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Navn:	Valeria ROus Og Gina A. Rieck

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Master Thesis

- The effect of volatility transmission around QE announcements on the Norwegian exchange rate and economy-

Supervisor:
Geir Høidal Bjønnes

Examination code and name:
GRA 19702 Master Thesis

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Master of Finance

Contents

Abstract

This paper investigates in how far Quantitative Easing announcements made by the Federal Reserve, the Bank of England, and the European Central Bank influence the Norwegian FX market. We measure the impact of these announcements on the corresponding exchange rates as well as the transmission to other exchange rates by examining the intraday exchange rate volatility. Moreover, we examine the effect of FX volatility on Norway's economy using a VAR model. This unique combination of approaches will add to the existing literature on causes of exchange rate volatility and on the effects of monetary policy announcements on the FX market and economy, to form a more fulfilled picture of the effect of monetary policy announcements on FX volatility and their impact on global economics.

Introduction

In this paper, we want to study the relationship between monetary policy announcements, exchange rate volatility, and macroeconomy. We want to examine how far quantitative easing (QE) announcements affect intraday exchange rate volatility transmission and moreover, how shocks to the exchange rate volatility impact the economy. Especially during the current events of COVID-19, many central banks around the world introduced new QE programs, which is why our study focuses on this time period.

Today, the foreign exchange market (FX market) is more than ever influenced by global news and policy announcements that affect not only exchange rates but also macroeconomics. This global interconnection led to two main strings of literature, one focuses on the effects of monetary policy on FX rates and the economy, and the other on causes of exchange rate volatility. Many theories have tried to explain the relationship between monetary policies and their effect on exchange rates as well as the economy. One of the most prominent open economy theories is Dornbusch's overshooting model which suggests that exchange rates overreact to monetary policy announcements in the short term and then depreciate back to equilibrium level (Dornbusch, 1976). However, research so far has mostly focused on the effect of monetary policies on the FX market or causes and effects of exchange rate volatility separately (Aastveit et al., 2013; Eichenbaum & Evans, 1995; Feng et al., 2021; Gould & Kamin, 2000; Huang, 1981). The aim of this paper is to link these two strings of literature to study the effect of monetary policy on exchange rate volatility and further, how changes in exchange rate volatility affect macroeconomic variables such as inflation, GDP, and interest rates.

Exchange rate volatility is a major economic indicator to measure a country's foreign trade stability and external environment which include financial market risk, foreign investment, and social welfare (Feng et al., 2021). Especially in countries that have an independent currency, the exchange rate and its volatility are important factors for the economy. The FX market is highly reactive to news and public information (Liu et al., 2019). The COVID-19 pandemic caused increased volatility which disrupted the foreign exchange market. These volatility shocks drive real economic activity significantly and are able to spread to the stock market through trading activity, financial market integration, or spillover effects (Mun, 2012). We observe that countries dealt differently with the pandemic and responded with several measures to reduce the impact of the shock on the financial system (Wei & Han, 2021). Besides many social restrictions, many monetary policies were used, including asset purchases and policy rate cuts, to stem the disruption in the market (Cepoi et al., 2022). We want to investigate how far these macro-stabilizing monetary policies affected exchange rate volatility and if this volatility has a measurable impact on foreign economies.

For our study, we want to focus on the Norwegian market. Unlike other countries, Norway did not engage in QE policies. Our paper concentrates on currencies that are frequently traded with the Norwegian krone (NOK): the US dollar (USD), the Euro (EUR), and the British pound (GBP). These currencies are some of the most liquid currencies traded with the Norwegian krone and are important currencies for Norway's trading relationships. Especially during the start of the pandemic, the Federal Reserve Board (FED), European Central Bank (ECB), and Bank of England (BOE) announced new asset purchase programs worth billions (Rachid et al., 2022). Consequently, debt levels increased to new highs which makes it important to research this new trend and its effects. Norway on the other side only introduced policy rate cuts and did not include QE as one of its monetary policies. This presents a unique opportunity to research how foreign QE announcements influence a market and an economy which does not engage in QE measures.

Most studies so far have focused on the main economic markets and frequently traded currencies such as USD, EUR, GBP, and Japanese YEN (Bernanke & Mihov, 1998; Bonser-Neal & Tanner, 1996; Kenourgios et al., 2015). We do not observe many studies that focus on smaller open economies. However, small open economies with independent currencies that trade with these major economic players might be as much if not more affected by foreign monetary policy announcements because their economy is highly influenced by exchange rate volatility. Bjørnland (2008) found a strong interdependence between monetary policy and exchange rates in small open economies focusing on Norway and its inflation-targeting policies. However, it has not been researched if external monetary policy shocks such as quantitative easing announcements by foreign countries will have a similar effect on exchange rates and macroeconomic variables. We aim to fill this gap in the literature with this study by focusing on the transmission of volatility around foreign QE announcements.

Moreover, we do not see many studies that have researched exchange rate volatility transmissions in recent years. Kenourgios et al. (2015) tested volatility transmission between the EUR, GBP, and YEN using data from 2009-2012. To our knowledge, there have not been any studies that use data from recent years. QE measures are a tool used by central banks especially during times of financial crisis. QE was heavily introduced during the financial crisis in 2008 and we observe a similar pattern during the financial crisis caused by the COVID-19 pandemic. This presents an interesting new data set that has not been fully researched yet.

Therefore, we want to investigate how the FX market reacted to changes in monetary policies during the COVID-19 pandemic. Our research paper is split into three parts. The first part aims to estimate the intraday exchange rate volatility, for the second part we study the volatility transmission between exchange rates and investigate in how far this transmission is affected by QE announcements, and lastly, the third part will identify if these assumed effects on the FX rates have a measurable impact on the economy.

We are applying methodology used by Kenourgios, Papadamou, and Dimitriou (2015) and Bjørnland (2009) in a unique way to investigate the relationship between monetary policy announcements, FX rate volatility, and macroeconomy.

We use an A-PARCH model introduced by Ding et al. (1993) to estimate intraday volatility, focusing on the Norwegian foreign exchange market. Using this intraday volatility, we will create dummy variables to test the effect of QE announcements on the FX rate as well as the transmission into other FX rates. Additionally, we want to use a VAR model to estimate how this transmission around policy announcements in the Norwegian FX market influenced the Norwegian economy. This additional part will enable us to link our findings to existing literature about Dornbusch's overshooting model by presenting a new angle. We test if we observe a similar pattern of economic and exchange rate movements that Dornbusch's theory predicts. Thereby we are linking the influence of foreign monetary policy shocks on Norway's economy through exchange rate fluctuations in our research.

This paper will continue as follows. First, we will give a more complete overview of the underlying theory and previous literature that has been conducted, secondly, we will present our hypotheses and our expected results, thirdly we will describe the methodology applied in this paper and the data used, finally, we will present and analyse our result.

Theory and Literature Review

Causes and Effects of exchange rate volatility

Several theories and empirical studies explain exchange rate volatility as a risk associated with unexpected movements. To properly explain currency fluctuations has been difficult for decades, but economic fundamentals such as interest rate, inflation, and trade are sources of exchange rate volatility as well as macro news when considering very short-term volatility. Huang (1981) looks at the relationship between exchange rates and a long average of money stocks differentials. He observes that exchange rate volatility may be inconsistent with models like interest rate parity and efficient market, by testing i) the property of implied variance bounds for exchange rate movements, and ii) the forecastability. The results show that unstable exchange rates are mainly caused by unstable underlying economic conditions governing international trade. Exchange rates are too volatile to be consistent with monetary models or an efficient market. Recent research has found that unpredicted events play a role when predicting exchange rate volatility. Sharma et al. (2019) find support for an increase in exchange rate volatility and government shutdown during the COVID-19 pandemic. Similarly, Feng et al. (2021) illustrate that the spread of COVID-19 does significantly raise the exchange rate volatility. Bonser-Neal & Tanner (1996) and Dominguez (1998) suggest in their studies that Central Bank intervention operations in general increase exchange rate volatility, in the event of the intervention not being secret.

Monetary Policy

Monetary policy tends to have multiple objectives using various tools available to the central banks. One of the most prominent examples is the dual mandate by the Federal Reserve which aims to stabilize prices to keep inflation around a 2% target and to achieve maximum employment (Federal Reserve, 2021). Monetary policy decisions have major effects on the economy, however, as it can be difficult to achieve all targets simultaneously, there is a disagreement in the literature if monetary policies are, in fact, stabilising the economy or if they are the cause for volatility and fluctuations (Mankiw, 1994).

Many economists have tried to explain the theoretical relationship between monetary policy and its effect on the economy. One of the most influential theories was the General Theory of Employment, Interest, and Money by Keynes in 1936 (Keynes, 2008). Keynes agreed that monetary policy can stabilise the economy by shifting the aggregate demand curve, and furthermore, he argued that the effectiveness of monetary policy depends on interest rate elasticity, meaning the rate at which the interest rate falls if money supply is increased (Fender, 2012). Another salient economic theory worth mentioning was the Phillips curve, developed in 1958 as a response to Keynes's model. This model developed by Phillips mentions a trade-off between wage inflation and maximum employment because the two variables have an inverse relationship (Fender, 2012). Therefore, monetary policy should aim to find the perfect combination of both. This theory was heavily criticized by Friedman in his book The Role of Monetary Policy (Broten & Collins, 2017). Friedman believed this did not take into account the difference between real and nominal values as people change behaviours when prices change, and therefore, the Phillips Curve can hold in the short run but will reverse in the long run. His idea of optimal monetary policy was to provide a steady money base for the economy to avoid unexpected shocks and to manage expectations by increasing money supply at a constant rate (Broten & Collins, 2017). All of these economic theories have influenced the monetary policies used in their era heavily, showing that monetary policy is not as fixed as it might sometimes seem but is changing drastically over decades.

However, the previously mentioned economic theories are based on closed economies. To study the effect of monetary policy in the modern world, one also needs to take into account that countries have open economies as we observe a growing interdependence of countries (Bain & Howells, 2009). Most monetary policies have domestic targets, but with the increase in global capital movements, the link between monetary policy and exchange rates has become more important (Cottarelli & Baliño, 1987). One of the most well-known theories that considers that economies are open and aims to explain the relationship between monetary policy and exchange rates is Dornbusch’s overshooting model. The model expects real exchange rates to depreciate in the long run as a response to a sudden but permanent increase in money supply, furthermore, the model predicts that the exchange rate will overshoot as an immediate response to the money supply shock and then will appreciate back to its new equilibrium model (Dornbusch, 1976). The same reaction of exchange rates was also found in a later model developed by Galí and Monacelli in 2005 (Galí, 2008). This strong relationship between monetary policy and exchange rates leads to the rapid transmission of macroeconomic shocks between countries, creating spillover effects (Bain & Howells, 2009).

Dornbusch’s Overshooting Model

The overshooting model argues that the foreign exchange rate will temporarily overreact to changes in monetary policy to compensate for sticky prices of goods in the economy (Hayes, 2022). Eichenbaum & Evans (1995) investigated the effects of shocks to U.S. monetary policy on exchange rates. They find a link between monetary policy and exchange rates. A contractionary shock to U.S. monetary policy leads to i) significant appreciations in U.S. nominal and real exchange rates and ii) deviations from UIP in favor of U.S. interest rates. This indicates that the U.S. dollar exhibits a “delayed overshooting” pattern compared to what the overshooting model predicts.

In the 2000s, Kalyvitis & Michaelides (2001) re-examined Eichenbaum and Evans´ research by using a new indicator of monetary policy developed by Bernanke and Mihov (1998). This indicator takes into account changes in the U.S. monetary policy targets. The researchers found the opposite effect of Eichenbaum and Evans, where the “delayed overshooting” is eliminated, and the U.S. dollar appreciates instantaneously, which is much closer to the classic overshooting pattern developed by Dornbusch. This finding is supported by the research of Bjørnland (2009), who finds support for the Dornbusch overshooting model to hold and to be consistent with UIP.

Effects of Monetary Policy on the FX Market

The effects monetary policy has on the FX market depend on which type of monetary policy is used. Expansionary monetary policy will increase the money supply, lower interest rates, and increase demand which causes the domestic currency to depreciate. This also means that if a country is heavily dependent on exports, it will suffer a loss from currency depreciation. On the other hand, contractionary monetary policy aims to decrease the money supply and works opposite to expansionary monetary policy. A lot of research has been done into the impact of monetary policy on exchange rates, but the findings seem to draw different conclusions. The results of Clarida, Gali, J., & Gertler (2002) find that the impact of monetary policy shocks on exchange rates can be relatively small and short-lived, while Gould & Kamin's (2000) study of the impact of monetary policy on the exchange rate during the financial crisis in Asia leads them to two possibilities. Either that monetary policy has no effect on the exchange rate, or that it systematically impacts the exchange rate, but only slowly and over a long-time horizon. Similarly, Dilmaghani & Tehranchian (2015) find support that monetary policy has an impact on the exchange rate over time. While Yang & Zhang (2021) finds support for instant exchange rate appreciation of the exchange rate on both conventional and unconventional monetary policy shocks during the 2008 financial crisis and the recovering period. Likewise, studies that look at small open economies find support for Dornbusch´s exchange rate overshooting hypothesis prediction where an immediate exchange rate appreciation accurse as a response to contractionary monetary policy shocks (Bjørnland, 2008; Kim & Lim, 2018).

