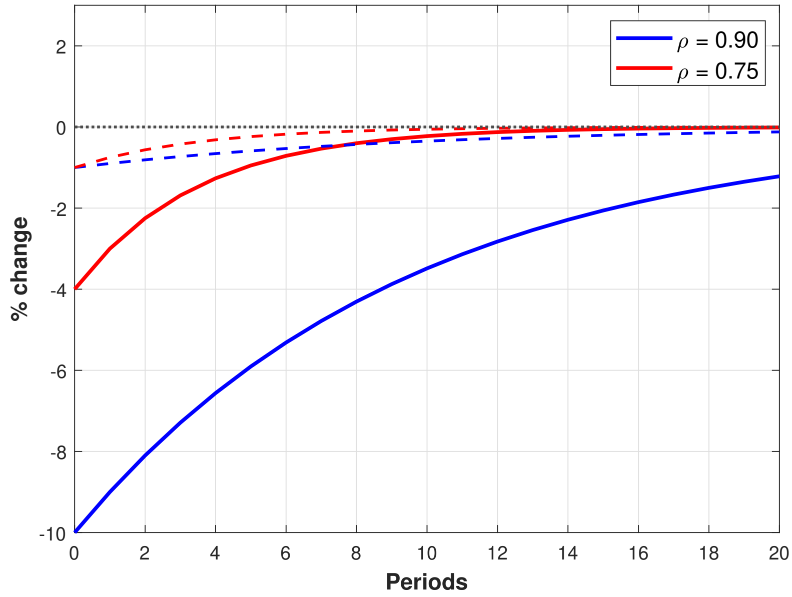
To find the *change* in the exchange rate between two periods, we can difference Equation 3 between period $t+1$ and period $t$, which yields

$$\begin{aligned} \Delta s_{t+1} = {} & \underbrace{(r_t - r_t^*) - z_t}_{\text{expected depreciation}} \\ & + \underbrace{(E_{t+1} - E_t)}_{\text{surprise component}} \left\{ \bar{e} - \sum_{k=1}^{\infty}\big[(r_{t+k} - \pi_{t+1+k}) - (r_{t+k}^* - \pi_{t+1+k}^*)\big] + \sum_{k=1}^{\infty} z_{t+k} \right\}. \end{aligned}$$

The change in the exchange rate consists of two components. The expected change equals, as we have seen, the current interest rate differential adjusted for risk. But in addition, there is a surprise component consisting of the information arriving between periods $t$ and $t+1$. We can decompose this term into the following:

1. **Equilibrium real exchange rate.** If investors increase their estimate of the long-term real exchange rate, implying a weaker equilibrium level, the exchange rate depreciates immediately and then remains at a weaker level, *ceteris paribus*.

Figure 1: Exchange rate response to unexpected monetary policy tightening




*Notes. The figure shows simulations of changes in the short-run interest rate (dotted lines, in percentage points) and the exchange rate (solid lines, in percent) according to the UIP condition in Equation 3, under the assumptions described in the text. The variables are simulated under two different assumptions on the persistence of the interest rate following a shock: high persistence ($\rho = 0.9$) and low persistence ($\rho = 0.75$).*

2. **Real interest rate differential.** If investors lower their forecast of the future real interest rate differential, the exchange rate depreciates immediately and then gradually appreciates. The value of the currency moves one-for-one with the cumulative change in the interest rate path. This revision of expectations can be either due to a change in nominal interest rates or because of a change in expected inflation domestically relative to abroad. For instance, if investors revise upwards their forecast of Norwegian inflation relative to foreign inflation, without a corresponding increase in the nominal interest rate differential, the exchange rate depreciates immediately and proportionally to the expected cumulative change in the real interest rate differential.

3. **Risk premium.** If investors raise their estimate of the risk premium on domestic currency, the exchange rate depreciates immediately and then gradually appreciates back to its pre-shock level. We can consolidate the interest rate differential and the risk premium into a "risk-adjusted" interest rate differential. A higher risk premium has the same effect on the exchange rate as a lower relative return on domestic currency.

According to Equation 2, there is an important distinction between the level of the interest rate differential and an unexpected change in this differential. If the risk-adjusted interest rate differential is positive, we should expect the exchange rate to depreciate. But if the risk-adjusted interest rate differential increases unexpectedly, the exchange rate will appreciate immediately, before gradually depreciating, given an unchanged expected long-run real exchange rate. More precisely, the surprise term in Equation 2 produces an immediate jump in the exchange rate, while the expected-change component subsequently guides the exchange rate back to equilibrium. For instance, a sudden increase in Norway's real interest rate immediately strengthens the krone. Since the interest rate differential is now higher, this also contributes to a gradual depreciation over time.[5]

Figure 1 illustrates how a jump in the domestic interest rate affects the exchange rate immediately and over time. In this simple example, I assume that inflation is identical domestically and abroad in all periods ahead, and that only domestic monetary policy changes in period $t = 0$.[6] Furthermore, suppose that the interest rate is given by $r_t = \rho r_{t-1} + \varepsilon_t$, where the monetary policy shock $\varepsilon_t$ jumps to a positive level $\bar{\varepsilon}$ at $t = 0$ and is zero thereafter. Then the interest rate at time $t$ is given by $r_t = \rho^t \bar{\varepsilon}$, while the nominal exchange rate is given by $s_t = \bar{e} + p_t - p_t^* - \frac{\rho^t}{1-\rho}\bar{\varepsilon}$. As illustrated in figure 1, a higher persistence parameter $\rho$ gives a stronger initial appreciation of the exchange rate and a slower rate of mean reversion. Both the exchange rate and the interest rate revert back to their pre-shock levels at the rate $\rho$.

## 3 Empirical Strategy

In this section, I present the empirical strategy used to estimate the effect of monetary policy on the exchange rate. I first present the local projection instrumental variable regression, then describe the high-frequency instruments used to identify surprise changes in monetary policy in Norway. In Section 3.2, I show how I identify the effect of changes to the policy rate forecast on the exchange rate.

[5] Here I have abstracted from changes in expected inflation caused by the movements in the policy rate. The logic of this paragraph holds as long as expected inflation does not *decrease* as a result of a higher nominal interest rate.

[6] In other words, and counterfactually, inflation does not react to monetary policy in this simple example. However, relaxing this restriction does not qualitatively change the result illustrated here.

### 3.1 Local Projection

Motivated by Equation 2, I estimate the effect of a surprise change in the interest rate $i_t$ on the nominal exchange rate $s_t$. The regression is given by the local projection

$$\frac{S_{t+h} - S_{t-1}}{S_{t-1}} = \alpha^h + \beta_r^h \Delta r_t + \varepsilon_{t,h}, \tag{4}$$

where $S_t$ is the exchange rate on day $t$, $\Delta r_t$ is the change in the interest rate at the interest meeting on day $t$, and $\varepsilon_{t,h}$ is an error term. The letter $h$ denotes the horizon of the regression. I run the regression at horizons (days) $h = 1, 2, 3, ...$, so that $\beta_r^h$ measures the effect of a one percentage point increase in the interest rate on the exchange rate $h$ days ahead.[7] The number of observations for each horizon is the number of interest rate meetings in the dataset. The interest rate $r_t$ is the overnight deposit rate, Norges Bank's main policy rate.

