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An Analysis of the Long-Term and Dynamic Effects of the US Money Market Fund Reform on NIBOR

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Abstract

NIBOR, the Norwegian Interbank Offered Rate, is an important reference rate for financial products in the Norwegian market. It has also become of increasing interest as conventional monetary policy tools have become less effective in influencing market rates. Furthermore, there has been an increase in the risk premium in NIBOR associated with quantitative easings in the eurozone, new Liquidity Coverage Ratio requirements and a US money market fund reform. We utilize daily data and investigate the long-term and dynamic effects of the US money market fund reform on the risk premium in NIBOR. We focus on the period from the announcement of the money market fund reform to its implementation on 23 July 2014 and 14 October 2016, respectively. We first estimate an error correction model (ECM) and analyze both long-term and short-term effects on the NIBOR risk premium. Then we expand the model into an ECM-GARCH(1,1) model, which allows for stochastic processes and time-varying volatility. We find indications of structural breaks on 23 September 2015 and 24 October 2016, respectively. The long-run estimates indicate that the reform accounts for an increase of 0.067 or 0.053 of approximately 0.4 percentage points in the risk premium and a greater effect of quantitative easings. In the short-term, there is a significant adjustment to the long-run relationship. We find mixed evidence of negative and positive short-term effects of total liquidity and market risk, respectively. We find mixed evidence of a year-end effect and a coinciding positive effect of the Liquidity Coverage Ratio requirements. The conditional variance of the first-differenced risk premium has a slowly decaying autocorrelation. The relationship between the long-run variables changes after the implementation of the reform. The subsequent decrease in the risk premium suggests that the model estimations may have underestimated the effect of the reform.

Acknowledgements

We decided to cooperate on our thesis in the spring of 2017 and have prepared for its conclusion for nigh a year. However, we have been in the trenches together for longer than that. We started out as classmates in Askim upper secondary school in 2009 and have been work colleagues since 2012. Although we enrolled in our bachelor's studies at NHH two years apart and did not intend to catch up or finish our studies at the same time, here we are.

We both took the elective course "ECN430 Empirical Methods and Applications in Macroeconomics and Finance" at NHH in the spring semester. We found the methods and econometrics we learned extremely interesting. It was also at that time we learned about the US money market fund reform and developed an interest in the Norwegian Interbank Offered Rate and time series analysis. We wanted to immerse in money markets and develop our understanding of econometrics and empirical analysis. We wrote a term paper on the topic for the course ECN430, before we worked further on the topic for this thesis. Different perspectives on macroeconomics, interest rates and financial markets and institutions from both Erlend's major in Economics and Sebastian's major in Finance have complemented each other and been beneficial to our work.

We would like to give special thanks to Professor Gernot Doppelhofer with the Department of Economics for supervising and advising us throughout our work on this dissertation. We would like to thank Kathrine Lund with Norges Bank for providing us with data that has been pivotal to our analysis. We would also like to thank everyone else who has helped us in various ways throughout the process by answering our questions and discussing implications of our findings. These include Torgeir Stensaker and Lars Løtvedt with Nordea Investment Management, Thomas Eitzen with SEB Markets, Professor Jan Tore Klovland with the Department of Economics and friends and fellow students. Your inputs have been valuable and highly appreciated.

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1. Background

In this dissertation, we investigate the effects of the US money market fund reform, effectuated in 2016, on the Norwegian Interbank Offered Rate, NIBOR, between the announcement and implementation of the reform and after the implementation (U. S. SEC, 2016). NIBOR is an important reference rate in the Norwegian market (Bernhardsen et al., 2012). Furthermore, the extent to which monetary policy makers are able to influence market rates determines the success of the transmission mechanism (Joyce et al., 2012). We study long-term effects related to the money market fund reform and quantitative easings as well as dynamic short-term effects caused by adjustments to the long-run relationship and fluctuations in the determinants of NIBOR. All series utilized in this dissertation are defined in more detail in chapter 5 and appendix A.

1.1 Key concepts

NIBOR is *"a collective term for Norwegian money market rates at different maturities. NIBOR is intended to reflect the interest rate level a bank require for unsecured money market lending in NOK to another bank"* (Finance Norway, 2017). That is, it is the best possible estimate of the rate a bank would require for unsecured lending to a leading bank in the Norwegian money market, had such a trade taken place. After the financial crisis, such loans have become rare, except for loans with the shortest maturities (Aamdal, 2014).

NIBOR can be decomposed into an expected overnight index swap (OIS) rate and a risk premium (Lund, Tafjord & Øwre-Johnsen, 2016). Unlike other interbank offered rates, it is quoted as a foreign exchange swap rate. This entails that it is implicitly a USD rate that is adjusted for the price of swapping USD into NOK in the foreign exchange swap market and further adjusted at the NIBOR panel banks' discretion (Norges Bank, 2013). The implicit USD rate on which it is based is called the Kliem rate, which reflects the price of unsecured loans in USD via EUR at EURIBOR, the European money market rate.

The “transmission mechanism” of monetary policy is a term for how *“[d]ecisions about [the] official interest rate affect economic activity and inflation through several channels”* (George et al., 1999). The transmission mechanism may be vulnerable to and disturbed by changes in the risk premium (Aamdal, 2014). Furthermore, conventional monetary policy instruments may become less effective as the nominal interest rates are close to zero. The “zero lower bound” is a term for the theoretical notion that interest rates can not be lower than zero, because rather than obtaining a negative interest rate, it would be more profitable to hold cash. This was the case in the aftermath of the financial crisis. Consequently, central banks have to a greater extent targeted quantity variables rather than interest rates. Such monetary policy measures have been termed “quantitative easings”.

The risk premium in NIBOR is given as the differential between NIBOR and the OIS rate. The latter is usually close to Norges Bank’s key policy rate and can be regarded as the market’s expected key policy rate. The key policy rate has reached a historically low level of 0.5 percent. Norges Bank seeks to maintain short-term money market interest rates close to the key policy rate through its liquidity policy (Aamodt & Tafjord, 2013). It does this by performing market operations and maintaining the level of total reserves in the Norwegian banking system within the targeted level.

Quantitative easings refers to the recent targeting of quantity variables rather than interest rates in the monetary policy of various central banks. Norges Bank does not utilize non-standard policy measures such as quantitative easings. However, the risk premium in NIBOR has been positively affected by the quantitative easings performed by the European Central Bank (Lund, Tafjord & Øwre-Johnsen, 2016).

In order to make the financial system more robust, money markets and the banking sector have increasingly been subject to more financial regulations and requirements. Examples of such are the regulations introduced in the regulatory framework Basel III and the US money market fund reform. Basel III originally introduced a minimum required Liquidity Coverage

Ratio for the banking sector in the European Union and members of the European Economic Area (BCBS, 2011). However, a version of Basel III has also been adopted by the US financial system (OCC, 2014).

The US money market fund reform was announced on 23 July 2014 and implemented on 14 October 2016 (U.S. SEC, 2014 & 2017). It has introduced new regulations for money market funds in order to address run risks and prevent exits in times of financial distress, particularly in prime funds (FED, 2017). The most important changes include the introduction of floating fund share prices and new tools that the fund boards can utilize in order to retain liquidity. The reform has affected the money market through an altered composition of prime fund and government fund assets. The reason is that the reform does not apply to government funds.

The term “risk” refers to *“exposure to a proposition of which one is uncertain”* (Holton, 2004). Risk premiums in interest rates are caused by market conditions. Risk can be decomposed into different categories of risk, such as credit risk, maturity risk, liquidity risk and inflation risk (Bernhardsen, 2011). The causes and relationship of interest rates and risk are addressed by numerous theories and models. Among these are the Capital Asset Pricing Model, the expectations hypothesis, the risk premium theory, the preferred habitat theorem and the theory of covered interest rate parity (Ayrapetova, 2012; Modigliani & Sutch, 1966). They consider factors such as investor expectations and preferences, risk aversion, foreign interest rates and liquidity constraints.

NIBOR tends to increase in periods of financial distress and increased risk, such as during the financial crisis and the crisis in the European government bond market (Lund, Tafjord & Øwre-Johnsen, 2016). Its risk premium is highly volatile and has also increased remarkably during the most recent years. This is likely due to factors such as considerable quantitative easings performed by ECB in the eurozone as well as financial regulations, particularly the announcement and subsequent implementation of the US money market fund reform. The role of NIBOR as an important reference rate and the implications the increase in its risk premium may have for the monetary transmission mechanism motivate an interesting study of the recent development.

This dissertation is structured as follows. In the continuation of chapter 1, we introduce key concepts, our motivation for investigating the effect of the money market fund reform, our main findings on NIBOR and other research on the topic. We review the literature and developments of the money markets and adjacent topics in chapter 2, before presenting NIBOR comprehensively in chapter 3. Chapter 4 reviews a selection of theories and models on risk and interest rate formation. The descriptive statistics of the time series that are utilized in our analysis and an explanation of how we treat the raw data series, are found in chapter 5. Chapter 6 describes our methods and presents the analysis of the effect of the money market fund reform on NIBOR. Finally, the results of the analysis and their implications are summarized and discussed in chapter 7.

1.2 Motivation

NIBOR is intended to reflect the interest rate of unsecured lending in the Norwegian money market (Finance Norway, 2017). A number of different factors affect the supply and demand of liquidity in the money market that continuously cause fluctuations in NIBOR. During different periods, the risk premiums in NIBOR and other interbank offered rates have increased to abnormal levels. The risk premium is typically high during periods of crisis and great distress. The increase in the risk premium that started in 2015 is related to quantitative easings as well as regulatory conditions. Lund, Tafjord & Øwre-Johnsen (2016) emphasize quantitative easings in the eurozone, new Liquidity Coverage Ratio requirements and the US money market fund reform that was implemented in 2016 (U.S. SEC, 2014).

The recent development in NIBOR is a relevant and interesting subject for an empirical study for at least three reasons. First, NIBOR is an important reference rate for various financial products in the Norwegian market (Bernhardsen et al., 2012). The development of

NIBOR will have consequences for a number of assets or liabilities that are subject to an interest rate that refers to NIBOR as a benchmark and their substitutes. Accordingly, the subject is a matter of great interest to banks, providers of funding and other participants who set prices or seek to gain profits in the money market.

Second, it is interesting to monetary policy makers because movements in NIBOR and related market rates may have consequences for the monetary policy transmission mechanism, which is the process through which monetary policy decisions affect economic activity and inflation (George et al., 1999). If the risk premium in the market rates increase or otherwise behave in a way that is not intended by monetary policy makers, it may interfere with the effectiveness of monetary policy tools. This may be the case particularly as the key policy rate approaches the theoretical zero lower bound and further reductions have a smaller effect on market rates and economic activity (Joyce et al., 2012).

Third, NIBOR is affected by the US money market fund reform that was recently implemented (U.S. SEC, 2014). It is intended to make the US financial system more robust by addressing run risks in money market funds. The reform requires share prices to be based on a floating net asset value and provides fund boards with new tools for retaining liquidity in periods of increased financial distress. However, as we shall explain in detail in chapter 6, it has also caused prime funds to convert to government funds and the level of remaining prime fund assets to decrease considerably.

Since Norwegian panel banks are active in the US money market and obtain funding from such money market funds, the reform has restricted the available funding for Norwegian panel banks. A consequence of lower access to funding may be a considerable increase in the risk premium in NIBOR. As we shall explain in detail in chapter 4, the reason is that a reduced supply of USD creates an increased liquidity premium in USD relative to EUR, which enters the NIBOR risk premium through the Kliem rate, which is the implicit USD rate in NIBOR.

1.3 Research question

The role of NIBOR as an important reference rate as well as the implications of the increase in its risk premium for the monetary policy transmission mechanism, motivate an interesting study of the recent development. We will address the effects the US money market fund reform may have had on NIBOR. We will consider the effects described by Lund, Tafjord & Øwre-Johnsen (2016) and investigate the development of prime fund assets, access to liquidity and risk during the transitional period between the announcement of the reform and its implementation. We intend to answer the following research question:

What are the long-term and dynamic effects of the US money market fund reform on NIBOR?

We will focus on the risk premium in the three-month NIBOR, which is the most important maturity and the NIBOR most often referred to in the literature. The event window of our analysis begins with the US Securities and Exchange Commission's announcement of the money market fund reform on 23 July 2014 and ends on 21 June 2017, which is the last date for which we have data on the risk premium in NIBOR. In order to assess the robustness of the models, we estimate the models for two overlapping parts of the analysis period. The first part starts with the announcement of the reform on 23 July 2014 and ends with the implementation of the reform on 14 October 2016. The second part starts on 25 September 2015, the day after one of Norges Bank's key policy rate meetings, which is associated with a structural break, and ends on 14 October 2016.

We estimate two econometric models. We start by estimating an error correction model (ECM) with Engle & Granger's two-step estimator, in which the US money market fund reform and quantitative easings in the eurozone are long-run determinants of NIBOR. Adjustments to the long-run relationship as well as short-term effects of the reform, quantitative easings, the level of total liquidity in the Norwegian banking system, market risk and the year-end calendar effect are determinants of the dynamic effects. We also estimate a error correction model generalized autoregressive conditional heteroscedasticity (ECM-

GARCH) (1,1) model in order to account for possible time-varying volatility. In contrast to previous research on the effects of the reform on NIBOR, we are able to analyze both long-term and short-term effects with this approach. Furthermore, we calculate the magnitudes of these effects. Although there is a lot of literature on NIBOR and a wide theoretical framework for risk and interest rate formation, there has been few attempts at calculating the exact magnitude of these effects.

We find that both the reform and quantitative easings have had a positive long-run effect on the NIBOR risk premium, that there is time-varying volatility present in the first-differenced risk premium and that there is a significant short-term adjustment to the long-run relationship, in addition to mixed evidence of short-term and dynamic effects of total liquidity, market risk, the year-end and the Liquidity Coverage Ratio requirements. We also find indications of structural breaks on 23 September 2015 and 24 October 2016. The estimated models suggest that the money market fund reform had an effect of 0.067 or 0.053 percentage points of a total increase of approximately 0.4 percentage points in the risk premium, and that quantitative easings in the eurozone had a greater effect. However, the long-run variables have no cointegrating relationship in the post-reform period. The post-implementation decrease in the NIBOR risk premium suggests that the models underestimate the effect of the reform.