Effectiveness of Monetary Policy Announcements

There has been a lot of research on the effectiveness of conventional monetary policy announcements. However, the results of this research are not consistent and provide different findings. Some empirical findings indicate that monetary policy is less effective when uncertainty is high (Aastveit et al., 2013) and less powerful in recessions (Tenreyro & Thwaites, 2016). On the other hand, Abbassi and Linzert (2012) find support for Central Banks having effective tools to manage monetary policy in times of crisis.

Quantitative Easing

Conventional monetary policies focus on changing the rate of interest the central bank pays on reserve balances that other banks hold at the central bank. However, as the financial structure is getting more complex, central banks started to use unconventional monetary policies such as quantitative easing. Quantitative easing is a monetary policy tool for which the central bank purchases securities or assets on the open market, such as government or corporate bonds (Rasure, 2022). The first significant use of quantitative easing was during the financial crisis in 2008 in order to stabilize the market by providing liquidity (Heise, 2019). However, the effect of quantitative easing on the economy is still being researched. Some argue that it is a useful additional tool to mitigate crises (Fender, 2012), whereas others argue that it needs to be used with consideration because it can also cause rising wealth inequality and lower retirement incomes (Heise, 2019).

Effects of Quantitative Easing

What impacts and how fast exchange rates react to news depend primarily on timing and characteristics. Andersen, Bollerslev, Diebold & Vega (2003) show that conditional mean adjustments of exchange rates to news occur quickly, effectively amounting to “jumps”. On the other hand, conditional variance adjustments are more gradual. The study finds that bad news has a greater impact than good news and that the most considerable exchange rate changes occur within ten seconds of a macroeconomic news announcement.

Kenourgios, Papadamou & Dimitriou (2015) examine the effects of QE announcements by the European Central Bank, the Bank of England, and the Bank of Japan on exchange rate volatility. They find a positive volatility transmission across EUR, JPY, and GBP and from EUR and JPY to the other currencies during the sample period (3 years). In contrast, GBP affects other volatilities negatively.

Lin, Ouyang & Zhang (2020) investigated the influence of macro news on the exchange rate volatilities of BRICS countries by dividing the sample period into three sub-samples according to the QE policy (pre-QE, QE, and post-QE). Their findings advocate that the news has an essential role regarding volatility. Moreover, the study shows that negative macro news has a greater impact on volatility. The highest explanation power is during the fluctuating QE time, which explains the short-term volatilities during different time periods.

Effect of exchange rate volatility on the Economy

Exchange rate volatility, which is defined as risk associated with unexpected movements in the exchange rate, affects the economy in many ways, including international trade, exports, prices, and economic growth. The debate among researchers on whether exchange rate volatility impacts international trade flow and economic growth is still ongoing. Literature reviews from the 60s until the early 2000s argued that the impact of exchange rate volatility on trading flows is mixed (Ozturk, 2006). Considering research done in modern times, results are still mixed. Whereas some researchers find that the volatility has a significant impact on economic growth, Barguellil et al. (2018), Latief & Lefen (2018), and others argue that it depends on the country's development of forward markets and how they benefit from it with respect to the exchange rate volatility (Viaene & de Vries, 1992), while Tenreyro (2007) finds support for no affection at all. Among those who find support for exchange rate volatility having a significant impact on economic growth, they all seem to agree that the effect of volatility depends on the regimes the country is following, economic openness as well as if the country is a developing or emerging country. However, research done so far has not focused on developed countries and the impact of exchange rate volatility on their trade flow and economic growth. We aim to test which effect exchange rate volatility has on the FX market and economy of a developed country.

Hypotheses

In this paper, we want to test in how far unconventional monetary policies, such as Quantitative Easing, affect the Norwegian exchange rate and economy. To test this, we want to study the reaction of the Norwegian exchange rate volatility to foreign QE announcements as well as the response of the Norwegian economy to increases in exchange rate volatility.

We expect that monetary policy announcements will have a considerable impact on exchange rates and exchange rate volatility. This expectation is supported by various researchers (Bjørnland, 2008; Dilmaghani & Tehranchian, 2015; Kim & Lim, 2018; Yang & Zhang, 2021). However, there has been contradictory evidence on whether this effect will increase or decrease exchange rate volatility or have any impact at all (Clarida et al., 2002; Gould & Kamin, 2000).

This paper studies the effect of QE announcements on exchange rate volatility. Firstly, this paper aims to add to the existing literature by examining the direct effect of QE announcements on the corresponding exchange rate. Based on previous literature, we expect to see an increase in exchange rate volatility around QE announcements.

1. The announcements of the use of unconventional monetary policies such as QE cause an increase in exchange rate volatility.

Most QE announcements made by central banks are introduced during financial crises with the intention of stabilising the market. Based on the reasoning, we expect to see a decrease in exchange rate volatility due to a stabilisation of the economy. Nevertheless, based on evidence from previous research (Andersen et al., 2003; Lin et al., 2020), we expect to see an increase in volatility around QE announcements due to an overshooting effect of exchange rates to a monetary policy shock.

Moreover, in this paper, we want to investigate the transmission of exchange rate volatility between exchange rates around QE announcements. We believe that QE announcements will not only increase the directly related exchange rate volatility but furthermore increase indirectly related exchange rate volatility as well.

2. QE announcements have an indirect impact on the international FX market by creating a positive volatility transmission into unrelated exchanges rates

The global FX market is highly interconnected. Therefore, we assume that big monetary policy decisions by major economic players such as the United States, England, and the Eurozone will influence the volatility of uninvolved exchange rates, which means that an important QE announcement in the United States might not only influence the USD/NOK exchange rate but also influences indirectly related exchange rates such as EUR/NOK and GBP/NOK. We would expect to see a similar result for part of our study compared to the test for our first hypothesis. A QE announcement of a foreign country will not only increase the volatility between itself and Norway but also between Norway and other foreign countries. The theory of financial market interconnectedness and spillover effects supports this expectation, as it suggests that shocks or policy actions in one market can transmit and impact other markets through various channels. In other words, this theoretical framework states that changes in one country's financial conditions or policies can spill over to other countries through interconnected financial markets (Forbes &

Rigobon, 2002; Obstfeld & Taylor, 2004). We will test this assumption with a panel regression using dummy variables.

Lastly, we study the effect of exchange rate volatility on the economy. Especially in a country like Norway, which economy is heavily dependent on its exchange rate, it is likely that an increase in exchange rate volatility will affect the economy significantly.

3. QE announcements can affect a country's economy through an increase in exchange rate volatility

For the third part of our study, we expect that foreign QE announcements will also impact the Norwegian economy. We will test in how far the Norwegian economy reacts to shocks to the exchange rate volatility. Following our expected results from Hypothesis 1 and 2, we expect that QE announcements will increase exchange rate volatility. To be consistent with these expectations, we would expect to see that this increase in volatility will severely impact the Norwegian economy as well. Norway's economy is highly dependent on its exchange rate; therefore, we would expect to see that a shock to exchange rate volatility will cause a weakening of the Norwegian economy. Based on previous papers (Bjørnland, 2009; Kalyvitis & Michaelides, 2001), we have seen that exchange rates tend to overshoot and stabilise in the long term at a new equilibrium. We expect to see a similar pattern in our study compared to Dornbusch's overshooting model because of the economic variables we are using in our study. Variables such as inflation (CPI), GDP, and interest rates all impact the volatility term. We will test this hypothesis using a VAR model in the third part of this paper.

Methodology

For our study, we want to test how strongly QE announcements during the pandemic affected the intraday volatility of the FX market and if these QE announcements influenced the Norwegian krone and economy. To test this, we will adapt approaches used by Kenourgios et al. (2015) and Bjørnland (2009) to fit our data and add a new unique methodology approach using a VAR.

Our methodology will consist of three main parts. Our first part focuses on testing the intraday volatility of each currency using an asymmetric power ARCH (A-

PARCH) model. In the second part, we research the transmission effect of QE announcements between currencies using dummy variables. The final part will link our results to one of the most prominent theories about exchange rate volatility and monetary policies, Dornbusch's overshooting theory (Dornbusch, 1976). In our third part, we want to study if the Norwegian economy reacts accordingly to the overshooting theory after there has been a shock to its exchange rate. Thereby, we want to test whether monetary shocks in foreign countries have explanatory power to explain the exchange rate movement. To test this theory, we will use a structural VAR model.

We want to focus on some of the most frequently traded and important currencies for trade in Norway: US Dollar, Euro, and the British Pound. Due to the large number of QE announcements during the pandemic and the time constraint on the thesis, we want to focus on announcements between January 2020 and December 2022. In this three-year period, we will gather data and focus on all QE announcements made by the FED, ECB, and BOE. The three central banks have made 92 total announcements concerning QE, which our study will be centred around. We will then estimate the volatility between the three exchange rates (USD/NOK, EUR/NOK, and GBP/NOK).

Part I

For the first part of our study, we will estimate the volatility of each currency using an A-PARCH model, which was introduced by Ding, Granger, and Engle (1993). The A-PARCH model is better suited than the general ARCH model because it can capture the leverage effect. In previous literature, there is some evidence that volatility can change differently to negative or positive news, leading to an asymmetric response (Andersen et al., 2003). Therefore, we will use the A-PARCH model to account for these differences shown in equation (1).

$$\sigma_t^\delta = \omega + \alpha_1(|\varepsilon_{t-1}| - \gamma\varepsilon_{t-1})^\delta + \beta_1\sigma_{t-1}^\delta \qquad \text{where} \qquad (1)$$

$$\varepsilon_t = \sigma_t e_t, \qquad e_t \sim N(0,1)$$
$$\omega > 0,$$
$$\delta \geq 0,$$
$$-1 \leq \gamma \leq 1$$

In the formula, γ will account for the leverage effect, δ is the Box-Cox power transformation of conditional standard deviation process parameter which linearizes non-linear models, and ε is the zero mean white noise parameter for the return equation.

Part II

For the second part of our study, we want to use an event study to test how the exchange rate volatility is affected by QE announcements. To do so, we will create dummy variables for different points in times around the QE announcements. We want to test (i) 1 hour before and after the announcement, (ii) 2 hours before and 1 hour after the announcement, (iii) 1 hour after the announcement, and (iv) 3 hours after the announcement. The dummy variables will be equal to one at those times and equal to zero otherwise. To test the effects of QE announcements on the intraday volatility, we will use the following formula:

$$\begin{aligned} \hat{h}_{i,t} = \delta_0 + \delta_1 \hat{h}_{i,t-1} + \delta_2 \hat{h}_{j,t-1} + \delta_3 dummy_{i,t-1} \hat{h}_{j,t-1} \\ + \delta_4 dummy_{j,t-1} \hat{h}_{j,t-1} + \delta_5 dummy_{i,t} + \delta_6 dummy_{j,t} + k_t \end{aligned} \quad (2)$$

We will use the estimated conditional variance of each currency from the first part of our study as our estimate for $\hat{h}_{i,t}$. We will test the regression for all three currency pairs (EUR/NOK, USD/NOK, and GBP/NOK). In the regression, we test $currency_i$ with its corresponding volatility $\hat{h}_i$ and dummy variable $dummy_i$ as well as the transmission from a different currency pair, $currency_j$ with its corresponding volatility $\hat{h}_j$ and dummy variable $dummy_j$. The regression tests in how far $currency_i$ and $currency_j$ are affected by both their own and the other currency's QE announcements.

In the regression δ_1 captures the first-order serial correlation in the regression because we found significant evidence from our first part by performing the Ljung-Box test that the data has severe serial correlation. δ_2 captures the volatility transmission of currency *j* to *i* over the entire sample period, δ_3 and δ_4 capture the volatility transmission at the tested point in times (i), (ii), (iii), and (iv) and, therefore, the indirect effect of the QE announcements on currency *j* and *i*, and δ_5 and δ_6 capture the direct effect of QE announcements on the currency *j* and *i*. Therefore, the second part of the study will help us understand in how far currencies are affected by other central banks and their QE announcements.

Part III

In addition to our first two parts, we want to understand if the exchange rate volatility in the Norwegian FX market also affects the Norwegian economy and if these effects follow the pattern of Dornbusch's overshooting theory. The theory suggests that a positive monetary shock will cause the exchange rate to appreciate in the short run but depreciate in the long run. Many scholars have used a VAR model to test Dornbusch's theory. We want to build on the approach used in the paper by Bjørnland (2009), who focused on exchange rates in Australia, Canada, New Zealand, and Sweden. Bjørnland (2009) finds evidence in her paper that the exchange rates react to monetary shocks indeed as such as Dornbusch's overshooting theory would predict. This finding is supported by Kearns & Manners (2006), who used intraday data in an event study, as well as Zettelmeyer (2004), who used daily data. All papers find a significant relationship between exchange rates and monetary policy. Using this strong evidence, we want to adapt our approach to focus on how the exchange rate volatility affects the economy. Previous papers have focused on the effect of interest rate shocks on the exchange rates and proved that Dornbusch's theory holds. We want to test how shocks to the exchange rate volatility affect the economy instead.