#### 3.1.1 Monetary Policy Instruments

Regression 4 cannot be estimated using ordinary least squares. Instead, we need one or more instruments for changes in the policy rate that are both correlated with changes in the policy rate $\Delta r_t$ and uncorrelated with all variables in market participants' information sets that affect the exchange rate through the error term $\varepsilon_{t,h}$. Following a large literature (see Gürkaynak et al. (2005), Gertler and Karadi (2015), and Jarociński and Karadi (2020), among others), I extract the surprise element of monetary policy announcements from high-frequency changes in market-based expectations on announcement days of the current and future policy rate. The expectations are based on the pricing of the first four forward rate agreements (FRAs), as well as ten swap rates referencing 6 month NIBOR.[8] The tenors of the latter range from 1 to 10 years in 1 year increments.[9] The FRA rates reflect the market's expectations of the short-run money market interest rate within the next year, while the longer swap rates reflect the expectations of money market rates over a longer time period. The instruments are defined as the change in the market pricing in a 30 minute window around the announcement time, from 10 minutes before the announcement to 20 minutes after the announcement.[10] The shorter the window, the less

[7] The exchange rate is recorded at the daily close.

[8] The same FRA contracts have previously been used by Brubakk et al. (2022) and Ahn et al. (2024) to generate monetary policy instruments for Norway. The Norwegian Interbank Offered Rate NIBOR is the main reference rate in the Norwegian market.

[9] For instance, the 1-year swap rate referencing 6-month NIBOR is the fixed interest rate in a one-year interest rate swap where one party pays this fixed rate while receiving a floating rate that resets every six months based on the 6-month Norwegian Interbank Offered Rate (NIBOR).

[10] Data for interest rates and exchange rates are observed at a 1 minute frequency. The variables are defined as the average of the ask and bid prices.

we expect the expectations to be affected by news about other macroeconomic conditions that might also be correlated with movements in the exchange rate, such as news about macroeconomic conditions domestically or abroad. At the same time, it is important to allow enough time for the market to process the monetary policy announcement and communication.[11]

With the instruments at hand, I estimate Equation 4 using two-stage least squares (2SLS). When $\Delta r_t$ is instrumented, regression 4 is a local projection instrumental variables (LP-IV) regression (Stock and Watson, 2018). The estimation period includes data from January 2001 until December 2024, a period that includes 187 interest rate meetings. Of these, 121 resulted in an unchanged policy rate, 39 an increased rate, and 27 a decreased rate. I estimate Equation 4 on three bilateral exchange rates against NOK. These are the currencies for Norway's three largest trading partners, the Euro (EUR), the United States dollar (USD), and the Swedish krona (SEK). Reported standard errors are robust to serial correlation.

#### 3.1.2 Foreign Monetary Policy Shocks

According to the UIP condition 2, the exchange rate should not only react to a surprise change to the interest rate domestically, but also to movements in the interest rate abroad. Furthermore, to the extent that a surprise increase in the interest rate abroad changes expectations of future real rates by the same amount, domestic and foreign interest rate shocks should have symmetric effects on the exchange rate.

I estimate the effect on the Euro/NOK exchange rate of a surprise change in the Euro area policy rate at interest rate meetings over the period 2001 – 2024. Using data from Altavilla et al. (2019), policy rate movements are instrumented by a set of high-frequency market surprises. The instrument set consists of changes in overnight interest swaps (OIS) at the 1 week, 1 month, 3 month, 6 month, 1 year and 2 year horizon in a 20 minute window around the release of the policy rate decision.[12]

### 3.2 Interest Rate Projections

Norges Bank has since 2005 published regular projections for the path of the policy rate. These projections are published in the Monetary Policy Report four times each year (three times a year before 2013) and consist of forecasts at quarterly frequency up until the end of the second

[11] Note that this 30 minute window excludes the press conference that follow 30 minute after the policy announcement and the release of the Monetary Policy Report.

[12] This is the "press release window" in Altavilla et al. (2019).

year following the year of the report. In total, there are 70 meeting dates in the dataset with an associated interest rate projection. The projections can provide information to the market about future monetary policy over and above that which is contained in the decision on the current policy rate.

I now test how changing the projected interest rate path for short, medium and long projection horizons affects the exchange rate. To this effect, I estimate the regression

$$\frac{S_{t+h} - S_{t-1}}{S_{t-1}} = \alpha_0 + \sum_{q \in \{0,4,8\}} \theta_q \left[ F^{\text{NB}}_{m_t} r_{t+q} - F^{\text{NB}}_{m_t - 1} r_{t+q} \right] + \varepsilon_t, \tag{5}$$

where $\Delta S_t$ is the change in the exchange rate on impact, in the 30 minute window around the interest rate announcement.[13] $F^{\text{NB}}_{m_t} r_{t+q}$ is Norges Bank's forecast of the policy rate $q$ quarters ahead published at the meeting on day $t$, $m_t$, while $F^{\text{NB}}_{m_t-1} r_{t+q}$ is the forecast for the same time period published at the previous meeting, $m_t - 1$. Hence, the term in brackets on the right-hand side of Equation 5 is the change in the projection for the interest rate 0, 4 and 8 quarters ahead since last interest rate meeting.

The coefficient $\theta_q$ measures the exchange rate effect of revising upwards the projection for the interest rate q quarters ahead by 1 percentage point, while leaving the projection for the policy rate at other horizons fixed. For instance, $\theta_8$ is a measure of the effect of increasing the projection for the policy rate at the long end of the curve while keeping the rate fixed at the short and medium horizons (quarters 0 and 4).