1.4 Previous work

The effect of the US money market fund reform has recently been touched upon by Pedersen & Pettersen (2017) in their master thesis “Hva driver risikopåslaget i tremåneders Nibor?” - *What drives the risk premium in three-month NIBOR?*[1] They attempt to determine how the reform can increase the risk premium in NIBOR through higher prices on short-term USD funding. They investigate the long-run effect of the reform by performing a series of

[1] Pages 77 - 87.

regressions and project the risk premiums in NIBOR and the Kliem rate on different explanatory variables for different periods.

Equivalently to our model estimations, one of Pedersen & Pettersen's dependent variables is the NIBOR risk premium. As we do in our analysis, they utilize US prime fund total assets as an explanatory variable in order to capture the effect of the money market fund reform. They also introduce three dummy variables that are intended to capture the effects of the announcement of the reform, the maturities of commercial papers 270 days before the implementation of the reform and the implementation of the reform itself, respectively, in the five subsequent business days.

However, Pedersen & Pettersen also project the risk premium on the AA financial commercial paper rate and the liquidity premium between EUR and USD rather than explaining why the liquidity premium has changed. Unlike our model estimations, they do not consider the excess liquidity in the eurozone caused by quantitative easings, total liquidity in the Norwegian banking system or market risk. We will illuminate the relationship between NIBOR and the Kliem rate and the composition of NIBOR in detail in chapter 4.

As the supplementary literature and our analysis suggest, Pedersen & Pettersen find that the reform has caused an increase in the risk premium. The effect of US prime fund assets on the risk premium in the Kliem rate is significant and negative in their estimations. Furthermore, the effect of the Kliem rate risk premium on the NIBOR risk premium is significant and positive. However, their model estimations do not consider short-term effects. Neither do they calculate the total effect of the money market fund reform or prime fund assets on the NIBOR risk premium, or explicitly show their total marginal effect on the NIBOR risk premium.

In their first regression, Pedersen & Pettersen project the risk premium in the Kliem rate on the prime fund total assets and the EURUSD OIS basis. In the second regression, they project NIBOR on the same variables, except that the EURUSD OIS basis is replaced by the USDNOK OIS basis and that the risk premium in Kliem is included as an explanatory variable. In the last regression, NIBOR is projected on the risk premiums in Kliem and the AA financial commercial paper rate as well as the USDNOK OIS basis.

More specifically, with Pedersen & Pettersen's exact notations, the following OLS regressions are performed:

$$Rp_{Kliem} = \beta_0 + \beta_1 Primefund_t + \beta_2 MMRA1U_t + \beta_3 MMR1M9U + \beta_4 MMRI1U + \beta_5 OISB_{EUR,\$,t} + \epsilon_t \quad , \tag{1.1}$$

where Rp_{Kliem} is the risk premium in the Kliem rate, $Primefund_t$ is US prime fund total assets, $OISB_{EUR,\$,t}$ is the OIS basis between EUR and USD and ϵ_t is the error term.

$$Rp_{Nibor} = \beta_0 + \beta_1 Rp_{Kliem,t} + \beta_2 Primefund_t + \beta_3 MMRA1U_t + \beta_4 MMR1M9U_t + \beta_5 MMRI1U + \beta_6 OISB_{\$,N,t} + \epsilon_t \quad , \tag{1.2}$$

where Rp_{Nibor} is the risk premium in NIBOR and $OISB_{\$,N,t}$ is the OIS basis between USD and NOK.

$$Rp_{Nibor} = \beta_0 + \beta_1 Rp_{Kliem,t} + \beta_2 Rp_{CP,t} + \beta_3 OISB_{\$,N,t} + \epsilon_t \, , \tag{1.3}$$

where $Rp_{CP,t}$ is the risk premium in the AA financial commercial paper rate.

We have some remarks on Pedersen & Pettersen's analysis. First, the estimated coefficients of the explanatory variables in their regressions and their levels of significance, are probably heavily encumbered by multicollinearity. The reform has affected the prime fund total assets, which in turn is one of the determinants of the OIS bases. Furthermore, the changes which the dummy variables capture are correlated with prime fund total assets and the OIS bases. And all of these are to a varying extent correlated with Kliem, which is an explanatory variable in two of the regressions. The fact that the sign, magnitude and significance of their estimated coefficients vary tremendously, reflects this multicollinearity.

Second, and related to our first remark, we will argue that Pedersen & Pettersen have misinterpreted their dummy variables. Each of the dummy variables are intended to capture the effect of the reform on five certain business days. However, this effect is already captured through the changes in prime fund total assets and the OIS bases. Consequently, the dummy variables only captures differences in the Kliem or NIBOR risk premiums from the base, which is all the other business days in the sample which are not explained by the other explanatory variables. Although they may capture an initial overreaction in the money market, our assessment is that the dummy variables cannot be interpreted as disclosing the full effect of the reform on the Kliem or NIBOR risk premiums.

Third, simultaneous equation bias arises when an explanatory variable is not truly exogenous. NIBOR can be regarded as a price of liquidity, whereas the OIS bases reflect the relative supply of liquidity. This suggests that NIBOR and the USDNOK OIS basis may be interdependent and that projections of one variable on the other may be subject to simultaneous equation bias. Pedersen & Pettersen have not considered that possibility.

Fourth, Pedersen & Pettersen perform regressions on the risk premiums in both the Kliem rate and NIBOR. As we shall explain in chapter 3, the NIBOR panel banks base their submissions on the Kliem rate. Although the banks make adjustments and use their discretion when submitting their estimates of the rates, NIBOR is nonetheless highly related to the Kliem rate. Consequently, performing regressions both on the Kliem rate and on NIBOR may be superfluous when assessing the effect of the money market fund reform on the rates in the Norwegian interbank market.

Fifth, unless the series are cointegrated, the estimated coefficients of a regression may incorrectly indicate a significant relationship between the variables even when there is none, when utilizing non-stationary time series. Pedersen & Pettersen project non-stationary time series on one another. They do not consider the unit root of the variables to any more extent than being aware that the model estimations may be spurious.

2. The money market

Liquidity is traded on the money market and in different currencies. NIBOR denotes the price of liquidity on the Norwegian interbank market, which is a part of the money market. In this chapter, we will review the literature and development of the money market, its participants and the determinants of the level of available liquidity.

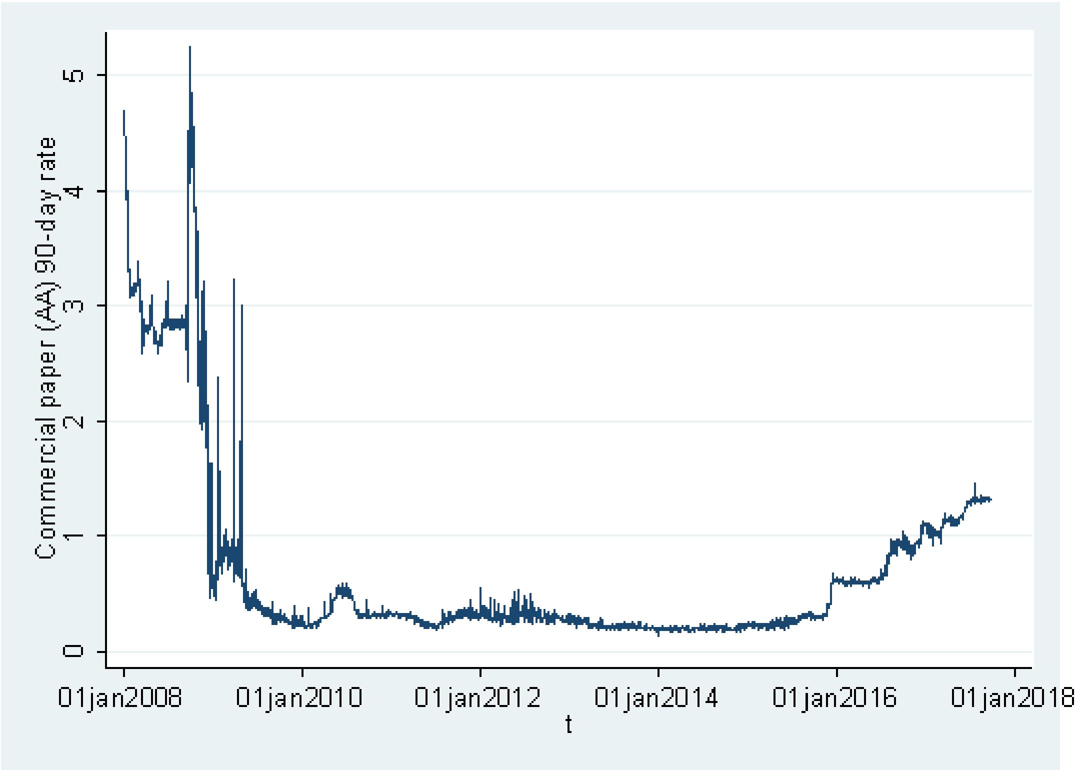
2.1 Segments of the money market

The money market consists of several loan markets. In these markets, the participants can invest and raise loans with maturities of up to one year. The interbank market is one segment of the money market. Interbank loans can be both secured and unsecured loans (Bernhardsen et al., 2012).

Secured interbank loans is a form of repurchase agreements, which is a loan backed by securities (Bernhardsen et al., 2012). Repurchase agreements are transactions where one party sells securities to another and agrees to repurchase the same securities later at a specified date and price (Madura, 2012). If the borrower defaults on the loan, the lender claims the securities. The borrower receives interest as it accrues on a repurchase agreement. They normally involve government bonds. However, they can involve other securities such as commercial papers as well (Madura, 2012). A currency swap agreement can also be acknowledged as a secured interbank loan. The only difference from a repurchase agreement is that the collateral is in the form of currency and not securities (Bernhardsen et al., 2012).

Interbank loans can also be unsecured. It is in this segment the interbank offered rates originate. These are indicative interest rates for unsecured interbank loans with maturities for up to one year. However, the activity in the unsecured interbank market is low for longer maturities (Bernhardsen et al., 2012). The reason is that the interbank market is primarily used for short-term liquidity management on a day-to-day basis. The main function of the interbank market is being a valve that provides liquidity at short notice for unexpected shortages. For this reason, the interbank loans are concentrated the most on the shortest maturities, which are overnight loans and two-day loans (Bernhardsen et al., 2012). Rather than interbank loans, banks primarily use the commercial paper market to obtain funding with maturities of up to 270 days (Madura, 2012).

Figure 2.1: AA commercial paper 90-day rate over time. Percentage points.



The commercial paper market is another segment of the money market. It is one of the most active markets to make short-term loans (Bernhardsen et al., 2012). Both banks and non-financial companies are issuers, but the major issuers are banks and financial holdings (Madura, 2012). The US commercial paper market is one of the largest and is particularly important for non-US banks. NIBOR panel banks receive most of their short-term USD funding in this market. The reason is that they can borrow much more USD and/or at a lower interest rate than in the Norwegian market (Bernhardsen et al., 2012). The Norwegian banks would borrow money in the US commercial paper market in order to fund their USD lending or investments, or to fund their NOK lending or investments. With the latter, the bank would need to utilize a currency swap in order to swap USD for NOK. The AA commercial paper 90-day rate is displayed in figure 2.1.

2.2 Money market funds

A money market fund is an investment company regulated by the United States Securities and Exchange Commission (U. S. SEC) (Brooks, 2014). Money market funds primarily invest in short-term money market securities with low risk. These funds are paramount for the financial ecosystem and act as financial intermediaries for creditors and borrowers.

There is different types of money market funds that invest in different types of securities. These are institutional-, municipal-, retail- and government money market funds, and the level of risk varies between them. A retail fund is a fund for individual investors whereas institutional funds are for corporations or financial institutions. Government money market funds are restricted to buy government securities, such as T-bills, whereas municipal funds invest in municipal investments. Retail funds and institutional funds can be classified as prime funds. The government money market funds are associated with the smallest amount of risk, whereas prime funds carry the most risk. Prime funds invest in commercial papers with higher yield, which is also known as high-grade debt. “High-grade” means that the note has a medium or high rating.

Features like return, market rate and liquidity are important for money market funds. Investors buy a share at net asset value (NAV) of one USD and receive dividends that reflects the short-term interest rate in the market. A money market fund wants to keep its NAV stable at par with the principal (one USD) and pays the return as a dividend. Consequently, there is no capital gains from investing in a money market fund. The NAV is equal to the fund’s net assets minus net liabilities. If the NAV decreases below one USD, it is termed “breaking the buck”. Such an event is considered to be rare. However, if a money market fund performs so poorly that it breaks the buck, the consequences may be critical, such as mistrust directed towards the fund, capital withdrawals and/or government interventions.

Furthermore, money market fund investments are considered safe investments (Brooks, 2014). The primary reason is that they are required to invest in high-quality assets. Organizations like Moody's and Fitch rate securities. Money market funds are regulated to invest only in first-tier securities and second-tier securities. First-tier securities are considered to be government securities with very low risk. A money market fund has to invest 95 percent of its funds in securities with a top-tier rating. Second-tier securities are ranked as one of the top two short-term ranks. They can only account for a maximum of five percent of a money market fund's investments. These rules are intended to help maintaining financial stability.

2.3 Structural liquidity

An important component of the liquidity in the Norwegian banking system is the structural liquidity (Aamodt & Tafjord, 2013). Structural liquidity is defined as *"the level of reserves in the banking system prior to market operations by Norges Bank to supply or drain reserves from the banking system"*. Reserves are the deposits that banks have on their accounts with Norges Bank (Aamodt et al., 2016). Central bank reserves are the only accepted means of interbank payments. Interbank transactions do not affect the total amount of reserves in the banking system or the structural liquidity. Only Norges Bank can create new reserves in the Norwegian banking system.

The primary determinant of the structural liquidity is transactions between the government and accounts in private banks (Aamodt & Tafjord, 2013). That is, transactions between the government's and the banking system's respective accounts with Norges Bank. Payments from the banking system to the government's account reduce structural liquidity whereas payments from the government to the banking system increase structural liquidity. Such transactions include the issuance of government obligations, repurchase and reverse repurchase agreements, foreign exchange purchases for the Government Pension Fund Global as well as redemptions of taxes and particularly oil taxes. Structural liquidity is also affected by public demand for cash. Factors determining structural liquidity, are called autonomous factors.