Therefore, our approach differs from Bjørnland's approach significantly in many ways. Firstly, instead of using quarterly data, such as Bjørnland did, we want to use daily data to examine the immediate effect of the exchange rate volatility shocks on the economy. This also allows us to have enough data points in our limited time period of only three years. Secondly, we want to focus on the economy's reaction to the exchange rate volatility. Bjørnland used the log difference in exchange rates, therefore focusing more on the changes in the level of the exchange rate compared to our focus on volatility shocks. Lastly, our study will focus purely on the Norwegian economy. We want to use a VAR model to study how exchange rate volatility shocks affect Norwegian macroeconomic variables in detail. Whereas Bjørnland's paper focused more on the effect of monetary policy shocks on the exchange rate, we will focus on the effect on the economy.

We will use the following variables to test our model: the log change in consumer price index (CPI), the log change in real gross domestic product (GDP), the Norwegian overnight weighted average (NOWA) interest rate (i), the log change in energy prices (E), and the exchange rate volatility calculated in part I ($\hat{h}_{i,t}$). The five variables form the vector $Z_t = [\hat{h}_{i,t}, GDP_t, CIP_t, i_t, E_t]$. We then run a VAR model on these variables with the lag order based on the Akaike Information Criteria. To interpret the data, we create impulse response functions for all variables to an implied shock to the exchange rate volatility.

Data

Part I

For the first part of our study, we will use data from Bloomberg. We use closing quotes for the intraday exchange rates from January 2020 to December 2022. We use hourly data for our research which provides us with between 19,154 to 19,237 observations for each currency pair. Each currency pair has a slightly different number of observations due to data points missing. Missing data points occur mainly around each region's public holiday to a varying extent. The most significant gap in data points is between GBP/NOK and EUR/NOK, with the latter missing 83 more data points. However, in the first part of our study, we are concerned with each currency pair's individual volatility, which is why we will use all the data points available for each to get the most accurate estimate. We use hourly data because it allows us to observe the immediate reaction of exchange rate volatility to QE announcements. Exchange rates tend to adapt quickly to news. Hence we want to use intraday data to capture this response. At the start and end of our research period, we observe the following rates for the three currency pairs USD/NOK, GBP/NOK, and EUR/NOK, presented in *Table 1*.

Table 1
Exchange Rate overview

The table reports the exchange rates of the three currency pairs investigated by this study at the beginning and at the end of the researched period as well as the number of observations in the period of 01.01.2020-31.12.2022.

	USD/NOK	**GBP/NOK**	**EUR/NOK**
Observations	19,184	19,238	19,155
01.01.2020	**8.7826**	**11.6487**	**9,8531**
(Time)	(19:00)	(18:00)	(00:00)
30.12.2022	**9.8038**	**11.8626**	**10.4994**
(Time)	(22:00)	(22:00)	(22:00)

Further, we also transform our closing prices into returns because we are more interested in the change in quotes rather than in the level. We use logarithmic differences to calculate the return using equation (3), with ret_t being the period's exchange rate return and $Close_t$ being the period's closing price.

$$ret_t = \ln(Close_t) - \ln(Close_{t-1}) \quad (3)$$

Part II

For the second part of our study, we gather the QE announcements from the official websites of the respective central bank, FED (Federal Reserve, n.d.), BOE (Bank of England, n.d.), and ECB (European Central Bank, n.d.). In total, there were 92 announcements made about QE. This includes the introduction of new QE programs, the continuation of existing QE programs, and the reduction or termination of QE programs. We use the time listed in the Bloomberg news portal as the time for each news announcement. *Table 2* presents an overview of the number of news announcements from each central bank.

Table 2
QE announcement data

The table reports details about the number of QE announcements made by the three central banks FED, ECB, and BOE.

	FED	**ECB**	**BOE**
Sample	01.2020-12.2022	01.2020-12.2022	01.2020-12.2022
Annoucements	34	28	30

We use the news announcement data to create dummy variables to run the regressions for part 2 of our research. To do so, we round every news announcement to the nearest hour and create the dummy variables correspondently. As mentioned above, each currency pair has different missing data points which cannot be ignored for the regressions. To avoid errors in the regressions, we exclude hours for which data is missing either for the volatility $\hat{h}_i$ or volatility $\hat{h}_j$ as defined in equation (2). *Table 3* presents the number of observations left after this data-cleaning process.

Table 3
Observations for regressions after data cleaning

The table reports details about the number of observations for each exchange rate after missing data has been excluded from the dataset. The exchange rates listed on the head of each column represents the response variables and are therefore equivalent for each currency pair's variance, whereas the exchange rates in each row represent the explanatory variable form the regression for each currency pair's variance.

	USD/NOK	EUR/NOK	GBP/NOK
USD/NOK	-	19,117	19,152
EUR/NOK	19,117	-	19,122
GBP/NOK	19,152	19,122	-

Additionally, we transform the conditional volatility measures in the first part of the study into conditional variance. The conditional volatility from part 1 is equivalent to standard deviation, therefore, we need to square our volatility as demonstrated in equation (4), with σ being the conditional volatility.

$$Var_t = \sigma_t^2 \tag{3}$$

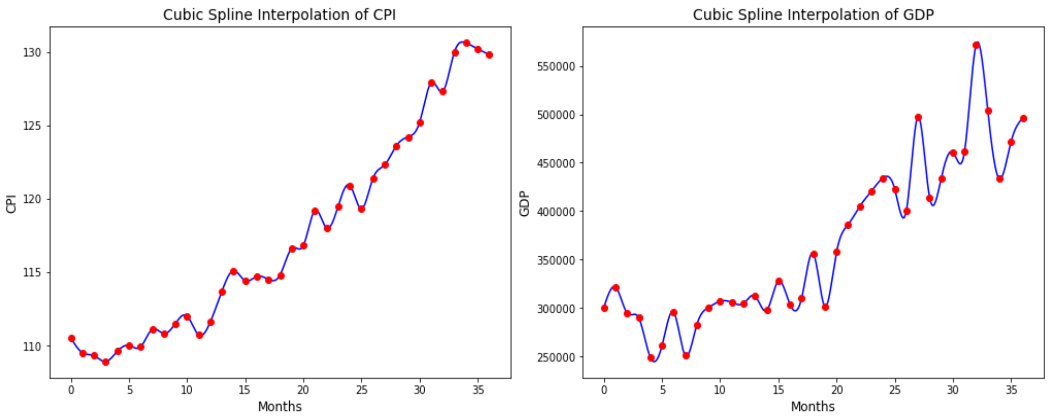
Our regression uses the first lag of the variance as well as a lagged dummy variable. Hence, we lose the first observation for each currency pair.

Part III

For the third part of our study, we use data from various sources, including Statistics Norway, Norges Bank, and Nord Pool. We find the consumer price index (CPI), the real gross domestic product (GDP), the domestic interest rate, and energy prices for Norway. We start by collecting monthly CPI data for Norway through Statistics Norway. CPI can be defined as the average cost of a consumption basket of goods per month. We also collect monthly data from the same source for Norway's GDP, which can be defined as the monthly value of all goods and services produced within Norway. Both CPI and GDP are only available in monthly frequencies, whereas our estimated volatility from part I is in hourly frequency.

To test how a shock to the exchange rate volatility affects macroeconomic variables such as CPI ad GDP in Part III, we need to adjust both variables to the same time frequency. We decided to turn our data into daily data. As macroeconomic variables tend to react slower to shocks and changes, this still allows us to be able to test the immediate response of these variables to volatility shocks. To convert our estimated exchange rate volatility from hourly data to daily data, we calculate the daily mean value. We use cubic spline interpolation to convert the CPI and GDP data from monthly into daily data. Research scholars have used cubic spline interpolation to turn economic data such as GDP and CPI into higher frequencies. It has been used to convert both annual and quarterly data into monthly data by various researchers with robust results supporting this method (Ajao et al., 2012; Wu & Turvey, 2021). Previous research, therefore, gives us confidence to use this methodology to convert the monthly CPI and GDP into daily data. Cubic spline interpolation connects each data point with a smooth curve to the next one. *Figure (1)* visualizes how the CPI and GDP data points are connected. We then extract the daily data from the curve of the cubic spline interpolation and create logarithmic differences to focus on the change in economic data rather than the level.

Figure 1 - *Cubic Spline Interpolation of the Norwegian Consumer Price Index (CPI, left), and the Gross National Product (GDP, right) from monthly data to daily data during the period of 01.01.2020-31.12.2022. In both graphs the X-axis is equivalent to the 36 months between January 2020 and December 2022, with 0 being equivalent to January 2020.*



Further, we want to include the Norwegian interest rate in our VAR. We collect the interest rate data from Norges Bank. We define the domestic interest rate as the daily Norwegian Overnight Weighted Average (NOWA) rate, which has been published by Norges Bank since 01.01.2020 when the timeframe for our study starts. As the NOWA rate is already available in daily frequency, we use the rate as it is.

Lastly, Nord Pool provided us with daily energy prices from Norway for the timeframe of our study. We use the logarithmic differences in daily energy prices of the NO2 region, which presents the energy prices for Southern Norway. According to the RME Report published in 2022 (Langset & Nielsen, 2022), the NO2 region in Norway engages in the highest level of importing and exporting energy to Europe (Denmark, Germany, Netherlands, and the United Kingdom). Hence, we consider this region to be mostly influenced by exchange rate volatility.

Results and Analysis

Part I

Intraday Conditional Volatilities

For the first part of our study, we run an AP-ARCH (1,1) model on each currency pair. The goal is to estimate the volatility in each foreign exchange rate. After running the AP-ARCH (1,1) model for all three currency pairs, we noticed that for two of the exchange rates, Gamma (γ) was insignificant. γ measures the leverage term and, therefore, the asymmetric response to good and bad news in the exchange rate. Following the paper by Kenourgios et al. (2015) and others, we expected to find a similar asymmetric response to news in our data, however, the model suggests that only the USD/NOK exchange rate shows an asymmetric response. Therefore, we decided to exclude the leverage term γ from the EUR/NOK and GBP/NOK model to avoid a biased model by including insignificant terms. Excluding the asymmetric term from the asymmetric power ARCH model leaves a power ARCH (P-ARCH) model. The models seem to be robust as almost all coefficients are highly significant with robust covariance estimators and no serial correlation. *Table 5* summarizes the results from the AP-ARCH (1,1) and P-ARCH (1,1) for each exchange rate.

Table 5
Estimation results of AP-ARCH (1,1) and P-ARCH (1,1) model

The table presents the results from the AP-ARCH (1,1) model following equation $\sigma_t^\delta = \omega + \alpha_1(|\varepsilon_{t-1}| - \gamma\varepsilon_{t-1})^\delta + \beta_1\sigma_{t-1}^\delta$ for each currency pair. The equation estimates the intraday volatility σ_t^δ on an hourly basis. Alpha and Beta represent the ARCH and GARCH parameter respectively, Delta represents the Box-Cox power transformation parameter, and Gamma represents the leverage term. Underneath each parameter is its corresponding t-statistic. *, **, and *** illustrate the significance level of the parameter at 10%, 5%, and 1% respectively.

	USD/NOK	**EUR/NOK**	**GBP/NOK**
Model	AP-ARCH	P-ARCH	P-ARCH
Omega	**4,5640e-04***	**5,7715e-03**	**6,3510e-03***
(t-stat)	*(1,923)*	*(1,433)*	*(2,832)*
Alpha	**0,0337***	**0,2581***	**0,3365***
(t-stat)	*(5,847)*	*(5,407)*	*(15,597)*
Beta	**0,9595***	**0,6821***	**0,5715***
(t-stat)	*(90,831)*	*(10,732)*	*(27,165)*
Delta	**1,8023***	**1,5541***	**1,7025***
(t-stat)	*(4,446)*	*(6,323)*	*(10,198)*
Gemma	**-0,1573***	n.a	n.a
(t-stat)	*(-2,327)*	n.a	n.a

Using the parameters from *Table 5*, we find the conditional volatility. *Figures (2), (3), and (4)* show the development of the conditional volatility over time, whereas *Table 6* summarizes key statistics for each exchange rate's volatility. The USD/NOK exchange rate seems to be the most stable rate with a low standard deviation and a very low range in rates. The EUR/NOK exchange rate has the most extensive range in rates due to having the largest spike at the beginning of Covid-19 at the start of 2020. Both the EUR/NOK and the GBP/NOK have a much larger spike during the beginning of the coronavirus pandemic, suggesting that the USD/NOK exchange rate was not impacted as much as the other two. However, with a larger mean volatility compared to the one from the EUR and GBP rate, one might argue that the US rate has a higher constant volatility but reacts less to news. Differences in the monetary policy regimes pursued by the central banks of the respective countries can contribute to varying responses to news. For instance, the FED may prioritize stability in interest rates, leading to relatively higher constant volatility. On the other hand, the ECB and the BOE may have different policy objectives or approaches that result in differing reactions to economic news. Another interesting observation is that the GBP/NOK rate has a second significant spike, as can be seen in *Figure (4)*, in the middle of 2022. The two spikes explain the higher standard deviation compared to the other two rates and were likely caused by the UK government crisis from July to October 2022 following the resignation of former prime minister Boris Johnson.