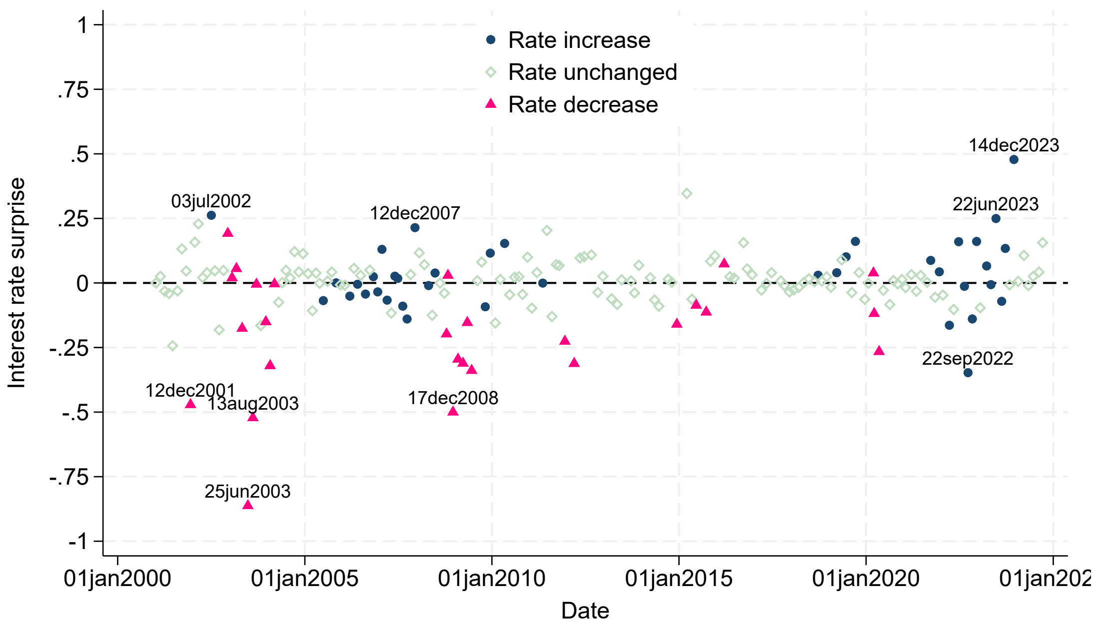
I estimate equation 5 by two-stage least squares using the full set of instruments described in section 3.1.1. Notably, this method allows for changes in market expectations at long maturities to instrument for forecast revisions at long horizons while short maturities instrument for revisions at shorter horizons.

# 4 Results

In this section I present the empirical results. In Section 4.1, I show that the predicted values from the first stage of the regression 4 can be interpreted as a series of monetary policy shocks. In Section 4.2, I show the effects of monetary policy both domestically and in the Euro zone on bilateral exchange rates. Finally, in Section 4.3, I show how changing interest rate projections affect the exchange rate.

[13] Results are similar if we instead use the change in the exchange rate from market close the previous day to close on the announcement day.

Figure 2: Surprise component of interest rate decisions in Norway, 2001 – 2024.



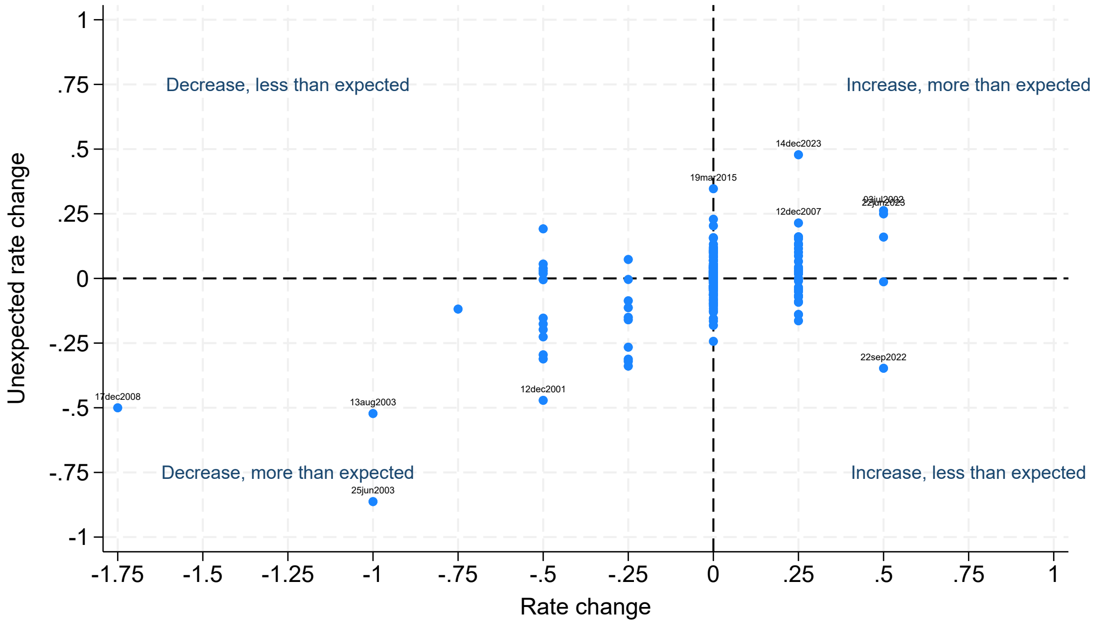

*Notes. The figure illustrates the monetary policy surprises constructed as the predicted value from the first stage in the local projection instrumental variables regression 4.*

## 4.1 Monetary Policy Shocks

The change in the market's interest rate expectations at the time of a policy announcement constitutes a measure of the surprise element of an announcement. Based on the surprises in all the instruments, I construct a series of monetary policy shocks by regressing the change in the policy rate at each meeting date on all the market surprises in a 30 minute window around the announcement. This is the first stage of the two-stage least squares regression 4. The fitted values of that regression constitutes a series of shocks that measure the surprise element of the monetary policy announcement. For instance, when the policy rate is increased by 0.25 percentage points while market participants on average expected an increase of 0.10 percentage points, the surprise component of the decision is 0.15 percentage points.

To aid the interpretation of the monetary policy shocks, consider the simple case of a single market-based monetary policy instrument. In that case, the shock series is a simple scaling of the changes in the single market rate. Since there is not necessarily full and immediate pass-through of a surprise change in the policy rate to all instruments, the scaling ensures that we can interpret the shock as the surprise component of the policy rate implied by the change in the market rate.

Figure 3: Actual and surprise changes in the interest rate in Norway, 2001 – 2024.




*Notes. The figure illustrates the monetary policy surprises constructed as the predicted value from the first stage in the local projection instrumental variables regression 4.* Scatter plot of actual changes in the policy rate against the surprise components.

For instance, since the one year swap rate moves less than one-for-one with the current policy rate since it is also based on expectations of the policy rate further out. When I include multiple instruments in the regression, each instrument will be scaled according to how much it typically moves with surprises in the policy rate.

Figure 2 shows the monetary policy shocks (surprises) over the years 2001 – 2024. The 10 largest monetary policy shocks are listed in table 1. The two monetary policy decision that contained the largest surprise components occurred in the summer of 2003, as the policy rate was lowered from 4% to 3% in June and from 3% to 2% in August, mostly due to inflation being persistently below target. During the Great Financial Crisis in 2008 – 2009, the policy rate was decreased multiple times by more than the market expected, with the largest surprise coming in December 2008. I also identify two large shocks during the high inflation period of 2022 – 2023, when the interest rate (and the interest rate projection) were initially increased by less than expected, and then in the latter half of 2023 by more than expected by the market. Figure 3 decomposes each interest rate decision into the expected and unexpected components.