The daily net of these transactions can be of a considerable magnitude, which causes the level of structural liquidity to be highly volatile (Aamodt & Tafjord, 2013). The majority of the transactions and fluctuations are recurrent because they reach their maturities on certain due dates. The volatility in the structural liquidity has gradually increased. The reason is that the government's fiscal budget has increased in nominal terms. Consequently, the nominal magnitudes of the transactions between the government's account and the banking system have increased in the same period.

2.4 Norges Bank's liquidity management

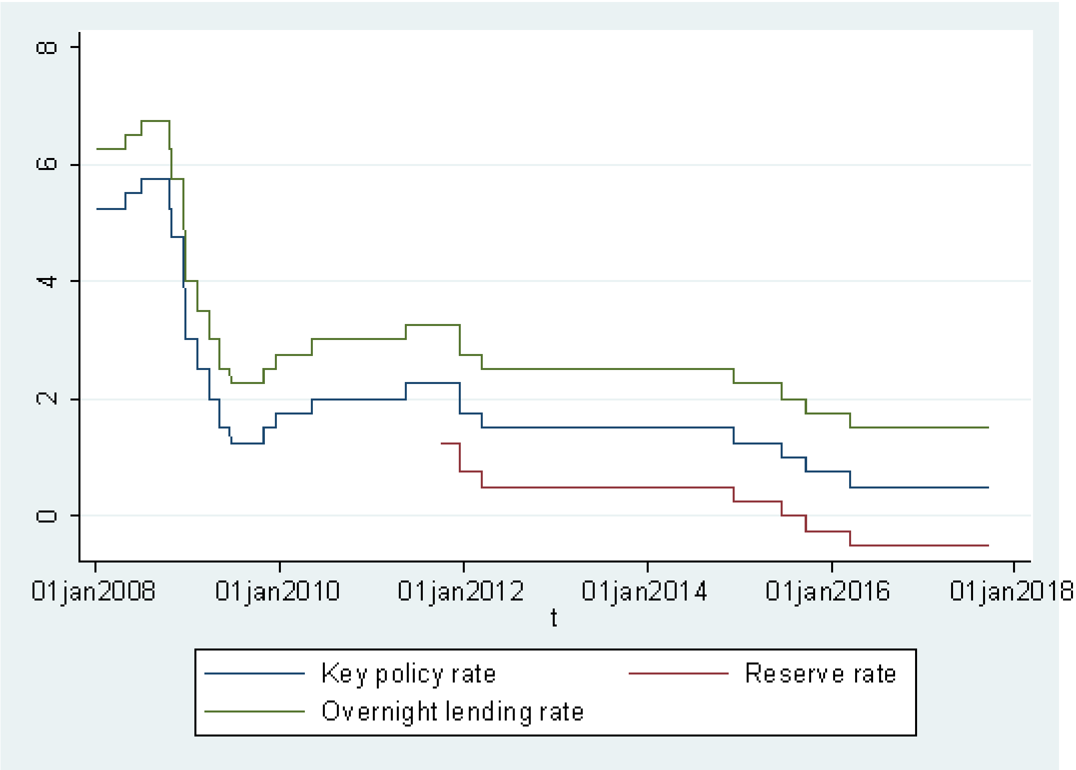
Norges Bank has a mandate to promote price stability (Norges Bank, 2017a). It targets a low and stable inflation through means of monetary policy (Aamodt et al., 2016). The process through which monetary policy decisions affect economic activity and inflation is called the "transmission mechanism" (George et al., 1999). The "transmission mechanism" of monetary policy is a term for how *"[d]ecisions about [the] official interest rate affect economic activity and inflation through several channels"*. Norges Bank's liquidity management system is intended to secure the transmission mechanism and implement the Executive Board's interest rate decisions. This is achieved by determining the conditions on which the banks can obtain funding or interest on their deposits with Norges Bank and managing the amount of reserves in the banking system.

Through its liquidity policy, Norges Bank seeks to maintain the short-term money market interest rates close to the key policy rate (Aamodt & Tafjord, 2013). Norges Bank performs market operations in order to maintain the desired level of total reserves. It can create new reserves in different ways. First, it can purchase foreign exchange or securities. However, except for reverse repurchase agreements, Norges Bank has not held securities denominated in NOK since 2004. Second, it can offer repurchase agreements (Flatner & Tornes, 2002). Third, it can lend funds to the banks. It typically offers secured “F-loans”, which are fixed-rate loans with maturities from one day up to three weeks. Equivalently, Norges Bank can withdraw liquidity from the banking system by borrowing from the banking system through “F-deposits”, which are fixed-rate deposits with the same maturities as F-loans. Structural liquidity and Norges Bank’s market operations sum up to the total liquidity in the banking system.

Up to October 2011, Norges Bank managed bank reserves through a “floor system” (Aamodt & Tafjord, 2013). In this system, there was no specific target for the level of reserves in the banking system. The interest rates paid on reserves on the banks’ accounts in Norges Bank were equivalent to the key policy rate for all the reserves. This rate establishes a “floor” in the market because no bank would be willing to lend out their reserves to a rate that is lower than the secure rate that is offered on their accounts with Norges Bank (Aamodt et al., 2016). Equivalently, the banks would normally not borrow funds from each other to a rate that is higher than the overnight lending rate offered by Norges Bank. A weakness of the floor system was that the banks did not have the need or an incentive to reallocate liquidity between themselves. Consequently, it was difficult to establish a market-based money market rate and the level of reserves gradually and unintentionally increased. This is the reason that the floor system was abolished.

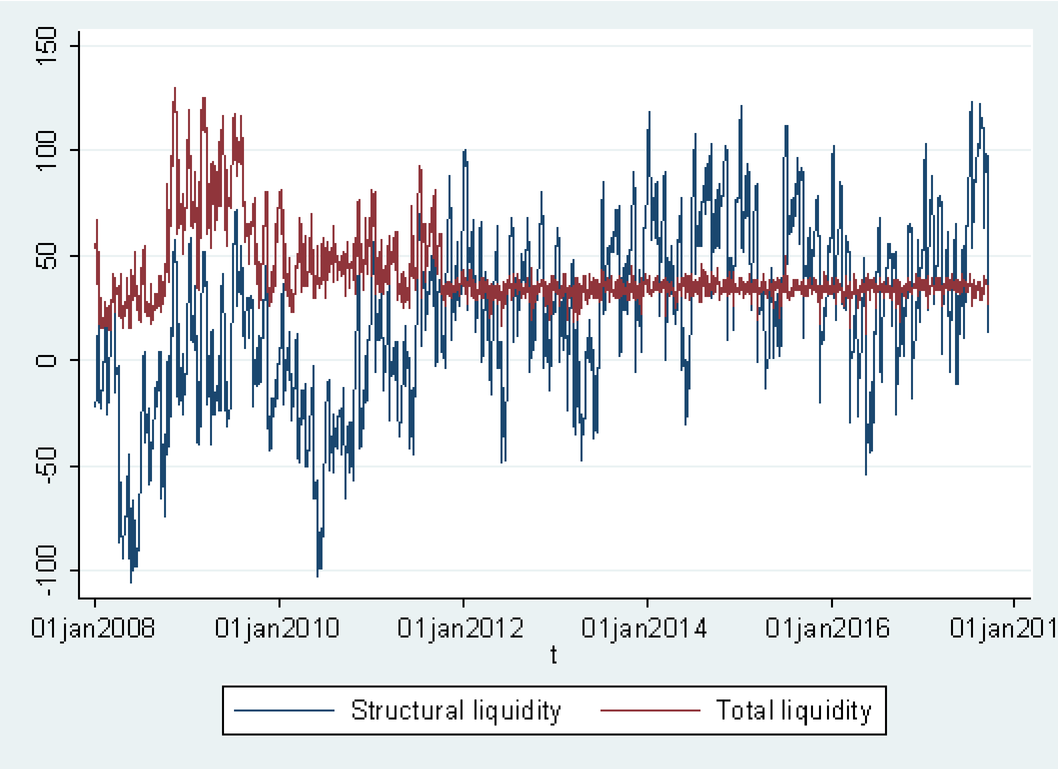
On 3 October 2011, Norges Bank established a new liquidity management system that resembles a “corridor system” (Aamodt et al., 2016). In a corridor system, the key policy rate is in between the central bank’s deposit rate and its overnight lending rate. The two latter form the “corridor”. The level of total central bank reserves is zero. Consequently, some banks have a surplus of reserves whereas other banks have a deficit at the end of the business day. Banks that have a deficit of reserves are forced to obtain funding. The banks will have an incentive to reallocate reserves between themselves. That way, the banks with a reserve surplus can obtain an interbank rate that is higher than the reserve rate offered on the deposits with the central bank. Banks with a deficit can borrow reserves at an interbank rate that is lower than the central bank's overnight lending rate. The short-term money market rate is usually close to the key policy rate. The rates offered by Norges Bank are displayed in figure 2.2.

Figure 2.2: Norges Bank's key policy rate, reserve rate and overnight lending rate over time. Percentage points.



Norges Bank's new system is a "quota system" (Aamodt et al. 2016). In this system, each bank obtains an interest rate equal to the key policy rate up to a certain quota of reserves whereas additional reserves are subject to Norges Bank's overnight lending rate. A pure corridor system was not considered expedient in Norway because the government's account in Norges Bank causes large fluctuations in the level of total reserves. The fluctuations in both the structural and the total liquidity are shown in figure 2.3. It has been more stable after the new liquidity management system was established in October 2011. Norges Bank's target for the level of total reserves is between 30 and 40 billion NOK. The sum of the banking system's quotas is 45 billion NOK and they are allocated on three groups of banks, where the NIBOR panel banks constitute the first group and receive the largest quotas.

Figure 2.3: Structural and total liquidity in the Norwegian banking system over time. Billions of NOK.



The key policy rate is determined by the Executive Board of Norges Bank on its monetary policy meetings (Norges Bank, 2017b). The frequency of the Executive Board's monetary policy meetings has varied throughout the years. It was particularly high during the years of the financial crisis. However, since 2012 there has been six monetary policy meetings annually. These meetings usually take place in March, May, June, September, October and December. Normally, the shortest money market rate is close to the key policy rate under Norges Bank's liquidity management system (Aamodt et al., 2016).

2.5 Quantitative easings

The term "quantitative easings" was first applied to Japan during the 1990s and refers to the targeting of quantity variables in the monetary policy rather than interest rates. The market operations of different central banks are designed to address different problems (Joyce et al., 2012). The Bank of Japan attempted to boost the level of cash reserves held by the banking system in order to handle a liquidity problem, whereas the Bank of England and the US Federal Reserve System's operations were designed to affect the prices and yields of a range of assets, particularly bonds issued to companies and households.

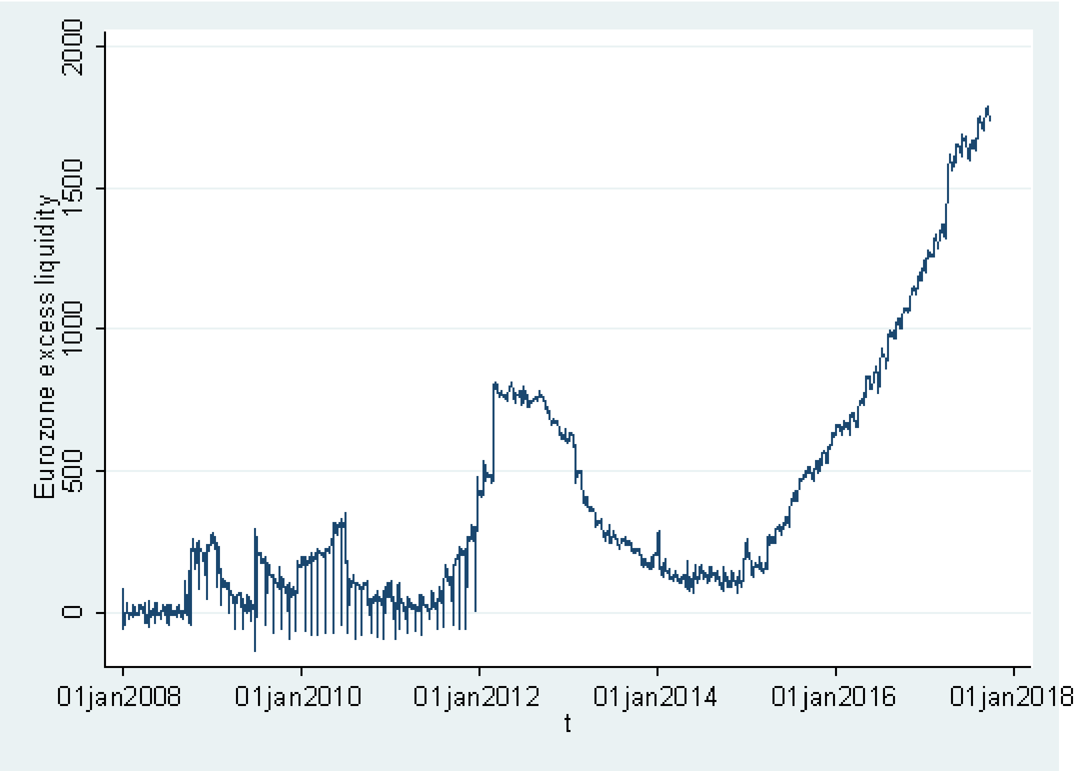
As the European Central Bank's key policy rate has approached the zero lower bound, it has utilized other non-standard policy measures to provide liquidity to the financial sector. These measures include two "longer-term refinancing operations" (LTROs) that were announced in December 2011 (ECB, 2011). The LTROs were a full allotment extension of the ECB's lending to banks with a maturity of 36 months. The increase in lending due to the LTROs was substantial and led to an increase in the amounts of sovereign bonds purchased by European banks (Krishnamurthy et al., 2015).

Furthermore, ECB announced series of "targeted longer-term refinancing operations" (TLTROs) in June 2014 and March 2016 (ECB, 2014a & 2016). The TLTROs are intended to strengthen the transmission mechanism of monetary policy by easing non-financial private sector credit conditions and stimulating credit conditions. The operations have maturities of up to four years. The rates on loans offered to the non-financial private sector decreased substantially immediately after the announcement of the first series (ECB, 2017a).