Figure 2 - *USD/NOK hourly exchange rate volatility from the 01.01.2020-31.12.2022. The X-axis shows the number of observations (19,184) where each data point is equivalent to our hourly observations from January 2020 to December 2022. Therefore, 0 on the axis is equivalent to the 01.01.2020 19:00.*

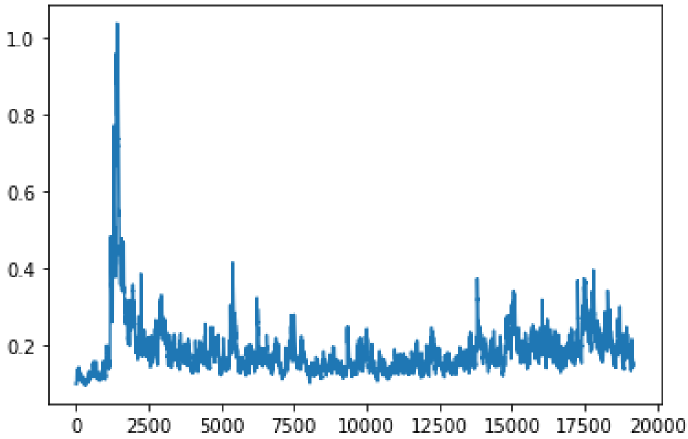


Figure 3 - *EUR/NOK hourly exchange rate volatility from the 01.01.2020-31.12.2022. The X-axis shows the number of observations (19,155) where each data point is equivalent to our hourly observations from January 2020 to December 2022. Therefore, 0 on the axis is equivalent to the 01.01.2020 00:00.*

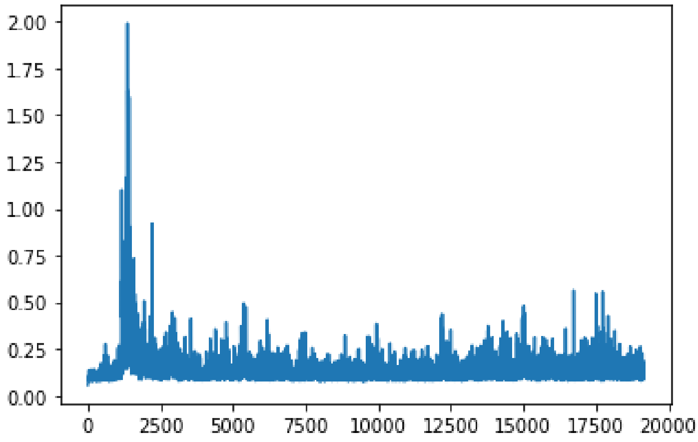


Figure 4 - *GBP/NOK hourly exchange rate volatility from the 01.01.2020-31.12.2022. The X-axis shows the number of observations (19,238) where each data point is equivalent to our hourly observations from January 2020 to December 2022. Therefore, 0 on the axis is equivalent to the 01.01.2020 18:00.*

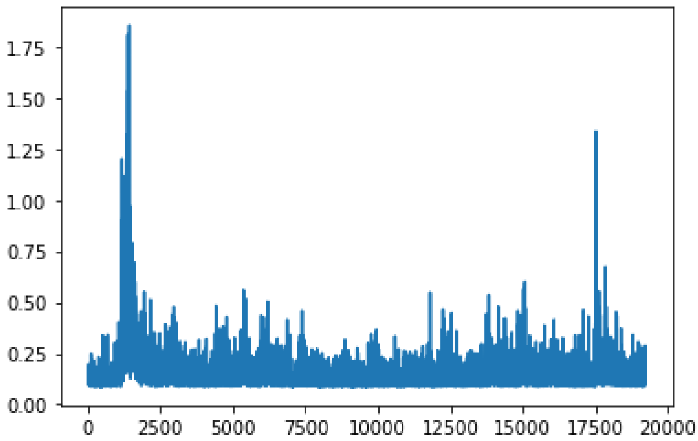


Table 6
Summary statistics of conditional volatilities

The table reports the summary statistics for each exchange rate's conditional volatility. This includes the conditional volatility's mean, standard deviation, minimum value, and maximum value for the period of 01.01.2020 -31.12.2022.

	USD/NOK	EUR/NOK	GBP/NOK
Mean	0,1836	0,1387	0,1476
Std.	0,0765	0,0762	0,0826
Min	0,0954	0,0572	0,0854
Max	1,0355	1,9902	1,8538

Non-asymmetric responses to news

Our estimated model suggests that only the USD/NOK exchange rate shows an asymmetric response. Since the model also suggests that the US rate has a higher constant volatility, one may argue that, in practice, it should be the opposite. The exchange rate involving the USD may exhibit a potentially stronger reaction to news, which in our case, is the USD/NOK exchange rate. Our finding differs from Omrane & Savaşer (2017), who find proof that the currency market reaction to FEDs rate news is larger in crisis, which indicates a symmetric response. However, we find some support for an asymmetric response for exchange rate involving the USD in Galati & Ho’s (2003) study, where they find support for asymmetric response in EUR/USD exchange rate but to different extents at different times.

Furthermore, our model does not find asymmetric responses to news in EUR/NOK and GBP/NOK exchange rates. While the leverage effect adds a reasonable explanation for asymmetry in the stock market, there is not much theoretical justification for its presence in the exchange market. Some studies can document the presence of asymmetry in the exchange market but with no apparent economic reason behind its appearance (McKenzie, 2002). A limited body of research on the NOK compared to other currencies requires an extensive exploration of the theoretical frameworks to understand the absence of asymmetry response to news. A theoretical perspective can provide valuable insights into this phenomenon, and we can develop a more comprehensive understanding.

One such theory is the Optimum Currency Area (OCA) theory developed by economist Robert Mundell (1961). According to the OCA framework, regions within the union should have similar economic structures and responses to shocks for a currency union to function effectively. We consider the eurozone as an optimum currency area which implies that the economic developments and news affect member countries in a relatively uniform manner. In the context of the NOK, the absence of asymmetry in its response to news could be explained by the high degree of economic integration among the eurozone countries, including Norway. Therefore, leading to a more symmetric response in the EUR/NOK exchange rate.

Additionally, the Efficient Market Hypothesis (EMH) (Fama, 1970) provides us with another theoretical perspective. This theory suggests that financial markets quickly incorporate available information into prices, leading to comparatively symmetric adjustments to news. Consequently, if the market for EUR/NOK is efficient and market participants have access to the same information, this would lead to a more symmetric response to news.

Incorporating these theories into our study allows for a deeper analysis of the absence of asymmetry in these two exchange rates' responses to news. Since empirical studies on especially the NOK may be limited, the theoretical framework contributes a groundwork for a better understanding of the underlying dynamics of the absence of asymmetric response.

Further, we want to shed light on some possible explanations for non-asymmetric response in GBP/NOK. There is a possibility that Norway and the United Kingdom share similar macroeconomic factors, which may contribute to a relatively symmetric reaction to news in their respective exchange rates. Furthermore, the economic relationship between the two countries is characterized by a balanced nature, lacking significant asymmetries. Notably, the United Kingdom holds a prominent position as one of Norway's key export markets, while British companies play a substantial role as major foreign investors in the Norwegian Stock Exchange (Griffiths, 2001)**.**

Part II

Below, *Table 7*, *Table 8*, and *Table 9* show the results of running *equation (2)* for GBP/NOK, EUR/NOK, and USD/NOK, respectively. We tested the volatility transmission between currencies as well as the volatility transmission, especially around QE announcements made by the corresponding central banks. In general, we see a strong positive volatility transmission between currencies. This means that an increase in exchange rate volatility in *currency i* correlates to an increase in volatility in *currency j*. However, we do not experience the same reaction for all currency pairs around QE announcements. QE announcements made by the BOE or the FED seem to have primarily an immediate stabilizing effect on exchange rate volatility. In contrast, QE announcements by the ECB seem to cause a slightly delayed increase in volatility.

Effect of different monetary policies on exchange rate volatility

It is essential to understand the differences between FED´s, ECB´s, and BOE´s monetary policies as they may be factors that influence exchange rate volatility and the implications for global financial markets. These banks differ in their monetary policies due to varying economic conditions, institutional frameworks, and policy objectives, and they play central roles in managing monetary policies within their respective jurisdictions. The FED's main dual mandate focuses on price stability, keeping inflation around a 2% target and achieving maximum employment, as well as supporting economic growth (Federal Reserve, 2021), while the ECB has a primary objective of maintaining price stability within the eurozone. In contrast, the BOE aims to maintain price stability while supporting the government´s economic policy objectives, including sustainable growth and employment. Further, these banks operate with different monetary policy tools. The FED primarily utilizes open market operations and interest rate targeting, as well as quantitative easing during economic stress and crisis. At the same time, the ECB sets interest rates on refinancing operations and asset purchase programs (which include quantitative easing) and employs targeted longer-term refinancing operations (TLTROs) (European Central Bank, 2023). The key tools for BOE are bank rates and quantitative easing. Lastly, these banks differ in their economic conditions and policy approaches. The FED´s policy approach is influenced by data-dependent decision-making, where factors such as inflation, GDP growth, and employment are considered. The ECB manages monetary policy for countries within the eurozone, taking into account the economic conditions of the entire currency union. For the BOE, the policy decisions are influenced by economic conditions within the UK, where inflation, employment, and growth prospects are in focus. All these differences in policy objectives, tools, and approaches contribute to variations in the impact of monetary policy on exchange rate volatility. Market participants react to different policy signals, modifying their expectations accordingly, leading to divergent movement in exchange rates. The degree of policy coordination within each jurisdiction, together with economic conditions, further influence exchange rate volatility.

Stabilization effect of QE announcements by the Bank of England

Table 7 shows the results of exchange rate volatility transmission into the GBP/NOK exchange rate. Panel A focuses on the volatility transmission from the EUR/NOK exchange rate around BOE as well as ECB QE announcements, whereas Panel B highlights the results from the volatility transmission from the USD/NOK exchange rate around BOE and FED QE announcements. In Panels A and B, the positive significant *delta 2* shows a significant volatility transmission from both the EUR/NOK and the USD/NOK exchange rate into the GBP/NOK exchange rate.

Table 7
Results for effect on the GBP/NOK exchange rate volatility

The table presents the result from the following regression $\hat{h}_{i,t} = \delta_0 + \delta_1 \hat{h}_{i,t-1} + \delta_2 \hat{h}_{j,t-1} + \delta_3 dummy_{i,t-1} \hat{h}_{j,t-1} + \delta_4 dummy_{j,t-1} \hat{h}_{j,t-1} + \delta_5 dummy_{i,t} + \delta_6 dummy_{j,t} + k_t$ which aims to estimate the exchange rate variance $\hat{h}_{i,t}$. In the table the GBP/NOK exchange rate represents $currency_i$ with its corresponding variance $\hat{h}_{i,t-1}$, and the dummy variables $dummy_{i,t}$ which represent the dummy variables for the Bank of England at the giving time (-2h, +1h), (-1h. +1h), (+1h), and (+3h). Panel A: This panel tests the volatility transmission from the EUR/NOK exchange rate and the QE announcements made by the European Central Bank to the GBP/NOK exchange rate. Therefore, in Panel A the EUR/NOK exchange rate represents $currency_j$ with its corresponding variance $\hat{h}_{j,t-1}$. Panel B: This panel tests the volatility transmission from the USD/NOK exchange rate and the QE announcements made by the Federal Reserve Bank to the GBP/NOK exchange rate. Therefore, in Panel B the USD/NOK exchange rate represents $currency_j$ with its corresponding variance $\hat{h}_{j,t-1}$. Underneath each parameter is its corresponding t-statistic. *, **, and *** illustrate the significance level of the parameter at 10%, 5%, and 1% respectively.