For the most part, the size of the surprises listed in table 1 correspond to the deviation between

Table 1: List of largest monetary policy shocks

| Date | $r_t$ | $\Delta r_t$ | surprise | surprise rank | pc rank | sum rank |
|---|---|---|---|---|---|---|
| June 25, 2003 | 5.00% | −1.00 pp. | −0.86 pp. | 1 | 11 | 11 |
| August 13, 2003 | 4.00% | −1.00 pp. | −0.52 pp. | 2 | 3 | 3 |
| December 17, 2008 | 4.75% | −1.75 pp. | −0.50 pp. | 3 | 20 | 18 |
| December 14, 2023 | 4.25% | 0.25 pp. | 0.48 pp. | 4 | 9 | 4 |
| December 12, 2001 | 7.00% | −0.50 pp. | −0.47 pp. | 5 | 4 | 5 |
| September 22, 2022 | 1.75% | 0.50 pp. | −0.35 pp. | 6 | 5 | 8 |
| March 19, 2015 | 1.25% | 0.00 pp. | 0.35 pp. | 7 | 7 | 2 |
| June 17, 2009 | 1.50% | −0.25 pp. | −0.34 pp. | 8 | 83 | 67 |
| January 28, 2004 | 2.25% | −0.25 pp. | −0.32 pp. | 9 | 55 | 38 |
| March 14, 2012 | 1.75% | −0.25 pp. | −0.31 pp. | 10 | 14 | 13 |

*Notes. The table lists the ten largest monetary policy shocks ranked according to the size of the surprise component of each monetary policy announcement. The surprise is the predicted value from the first stage in the local projection instrumental variables regression 4. The first column shows the date of the announcement, the second column the level of the main policy rate before the announcement, the third column the change in the announced change in the policy rate (in percentage points), the fourth column the surprise component of the change, and the fifth column the rank of the surprise amongst all surprises between 2001 and 2024. The sixth column shows the rank of the announcement according to the first principal component of all the changes in market instruments, while the seventh column shows the rank according to the sum of all the changes in the instruments.*

the policy rate decision and the decision expected by macroeconomists who follow Norges Bank closely.[14] For instance, the consensus ahead of the August, 2003 meeting was that the policy rate would be lowered by 0.50 percentage points, implying a surprise component of 0.50 percentage points, similar to the identified shock of 0.52 percentage points. Similarly, economists expected a cut of 1 – 1.25 percentage points in December, 2008, while the policy rate was in fact lowered by 1.75 percentage points.

I also provide two alternative rankings of monetary policy surprises. The first one is based on the first principal component of all the high-frequency changes in market-based instruments. The first principal component is the linear combination of each of the changes in market interest rates that captures the greatest possible variance in these rates, effectively summarizing the most important common variation in the market rates at announcement dates. The second column is based on the sum of the changes in the market instruments. As shown in table 1, these three measures largely agree on the ranking of monetary policy surprises.

[14] This is based on a reading of Norwegian newspapers published on the day following the policy announcement.

## 4.2 Effect of Policy Rate on the Exchange Rate

In Figure 4, I show the bivariate relationship between, on the one hand, the change in the Euro/NOK exchange rate and, on the other, changes in each of the 14 market interest rate instruments in a 30 minute window around each interest rate announcement. Since these instruments typically move in the same direction in response to a surprise monetary policy announcement, an appreciation of the NOK is associated with an increase in each of the instruments. Figure 5 shows the relationship between the interest rate surprise, which is based on information from all of the individual interest rate instruments, and the change in the exchange rate. There is a negative relationship between interest rate shocks and the exchange rate, indicating that when the policy rate announcement leads to a rate that is higher than expected by the market, the exchange rate tends to appreciate immediately.

To understand how a surprise change in the policy rate affects the exchange rate both on impact and over time, I estimate Equation 4 for every horizon (day) after the interest rate change, using all the interest rate decisions over the period 2001 – 2024. Figure 6 shows the estimated coefficient $\beta_r^h$ from 1 to 100 for the Euro/NOK exchange rate (panel a), the USD/NOK exchange rate (panel b) and the SEK/NOK exchange rate (panel c), respectively. The exchange rates all appreciate on impact when the interest rate increases unexpectedly, with a 1 percentage point higher interest rate resulting in an appreciation of around 2 percent in the short run for all the bilateral exchange rates.[15] The exchange rate continues to appreciate within the next month, before it gradually depreciates. After 3 months, all of the exchange rates are back to the pre-shock level.

To interpret the timing of the effects in figure 6, we can consider the effect of an unexpected increase in the policy rate on the policy rate itself over time. Figure 7 shows how the policy rate responds to an initial one percentage point tightening that was unexpected by the market, over a 600 days horizon The policy rate continues to increase until reaching a peak of around 2 percentage points after half a year, before it gradually decreases. The effect is much more persistent than the effect of the same monetary policy shock on the exchange rate. While the exchange rates are back to their pre-shock level within 3 months, the policy rate itself is still as high as the initial increase after almost 2 years.

[15]The size of this effect is lower than the regression coefficient in a bivariate regression of the change in the exchange rate on the change in one of the market rates, as plotted in figure 4. The main reason is that, on average, the market rates move less than one-for-one with the interest rate in the 30 minute window around policy announcements. In other words, surprise movements in the policy rate do not immediately pass through to market rates.

To understand whether the exchange rate effect of the interest rate has changed over time, I now estimate regression 4 by 10 year subperiods. Figure 8 shows the effects on impact. The effect of an unexpected policy rate change of the same size is estimated to be stronger in the first half of the sample than in the latter half, more than doubling in size between the period 2001 – 2011 and the period 2009 – 2019. It is also worth noting that the standard errors are larger in the latter part of the sample, and the coefficient estimates in later years are not significantly different from those in earlier years.

What is the effect on the exchange rate of monetary policy abroad? Figure 9 shows the estimated response of the Euro/NOK exchange rate to a 1 percentage point surprise increase in the Euro area policy rate. The exchange rate depreciates on impact, and the effect becomes gradually stronger for around 2 months following the interest rate decision. Thereafter, the krone gradually appreciates against the Euro. While the effect is slightly weaker than an equivalent change in the domestic rate in the short run, it is somewhat stronger at the 1 – 2 month horizon. On average throughout the 100 day horizon, the effect is of a similar size. Interpreting these results in light of the theory in Section 2, they indicate that expected future real interest rates react in a similar manner to a surprise change in the policy rate of the same size originating in the Euro zone and in Norway.