ECB also uses asset purchase programs (APPs) as a measure of quantitative easings (ECB, 2017b). The current APP has been extended and will continue until the end of December 2017 or beyond. An APP entails that ECB purchases securities, bonds or sovereign debt (Szczerbowicz, 2015). The intention is to reduce the quantity of selected assets available for investors in order to cause an increase in prices and a decrease in yields. Moreover, APPs can reduce the required liquidity compensation for private investors because they are able to easily sell their assets to ECB.

Before the quantitative easings, ECB's liquidity management framework of the eurosystem was basically a corridor system similar to Norges Bank's liquidity management framework, except that it targeted neutral liquidity and did not offer quotas with a rate more favorable than its overnight lending rate (ECB, 2014b). That is, the level of total reserves usually fluctuated around zero. However, as a result of ECB's policy measures, excess liquidity in the eurozone banking system has increased considerably. Excess liquidity is defined as *"deposits at the deposit facility net of the recourse to the marginal lending facility, plus current account holdings in excess of those contributing to the minimum reserve requirements"* for the European banking system. It has also caused a decrease in the liquidity premium of EUR relative to USD and other currencies (Lund, Tafjord & Øwre-Johnsen, 2016).

Figure 2.4: Excess liquidity in the eurozone over time. Billions of EUR.



In figure 2.4, we see the development of excess liquidity in the eurozone. It was close to zero until late 2008. It was particularly volatile with regular temporary drops from late 2008 through 2011. This period coincides with the financial crisis of 2008 and 2009, the crisis in the European government bond market in 2011 and 2012 (the "liquidity crisis"), and the time in between (Lund, Tafjord & Øwre-Johnsen, 2016).

The US Federal Reserve System has also performed quantitative easings under the programs called QE1, QE2 and QE3 (Fischer, 2015). The latter, QE3, which is still operative, was announced in December 2012 (FOMC, 2012). Bonds that were purchased under the first two quantitative easings programs have started to mature. The level of total assets in the US banking system has been stable since the second half of 2014 (FRED, 2017).

2.6 The Basel III Liquidity Coverage Ratio requirements

Basel III is a regulatory framework for the banking sector in the European Union (BCBS, 2011). The objective of the regulatory framework is raising the resilience of the banking sector and enhancing the risk coverage of the capital framework. One of the measures introduced in the framework is a minimum required "Liquidity Coverage Ratio" (LCR). The LCR is the ratio of high quality liquid assets after "haircuts", which are reductions in their face value, to the total net cash outflows over the next 30 calendar days.

$$LCR = \frac{Stock\,of\,HQLA}{Total\,net\,cash\,outflows} \tag{2.1}$$

The LCR has created incentives for the banks to obtain unsecured funding with a maturity of more than 30 days relative to funding with a maturity of less than 30 days (Lund, Tafjord & Øwre-Johnsen, 2016). This may cause the risk premium in the former to increase and the risk premium in the latter to decrease. It has also created an incentive to obtain funding through customer deposits rather than through the money market because bank deposits represent a more stable source of funding (Christensen et al., 2014).

The minimum LCR requirements are implemented progressively as follows (European Commission, 2014):

- 60 percent from 1 October 2015
- 70 percent from 1 January 2016
- 80 percent from 1 January 2017
- 100 percent from 1 January 2018

As a member of the European Economic Area, Norway also has to adapt to the LCR in Basel III. However, Norwegian liquidity regulation requires systemically important banks to meet a 100 percent LCR requirement already from 1 January 2016 (Norges Bank, 2015). Norwegian banks satisfy the LCR requirements with a sufficient margin (Norges Bank, 2016).

A version of the Basel III framework and the LCR has also been implemented in the US (OCC, 2014). The LCR applies to US banks and other important financial institutions. The US transitional period for LCR is shorter than the European transitional period. The minimum LCR requirements are implemented as follows in the US:

- 80 percent from 1 January 2015
- 90 percent from 1 January 2016
- 100 percent from 1 January 2017

2.7 The US money market fund reform

The US money market provides short-term funding to the NIBOR panel banks (Lund, Tafjord & Øwre-Johnsen, 2016). New regulations that were introduced in a US money market fund reform (MMR) have caused an increase in NIBOR (U.S. SEC, 2014 & 2017). The reform, which was announced on 23 July 2014 and implemented on 14 October 2016, addresses run risks in money market funds. One of the most important changes introduced in MMR is that the share prices are now required to float along with changes in the market-based value of money market fund assets. Whereas the institutional prime money market funds used to be allowed to maintain a constant share price of 1.00 USD, they are now required to consider market-based factors and sell and redeem shares based on a floating net asset value.

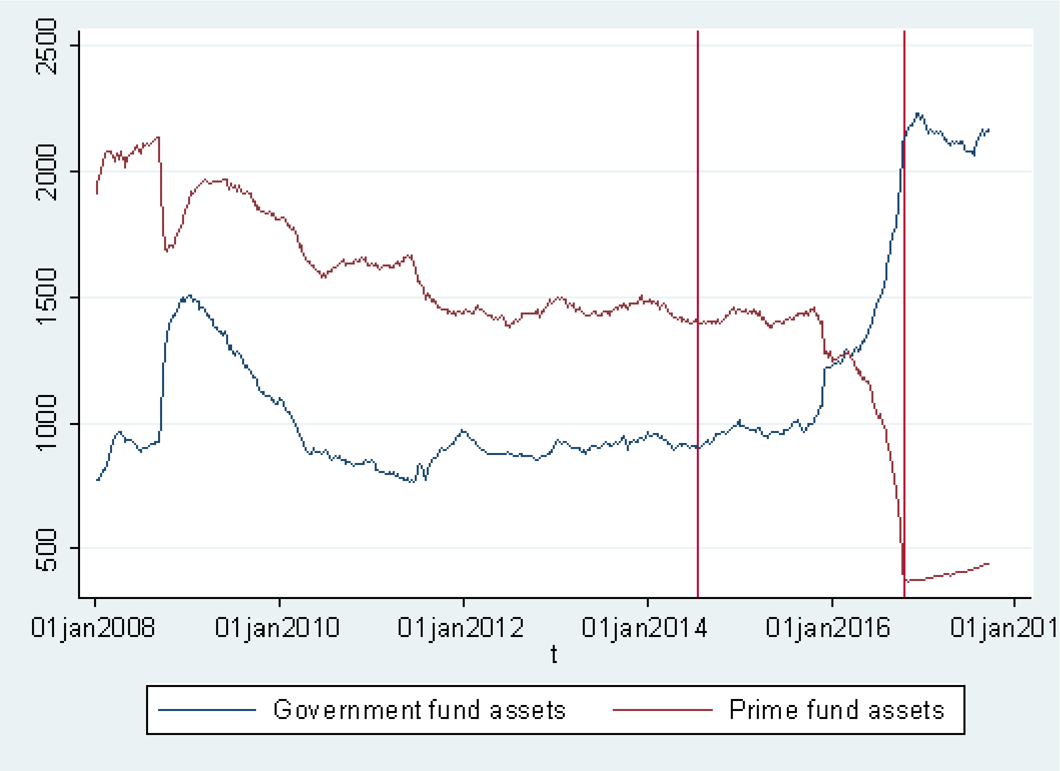
The other major change is that MMR provides the fund boards the possibility to impose liquidity fees or suspend redemptions temporarily in order to maintain weekly liquid assets at a level of 30 percent of its total assets. Redemptions can be suspended in a maximum of 10 business days. The fund boards are required to impose a liquidity fee if the level of weekly liquid assets falls below 10 percent. Weekly liquid assets include cash, US treasury securities and certain government securities with remaining maturities of up to 60 days.

Furthermore, the reform package involves enhanced disclosure requirements, immediate reporting of fund portfolio holdings, improved private liquidity fund reporting, stronger diversification requirements and enhanced stress testing. In total, MMR is designed to reduce the first-mover advantage associated with exiting a fund in times of financial distress (FED, 2017). The long term effect of the reform on the stability of the financial industry depends on the extent to which assets are moved to other kinds of investments in the US money market.

The floating share prices and the fund boards' new tools represent a risk to the investors (Lund, Tafjord & Øwre-Johnsen, 2016). Fund providers have to some extent converted their prime fund assets into government money market funds, which is apparent in figure 2.5. The reason is that the money market fund reform does not apply to government money market funds. Furthermore, the affected funds have to a greater extent invested in short-term commercial papers to prepare for possible further withdrawals of capital.

This has resulted in less available bank funding in the US money market. Norwegian banks have experienced a restricted access to short-term USD funding and potentially an increased refinancing risk (Norges bank, 2015). Because the supply of USD relative to other currencies has decreased, the relative liquidity premium in USD has increased. The concept of a relative liquidity premium shall be explained in more detail in chapter 4. The price of issuing commercial papers in the US market has also increased.

Figure 2.5: Government fund total assets and prime fund total assets over time. Billions of USD.



The red lines in figure 2.5 represent the announcement and implementation of the money market fund reform, respectively.

3. The Norwegian Interbank Offered Rate

This chapter contains an extensive examination of NIBOR. The Norwegian Interbank Offered Rate, NIBOR, is defined as *“a collective term for Norwegian money market rates at different maturities. NIBOR is intended to reflect the interest rate level a bank require for unsecured money market lending in NOK to another bank”* (Finance Norway, 2017). NIBOR serves as the most important benchmark for the interest rates of various financial products in the Norwegian market (Bernhardsen et al., 2012). Equivalent interbank offered rates serve the same purpose in other countries.

3.1 Fundamentals of NIBOR

Compliance with the rules for the calculation and publication of NIBOR is monitored by the NIBOR compliance committee (NoRe, 2017). As indicated in its definition, NIBOR is intended to reflect the interest rate a bank would require for an unsecured loan in NOK offered to a leading bank in the Norwegian money market and foreign currency exchange markets. Trades like this rarely take place except for loans with maturities of one or two days (Høien, 2014). When banks need longer-term funding, they issue certificates or bonds. Consequently, NIBOR is not a rate that is observed in the market. It should be regarded as a best possible estimate of what the rate would have been in such a trade and is derived with discretion.

NIBOR is quoted with maturities of one week, one month, two months, three months and six months (NoRe, 2017). NIBOR is fixed at 12 noon CET every trading day, or 10 a.m. CET on days with shorter trading hours in the Norwegian foreign exchange market. The calculation of NIBOR is based on the submitted rates of six panel banks. For each maturity, a simple average of the submitted rates is calculated, where the lowest and highest submissions are omitted. The NIBOR panel currently consists of six panel banks (Norges Bank, 2013). These are DNB, Nordea, Danske Bank, Handelsbanken, SEB and Swedbank.

The need for an interbank market arises because of insecurities regarding the balances on the banks' accounts in Norges Bank because of frequent transactions between the banks and the Norwegian government (Høien, 2014). Furthermore, the overnight lending rate in Norges Bank is unattractive. The banks can avoid overnight loans in Norges Bank by offering each other loans when there is a positive balance on their accounts. However, one should notice that NIBOR is a rate for unsecured loans, whereas the deposits and overnight loans in Norges Bank are secured (Aamdal, 2014). This suggests that NIBOR and the key policy rate are not directly comparable.

Unsecured interbank trades used to be far more extensive before the financial crisis of 2008 and 2009 (Aamdal, 2014). Three points are mentioned as an explanation for the decrease in such trades. First, the financial crisis revealed a considerable counterparty risk. Second, the banks are subject to stricter capital requirements. Third, the banks' liquidity has been placed under closer scrutiny and the banks do not wish to bind excess liquidity in loans to other banks except for loans with the shortest maturities.

The Financial Supervisory Authority of Norway and Norges Bank have assessed whether NIBOR correctly reflects the price of an unsecured interbank loan and its robustness (Norges Bank, 2013). Although NIBOR does not reflect observed trades, it should be related to the banks' marginal funding costs, such that it compensates for poorer liquidity and credit risk. The NIBOR panel banks' submissions are close to the Kliem rate, which is higher than the rate the most creditworthy banks have to pay in the markets for commercial papers and certificates of deposit, which are also unsecured. This suggests that NIBOR is higher than the actual funding costs that the banks face. On the other hand, it can be pointed out that in principle, it should be possible to obtain funding on short notice in the interbank market, as opposed to the market for certificates.

Furthermore, the robustness of NIBOR is vulnerable to manipulation on the panel banks' hand (Norges Bank, 2013). The banks are subject to rates that are linked to NIBOR and may profit from a lower or higher NIBOR depending on their net assets and liabilities. Due to the high volatility in NIBOR, it would be easy to influence NIBOR by submitting a rate that is too high or too low and still within the normal volatility. Moreover, one bank's submission may influence the other banks' submissions. Trandum & Njølstad (2015) found that this is likely the case and that there is inconsistencies across time in the relationship between the domestic premium and the underlying credit risk for the NIBOR panel banks.

3.2 What affects NIBOR?

NIBOR is highly volatile. The reason for this is that NIBOR, unlike other interbank offered rates, is quoted as a foreign exchange swap rate (Lund, Tafjord & Øwre-Johnsen, 2016). This entails that it is based on a USD rate. This rate is adjusted for the price of swapping USD into NOK in the foreign exchange swap market, given by the forward point, which is the difference between the forward and spot exchange rates. Consequently, in contrast to interbank offered rates such as the USD LIBOR, NIBOR is based on underlying components that cause high volatility.

NIBOR is also highly volatile because it is determined by the supply and demand for liquidity in the money markets (Flatner & Tornes, 2002). The liquidity is affected by a lot of recurrent and occasional commercial flows. These include factors such as financial policy and transactions in the public accounts, the due dates of taxes and government liabilities, the issuance of government securities and treasury bills, the amount of cash and consumer behaviour related to holidays. NIBOR is also affected by financial unrest in the eurozone (Bernhardsen et al., 2012).

NIBOR can be decomposed into an expected overnight index swap (OIS) rate and a risk premium (Lund, Tafjord & Øwre-Johnsen, 2016). The overnight index swap rate can be regarded as the market's expected key policy rate. Fluctuations in the risk premium will cause fluctuations in NIBOR and other interest rates even when the expected key policy rate is unchanged. This may create challenges for Norges Bank and its monetary policy because it causes disturbances in the monetary policy transmission mechanism in Norway (Aamdal, 2014). This is the case particularly when the key policy rate is close to the zero lower bound and conventional monetary policy tools are less effective. Furthermore, it suggests that it is difficult to model NIBOR and assess the causes of movements in NIBOR or the impacts of new financial regulations.