Panel A: EUR-GBP

Coefficient	Variable	(-2h, +1h)	(-1h, +1h)	(+1h)	(+3h)
δ_0	**Constant**	**0,0050*** **	**0,0052*** **	**0.0052*** **	**0,0054*** **
	(t-stat.)	*(13,265)*	*(13,704)*	*(13,774)*	*(14,411)*
δ_1	$\boldsymbol{\hat{h}_{i,t-1}}$	**0,4331*** **	**0,4293*** **	**0,4348*** **	**0,4419*** **
	(t-stat.)	*(42,852)*	*(42,278)*	*(42,875)*	*(43,458)*
δ_2	$\boldsymbol{\hat{h}_{j,t-1}}$	**0,4468*** **	**0,4439*** **	**0,4335*** **	**0,4135*** **
	(t-stat.)	*(39,670)*	*(39,230)*	*(38,531)*	*(37,096)*
δ_3	$\boldsymbol{dummy_{i,t-1}\hat{h}_{j,t-1}}$	**-0,3021*** **	**-0,2779*** **	**-0,2656*** **	**-0,1915*** **
	(t-stat.)	*(-18,264)*	*(-15,174)*	*(-12,965)*	*(-5,026)*
δ_4	$\boldsymbol{dummy_{j,t-1}\hat{h}_{j,t-1}}$	**-0,2033** **	**-0,0807**	**0,0796**	**2,3628*** **
	(t-stat.)	*(-2,265)*	*(-0,714)*	*(0,432)*	*(14,970)*
δ_5	$\boldsymbol{dummy_{i,t}}$	**0,0455*** **	**0,0326*** **	**0,0872*** **	**0,0150* **
	(t-stat.)	*(7,201)*	*(5,131)*	*(9,739)*	*(1,670)*
δ_6	$\boldsymbol{dummy_{j,t}}$	**0,0024**	**0,0065**	**0,0145**	**0,0137**
	(t-stat.)	*(0,363)*	*(0,987)*	*(1,562)*	*(1,478)*
Adj. R^2		0,642	0,640	0,640	0,640

Panel B: USD-GBP

Coefficient	Variable	(-2h, +1h)	(-1h, +1h)	(+1h)	(+3h)
δ_0	**Constant**	**-0,0002**	**-0,0002**	**-0,0001**	**0,0005**
	(t-stat.)	*(-0,449)*	*(-0,424)*	*(-0,134)*	*(1,063)*
δ_1	$\boldsymbol{\hat{h}_{i,t-1}}$	**0,6877*** **	**0,6893*** **	**0,6903*** **	**0,6695*** **
	(t-stat.)	*(112,284)*	*(113,730)*	*(112,854)*	*(113,695)*
δ_2	$\boldsymbol{\hat{h}_{j,t-1}}$	**0,2266*** **	**0,2277*** **	**0,2214*** **	**0,2274*** **
	(t-stat.)	*(28,792)*	*(28,937)*	*(28,094)*	*(28,730)*
δ_3	$\boldsymbol{dummy_{i,t-1}\hat{h}_{j,t-1}}$	**-0,3999*** **	**-0,3114*** **	**-0,3293*** **	**-0,2961*** **
	(t-stat.)	*(-10,326)*	*(-8,034)*	*(-6,103)*	*(-5,499)*
δ_4	$\boldsymbol{dummy_{j,t-1}\hat{h}_{j,t-1}}$	**-0,2890*** **	**-0,4884*** **	**-0,5465*** **	**0,4474*** **
	(t-stat.)	*(-7,275)*	*(-12,261)*	*(-11,277)*	*(9,612)*
δ_5	$\boldsymbol{dummy_{i,t}}$	**0,0509*** **	**0,0340*** **	**0,0881*** **	**0,0164* **
	(t-stat.)	*(7,949)*	*(5,306)*	*(9,750)*	*(1,808)*
δ_6	$\boldsymbol{dummy_{j,t}}$	**0,0545*** **	**0,0494*** **	**0,0899*** **	**-0,0220** **
	(t-stat.)	*(9,051)*	*(8,195)*	*(10,595)*	*(-2,570)*
Adj. R^2		0,632	0,632	0,634	0,629

However, in Panel A, although there seems to be a significant volatility transmission between EUR/NOK and GBP/NOK, this transmission is not as evident around QE announcements made by ECB. *Delta 4* is only significant at a 1% level at 3 hours after the announcement. This shows that there is no immediate volatility transmission after the ECB makes a QE announcement but rather a delayed reaction that causes a substancial increase in exchange rate volatility 3h after. This differs significantly from the volatility transmission after BOE QE announcements. *Delta 3* is negative and significant at all times that were tested in this study. This suggests that QE announcements made by the BOE have a stabilizing effect on exchange rate volatility. This is supported by the significant effect of *Delta 5,* which shows that QE announcements by the BOE have a direct effect on the GBP/NOK exchange rate.

In contrast to Panel A, Panel B highlights a significant volatility transmission around QE announcements made by the BOE and by the FED. Both *Delta 3* and *Delta 4* and significant at all times. We can again observe a negative sign for *Delta 3,* which supports the stabilizing effect of BOE QE announcements that is also evident in Panel A. QE announcements made by the FED also seem to have a stabilizing indirect effect. However, 3h after the QE announcements by the FED, *Delta 4* turns positive, which suggests that although we see an immediate exchange rate stabilization after the announcement, the exchange rate volatility increases again shortly after. It is difficult to state a specific reason for the observed increase in exchange rate volatility after the initial stabilization following the FED QE announcement. However, it is possible that factors such as market expectations, global events, economic data releases, market sentiment, and speculative trading can influence the volatility transmission following the FED´s QE announcement. Market participants may initially react positively to the FED´s QE announcement and expect it to have a stabilizing effect on the economy and the exchange rate, as we see from our *Delta 4*. However, market expectations may adjust if subsequent economic data releases or central bank communications suggest a different economic outlook. This shift in expectations may lead to an increase in uncertainty and volatility. The paper by Bacchetta & Wincoop (2012) supports the concept of market expectations and their potential impact on exchange rates, as it examines the role of market expectations in the context of the global financial crisis, which can be linked up to the Covid19 crisis. Further, economic indicators such as GDP growth, inflation rates, or employment data can have a significant impact on exchange rates. If such data releases following the FED´s QE announcement indicate unexpected weakness or strength in the economy and can lead to a reassessment of the initial stabilization effect and influence exchange rate volatility. According to the theory of “news-based trading/information-based trading” in foreign exchange markets, market participants react to new information and adjust their trading accordingly, which can impact exchange rates and increase volatility (Fleming & Remolona, 1999; Sarno & Taylor, 2001).

Delayed response to QE announcements by the European Central Bank

Table 8 presents the results for the volatility transmission into the EUR/NOK exchange rate by both the GBP/NOK exchange rate and BOE QE announcements (see Panel A), as well as the USD/NOK exchange rate and FED QE announcements (see Panel B). A positive significant *Delta 2* in Panel A and B show that we find evidence of volatility transmission from both currency pairs into the EUR/NOK exchange rate.

Panel A shows the effect of the GBP/NOK exchange rate on the EUR/NOK exchange rate as well as the indirect and direct effect of this volatility transmission around QE announcements made by the BOE and ECB. Similar to the result found in *Table 7,* we find significant negative volatility transmission around QE announcements made by the BOE. This means that QE announcements made by the BOE do not only seem to stabilize the directly affected GBP/NOK exchange rate but also indirectly stabilize the EUR/NOK exchange rate. On the other hand, announcements made by the ECB are statistically insignificant until 3h after the announcements were made. This highlights the delayed response of the exchange rate to ECB announcements, which is also evident in *Table 7*. This means that ECB announcements seem to not immediately affect the EUR/NOK exchange rate but rather cause a delayed extreme increase in exchange rate volatility. It is also worth noting that the announcements made by the ECB do not have a significant direct impact on the EUR/NOK volatility noted by the insignificant *Delta 5,* which supports the lack of impact of the ECB announcements on the EUR/NOK rate.

Panel B shows a similar pattern to Panel A. A negative significant *Delta 4* highlights the indirect stabilizing volatility transmission around QE announcements made by the FED. This shows that QE announcements by the FED seem to not only stabilize the GBP/NOK exchange rate but also the EUR/NOK exchange rate. In Panel B, we see some significance around QE announcements made by the ECB.

Table 8
Results for effect on the EUR/NOK exchange rate volatility

The table presents the result from the following regression, $\hat{h}_{i,t} = \delta_0 + \delta_1\hat{h}_{i,t-1} + \delta_2\hat{h}_{j,t-1} + \delta_3 dummy_{i,t-1}\hat{h}_{j,t-1} + \delta_4 dummy_{j,t-1}\hat{h}_{j,t-1} + \delta_5 dummy_{i,t} + \delta_6 dummy_{j,t} + k_t$ which aims to estimate the exchange rate variance $\hat{h}_{i,t}$. In the table the EUR/NOK exchange rate represents $currency_i$ with its corresponding variance $\hat{h}_{i,t-1}$, and the dummy variables $dummy_{i,t}$ which represent the dummy variables for the European Central Bank at the giving time (-2h, +1h), (-1h. +1h), (+1h), and (+3h). Panel A: This panel tests the volatility transmission from the GBP/NOK exchange rate and the QE announcements made by the Bank of England to the EUR/NOK exchange rate. Therefore, in Panel A the GBP/NOK exchange rate represents $currency_j$ with its corresponding variance $\hat{h}_{j,t-1}$. Panel B: This panel tests the volatility transmission from the USD/NOK exchange rate and the QE announcements made by the Federal Reserve Bank to the EUR/NOK exchange rate. Therefore, in Panel B the USD/NOK exchange rate represents $currency_j$ with its corresponding variance $\hat{h}_{j,t-1}$. Underneath each parameter is its corresponding t-statistic. *, **, and *** illustrate the significance level of the parameter at 10%, 5%, and 1% respectively.

Panel A: GBP-EUR

Coefficient	Variable	(-2h, +1h)	(-1h, +1h)	(+1h)	(+3h)
δ_0	**Constant**	**0,0043*** **	**0,0043*** **	**0.0043*** **	**0,0042*** **
	(t-stat.)	*(12,740)*	*(12,928)*	*(12,934)*	*(13,321)*
δ_1	$\boldsymbol{\hat{h}_{i,t-1}}$	**0,7594*** **	**0,7587*** **	**0,7553*** **	**0,7547*** **
	(t-stat.)	*(76,044)*	*(75,876)*	*(75,892)*	*(80,872)*
δ_2	$\boldsymbol{\hat{h}_{j,t-1}}$	**0,0608*** **	**0,0588*** **	**0,0607*** **	**0,0534*** **
	(t-stat.)	*(6,762)*	*(6,531)*	*(6,753)*	*(6,266)*
δ_3	$\boldsymbol{dummy_{i,t-1}\hat{h}_{j,t-1}}$	**-0,0714**	**-0,0207**	**0,0358**	**4,9158*** **
	(t-stat.)	*(-1,149)*	*(-0,270)*	*(0,372)*	*(49,051)*
δ_4	$\boldsymbol{dummy_{j,t-1}\hat{h}_{j,t-1}}$	**-0,1342*** **	**-0,1319*** **	**-0,1304*** **	**-0,0800*** **
	(t-stat.)	*(-8,711)*	*(-7,391)*	*(-6,760)*	*(-3,264)*
δ_5	$\boldsymbol{dummy_{i,t}}$	**-0,0004**	**0,0023**	**0,0052**	**0,0082**
	(t-stat.)	*(-0,064)*	*(0,401)*	*(0,628)*	*(1,054)*
δ_6	$\boldsymbol{dummy_{j,t}}$	**0,0294*** **	**0,0258*** **	**0,0607*** **	**0,0003**
	(t-stat.)	*(5,232)*	*(4,579)*	*(7,643)*	*(0,046)*
Adj. R^2		0,658	0,657	0,658	0,695

Panel B: USD-EUR

Coefficient	Variable	(-2h, +1h)	(-1h, +1h)	(+1h)	(+3h)
δ_0	**Constant**	**-0,0003**	**-0,0004**	**-0,0003**	**0,0001**
	(t-stat.)	*(-0,935)*	*(-0,973)*	*(-0,878)*	*(0,409)*
δ_1	$\boldsymbol{\hat{h}_{i,t-1}}$	**0,7037*** **	**0,7042*** **	**0,7016*** **	**0,7119*** **
	(t-stat.)	*(120,870)*	*(120,881)*	*(120,484)*	*(151,027)*
δ_2	$\boldsymbol{\hat{h}_{j,t-1}}$	**0,1953*** **	**0,1953*** **	**0,1929*** **	**0,1661*** **
	(t-stat.)	*(27,366)*	*(27,338)*	*(27,031)*	*(28,468)*
δ_3	$\boldsymbol{dummy_{i,t-1}\hat{h}_{j,t-1}}$	**-0,1573*** **	**-0,1269** **	**-0,0831**	**6,9356*** **
	(t-stat.)	*(-2,699)*	*(-2,135)*	*(-0,962)*	*(97,947)*
δ_4	$\boldsymbol{dummy_{j,t-1}\hat{h}_{j,t-1}}$	**-0,1324*** **	**-0,1582*** **	**-0,2098*** **	**0,0335**
	(t-stat.)	*(-3,933)*	*(-4,688)*	*(-5,102)*	*(1,024)*
δ_5	$\boldsymbol{dummy_{i,t}}$	**-0,0003**	**0,0017**	**0,0044**	**0,0084**
	(t-stat.)	*(-0,050)*	*(0,306)*	*(0,549)*	*(1,279)*
δ_6	$\boldsymbol{dummy_{j,t}}$	**0,0357*** **	**0,0322*** **	**0,0649*** **	**-0,0035**
	(t-stat.)	*(6,884)*	*(6,192)*	*(8,863)*	*(-0,590)*
Adj. R^2		0,669	0,669	0,670	0,779

We see some indirect stabilizing volatility transmission at 2h before and 1h after the announcements, however, worth highlighting is the extremely positive *Delta 3* at 3h after the announcements. This finding suggests a very large increase in volatility transmission from the USD/NOK rate to the EUR/NOK rate at 3h after ECB QE announcements. The specific reason for this observation 3-hours after the ECB QE announcement may require further analysis and research. However, we are suggesting a few potential factors that could contribute to this pattern. According to the Market Microstructure theory, market participants process and incorporate information into their trading decisions. According to Market Microstructure theory (O'Hara, 1995), market participants process and incorporate information into their trading decisions. It is possible that at the 2-hour and 1-hour mark, there is an initial indirect stabilization effect as the participants digest the news. However, at the 3-hour mark, new information or revised market expectation could lead to a surge in volatility transmission from the USD/NOK rate to the EUR/NOK rate. This could happen if the participants reassess their position based on factors such as economic releases or other relevant information. Also, unforeseen events or news releases occurring around the 3-hour mark may affect and trigger increased volatility transmission. These factors could be unrelated to the ECB QE announcement but coincide with the timing, leading volatility to spike. An example of these factors could be political developments or global financial conditions. As already mentioned, this is a suggestion of potential factors, and it is important to state that various market factors can influence the specific dynamics of volatility transmission and may vary across time periods or economic contexts.