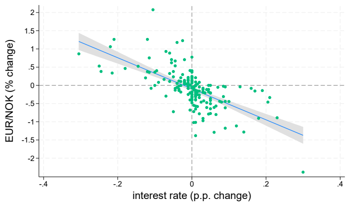
### 4.3 Effect of Revisions of Policy Rate Projections

I now investigate how changes to the interest rate forecasts published by Norges Bank affect the exchange rate. The results from regression 5 for the Euro/NOK exchange rate are presented in table 2. The first column replicates the effect of a change in the policy rate on impact. The second column shows that this result is virtually the same if we only use information from the 70 interest rate meetings where a full interest rate projection has been published, indicating that there is no systematic difference between meetings where a full Monetary Policy Report is published and meetings with no report. In the third column, I replace changes in the current policy rate by changes in the projected average policy rate within the quarter in which the interest rate meeting takes place. As expected, the estimated coefficient is close to those in the first two columns, albeit with a higher standard error.

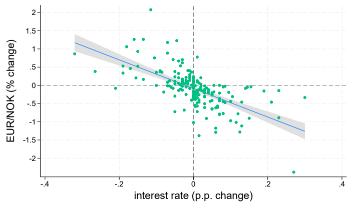
Now I investigate the effect of changing the interest rate projection at only one horizon, while keeping the projection at other horizons fixed. The estimates in column 4 show that the effect of increasing the projected interest rate by 1 percentage point within the current quarter drops from $-2.20$ to $-0.88$ if we hold the projections at quarter 4 (approximately one year ahead) fixed. Furthermore, the effect of changing the projection at longer horizons is stronger. This might be an indication that changes to the interest rate projections further out are expected by market participants to be of a more lasting nature than those revisions that only occur within the quarter of the interest rate meeting. Promising changes to the policy rate only at the short end of the curve has a small effect on the exchange rate, while movements in the rate that are expected to be persistent have a strong effect. This is consistent with the theory presented in Section 2 and the example in Figure 1. Moving to the longest end of the projection period, column 5 shows that the coefficient on the current quarter interest rate change drops even more if we hold fixed changes two years (8 quarters) ahead.