Figure 3.1: Three-month NIBOR and the OIS rate over time. Percentage points.

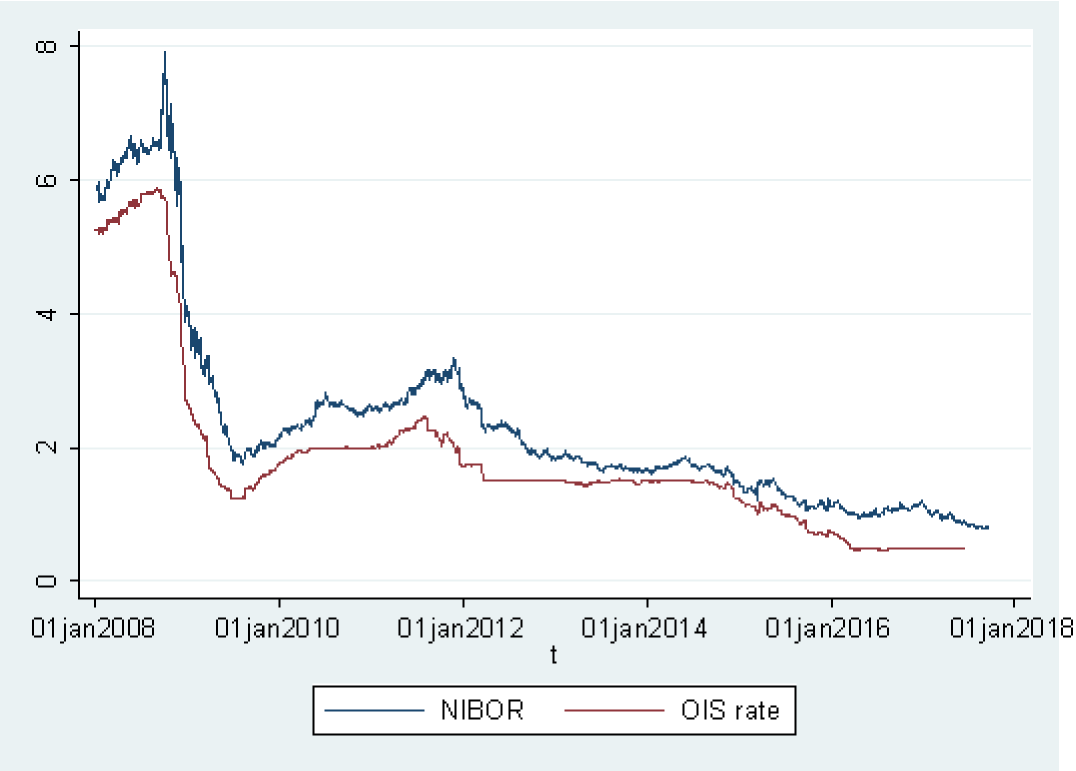


Figure 3.1 shows the development of the three-month NIBOR and the estimated OIS rate. The risk premium in NIBOR is given as the differential between those two series. It tends to increase during periods of financial distress, such as the financial crisis of 2008 and 2009 and the crisis in the European government bond market in 2011 and 2012 (Lund, Tafjord & Øwre-Johnsen, 2016).

3.3 Other rates affecting NIBOR

The NIBOR panel bank base their NIBOR submissions on a USD rate that reflects the price of unsecured interbank loans in USD between banks in the money market (Lund, Tafjord & Øwre-Johnsen, 2016). Until the financial crisis, NIBOR was based on the USD LIBOR, the interbank offered rate in the US money market (ICE Benchmark Administration, 2016). It is called USD LIBOR (London Interbank Offered Rate) because USD is one of five currencies whose interbank offered rate is fixed in London on London business days. LIBOR is the primary benchmark for interest rates globally. LIBOR currencies are quoted with seven maturities, including three-month rates. The definition of LIBOR is the answer to the following question *"At what rate could you borrow funds, were you to do so by asking for and then accepting inter-bank offers in a reasonable market size just prior to 11 am?"*

For LIBOR, the definition is amplified (Bradley, 2013). The expanded definition states that *"Contributions must represent rates at which a bank would be offered funds in the London interbank market"*. Furthermore, it states that *"Contributions must be for the specific currency concerned and not the cost of producing the currency by borrowing in a different currency and obtaining the required currency via the foreign exchange markets"*. Consequently, one can derive two important differences between NIBOR and LIBOR. First, LIBOR is a borrowing rate (Aamdal, 2014). NIBOR, on the other hand, is a lending rate, as its definition reflects. Furthermore, it is explicitly stated that LIBOR is not a foreign exchange swap rate, unlike NIBOR (Norges Bank, 2013). The development of the USD LIBOR is shown in figure 3.2. It was particularly high during the financial crisis of 2008 and 2009.

Figure 3.2: Three-month USD LIBOR over time. Percentage points.

Because there to a greater extent was actual transactions in the interbank and futures market before the financial crisis, NIBOR was to a great extent based on observable market prices (Aamdal, 2014). During the financial crisis, the interbank trades in the US money market stopped, except for loans with the shortest maturities. It was also revealed that the USD LIBOR panel banks had manipulated the USD LIBOR quotations. To cover up poor liquidity, the USD LIBOR banks intentionally submitted rates that were too low. Consequently, USD LIBOR underestimated the actual rates that the banks were subject to in the interbank market, which in turn caused NIBOR to be quoted too low.

Since the financial crisis, the NIBOR panel banks have based their submissions on the Kliem-rate, which is a USD rate that is published by the brokerage house Carl Kliem in Frankfurt (Lund, Tafjord & Øwre-Johnsen, 2016). Like NIBOR, the Kliem rate is quoted as a foreign exchange swap rate and is intended to reflect the price of unsecured loans in USD via EUR at the eurozone money market rate EURIBOR. Considering that the NIBOR panel banks base their submissions on the Kliem rate, NIBOR is implicitly based on the risk premium for European banks (Bernhardsen et al., 2012). Although credit risk is normally priced lower for NIBOR panel banks than for EURIBOR panel banks, the level of NIBOR indicates that the NIBOR panel banks also consider credit risk of corresponding European banks.

However, there is no unambiguous relationship between Kliem and NIBOR (Aamdal, 2014). The NIBOR banks frequently use their discretion and consider funding costs, alternative costs, analyses and the risk premiums in other currencies as well. The volatility in NIBOR is somewhat lower than the volatility in the implicit NOK rate in Kliem (Norges Bank, 2013). A possible explanation is that the panel banks submit a rate that is close to the implicit NOK rate in Kliem, but disregard the largest fluctuations from one day to another.

As a result, NIBOR was highly correlated with USD LIBOR up to the financial crisis of 2008 (Lund, Tafjord & Øwre-Johnsen, 2016). Afterwards, it has followed Kliem more closely. The level of Kliem has been higher than the level of USD LIBOR. However, the NIBOR panel banks are free to use their discretion and adjust the rate to be the best possible estimate of the price of an unsecured loan in NOK. The NIBOR submissions can be affected by the fact that NIBOR panel banks retrieve short-term funding directly in the USD money market. Thus, also the price of issuing commercial papers in the US market may cause the NIBOR banks to submit different rates and consequently cause the USD rate in NIBOR to deviate from Kliem.

3.4 The recent development of NIBOR

The value of the risk premium in NIBOR is usually between 0.2 and 0.3 percentage points (Lund, Tafjord & Øwre-Johnsen, 2016). It tends to increase in periods of great distress and high perceived risk, such as the financial crisis and the crisis in the European government bond market. The risk premium has also increased since the end of 2014.

There is three major explanations for the latest increase (Lund, Tafjord & Øwre-Johnsen, 2016). First, the supply of liquidity in the eurozone has increased through quantitative easings programs. These programs created a "surplus supply" which has caused the price of borrowing EUR to decrease. Moreover, it has caused the liquidity premium between EUR and USD to increase and it has entered NIBOR through the Kliem-rate. Second, banks have adjusted to the minimum "Liquidity Coverage Ratio" (LCR) required in the regulatory framework Basel III by withholding liquidity. The third cause of the increase in NIBOR is the US money market fund reform that has caused investors to reduce the level of US prime fund assets.

Consequently, the increase in NIBOR has to a great extent been caused by an increase in the risk premium in USD LIBOR and a surplus of EUR (Norges Bank, 2017c). In 2017, the risk premium in NIBOR has fallen somewhat faster than expected by Norges Bank. Onwards, the three-month risk premium is expected to stabilize at the current level. The key policy rate is expected to be unchanged until 2019 and then increase.

4. **Risk and interest rate formation**

Theories about risk and interest rate formation are presented in this chapter. First, we describe the general sources of risk and explain how these affect interest rates. Furthermore, we illuminate the capital asset pricing model (CAPM) and how risk is associated with fluctuations in the general market economy, before we describe the term structure of interest rates and introduce theories regarding its form. Next, we explain how interest rates are linked across economies as well as the impact of international conditions. Finally, we consider quantitative easings and the year-end effect.

4.1 Decomposition of risk

Risk is defined as *"exposure to a proposition of which one is uncertain"* (Holton, 2004). In order to accept risk in the market, an investor requires compensation. Such compensation is an additional return beyond the risk-free rate. This risk is termed the "risk premium". There is risk premiums present in NIBOR and other interbank rates. The risk premiums arise from general market conditions and from the bank's credit ratings (Bernhardsen et al., 2012). The risk premium generally has four sources. These are credit risk, maturity risk, liquidity risk and inflation risk (Bernhardsen, 2011).

Credit risk is the risk that the creditor will default on his obligations. Credit risk increases with the duration of the interest rate, as long as termination leads to increased risk of default. The primary tendency is that the credit risk is an inversely proportional function of the borrower's credit rating. The credit risk increases with increased probability of default. This suggests that an interbank rate will usually be greater than the yield of a government bond with equal maturity. Factors that are controlled by the central bank do not affect a bank's solvency to a great extent. Consequently, the central bank cannot easily control the credit risk spread for any particular bank. However, the central bank's monetary policy could affect the general credit risk in the market. By increasing the money supply, and consequently the activity in the interbank market, the credit risk will decrease. The reason is that increased activity will in general cause the rate of banks that are defaulting on their obligations to decrease. This is closely related to liquidity risk.

Liquidity risk arises because securities are less liquid than cash or bank deposits. Consequently, an investor would require an additional return in exchange for liquid assets. In general, investors require higher compensation for liquidity under certain conditions. This is the case if the market is small, if the turnover is low or if there is a large spread in the purchase and selling price (Bernhardsen et al., 2016). These are characteristics of markets with few buyers. Under such conditions, it is more difficult to sell securities. In turn, that difficulty imposes a risk premium on the securities. Correspondingly, an increased liquidity risk tends to appear in the interbank market under certain conditions. These conditions arise if the banks are not able to cover their short-term obligations, liquidate assets or if the market is extraordinarily illiquid. Consequently, the banks are not able to borrow funds because of the excessive cost of funding (Acerbi & Scandolo, 2007). If all of these cases arise simultaneously, the banks are not able to finance themselves. An example of such a situation was the financial crisis of 2008.

Maturity risk arises when the investment horizon may differ from the maturity of interest rates. In such cases, there is increased uncertainty regarding interest rate developments. An investor would require a compensation for this kind of uncertainty. Such compensation can be considered a risk premium for the maturity. In the money market, one can observe a higher risk premium in NIBOR for longer maturities. This suggests that there is a risk premium associated with the maturity in NIBOR. However, the effect of maturity on the risk premium can be both positive and negative, depending on the preferred maturity. If the investor prefers holding long maturities over short maturities, the effect on the risk premium is negative. Consequently, rates with longer maturities are associated with a higher risk premium than the average risk premium of implied forward rates (Bernhardsen et al., 2016).

Inflation risk may occur in a market interest rate. Future inflation is to some extent uncertain, which may lead an investor to require additional compensation. Uncertainty regarding inflation may in turn cause uncertainty regarding future real returns. We can decompose the inflation risk into two parts: an inflation expectation risk and an actual inflation risk. The part of the inflation risk with regard to expectations can be rationalized as follows: The investor needs to be compensated for a future decrease in the real value of nominal units of a currency (Bernhardsen et al., 2016). The second part of the inflation risk can be considered the risk for the real value of the currency to decrease more than expected. The central bank can reduce the overall inflation risk with a consistent and credible monetary policy.

4.2 The Capital Asset Pricing Model

The Capital Asset Pricing Model (CAPM) is a model for determining the appropriate rate of return on an asset (Ayrapetova, 2012). The model builds on diversification and modern portfolio theory and considers risk in relation to overall market fluctuations. It can be applied to the money market.

The model is based on a few assumptions (Ayrapetova, 2012). First, it is assumed that there is no transaction costs. The bidders in the market have the same information and expectations about the mean rates of return, covariances and variances and can borrow and lend unlimitedly at the risk free rate. The bidders are risk-averse and rational and they face the same optimization problem. Furthermore, the bidders only care about systematic risk in the asset. Systematic risk is the risk that cannot be eliminated through diversification because it reflects the risk that is inherent in the market. An example of such a risk is the risk of global financial distress and crises. The non-systematic risk is uninteresting because the bidder can eliminate it by diversifying investments.

The CAPM is derived as follows (Sigman, 2005). We let $\overline{r_i}$ denote the rate of return on asset *i*, r_f denote the risk free rate of return, $\overline{r_M}$ denote the market rate of return, $\sigma_{M,i}$ denote the covariance of the market with asset *i* and σ_M^2 denote the variance of the market. Then the model states that

$$\bar{r_i} - r_f = \beta_i(\bar{r_M} - r_f)\,, \tag{4.1}$$

where

$$\beta_i = \frac{\sigma_{M,i}}{\sigma_M^2} \tag{4.2}$$

is called the beta of asset *i* and is a measure of its systematic risk. The beta can be both positive and negative. The beta is measured by the covariance of the market with asset *i* relative to the overall variation of the market. If the value of the asset to a great extent fluctuates jointly with the value of the market, the beta will be large. The sign of the beta determines if the required risk premium should be positive or negative.

Equation 4.1 states that in order to take accept risk in the market, a creditor requires an additional return beyond the risk-free rate of return. This additional return is called the market risk premium $(r_M - r_f)$. In order to accept risk in an asset *i*, an investor requires a risk premium equal to $(r_i - r_f)$.