Delta 5 also remains insignificant in Panel B, while *Delta 6* shows some significance in Panel B as well as Panel A. This suggests that both QE announcements by the FED and BOE directly affect the EUR/NOK exchange rate, while announcements by the ECB have no direct impact. There are several potential explanations for this observation based on theoretical frameworks and empirical evidence. It is important to note that these explanations are speculative as there has not yet been much research and analysis specific to the EUR/NOK exchange rate. Firstly, there may be market differentiation as the market may differentiate between the impact of QE announcements by different banks. The ECB could have a more limited or indirect impact on the EUR/NOK exchange rate compared to the actions of the FED or BOE based on the perceptions of market participants. This differentiation could be driven by factors such as the size of the QE program, market expectations, or the effectiveness of the respective central banks´ policies. Secondly, the transmission channels through which QE announcements affect exchange rates may differ across central banks. We suggest that the FED and BOE may have stronger and more direct channels where their policies impact the EUR/NOK exchange rate, such as stronger trade. On the other hand, policies provided by ECB may have a more indirect and nuanced impact on the EUR/NOK exchange rate, potentially through spillover effects or broader market sentiment. Forbes & Chinn (2004) examined the decomposition of global linkages in financial markets over time, shedding light on the transmission channels that connect central banks' policies to exchange rates. Their analysis suggests that the transmission channels through which QE announcements affect exchange rates can vary across central banks. Their paper contributes to our understanding of how central bank policies influence exchange rates.

Significant effect of the FED's QE announcements

Table 9 shows the results of the volatility transmission from the GBP/NOK rate and the EUR/NOK rate to the USD/NOK rate. Panel A includes the volatility transmission of GBP/NOK to the USD/NOK exchange rate around QE announcements by the FED and BOE. Panel B presents the results from the volatility transmission from EUR/NOK rate to the USD/NOK exchange rate around QE announcements by the FED and the ECB. Both Panel A and B show a significant volatility transmission between exchange rates.

Panel A highlights that both QE announcements by the FED and BOE have a stabilizing effect on the USD/NOK exchange rate. *Delta 3* and *Delta 4* are significantly negative, which means that there is a negative volatility transmission around BOE and FED QE announcements from the GBP/NOK exchange rate to the USD/NOK rate. QE announcements by the BOE even seem to have an immediate direct impact on the USD/NOK exchange rate as *Delta 6* is significant at 1h after the announcement.

Panel B presents the results of volatility transmission from the EUR/NOK exchange rate to the USD/NOK exchange rate. Like the results in Panel A, we see a stabilization effect around QE announcements made by the FED. However, we only observe some indirect volatility transmission around ECB QE announcements.

Table 9
Results for effect on the USD/NOK exchange rate volatility

The table presents the result from the following regression, $\hat{h}_{i,t} = \delta_0 + \delta_1\hat{h}_{i,t-1} + \delta_2\hat{h}_{j,t-1} + \delta_3 dummy_{i,t-1}\hat{h}_{j,t-1} + \delta_4 dummy_{j,t-1}\hat{h}_{j,t-1} + \delta_5 dummy_{i,t} + \delta_6 dummy_{j,t} + k_t$ which aims to estimate the exchange rate variance $\hat{h}_{i,t}$. In the table the USD/NOK exchange rate represents $currency_i$ with its corresponding variance $\hat{h}_{i,t-1}$, and the dummy variables $dummy_{i,t}$ which represent the dummy variables for the Federal Reserve Bank at the giving time (-2h, +1h), (-1h. +1h), (+1h), and (+3h). Panel A: This panel tests the volatility transmission from the GBP/NOK exchange rate and the QE announcements made by the Bank of England to the USD/NOK exchange rate. Therefore, in Panel A the GBP/NOK exchange rate represents $currency_j$ with its corresponding variance $\hat{h}_{j,t-1}$. Panel B: This panel tests the volatility transmission from the EUR/NOK exchange rate and the QE announcements made by the European Central Bank to the USD/NOK exchange rate. Therefore, in Panel B the EUR/NOK exchange rate represents $currency_j$ with its corresponding variance $\hat{h}_{j,t-1}$. Underneath each parameter is its corresponding t-statistic. *, **, and *** illustrate the significance level of the parameter at 10%, 5%, and 1% respectively.

Panel A: GBP-USD

Coefficient	Variable	(-2h, +1h)	(-1h, +1h)	(+1h)	(+3h)
δ_0	**Constant**	**0,0002*** **	**0,0002*** **	**0.0002*** **	**0,0003*** **
	(t-stat.)	*(4,417)*	*(4,666)*	*(4,706)*	*(5,067)*
δ_1	$\boldsymbol{\hat{h}_{i,t-1}}$	**0,9816*** **	**0,9826*** **	**0,9820*** **	**0,9838*** **
	(t-stat.)	*(1018,502)*	*(1018,351)*	*(1020,490)*	*(1022,317)*
δ_2	$\boldsymbol{\hat{h}_{j,t-1}}$	**0,0165*** **	**0,0147*** **	**0,0153*** **	**0,0134*** **
	(t-stat.)	*(21,334)*	*(19,298)*	*(20,241)*	*(18,682)*
δ_3	$\boldsymbol{dummy_{i,t-1}\hat{h}_{j,t-1}}$	**-0,0198*** **	**-0,0115*** **	**-0,0181*** **	**-0,0228*** **
	(t-stat.)	*(-11,347)*	*(-6,456)*	*(-9,844)*	*(-4,349)*
δ_4	$\boldsymbol{dummy_{j,t-1}\hat{h}_{j,t-1}}$	**-0,0123*** **	**-0,0095*** **	**-0,0058** **	**-0,0219*** **
	(t-stat.)	*(-5,796)*	*(-3,885)*	*(-2,166)*	*(-6,047)*
δ_5	$\boldsymbol{dummy_{i,t}}$	**0,0097*** **	**0,0083*** **	**0,0173*** **	**-0,0010**
	(t-stat.)	*(13,329)*	*(11,267)*	*(16,737)*	*(-0,986)*
δ_6	$\boldsymbol{dummy_{j,t}}$	**0,0009**	**0,0007**	**0,0031*** **	**-0,0002**
	(t-stat.)	*(1,144)*	*(0,941)*	*(2,862)*	*(-0,148)*
Adj. R^2		0,990	0,990	0,990	0,990

Panel B: EUR-USD

Coefficient	Variable	(-2h, +1h)	(-1h, +1h)	(+1h)	(+3h)
δ_0	**Constant**	**0,0003*** **	**0,0003*** **	**0,0003*** **	**0,0003*** **
	(t-stat.)	*(5,542)*	*(5,657)*	*(5,632)*	*(5,672)*
δ_1	$\boldsymbol{\hat{h}_{i,t-1}}$	**0,9820*** **	**0,9823*** **	**0,9819*** **	**0,9828*** **
	(t-stat.)	*(968,654)*	*(966,809)*	*(970,834)*	*(979,589)*
δ_2	$\boldsymbol{\hat{h}_{j,t-1}}$	**0,0157*** **	**0,0149*** **	**0,0155*** **	**0,0141*** **
	(t-stat.)	*(18,628)*	*(17,659)*	*(18,483)*	*(17,284)*
δ_3	$\boldsymbol{dummy_{i,t-1}\hat{h}_{j,t-1}}$	**-0,0200*** **	**-0,0117*** **	**-0,0191*** **	**-0,0205*** **
	(t-stat.)	*(-8,510)*	*(-4,901)*	*(-7,840)*	*(-4,815)*
δ_4	$\boldsymbol{dummy_{j,t-1}\hat{h}_{j,t-1}}$	**-0,0227** **	**-0,0118**	**0,0238**	**0,4209*** **
	(t-stat.)	*(-2,036)*	*(-0,843)*	*(1,048)*	*(21,739)*
δ_5	$\boldsymbol{dummy_{i,t}}$	**0,0100*** **	**0,0085*** **	**0,0174*** **	**-0,0013**
	(t-stat.)	*(-13,538)*	*(11,502)*	*(16,764)*	*(-1,274)*
δ_6	$\boldsymbol{dummy_{j,t}}$	**-0,0002**	**0,0003**	**0,0008**	**0,0028** **
	(t-stat.)	*(-0,209)*	*(0,352)*	*(0,676)*	*(2,442)*
Adj. R^2		0,990	0,990	0,990	0,990

Similar to the results in *Table 7, Delta 4* is only positively significant at a 1% level at 3h after the ECB announcements. However, *Delta 4* is far less positive compared to results found in *Table 7* and *Table 8* which suggests that although there is a positive volatility transmission, the increase in volatility is not as strong in the USD/NOK exchange rate.

The results from *Table 9* show that the R^2 is suspiciously high for all regressions. This can have many causes and needs to be investigated in order to have reliable results. Firstly, we investigated if the dummy variables caused the almost perfect R^2. We observe an extreme spike in volatility at the beginning of our sample, which is visible in *Figure 2*. It is possible that one of the dummy variables captures this spike perfectly and therefore affects the regression in a biased way. To test this theory, we exclude the first six months from our sample data and rerun the regression. Excluding the first six months also excludes the big volatility spike at the beginning of 2020.

Therefore, if one of the dummy variables captured this spike perfectly, it would be excluded from the regression, and we would observe a lower R^2. However, excluding the first 6 months did not lower the R^2, which means that the dummy variables do not cause the biased R^2.

Secondly, we investigated if the R^2 is caused by the lagged USD/NOK exchange rate volatility. *Delta 1* is very close to 1, which means that the volatility lag and the exchange rate volatility almost move perfectly together. Through the FED's monetary policy of prioritizing stability in interest rates, we observe less standard deviation in the USD/NOK exchange rate compared to the other two exchange rates. This constant volatility means that the exchange rate volatility from the period before has a lot of explanatory power about the exchange rate volatility of the current period, which increases R^2. To test this theory, we exclude *Delta 1* from the regression. The results from the regressions without *Delta 1* can be found in *Table 10*. Once the lagged exchange rate volatility is removed, R^2 drops significantly. Panel A presents the findings for the volatility transmission from the GBP/NOK exchange rate to the USD/NOK rate. The results are very similar to the one found in *Table 9*. Both announcements by the BOE and the FED cause a negative significant volatility transmission which stabilizes the USD/NOK exchange rate. Furthermore, both central banks' QE announcements have an immediate direct effect on the USD/NOK exchange rate at 1h after the announcements.