Figure 4: Market interest rates and the Euro/NOK exchange rate

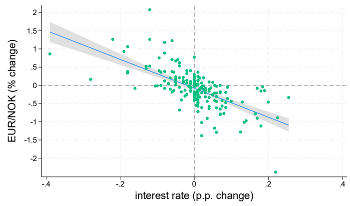
(a) FRA 1



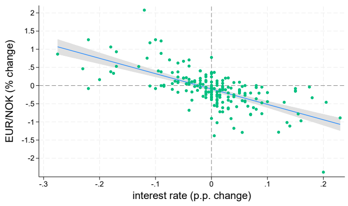

(b) FRA 2



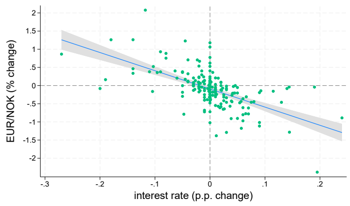

(c) FRA 3



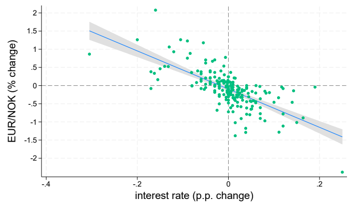

(d) FRA 4



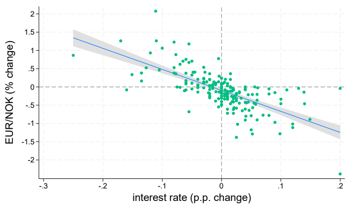

(e) Swap rate, 1 year



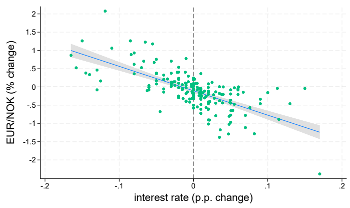

(f) Swap rate, 2 years



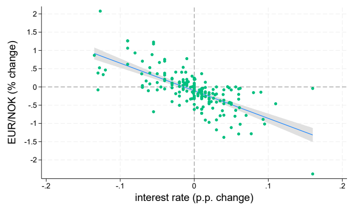

(g) Swap rate, 3 years



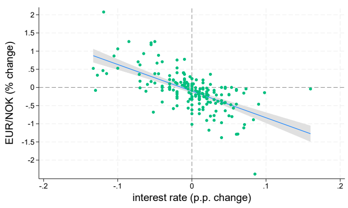

(h) Swap rate, 4 years



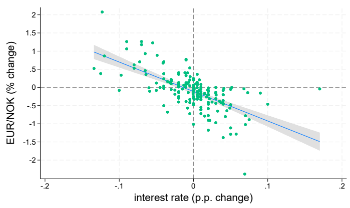

(i) Swap rate, 5 years



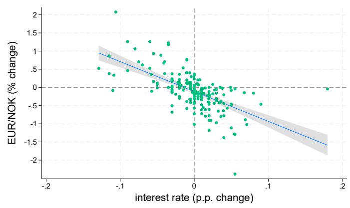

(j) Swap rate, 6 years



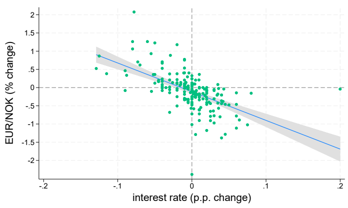

(k) Swap rate, 7 years



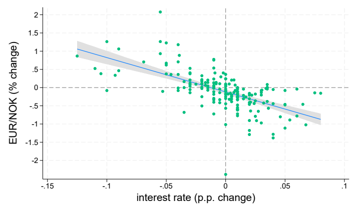

(l) Swap rate, 8 years




(m) Swap rate, 9 years

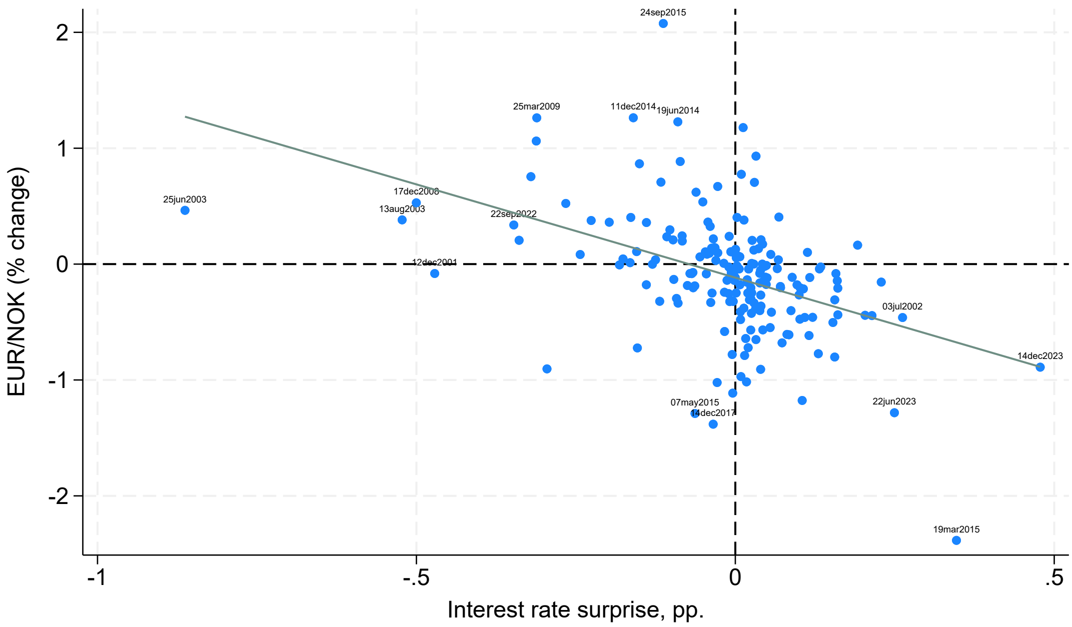



(n) Swap rate, 10 years




*Notes. The figures illustrate the relationship between changes in market interest rate instruments and the Euro/NOK exchange rate in a 30 minute window around the monetary policy announcement, for each announcement. Each subfigure is one separate instrument, with the first four Forward Rate Agreements (FRA) and swap rates against the 6 month NIBOR rates at durations from 1 to 10 years.*

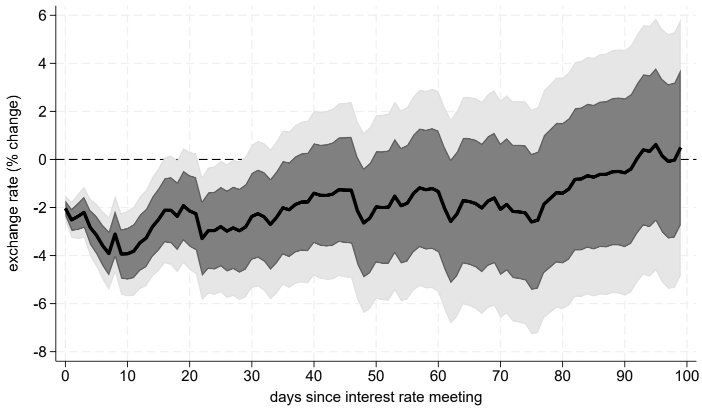
Figure 5: Surprise interest rate change and change in Euro/NOK exchange rate



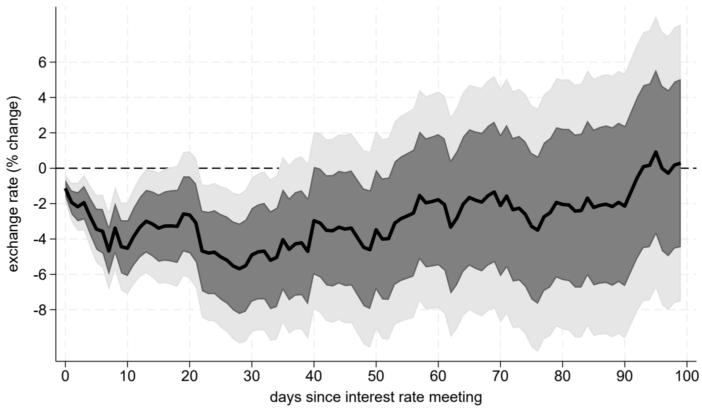

*Notes. The figure illustrates the relationship between changes in the monetary policy shock and the Euro/NOK exchange rate in a 30 minute window around the monetary policy announcement, for each announcement. The shocks are the predicted values from the first stage in the local projection instrumental variables regression 4.*

Figure 6: Effect of unexpected increase in policy rate on NOK exchange rates.

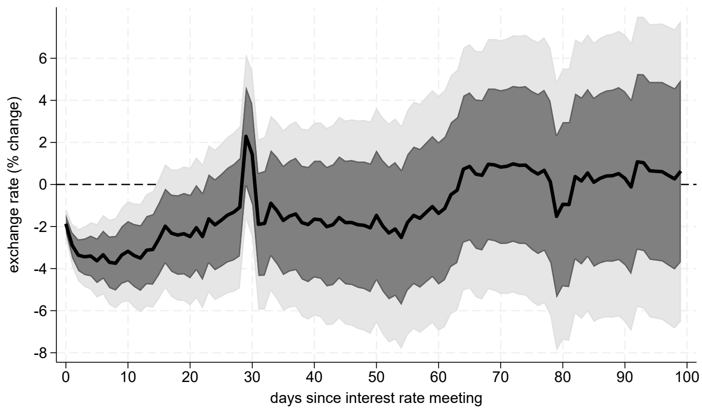
(a) Euro




(b) US dollar

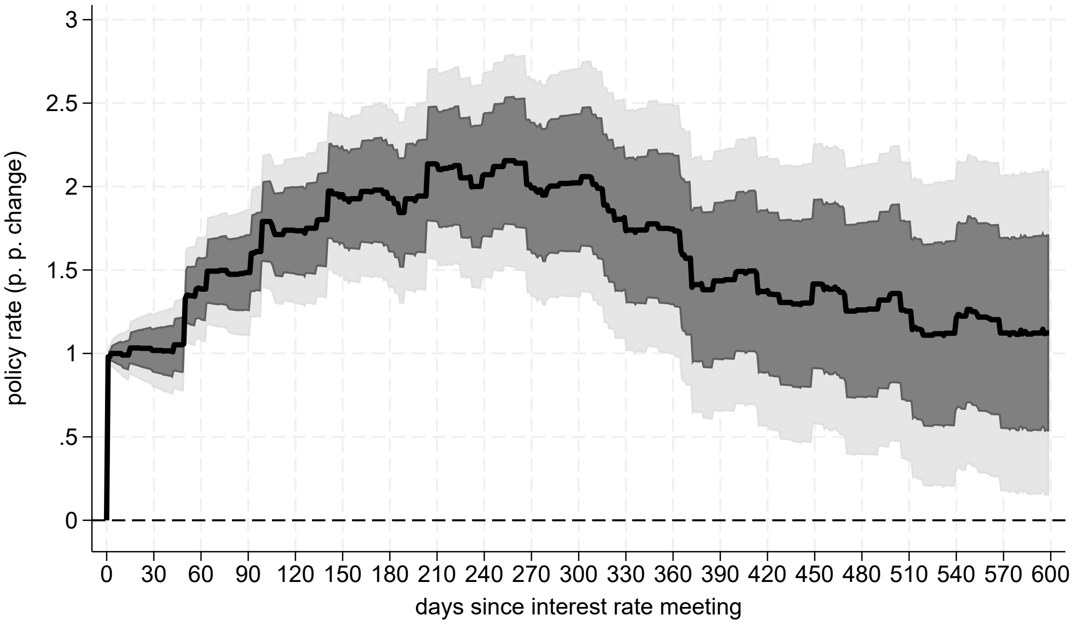



(c) Swedish krona




*Notes. The figures show the estimated dynamic response of three bilateral exchange rates to a* 1 *percentage point initial innovation to the short-run policy rate, from the local projection IV specification in Equation 4 estimated on daily data over the period* 2001 – 2024*. The shaded areas show* 68% *and* 95% *confidence intervals based on robust standard errors.*