The CAPM formula can also be expressed as a function of the rate of return on asset *i* as

$$r_i = r_f + \beta_i(r_M - r_f) + \epsilon_i\,, \tag{4.3}$$

where

$$\epsilon_i = r_i - r_f - \beta_i(r_M - r_f) \tag{4.4}$$

is an error term that allows for deviations from the general implication of the determinants of the risk premium.

The model suggests that the higher the systematic risk of an asset, the higher rate of return a risk-averse and rational bidder should demand of an asset. Or, in other words, the bidder should demand a high risk premium if the value of the asset is highly vulnerable to fluctuations in the market. Examples of such bidders and assets could be banks and unsecured debt receivables in the Norwegian money market. The model can be further expanded in order to regard additional factors, such as magnitude, value and profitability (Fama & French, 2015).

4.3 The term structure of interest rates

The term structure of interest rates, often referred to as the yield curve, is the curve of points recording observed yield and time to maturity for a given class of securities (Nelson & Siegel, 1985). Within the yield curve, there is also information about the forward interest rates. For example, if we observe the three-month rate and the six-month rate, we can find the three-month forward interest rate three months from today. An upward (downward) slope between the three-month rate and six-month rate, indicates that the expected future three-month rate will increase (decrease).

In general, the yield of a contract with maturity in *T* periods is written as r_T. The yield expected by the market from time *t* to time *T* is written as $f_{t,T}$. Furthermore, we let p_T denote the discount rate for a contract that matures in time *T*, with maturity value equal to 1

(Vasicek, 1977). That is, p_T is equal to the present value of receiving 1 at time *T*. If the yield curve is known, the following relationship is true for the discount curve:

$$p_T = e^{-r_T T}\,, \tag{4.5}$$

where $T > 0$. With the discount rate, we can quantify the yield curve, as shown by Vasicek (1977):

$$r_T = -\frac{1}{T}\log p_T\,. \tag{4.6}$$

The yield curve contains information about the forward rates. We have the following relationship between the yield to maturity and the forward rates:

$$Tr_T = f_{0,1} + f_{1,2} + \cdots + f_{T-1,T}\,, \tag{4.7}$$

where $f_{0,1} = r_1$. r_T is rearranged and defined as follows:

$$r_T = \frac{1}{T}\int_0^T f_\varsigma d\varsigma\,, \tag{4.8}$$

where f_ς is the yield we can currently be certain of obtaining for the period from time ς to time $\varsigma + \Delta\varsigma$.

Equation 4.6 shows that if an investor deposits 1 NOK for *T* periods, the investor will receive the *T*-period rate for *T* periods. Alternatively, an investor can deposit 1 NOK for *t* periods and receive the rate r_t for *t* periods and agree to reinvest at the forward rate $f_{t,T}$ *t* periods from today for *T* - *t* more periods. The implied forward rate is the rate at which these strategies are equivalent (Bernhardsen, 2011). Consequently, we can solve for the implied rate *t* periods from today and with maturity at time *T*, that is $f_{t,T}$.

$$f_{t,T} = \frac{Tr_T - tr_t}{T - t}, T > t \tag{4.9}$$

In the three following sections, we will introduce theories that illuminate the term structure between short-term and long-term interest rates.

4.3.1 The expectations hypothesis

The pure expectation hypothesis suggests that the return is equal for any investment, regardless of maturity, if the risk is the same for all securities (Modigliani & Sutch, 1966). If the expectations hypothesis holds, the expected yield from time *t* with maturity at time *T*, $E_t(r_{t,T})$, equals the implied forward rate. That is,

$$f_{t,T} = E_t(r_{t,T}), \tag{4.10}$$

where $E_t()$ denotes expectations at time *t.*

Whether it be an investment with a long maturity or rolling investments with shorter maturities, the return is expected to be equal if the expectations hypothesis hold and the risk for all securities are equal. Consequently, the expectations hypothesis contradicts the notion of a maturity premium in the risk premium.

4.3.2 The risk premium theory

The risk premium theory builds on the simple expectations hypothesis. The theory states that an interest rate that spans over T periods is equal to the average of the T one-period interest rates in addition to a risk premium. The return is considered to be certain on short-term securities and uncertain on longer maturities and consequently, a premium is imposed on securities with longer maturities (Modigliani & Sutch, 1966). This can be stated as follows (Vasicek, 1977):

$$r_T = E_0\left(\frac{1}{T}\int_0^T r_\varsigma d\varsigma\right) + \overline{\pi}\ , \tag{4.11}$$

where $E_0()$ denotes the expectations today and $\overline{\pi}$ is an increasing function of time to maturity for the yield, which increases with the time to maturity. The first part of the right hand side of equation 4.11 is practically the same as the right hand side of equation 4.8. That is, the risk premium theory builds on the expectations hypothesis. This is in accordance with equation 4.10.

The difference from the expectations hypothesis is that investors would require a risk premium to hold securities with longer maturities because of the higher uncertainty associated with the corresponding payoffs. The expected yield on one asset affects the expected yield of another asset with a different maturity. Consequently, the theory suggests that interest rates with shorter maturities are not perfect substitutes for interest rates with longer maturities, in contrast to the simple expectations hypothesis.

4.3.3 The preferred habitat theory

The preferred habitat theory is a combination of the previous two theories and builds on the assumption that an investor prefers one maturity over another. That is, the investor has a preferred habitat (Modigliani & Sutch, 1966). The yield structure is believed to be controlled by the expectations hypothesis, but modified for risk premiums, as described in the risk premium theory. However, the preferred habitat theory differs in one fundamental respect.

An assumption of the risk premium theory is that the investors are concerned with the short-term return. Furthermore, anyone holding securities with longer maturities retains risk associated with the uncertainty of future payoffs. This is believed to be reflected in the longer maturities, together with the implied forward rates. However, these assumptions would apply only if every investor desires to turn their portfolio into cash at the end of the short-term period (Modigliani & Sutch, 1966). This would imply that every investor has a short habitat. However, in the real world, different investors have different habitats.

Suppose an investor has a *t*-period habitat. The investor would require a risk premium in order to invest in any maturity outside of his investment horizon, even if the maturity is shorter. Since the preferred habitat theory builds on the expectations hypothesis and the risk premium theory, it can be written exactly as equation 4.11. However, the function $\overline{\pi}$ needs to be altered with a specification that accounts for preferred maturities (Vasicek, 1977). It differs from the specification for $\overline{\pi}$ in the risk premium theory section, which unambiguously is an increasing function of time to maturity. Consequently, the investment horizon may be a determinant of the interest rates according to the preferred habitat theory. The preferred habitat theory can help explain observations in the yield curve that are not adequately explained by the simple expectations hypothesis or the risk premium theory.

4.4 Components of NIBOR

Now we introduce theories that explain the connection between interest rates denoted in different currencies and how they are connected to other macroeconomic variables.

4.4.1 The theory of covered interest rate parity

The theory of covered interest rate parity considers how interest rates across different currencies and foreign exchange rates are related. According to the theory of covered interest parity, arbitrage should not be possible through foreign exchange (Lund, Tafjord & Øwre-Johnsen, 2016). This can be derived from the following equation:

$$\frac{1+i_N}{1+i} = \frac{F}{E}, \tag{4.12}$$

where i_N is the interest rate in Norway, i is the interest rate abroad, and F and E are the forward and spot exchange rates in levels, respectively. Equation 4.12 implies that the ratio of one plus domestic and foreign interest rates, respectively, over time must equal the ratio of the forward and spot exchange rates.

In order to illuminate the implications of the theory of covered interest rate parity, we solve for the domestic interest rate. First, we utilize logarithmic forms. When applying the logarithmic rules, we have that

$$ln(1+i_N) - ln(1+i) = lnF - lnE, \tag{4.13}$$

where $\ln F$ and $\ln E$ are the forward and spot exchange rates in natural logarithms, respectively. We substitute $\ln F$ with f and $\ln E$ with e. Furthermore, we assume that $\ln(1+i) \approx i$ and $\ln(1+i_N) \approx i_N$ for small values, and substitute correspondingly. That leads to the following equation:

$$i_N = i + (f - e), \tag{4.14}$$

where f and e are the forward and spot exchange rates in natural logarithms, respectively. Consequently, the domestic interest rate is approximately equal to the sum of the foreign interest rate and the term supplement for swapping the currencies. Otherwise, it would be possible to obtain a risk free profit. The term supplement reflects the difference in interest rate levels between the economies (Lund, Tafjord & Øwre-Johnsen, 2016).

The theory of covered interest rate can be applied to NIBOR. The foreign exchange forward points compensate for the expected differential between the overnight index swap rates. This suggests that the NIBOR banks cannot obtain a higher risk premium in another currency.

Interbank offered rates can be interpreted as the sum of the expected overnight index swap rate for a given period and a risk premium (Lund, Tafjord & Øwre-Johnsen, 2016). Such a decomposition can be given as

$$i = OIS + rp, \tag{4.15}$$

where i denotes the interbank offered rate, OIS denotes the expected overnight index swap rate and rp denotes the risk premium. For NIBOR, we use the subscript N, such that

$$i_N = OIS_N + Nrp\,, \tag{4.16}$$

where i_N is NIBOR, OIS_N is the Norwegian overnight index swap rate and Nrp is the risk premium in NIBOR.

Norway does not have its own OIS market, which complicates the decomposition (Aamdal, 2014). However, OIS_N is considered a secure rate and is normally close to Norges Bank's key policy rate. The reason is that the OIS rate is derived from interest rate swap agreements. For example, if bank A pays bank B a geometric average of a daily floating key policy rate for the next 90 days, then this rate is known only ex post. On the other side of the swap agreement, bank B pays an OIS rate, which is agreed upon between the two banks in advance. It is reasonable to consider the OIS rate as a reflection of the future expectations of the key policy rate over the maturity of NIBOR, which in this case is three months. Consequently, OIS is called the expected key policy rate (Bernhardsen, 2011). The OIS_N and Nrp in NIBOR are estimated daily by Norges Bank with cross-check calculations and at their discretion (Lund, Tafjord & Øwre-Johnsen, 2016).

NIBOR differs from other interbank offered rates because it is constructed as a foreign exchange swap rate. The NIBOR panel banks base their NIBOR submissions on a USD rate that reflects the price of an unsecured interbank loan. The USD rate is adjusted for the price of swapping USD for NOK. This adjustment is given by the forward point, which is the difference between the forward and spot exchange rates. Then NIBOR is given by

$$i_N = i_{\$,N} + (f_{\$,N} - e_{\$,N})\,, \tag{4.17}$$

where $i_{\$,N}$ is the USD rate in NIBOR, $f_{\$,N}$ is the forward exchange rate, $e_{\$,N}$ is the spot exchange rate and $(f_{\$,N} - e_{\$,N})$ is the foreign exchange forward points. The foreign and spot exchange rates are defined as NOK per USD. Both are given in natural logarithms.

NIBOR is given as a NOK rate that is intended to reflect the price of an unsecured interbank loan.

4.4.2 Liquidity premiums

Money market rates do not always comply with the theory of covered interest parity. The interest rate differential in the foreign exchange market may deviate from the implied differential in the expected key policy rates. Such deviations arise because relative differences in the supply or demand for one currency cause differences in the access to funding between currencies. Deviations can be regarded as relative liquidity premiums. We allow for differences between the risk premiums in NIBOR and the implicit USD rate by stating that

$$Nrp = rp_{\$,N} + (f_{\$,N} - e_{\$,N}) - (OIS_N - OIS_{\$}), \tag{4.18}$$

where $rp_{\$,N}$ is the risk premium in the implicit USD rate in NIBOR and OIS_N and $OIS_{\$}$ are the Norwegian and US OIS rates, respectively. The relative liquidity premium is also referred to as the overnight index swap basis, or the OIS basis. The OIS basis between USD and NOK, $OISB_{\$,N}$, is given by

$$OISB_{\$,N} = (f_{\$.N} - e_{\$,N}) - (OIS_N - OIS_{\$}). \tag{4.19}$$

Equation 4.19 is consistent with equation 4.16. If the OIS basis differs from zero, the foreign exchange forward points compensate for a liquidity premium as well as the difference between the overnight index swap rates.

Furthermore, substituting equation 4.19 into equation 4.18, we see that

$$Nrp = rp_{\$,N} + OISB_{\$,N} \,, \tag{4.20}$$

and consequently, that

$$i_N = OIS_N + rp_{\$,N} + OISB_{\$,N} \,. \tag{4.21}$$

We can infer that theoretically, NIBOR is determined by Norges Bank's expected key policy rate, the risk premium in the implicit USD rate and the relative liquidity.

4.4.3 The Kliem rate in NIBOR

There is several other ways of decomposing NIBOR. The rate can be decomposed into components that are observable in the market. That would allow us to better understand how the theory of covered interest rate parity can be violated and to quantify the liquidity premium in USD relative to EUR. In order to conduct this decomposition, we should study the dynamics of NIBOR and the Kliem rate more closely. Furthermore, we need to assume that the implicit USD rate in Nibor is approximately equal to the Kliem rate.

We will proceed by decomposing NIBOR in two parts, as shown by Lund, Tafjord and Øwre-Johnsen (2016).[2] The first part is the rate at which an individual panel bank believes it could lend out USD unsecured in the interbank market. This rate usually follows the Kliem

[2] From this point forward, we use a slightly different notation. That is, we denote NIBOR, EURIBOR and the term supplement differently in order to make the derivation more consistent with intuition.

rate closely, because the Norwegian panel banks base their submissions on the Kliem rate. Therefore, we denote the first part as Kliem. The second part, $tp_{\$,N}$, is the term supplement, which equals the difference between the forward rate and the spot price of swapping USD into NOK (Lund, Tafjord & Øwre-Johnsen, 2016).

$$NIBOR = Kliem + tp_{\$,N} \,. \tag{4.22}$$

In order to understand which elements that influence NIBOR, we need to understand the nature of the different parts of NIBOR. We recall that EURIBOR is the interbank offered rate in the eurozone. The Kliem rate is the biggest component in NIBOR. Practically, it is EURIBOR swapped into USD. Consequently, we can decompose the Kliem rate into EURIBOR and a term supplement of swapping USD into EUR:

$$Kliem = EURIBOR + tp_{E,\$} \,, \tag{4.23}$$

where $tp_{E,\$}$ is the term supplement of the swap and equals the difference in interest rate levels.