Table 10
Results from rerunning the USD/NOK regression without lagged variable

The table presents the result from the following regression, $\hat{h}_{i,t} = \delta_0 + \delta_2 \hat{h}_{j,t-1} + \delta_3 dummy_{i,t-1}\hat{h}_{j,t-1} + \delta_4 dummy_{j,t-1}\hat{h}_{j,t-1} + \delta_5 dummy_{i,t} + \delta_6 dummy_{j,t} + k_t$ which aims to estimate the exchange rate variance $\hat{h}_{i,t}$. It is the same regression used in the table above (*Table 9*), without the lagged variables of USD/NOK exchange rate volatility. In the table the USD/NOK exchange rate represents $currency_i$ with the dummy variables $dummy_{i,t}$ which represent the dummy variables for the Federal Reserve Bank at the giving time (-2h, +1h), (-1h. +1h), (+1h), and (+3h). Panel A: This panel tests the volatility transmission from the GBP/NOK exchange rate and the QE announcements made by the Bank of England to the USD/NOK exchange rate. Therefore, in Panel A the GBP/NOK exchange rate represents $currency_j$ with its corresponding variance $\hat{h}_{j,t-1}$. Panel B: This panel tests the volatility transmission from the EUR/NOK exchange rate and the QE announcements made by the European Central Bank to the USD/NOK exchange rate. Therefore, in Panel B the EUR/NOK exchange rate represents $currency_j$ with its corresponding variance $\hat{h}_{j,t-1}$.
*, **, and *** illustrate the significance level of the parameter at 10%, 5%, and 1% respectively.

Panel A: GBP-USD

Coefficient	Variable	(-2h, +1h)	(-1h, +1h)	(+1h)	(+3h)
δ_0	**Constant**	0,0244***	0,0247***	0.0245***	0,0254***
δ_2	$\boldsymbol{\hat{h}_{j,t-1}}$	0,5298***	0,5206***	0,5251***	0,4912***
δ_3	$\boldsymbol{dummy_{i,t-1}\hat{h}_{j,t-1}}$	-0,2631***	-0,2295***	-0,2685***	0,2797***
δ_4	$\boldsymbol{dummy_{j,t-1}\hat{h}_{j,t-1}}$	-0,1253***	-0,0810***	-0,1530***	0,0046
δ_5	$\boldsymbol{dummy_{i,t}}$	0,0189***	0,0172***	0,0276***	0,0104
δ_6	$\boldsymbol{dummy_{j,t}}$	0,0048	0,0062	0,0206**	-0,0023
Adj. R^2		0,457	0,453	0,456	0,445

Panel B: EUR-USD

Coefficient	Variable	(-2h, +1h)	(-1h, +1h)	(+1h)	(+3h)
δ_0	**Constant**	0,0250***	0,0250***	0,0250***	0,0253***
δ_2	$\boldsymbol{\hat{h}_{j,t-1}}$	0,5755***	0,5739***	0,5766***	0,5606***
δ_3	$\boldsymbol{dummy_{i,t-1}\hat{h}_{j,t-1}}$	-0,2097***	-0,1889***	-0,2305***	0,0851***
δ_4	$\boldsymbol{dummy_{j,t-1}\hat{h}_{j,t-1}}$	-0,4058***	0,5544***	0,4810***	0,5782***
δ_5	$\boldsymbol{dummy_{i,t}}$	0,0240***	0,0233***	0,0317***	0,0096
δ_6	$\boldsymbol{dummy_{j,t}}$	-0,0016	0,0016	0,0038	0,0034
Adj. R^2		0,491	0,490	0,491	0,486

Panel B shows the results from the volatility transmission from the EUR/NOK exchange rate to the USD/NOK exchange rate. A noticeable difference to the results in *Table 9* after excluding the lagged exchange rate volatility is the effect of the volatility transmission around ECB QE announcements on the USD/NOK exchange rate. In *Table 9,* we observed a significant positive effect after 3h after the announcements as well as a significant negative volatility transmission at 2h before and 1h after the announcements. After excluding the lagged variable, we now observe a highly significant positive volatility transmission around QE announcements at 1h before and after, 1h after, and 3h after the announcements. This suggests that around QE announcements made by the ECB, there is a positive volatility transmission from the EUR/NOK exchange rate into the USD/NOK exchange rate. However, the ECB QE announcements keep having no significant direct effect on the USD/NOK exchange rate.

Effect of international monetary policy announcements on the Norwegian exchange rate

Our results show that monetary policies from different countries affect the Norwegian exchange rates in various ways. While QE announcements made by the FED and BOE seem to have a strong influence on the Norwegian exchange rate, announcements made by the ECB have less of an influence. We observe that both BOE and FED QE announcements not only affect their own exchange rate with the NOK, but also influence other exchange rates with the NOK indirectly. This shows that the global FX market is interlinked, and monetary policies made by national central banks can have an international impact. For small open economies that rely heavily on trade, such as Norway, this means that foreign unconventional monetary policies can have a major impact on its exchange rates and, furthermore, on its economy. A study by Kim & Lim (2018) supports our results as they suggest that monetary policy shocks have significant effects on exchange rates in small open economies, with relatively short delays in adjustment and limited deviations from the UIP condition.

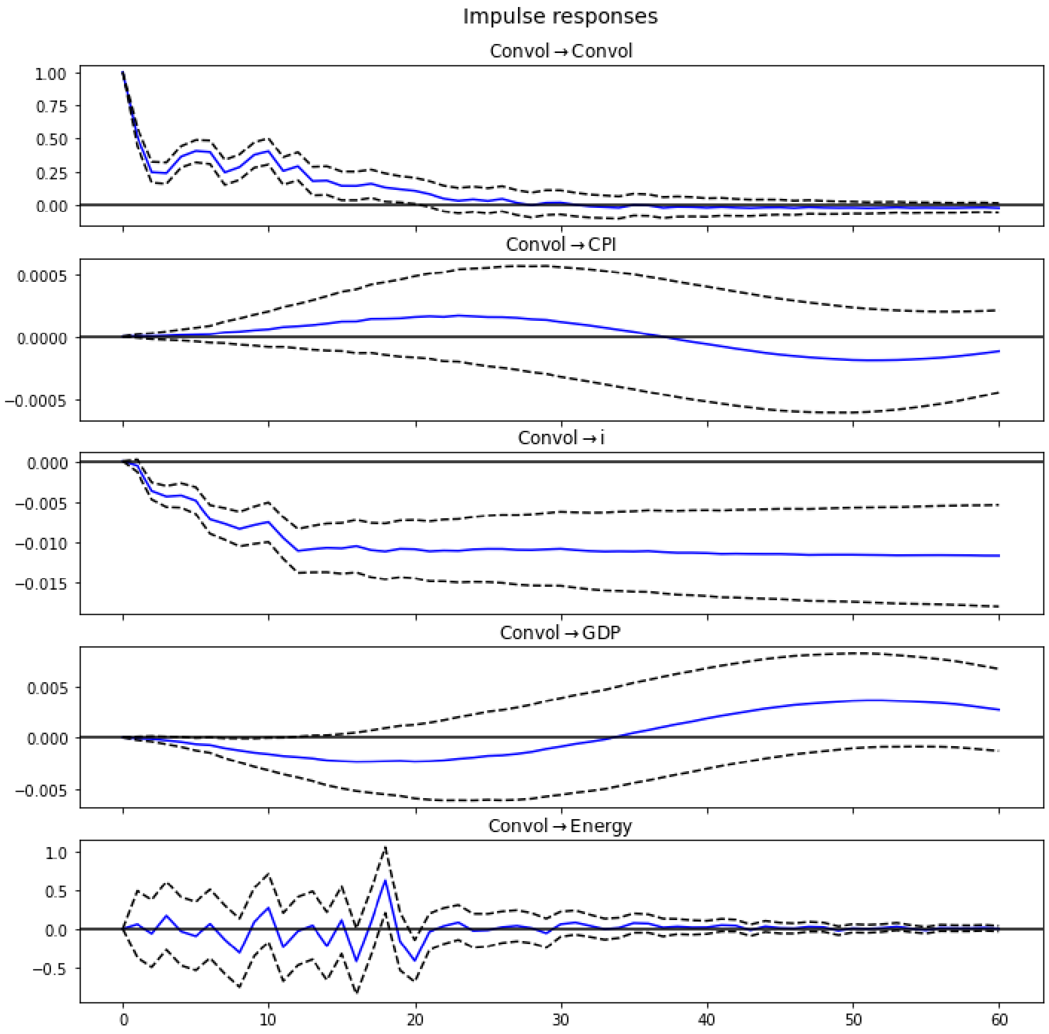
Part III

Impulse Responses to exchange rate volatility shock

Below, *Figure (5)*, *Figure (6)*, and *Figure (7)* show the results of the impulse response functions from the VAR for the EUR/NOK, USD/NOK, and GBP/NOK exchange rates, respectively. We observe very similar impulse reactions to shocks in exchange rate volatility in all three exchange rates.

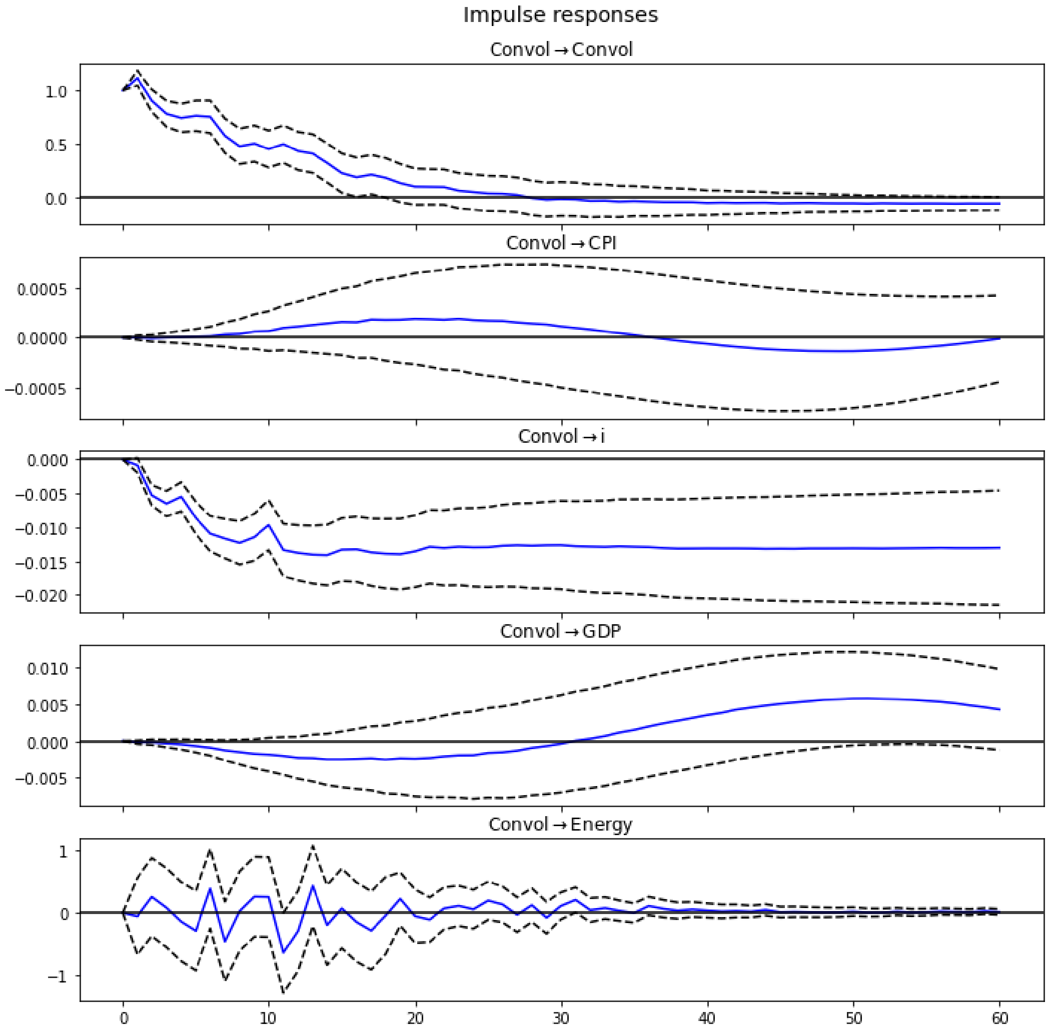
In general, the results show a slow increase in CPI after the shock to the exchange rate volatility, which is followed by a slow decrease after about 20 days after the shock. CPI can be interpreted as Norwegian inflation. Therefore, we observe a slight increase in inflation after an immediate increase in exchange rate volatility. However, it is worth mentioning that this change in inflation is very small. The Dornbusch overshooting theory suggests that in the short run, exchange rates can deviate from their long-run equilibrium levels due to various shocks, including shocks to exchange rate volatility. The slow increase in CPI (Norwegian inflation) followed by a slow decrease after about 20 days in response to an exchange rate volatility shock is consistent with overshooting theory, as it states that exchange rate volatility can influence inflation expectations. The initial increase in inflation can be attributed to the uncertainty and expectations of future exchange rate movements caused by the shock. However, the magnitude of the change in inflation is small, indicating that the impact of exchange rate volatility on inflation is limited, which also aligns with the theory´s premise of a temporary overshooting effect. Secondly, our result indicated that an increase in exchange rate volatility brings Norwegian interest rates to a lower level. This is also in line with overshooting theory as it suggests that exchange rate volatility affects expectations of future exchange rates, and central banks may respond to stabilize the economy.