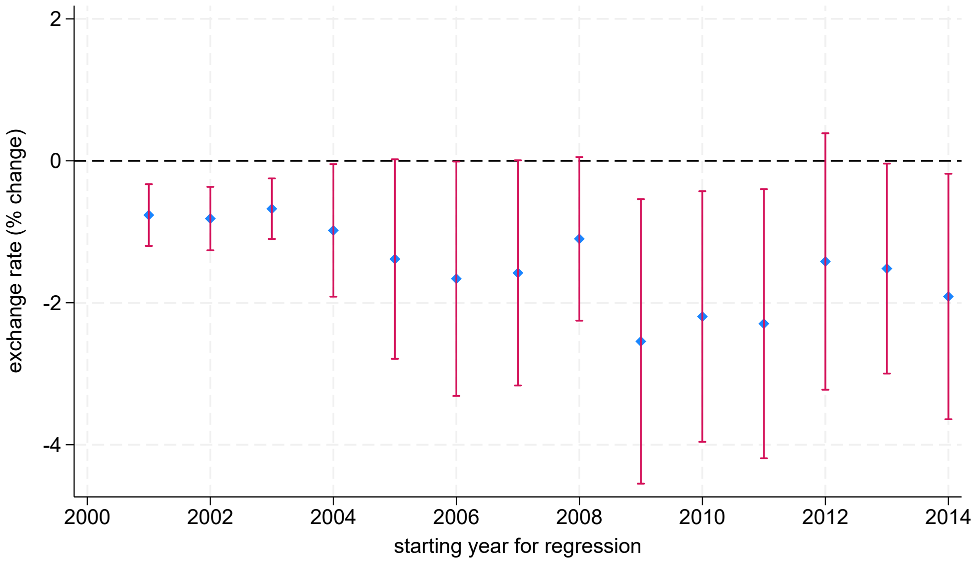
Figure 7: Effect of surprise monetary policy tightening on the policy rate



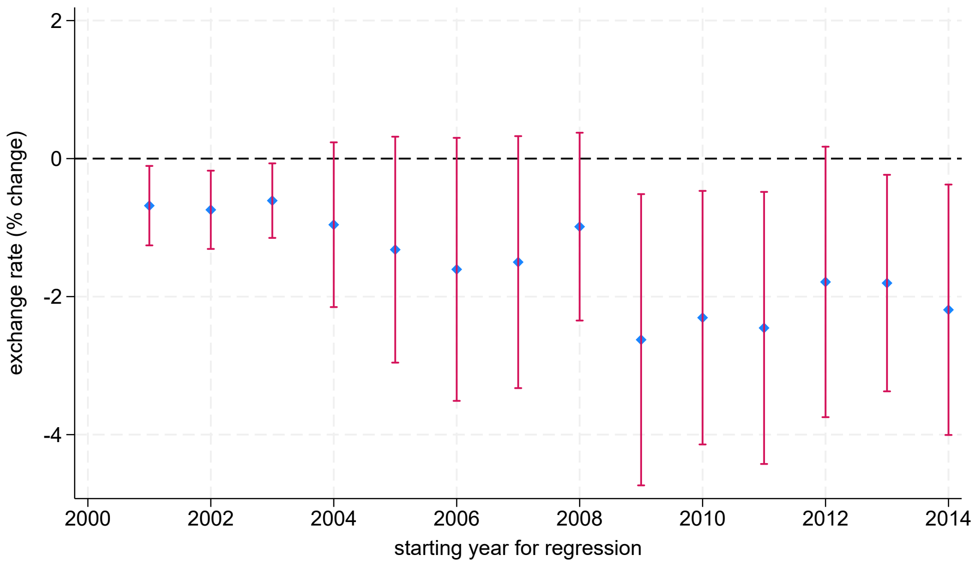

*Notes. The figure show the estimated dynamic response of the policy rate in Norway to a* 1 *percentage point initial innovation to the policy rate itself, from the local projection IV specification in Equation 4 estimated on daily data over the period* 2001 – 2024*. The shaded areas show* 68% *and* 95% *confidence intervals based on robust standard errors.*

Figure 8: Effect of unexpected increase in policy rate on NOK exchange rates, on impact. By 10-year subperiods.

(a) Euro

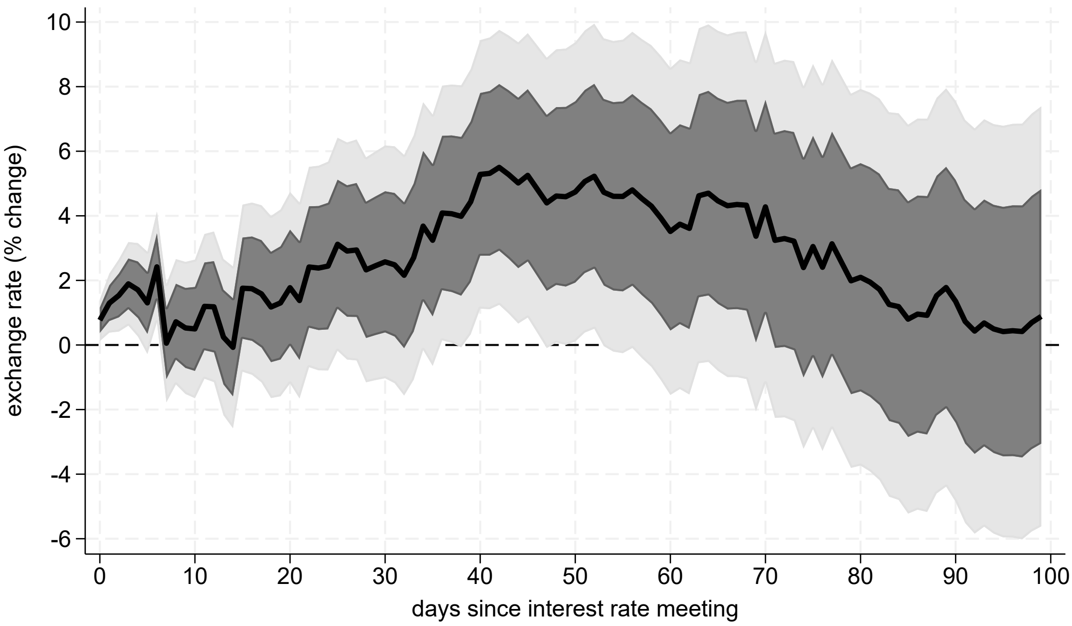



(b) US dollar




*Notes. The figure show the estimated response of the Euro/NOK (figure a) and USD/NOK (figure b) exchange rates to a 1 percentage point initial innovation to the short-run policy rate, from the local projection IV specification in Equation 4. The response is on impact in a 30 minute window around the policy rate announcement. Each dot is an estimate based on a 10 year subperiod. The red bars show the 95% confidence intervals.*

Figure 9: Effect of unexpected increase in Euro area policy rate on Euro/NOK exchange rate.