Equivalently with NIBOR, we can decompose EURIBOR into two parts. These are an overnight indexed swap rate, OIS_E, and a risk premium, rp_E. The risk premium is an expression for the risk exposure in the eurozone. Furthermore, we can derive that NIBOR is directly affected by changes in the risk in the eurozone. OIS_E is considered a risk free interest rate and is usually close to the European Central Bank’s key policy rate.

$$EURIBOR = OIS_E + rp_E \,. \tag{4.24}$$

With this equation for EURIBOR, we can substitute into equation 4.23 and rewrite the Kliem rate as a function of OIS_E, rp_E and $tp_{E,\$}$:

$$Kliem = OIS_E + rp_E + tp_{E,\$} \, . \tag{4.25}$$

The Kliem rate can also be expressed with the OIS_E swapped into USD, which equals an implicit US OIS rate:

$$OIS_{\$,E} = OIS_E + tp_{E,\$} \, , \tag{4.26}$$

where $OIS_{\$,E}$ is the implicit US OIS rate in OIS_E. $OIS_\$$ is observable in the market. If $OIS_{\$,E}$ is greater than $OIS_\$$, there is a deviation from covered interest rate parity. The deviation can be considered a liquidity premium in USD relative to EUR. The origin of the liquidity premium is a higher relative demand for USD in the currency forward market. This liquidity premium is called the EURUSD basis spread, which is denoted as $OISB_{E,\$}$.

$$OISB_{E,\$} = OIS_{\$,E} - OIS_\$ \, . \tag{4.27}$$

Now we have the information we need to derive the Kliem rate as a function of $OIS_{\$,E}$, which emphasizes the violation of the covered interest rate parity. We substitute equation 4.26 in equation 4.25 and find that

$$Kliem = OIS_{\$,E} + rp_E \, . \tag{4.28}$$

Finally, we substitute equation 4.27 into equation 4.28. This leaves us with the Kliem rate as a function of the relative liquidity premium between USD and EUR, the US OIS rate and the risk premium in EURIBOR.

$$Kliem = OISB_{E,\$} + OIS_{\$} + rp_E \, . \tag{4.29}$$

We see that if the relative liquidity premium for USD increases, the Kliem rate increases. With equation 4.29, one can easily derive an equation that shows that the liquidity premium in USD affects NIBOR equivalent to how it affects the Kliem rate. As we can see from equation 4.22, NIBOR consists of the Kliem rate and a term supplement. We substitute equation 4.29 into equation 4.22, which results in the following equation:

$$NIBOR = OISB_{E,\$} + OIS_{\$} + rp_E + tp_{\$,N} \tag{4.30}$$

Equation 4.30 suggests that NIBOR is an increasing function of $OIS_{\$}$. However, changes in the expected FED funds rate are supposed to be compensated by the term supplement, $tp_{\$,N}$ (Lund, Tafjord & Øwre-Johnsen, 2016). Consequently, changes in the $OIS_{\$}$ are cancelled by corresponding changes in $tp_{\$,N}$ and do not affect NIBOR.

The basis spread between EUR and USD, $OISB_{E,\$}$, affects the Kliem rate if there is a change in the demand for or supply of USD relative to the demand for or supply of EUR. As we see in equation 4.29 and 4.30, this effect is directly imported into NIBOR. If covered interest rate parity were to hold, the EURUSD basis would be zero. The fact that the EURUSD basis differs from zero, implies that there is a violation of covered interest rate parity.

4.5 Non-standard monetary policy measures

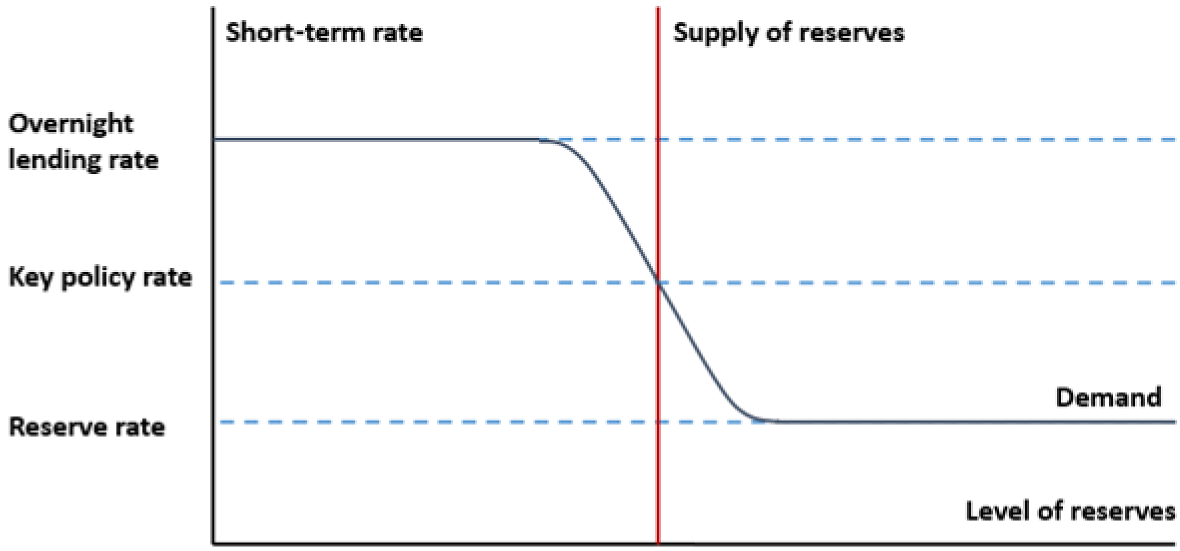
Now we illuminate the effect of non-standard monetary policy measures on the interest rates. A challenge related to conventional monetary policy instruments is that they become less effective as the nominal interest rates approach the theoretical zero lower bound (Joyce et al., 2012). The zero lower bound is a problem that arises because it may be regarded as more profitable to hold cash than obtaining a negative interest rate on deposits with a bank. The fact that the usual monetary policy transmission mechanism did not affect market rates as expected in the aftermath of the financial crisis has led central banks to consider other forms of intervention.

“Non-standard policy measures” usually refers to the quantitative easings that have been performed by various central banks in recent years. “Quantitative easings” are monetary policy measures that target quantity variables in the monetary policy rather than interest rates (Joyce et al., 2012). Quantitative easings entail that a central bank either supplies the banking system directly with liquidity or that it increases the level of total reserves in the banking system by purchasing government securities, bonds or treasuries or by offering repurchase agreements.

The intention of such market operations is stimulating demand, encouraging lending into the broader economy and maintaining inflation expectations by reducing the price of liquidity, increasing prices of assets and reducing the yields of these assets (Bernhardsen et al., 2016). An increase in asset prices and a decrease in yields will generate capital gains for the owners of these assets and may in turn cause an increase in consumption and investments. There may be a greater effect on the assets that the central bank purchases and their closest substitutes than on other assets. This can be explained by the preferred habitat theory.

If the level of total reserves is positive in a normal corridor system with a targeted neutral liquidity, there will be a downward pressure on the money market rates, particularly the short-term rate, and it will move towards the central bank’s reserve rate (Aamodt et al., 2016). Similarly, if the level of total reserves is negative, there will be an upward pressure on the short-term rate and it will move towards the central bank's overnight lending rate. The short-term equilibrium rate is illustrated in figure 4.1. Quantitative easings will cause an increase in the level of reserves in the banking system, which creates excess liquidity. Excess liquidity is defined as *"deposits at the deposit facility net of the recourse to the marginal lending facility, plus current account holdings in excess of those contributing to the minimum reserve requirements"* (ECB, 2014b). Excess liquidity pushes the short-term rate towards the floor of the corridor system and may in effect mean that the central bank's liquidity management system has turned into a floor system.

Figure 4.1: Short-term equilibrium rate in a corridor system.



4.6 The year-end effect

Before the balance date at the end of the year, there is an increased focus on credit and liquidity risks in financial institutions (Christensen et al., 2014). The reason is that financial regulations create an incentive for the banks to keep their balances as lean as possible. Moreover, banks and other financial institutions would like to present balances with little risk and ample liquidity to investors, the government, credit rating agencies and other stakeholders.

The year-end effect is a calendar effect that causes the banks to be less willing to provide unsecured loans and give up their reserves shortly before the end of the year (Christensen et al., 2014). Consequently, there is an upward pressure in the money market rates that increases as the year approaches its end. Then the rates usually decrease and fall back to their normal levels at the beginning of the following year. Although to a smaller extent, indications of the same effect are also found close to the balance dates at the end of each quarter and the end of each month.

5. Descriptive statistics

In this analysis, we utilize data on different interest rates, liquidity and risk, obtained from various sources. Details on data sources and summary statistics for all the original series utilized for illustrative or analytical purposes in this dissertation, are found in appendix A. The analysis period starts with the announcement of the US money market fund reform on 23 July 2014 and ends on 21 June 2017, which is the last date for which we have data on the NIBOR risk premium.

5.1 Key variables

In the analysis, we construct models with five time series. These are the NIBOR risk premium, which is the dependent variable, and US prime fund total assets, excess liquidity in the eurozone, total liquidity in the Norwegian banking system and the VSTOXX index, which are explanatory variables. All series contain daily observations except for the US prime fund total assets, which contains weekly observations. However, for most of the series, observations are only submitted on business days, from Monday through Friday.

The series have missing or non-updated observations for non-business days. These essentially include every weekend and holidays that fall on weekdays. However, the different series do not necessarily have missing observations on the same weekdays. The reason is that the Norwegian, US and European economies have different holidays.

There is an irregularity in the data for eurozone excess liquidity. The series contain only four observations per week for Monday through Thursday in the period from January to October 2016. The whole series before January 2016 contains five observations per week. However, these observations are consequently submitted for Sunday through Thursday. It is tempting to assume that there is a systematic error in the data set, or at the very least that the observations from Sunday through Thursday are in reality intended to reflect the excess liquidity that applies to the normal business week from Monday through Friday.

In order to make the data applicable for our analysis, we will create a business calendar where we omit weekends and consequently use five-day business weeks. Furthermore, we will make a few assumptions. For the data on the eurozone excess liquidity, we will move every observation before January 2016 up one date, according to the systematic error we believe exists in the series.

There is only weekly data on prime fund assets. In order to create daily series, we will assume that the level of prime fund total assets changes linearly on the business days between each Wednesday. Consequently, in the five-day business week, of the change between one Wednesday and the next, we will assume that one fifth of the change takes place on Thursday, the next fifth takes place on Friday and so on, which effectively allows for no irregularities in the movement between one Wednesday and the next. This is probably not the case in reality, but such an approximation may be sufficient for the intentions of our analysis.

In the eurozone excess liquidity and VSTOXX index series, there is still missing observations when weekends are omitted from the business calendar. Whether it be because of holidays or other reasons, we will assume that the missing value is equal to the last observed value and fill them in accordingly. Consequently, the modified series that we apply in our analysis have no missing values.

We also divide the prime fund assets, eurozone excess liquidity and total liquidity series, which are originally quoted in millions, by one thousand, in order to have them quoted in billions of USD, EUR and NOK, respectively. NIBOR risk premium is quoted in percentage points. Table 5.1 shows the summary statistics for the modified data series which we utilize in the model estimations of our analysis. The summary statistics include the period for which we have data within the analysis period, the number of observations, the mean values of the series, the standard deviations and the minimum and maximum values.

Table 5.1: Summary statistics for modified data series. 23 July 2014 - 21 June 2017.

DATA SERIES	Obs	Mean	S. d.	Min	Max
NIBOR risk premium (percentage points)	761	0.409	0.140	0.130	0.710
Prime fund assets (billions of USD)	761	1,077	425.6	371.2	1,459
Eurozone excess liquidity (billions of EUR)	761	689.2	467.1	70.89	1,688
Total liquidity (billions of NOK)	761	34.64	3.685	12.89	49.65
VSTOXX index	761	21.90	5.229	11.16	40.80

Table 5.2 shows the Pearson's and Spearman's correlation coefficients of the explanatory variables. The Pearson's correlation coefficients are a measure of the extent to which there is a linear relationship between two variables (Pearson, 1895). There is a strong linear relationship between NIBOR risk premium and prime fund assets, NIBOR risk premium and eurozone excess liquidity and prime fund assets and eurozone excess liquidity, respectively. Otherwise, the linear relationships between two variables are moderate or weak. Spearman's rank correlation coefficients are a measure of the extent to which there is a monotonic relationship between two variables, which allows for non-linear relationships (Spearman, 1904). Spearman's coefficients do not differ notably from Pearson's coefficients.

Table 5.2: Correlation coefficients of modified variables. 23 July 2014 - 21 June 2017.

	NIBOR risk premium	Prime fund assets	Eurozone excess liquidity	Total liquidity	VSTOXX index
NIBOR risk premium		-0.817	0.814	-0.072	-0.112
Prime fund assets	-0.712		-0.862	-0.036	0.386
Eurozone excess liquidity	0.745	-0.922		0.025	-0.281
Total liquidity	-0.082	-0.071	0.037		-0.065
VSTOXX index	-0.116	0.482	-0.333	-0.059	
Lower-triangular cells report Pearson's correlation coefficients, upper-triangular cells are Spearman’s rank correlation.					

5.2 Dummy variables

In addition to the time series in the summary statistics in table 5.1, we also construct dummy variables which we utilize in our analysis. Because balance dates and financial regulations cause banks to hold on to liquidity and become less willing to provide unsecured loans, there may be a positive effect on NIBOR risk premium leading up to the end of the year. It is difficult to tell exactly when the year-end effect arises, but it is reasonably expected to be gradual and largest in the last few business days of the year.

In order to account for the possible gradual year-end effect, we create dummy variables that are intended to capture the effect. In our time-dependent dummy variables, we would like to include enough time before the year-end to capture the full-year end effect. However, we would also like to avoid including too much time, such that the dummy variables capture other effects or random errors.

We create four dummy variables for the four last business weeks leading up to the year-ends, respectively. That is, we create dummy variables that are intended to capture any year-end effect on the five last weekdays before the year passes, the five weekdays before that and so on.

- *Ddecw1* is equal to 1 for the dates 4 December - 10 December, otherwise 0.
- *Ddecw2* is equal to 1 for the dates 11 December - 17 December, otherwise 0.
- *Ddecw3* is equal to 1 for the dates 18 December - 24 December, otherwise 0.
- *Ddecw4* is equal to 1 for the dates 25 December - 31 December, otherwise 0.