Figure 5 - *Showing the impulse response functions to shocks to the EUR/NOK exchange rate volatility (Convol) on the Norwegian Consumer Price Index, interest rate, Gross Domestic Product, and Energy prices.*



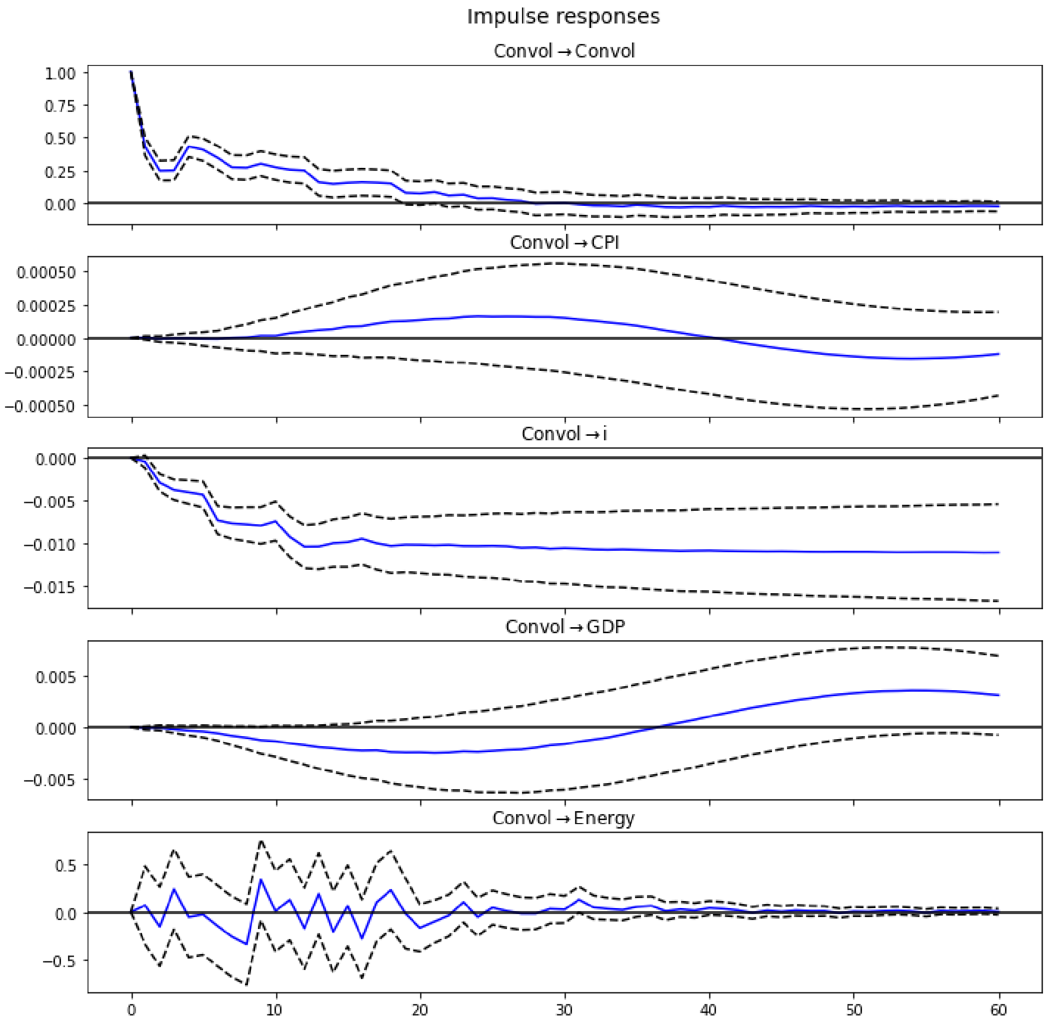
A shock to the exchange rate volatility seems to bring Norwegian interest rates to a lower level. We observe that an immediate increase in exchange rate volatility decreases the Norwegian interest rate by about 1% to a new permanent level. This reflects the adjustment in response to the shock and is in line with the overshooting theory of a long-run adjustment in interest rates. This finding is most important for international investors, as changes in interest rates might impact investment decisions and economic activity.

Figure 6 - *Showing the impulse response functions to shocks to the USD/NOK exchange rate volatility (Convol) on the Norwegian Consumer Price Index, interest rate, Gross Domestic Product, and Energy prices.*



The results also highlight a small effect on GDP. GDP reacts to a shock to exchange rate volatility with a slow decrease which is followed by a slow but steady increase after about 15 days. Similar to the reaction by the CPI, GDP also only reacts very slowly and not as strongly as some of the other variables. This is most likely caused by the fact that these two variables are economic indicators that tend to react much slower to news than traded financial variables such as exchange rates or energy prices. This pattern aligns with the overshooting theory´s premise that real variables, such as GDP, may react slowly to exchange rate fluctuations.

Figure 7 - *Showing the impulse response functions to shocks to the GBP/NOK exchange rate volatility (Convol) on the Norwegian Consumer Price Index, interest rate, Gross Domestic Product, and Energy prices.*



Lastly, we observe the reaction of energy prices to a shock in exchange rate volatility. We see that energy prices seem to be much more volatile after an increase in exchange rate volatility before the prices stabilize again after around 20 days. Notably, a shock to the USD/NOK and the EUR/NOK exchange rate cause a much higher volatility in the energy prices compared to the GBP/NOK exchange rate. As Norway is trading energy, especially with the EU and the UK, we expected to see a much stronger reaction in those two graphs, however, the results do not support this expectation. One reason for this outcome might be that energy prices are calculated using hourly submitted purchase and sell orders (NordPool, n.d.). This means that energy prices are not exclusively dependent on trade but also have many other economic and speculative factors that influence them. Exchange rate volatility can influence energy prices through various channels, including changes in import/export competitiveness and global market dynamics. The higher volatility in energy prices, particularly in response to the USD/NOK and EUR/NOK exchange rates compared to the GBP/NOK exchange rate, indicates the sensitivity of energy prices to exchange rate movements. The US and the EU are much bigger trading partners to Norway and, therefore, might have a stronger influence on the general economy. This could cause the unexpected result of a weaker reaction to exchange rate volatility shocks in the GBP/NOK rate.

Overall, our result of the impulse responses to exchange rate volatility shocks aligns with the key predictions of the Dornbusch overshooting theory. Our results are consistent with several other studies (Bjørnland, 2008; Kalyvitis & Michaelides, 2001; Kim & Lim, 2018), as their result also find support for Dornbusch overshooting theory to hold.

Exchange rate volatility can have varying effects on different economic variables. According to the theory of exchange rate pass-through, changes in exchange rates can influence import prices and subsequently affect CPI. Research by Campa & Goldberg (2005) has explored the relationship between exchange rate movements and import price pass-through, providing a theoretical basis for the observed slight increase in CPI following an immediate increase in exchange rate volatility.

In terms of interest rates, the transmission mechanism of monetary policy plays a crucial role. Mishkin (1996) discusses how changes in interest rates can affect various economic variables through channels such as consumption, investment, and exchange rates. Therefore, a shock to exchange rate volatility can decrease Norwegian interest rates, as observed in our result. This adjustment in interest rates reflects the monetary policy response to exchange rate fluctuations and aims to stabilize the economy. As an indicator of economic activity, GDP tends to react more slowly to shocks compared to traded financial variables. The theory of economic fluctuations and business cycles, as outlined by Kydland & Prescott (1982), suggests that the dynamics of GDP are influenced by various factors, including investment, consumption, and government spending. Therefore, the slower reaction of GDP to exchange rate volatility can be attributed to its inherent lagged response to economic shocks. On the other hand, energy prices are influenced by a range of factors beyond exchange rates, including supply and demand dynamics, market structure, and pricing mechanisms. In the context of Norway´s energy trading relationships with the EU, the unexpectedly weaker reaction of energy prices to exchange rate volatility in the GDB/NOK exchange rate could be attributed to other economic and speculative factors that influence energy prices rather than solely relying on trade patterns.

Implications for the Norwegian Economy

Our results have important implications for the Norwegian economy and can be related to theories that examine the impact of exchange rate volatility, especially for countries that are heavily dependent on the exchange rate. Additionally, our results show implications concerning the impact of monetary policies from different countries on the exchange rate.

Firstly, our findings indicate that an increase in exchange rate volatility leads to a slight increase in inflation, as measured by CPI. Secondly, we observe that an immediate increase in exchange rate volatility results in a decrease in Norwegian interest rates. This adjustment reflects the monetary policy response to exchange rate fluctuations and aims to stabilize the economy. Under the pandemic, the interest rates in Norway were at 0%. This is unsurprising as it was a necessary monetary policy measure to stabilize the Norwegian economy.

Furthermore, our result indicates a small effect on GDP in response to exchange rate volatility shocks. This slower and gradual reaction of GDP can be attributed to the inherent lagged response of real variables, as discussed in theories on economic fluctuations and business cycles (Kydland & Prescott, 1982). Further, the findings reveal that monetary policy announcements, specifically QE decisions made by the FED and BOE, exert a substantial influence on Norwegian exchange rates, affecting not only the respective exchange rates between the FED/BOE currencies and NOK but also other exchange rates involving the NOK.

Lastly, our findings reveal that energy prices become more volatile in response to an increase in exchange rate volatility, with subsequent stabilization after approximately 20 days. This highlights the sensitivity of energy prices to exchange rate movements and aligns with the notion that energy prices are influenced by several factors beyond exchange rates, including supply and demand dynamics, market structure, and pricing mechanisms. This is consistent with our earlier explanation that energy prices are not solely dependent on trade patterns but are influenced by other economic and speculative factors.

Therefore, the implications of our results for the Norwegian economy are twofold. Firstly, it emphasizes the need for policymakers in Norway to closely monitor and assess the potential spillover effects of foreign monetary policies on domestic exchange rates. Secondly, it highlights the importance of maintaining a robust and flexible economic framework that can effectively respond to the impact of global monetary policy decisions and mitigate potential adverse effects on trade and economic stability.

Conclusion

In this paper, we investigated the effect of QE announcements on the Norwegian exchange rate volatility and economy. We started by examining the extent of volatility transmission in the FX market by focusing on the Norwegian exchange rates with the USD, EUR, and GBP. Our results support the findings by Kenourgios et al. (2015) that there is strong evidence for volatility transmission in the international FX market. As this is the only study that has focused their research on the Norwegian market, we had the unique position to analyse the impact of QE announcements on the Norwegian exchange rate volatility.

Our results show that around QE announcements, we see a different reaction of the exchange rate volatility depending on the country from which the announcement is coming. We observe that QE announcements made by the FED or the BOE correlate with a stabilisation of the exchange rate volatility. The sample period in this study covers the international and financial crisis of COVID-19, in which many new QE packages were introduced to stabilize the market. Although we do not examine the effect of these QE packages on the domestic market, our results show that the introduction of new QE measures from the FED and BOE stabilises the Norwegian exchange rates. Moreover, we observe a negative volatility transmission around QE announcements by the FED and BOE, indicating that these announcements also indirectly stabilize other exchange rates. On the other hand, we find a different result for QE announcements made by the ECB. Exchange rate volatility seems to increase significantly 3h after QE announcements by the ECB. This delayed increase in exchange rate volatility is also transmitted into other exchange rates.

These contradicting findings of a different response to QE announcements by the ECB compared to the response by the FED and BOE are something that we can also find in the literature. While some scholars find an increase in volatility around QE announcements (Lin et al., 2020), others, such as Feng et al. (2021), find evidence for a decrease in exchange rate volatility after the introduction of fiscal policy measures. This shows that there is still a demand for future research. Our research focused on all QE announcements that were made in the period from January 2020 to December 2022, therefore not distinguishing between QE announcements that increased, continued, or decreased the amount of QE. This would be a value-adding future research topic that could add to the existing research that has been conducted on the causes of exchange rate volatility.

Lastly, our research finds that exchange rate volatility has a strong effect on the Norwegian economy. A shock increase in exchange rate volatility causes an adverse response in the economy. We tested macroeconomic variables such as CPI, GDP, interest rates, and energy prices, which all react to the volatility shock following the Dornbusch overshooting theory. Following our previous findings, we conclude that the increase in exchange rate volatility that correlates with QE announcements made by the ECB is most likely to have an unfavourable effect on the Norwegian economy. Such effects include an increase in inflation, higher volatility in energy prices which can cause instability, as well as a decrease in GDP. However, due to the opposite findings around QE announcements by the FED and BOE, we would expect to see a stabilization of the Norwegian economy following those announcements.

Our research shows that international monetary policy can affect other countries through the FX market. For countries such as Norway that are heavily dependent on the exchange rate, this means that foreign monetary policy decisions can have a measurable impact on the domestic economy. Although Norway does not engage in QE measure, it is still affected by QE introductions from its important trading partners. This shows to what extent the international FX market is interconnected and that Norwegian policymakers and international investors must be aware of the exchange rate volatility transmission between countries and, ultimately, into the domestic economy.

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