*Notes. The figure shows the estimated dynamic response of the Euro/NOK exchange rate to a 1 percentage point initial innovation to the short-run policy rate in the Euro zone, from the local projection IV specification in Equation 4 estimated on daily data over the period 2000 – 2024. The monetary policy innovations are instrumented using high-frequency instruments from Altavilla et al. (2019). The shaded areas show 68% and 95% confidence intervals based on robust standard errors.*

Table 2: Estimated effect of changing the interest rate path

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| $\Delta r_t$ | $-1.57^{***}$ | $-1.58^{***}$ | | | | |
| | (0.32) | (0.49) | | | | |
| Q0 | | | $-2.20$ | $-0.88$ | $-0.27$ | $-0.38$ |
| | | | (1.15) | (1.34) | (1.34) | (1.39) |
| Q4 | | | | $-1.30^{**}$ | | $-0.37$ |
| | | | | (0.37) | | (0.89) |
| Q8 | | | | | $-1.41^{***}$ | $-1.06$ |
| | | | | | (0.37) | (0.93) |
| N | 187 | 70 | 70 | 70 | 70 | 70 |

*Notes. The table shows the estimated effects of changes in Norges Bank's policy rate projections on the Euro/NOK exchange rate, in a 30 minute window around the policy rate announcement. Robust standard errors in parentheses. Estimates marked ** and * * * are statistically significant from zero at the two and three standard deviation level, respectively. The rows show which parts of the interest rate curve are included in the regression. The first row is the change in the short-run policy rate, the second row revisions in the forecast of the average policy rate in the quarter of the policy meeting, the third row the revision of the projection four quarters ahead, and the fourth row the revision of the projection eight quarters ahead. The first two columns show that estimates are similar whether we include all of the policy meetings (column 1) or just the meeting dates on which projections have been published (column 2). Columns 3-6 show results across specifications that include different combinations of forecast revisions.*

# 5 Conclusion

The effect of monetary policy on the exchange rate is an important channel of monetary policy transmission in small, open economies. In this paper, I estimate the high-frequency response of bilateral exchange rates against the NOK to a surprise change in the policy rate. For three important bilateral exchange rates, I find that the NOK appreciates by around 2% on impact in response to a 1 percentage points higher policy rate, but that the exchange rate is back to its pre-shock level within 3 months. The results are qualitatively similar for monetary policy shocks originating in the Euro zone. Changes to official interest rate projections that are unexpected by the market also affect the exchange rate, but more so for changes at the long end of the forecast horizon. These results indicate that monetary policy does affect the exchange rate in Norway, but that the effect is short lived.

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# Appendix

## A Derivation of the UIP condition

Let us start with the pricing equation

$$E_t\{R_{i,t+1}\, m_{t+1}\} = 1, \tag{6}$$

where $R_{i,t+1}$ is the return on any asset, and $m_{t+1}$ is the stochastic discount factor (often called the pricing kernel because it determines the asset's equilibrium price). This equation is very general, only requiring the assumption that investors choose how much of each asset to hold in a way that maximizes their utility.[16] The pricing equation applies both nominally and in real terms, the difference being whether the discount factor is stated in nominal or real terms. Here, let $R_{i,t+1}$ refer to a nominal return. For standard preferences, we have

$$m_{t+1} = \beta \frac{u'(C_{t+1})}{u'(C_t)} \frac{P_{t+1}}{P_t},$$

where $C_t$ is consumption, $P_t$ is the price level and $u(C_t)$ is the utility function.

From the pricing Equation 6, an asset has a higher expected return than others when it typically pays off more in states of the world in which consumption is low (when $m_{t+1}$ is high). This is the source of the risk premium in the foreign exchange market, as we will see shortly. Because Equation 6 must hold for all assets, it implies that no asset can offer a higher expected risk-adjusted return than another. Otherwise, investors could increase their utility by selling the second asset and buying more of the first.

Now apply this condition in the foreign exchange market. The two assets are risk-free bonds in domestic and foreign currency, respectively. The exchange rate is $S_t$. An investor holding domestic currency can earn the risk-free return $R_t$, or can convert that amount to foreign currency at time $t$, earn a foreign currency return $R_t^*$, and then convert back into domestic currency, yielding $R_t^* \frac{S_{t+1}}{S_t}$. These returns are known at the start of period $t$. Thus, the pricing equation becomes

$$R_t\, E_t\{m_{t+1}\} \;=\; R_t^*\, E_t\Big\{\frac{S_{t+1}}{S_t}\, m_{t+1}\Big\}. \tag{7}$$

Using the definitions of covariance and correlation, we get

$$\frac{R_t}{R_t^*} \;=\; E_t\Big\{\frac{S_{t+1}}{S_t}\Big\}\,\big[1 + \text{corr}\big(\tfrac{S_{t+1}}{S_t}, m_{t+1}\big)\big]. \tag{8}$$

Letting lowercase letters be the logs of their uppercase counterparts, $x \equiv \log(X)$, and taking the logarithm of both sides, we obtain

$$r_t - r_t^* \;=\; E_t s_{t+1} - s_t \;+\; \Big[\log\, E_t\Big\{\frac{S_{t+1}}{S_t}\Big\} - E_t \Delta s_{t+1}\Big] \;+\; \log\big[1 + \text{corr}\big(\tfrac{S_{t+1}}{S_t}, m_{t+1}\big)\big].$$

Thus, we have the UIP condition

$$E_t s_{t+1} - s_t = (r_t - r_t^*) - z_t, \tag{9}$$

[16] For a complete derivation of the pricing equation, see for example Cochrane (2009).

where the risk premium $z_t$ is given by

$$z_t \;=\; \Big[\log\, E_t\Big\{\tfrac{S_{t+1}}{S_t}\Big\} - E_t \Delta s_{t+1}\Big] \;+\; \log\Big[1 + \mathrm{corr}\big(\tfrac{S_{t+1}}{S_t}, m_{t+1}\big)\Big]. \tag{10}$$

We see that the risk premium has two components. The first arises from Jensen's inequality and is always positive; it grows when exchange rate movements are more volatile.[17] Investors require a higher expected return to hold currencies that fluctuate widely, since returns also vary more. The second term increases with the correlation between future domestic currency depreciations and the stochastic discount factor. The term is positive if the domestic currency typically depreciates in bad times, i.e., when consumption is low. Investors will require either a higher average return or an expected appreciation when investing in a currency whose payoff is especially poor in states of the world in which consumption is low.

[17]When $\frac{S_{t+1}}{S_t}$ is log-normally distributed, this term is exactly $\frac{1}{2}\,\mathrm{Var}(\Delta s_{t+1})$.