Consequently, *Ddecw1*, *Ddecw2*, *Ddecw3* and *Ddecw4* are equal to *1* on 19 to 15, 14 to 10, 9 to 5 and 4 to 0 business days before the end of the year, respectively. However, one should be cautious when interpreting these dummy variables because it may be that they capture other effects than a general year-end effect. An example of such an effect is the effect of the Liquidity Coverage Ratio requirements from the Basel III framework, which are introduced in EU, Norway and the US, which through all three economies may have an effect on the NIBOR risk premium. It is implemented gradually with new LCR requirements on 1 January 2015, 1 January 2016 and 1 January 2017 in the analysis period. If the LCR requirements do have an effect on the risk premium, we would expect that as well to cause a gradual increase in the demand for liquidity leading up to the end of the previous year. If this is the case, we will not be able to discern the effect of the LCR requirements from the normal year-end effect in our analysis.

We have described a number of events, factors and mechanisms that may explain the formation of NIBOR. In the following analysis, we will assess the effect of the US money market fund reform (MMR) on the risk premium in NIBOR.

6. Effects of the money market fund reform

6.1 Unit root and cointegration tests

To determine the effects of MMR and other factors on the NIBOR risk premium, we need to project the latter, our dependent variable, on the explanatory variables that we have summarized in chapter 5. Before considering models that may fit the data, we will assess whether our series are stationary (Bjørnland & Thorsrud, 2015).

6.1.1 Dickey-Fuller unit root tests

In general, one should be careful with using non-stationary time series. Highly persistent, non-stationary series may cause spurious regressions that incorrectly indicate significant relationships when there is none. Non-stationary series can be detected through graphical analysis or through a Dickey-Fuller unit root test. Dickey-Fuller tests can detect unit root in series of three autoregressive forms. We have the forms

1. $$\Delta y_t = \theta y_{t-1} + e_t \,, \tag{6.1}$$

where θ is the coefficient of the first lag and ϵ_t is the error term,

2. $$\Delta y_t = \alpha + \theta y_{t-1} + e_t \,, \tag{6.2}$$

where α is the constant term, and

3. $$\Delta y_t = \alpha + \delta t + \theta y_{t-1} + e_t \,, \tag{6.3}$$

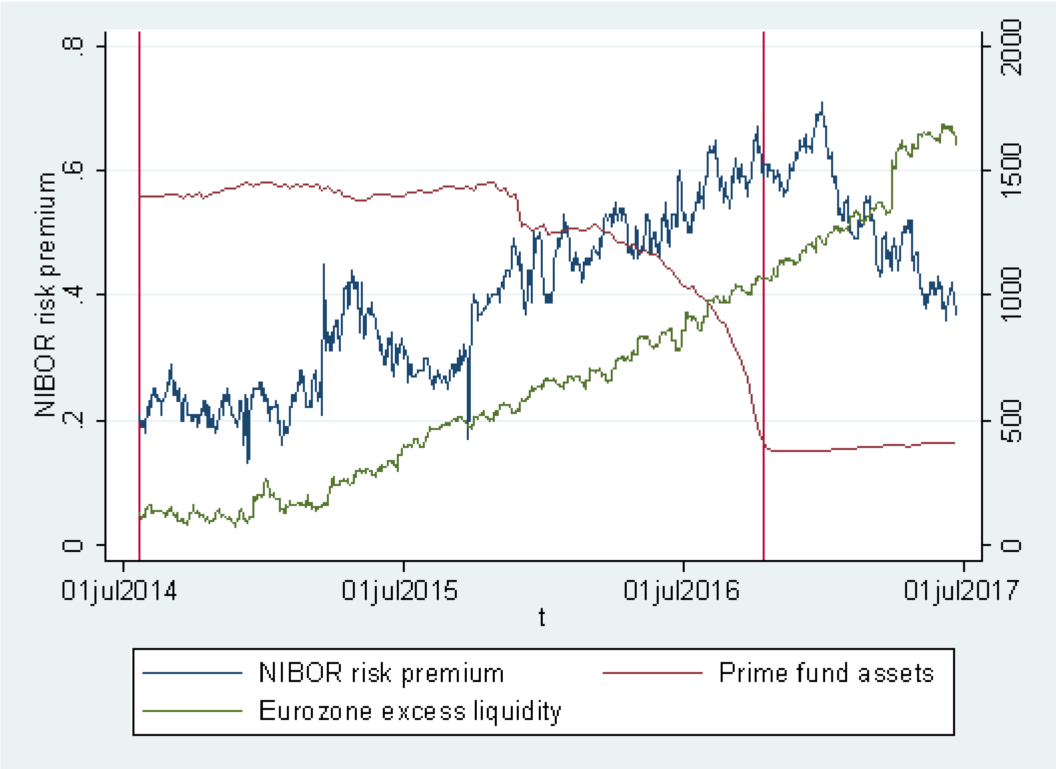
where δ is a trend coefficient.

A series has a unit root and is non-stationary if θ is equal to 1. When looking at the plotted series in figures 6.2 - 6.7, the NIBOR risk premium, prime fund assets and eurozone excess liquidity look like they may have a trend, whereas total liquidity and the VSTOXX index appear to be fluctuating around a non-zero sample average. For the three and two series we perform the third and second version of the Dickey-Fuller test, respectively. The tests indicate that NIBOR risk premium, prime fund assets and eurozone excess liquidity may be non-stationary. The tests reject the hypothesis of unit root in total liquidity and the VSTOXX index. Test statistics are found in tables B.1 - B.5 in appendix B.

6.1.2 Engle-Granger cointegration tests

Unit root suggests that projections on the time series may cause spurious results. However, there is an exception for non-stationary series that are cointegrated. In that case, the series share similar stochastic trends and there is a linear combination of the series that has stationary residuals and is integrated. Figure 6.1 shows the non-stationary series in question jointly. The red lines mark the announcement of MMR and its implementation on 23 July 2014 and 14 October 2016, respectively.

Figure 6.1: NIBOR risk premium, prime fund assets and eurozone excess liquidity. Percentage points on LHS. Billions of USD or EUR on RHS. 23 July 2014 - 21 June 2017.



Although there is some short-term dynamics in the NIBOR risk premium that are not present in the other two variables, the long-term comovement between the series suggests that they may have a cointegrated relationship. However, two parts differ from the period otherwise. First, there is the period from 19 March 2015 to 24 September 2015 that differs from the time before and after. We discuss that in section 6.2. Second, there appears to be a break in the trend in the NIBOR risk premium and prime fund assets series on or close to the implementation of MMR on 14 October 2016, marked by the red vertical line on the right.

In order to determine if the non-stationary series are cointegrated, we perform cointegration tests on NIBOR risk premium, prime fund assets and eurozone excess liquidity. First, we perform an Engle-Granger cointegration test on the series in the period from the announcement of MMR on 21 July 2014 up to 21 June 2017. The Engle-Granger test indicates that the three series are not cointegrated in the complete analysis period.

We also perform a corresponding Engle-Granger cointegration test on the period from the announcement on 21 July 2014 to the implementation of MMR on 14 October 2016 to determine if the series are cointegrated before the break in the NIBOR risk premium and prime fund assets. The test indicates that the series are cointegrated in that period.

Table 6.1: Engle-Granger cointegration tests. NIBOR risk premium, prime fund assets and eurozone excess liquidity.

Period	Test statistic	Critical values		
		1 %	*5 %*	*10 %*
23.07.2014 - 21.06.2017	-2.579	-4.313	-3.752	-3.460
23.07.2014 - 14.10.2016	-5.766	-4.319	-3.755	-3.463
14.10.2016 - 21.06.2017	-2.250	-3.959	-3.371	-3.068

The test statistics of the Engle-Granger tests are presented in tables C.1 - C.3 in appendix C. They are also summarized in table 6.1. The test statistics of the cointegration tests for the periods from 23 July 2014 to 21 June 2017 and from 14 October 2016 to 21 June 2017, respectively, are both higher than the critical values of a ten percent level of significance. That indicates that we cannot reject the null hypothesis that the series are not cointegrated in the respective periods. The test statistic for the period from 23 July 2014 to 14 October 2016 is lower than the critical value of a one percent level of significance. This strongly indicates that the series are cointegrated in that period.

6.1.3 Gregory-Hansen cointegration tests

We proceed to perform Gregory-Hansen cointegration tests (Gregory & Hansen, 1996). The Gregory-Hansen procedure is an extension of similar unit root tests that allows for one endogenous structural break in the time series when testing for cointegration. The Gregory-Hansen test can be applied to four model specifications (Rao & Kumar, 2007). We will test for the general and most extensive model. It allows for breaks in the intercept, slope coefficients and the trend. For simplicity, it is specified with only one dependent and one explanatory variable here:

$$Y_t = \alpha_1 + \alpha_2 D_k + \delta_1 t + \delta_2 t D_k + \beta_1 X_t + \beta_2 X_t D_k + \epsilon_t \tag{6.4}$$

where Y_t is the dependent variable, X_t is the explanatory variable, α_1 and α_2 are intercept coefficients, δ_1 and δ_2 are trend coefficients, β_1 and β_2 are variable coefficients and D_k is a dummy variable that equals 1 after the break date *k*.

As with the Engle-Granger test, we perform the Gregory-Hansen test on the NIBOR risk premium, prime fund assets and eurozone excess liquidity series. First, as with the Engle-Granger test, we perform the Gregory-Hansen test on the series in the period from July 21 2014 up to 21 June 2017. The test indicates that there is a structural break on 23 September 2015[3]. That is the day before one of Norges Bank's monetary policy meetings on 24 September 2015.

We then perform the Gregory-Hansen test on the series in the period from 24 September 2015 up to 21 June 2017, which is the period following the possible structural break on 23

[3] Alternatively, we could have estimated a partial structural change model in order to identify multiple possible structural breaks (Bai & Perron, 1998). That is beyond the scope of this dissertation.

September 2015. Now the test indicates that there is a structural break on 24 October 2016. That is ten days, or six business days, after the implementation of MMR. This is plausible considering the apparent break in figure 6.1 and that the market and NIBOR panel banks may have needed a few days to adjust after the implementation of an intervening reform.

Furthermore, the Gregory-Hansen test indicates that the time series are cointegrated when allowing for a structural break on 24 October 2016. Although the Engle-Granger test failed to reject the null hypothesis of no cointegration, the Gregory-Hansen test indicates that the series are cointegrated in the periods from 24 September 2015 to 24 October 2016 and from 25 October 2016 to 21 June 2017, respectively.

Table 6.2: Gregory-Hansen cointegration tests. NIBOR risk premium, prime fund assets and eurozone excess liquidity.

Period	Test statistic	Break date	Critical values		
			1 %	*5 %*	*10 %*
23.07.2014 - 21.06.2017	-7.29	23.09.2015	-6.45	-5.96	-5.72
25.09.2015 - 21.06.2017	-9.29	24.10.2016	-6.45	-5.96	-5.72

The test statistics are found in tables C.4 - C.5 in appendix C and summarized in table 6.2. The test statistics of the cointegration tests for the periods from 23 July 2014 to 21 June 2017 and from 25 September 2015 to 21 June 2017, respectively, are both lower than the critical values of a one percent level of significance. This strongly indicates that the series are cointegrated when allowing for one structural break. The tests indicate that there is structural breaks on 23 September 2015 and 24 October 2016, respectively.

6.2 The NIBOR risk premium

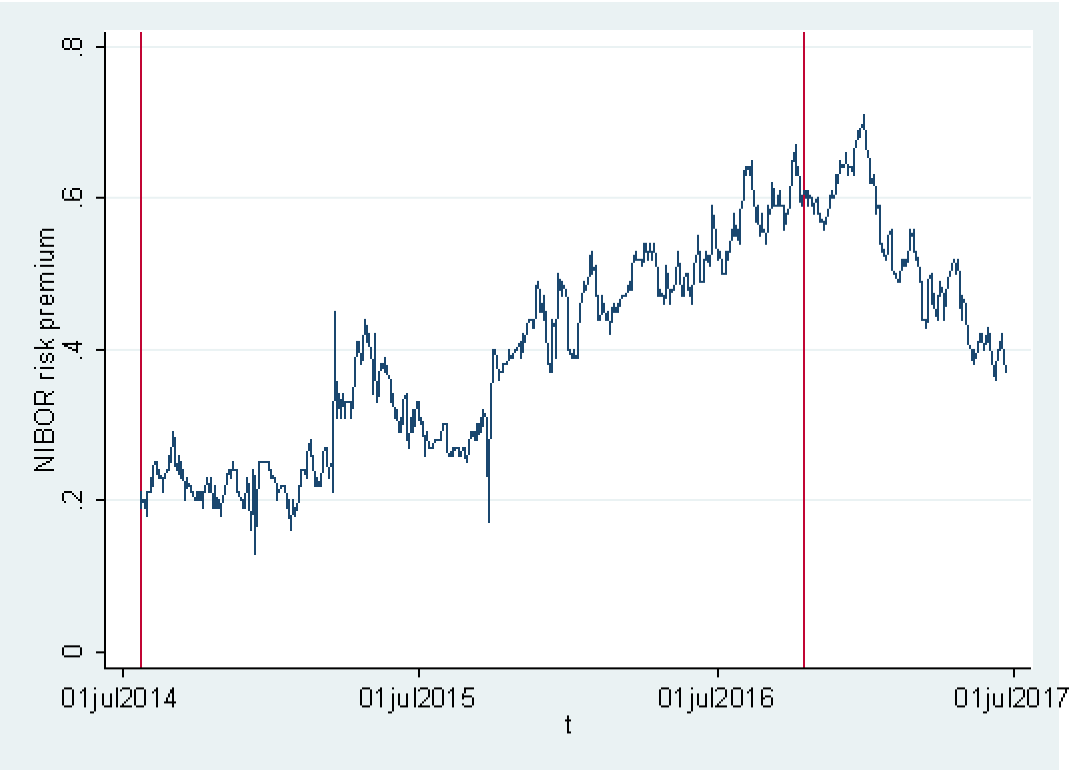
We recall that NIBOR can be decomposed into an overnight index swap (OIS) rate and a risk premium. The OIS rate is usually close to the key policy rate and can be considered the expected key policy rate over the next three months. Since Norway does not have its own OIS market, the OIS rate is estimated daily by Norges Bank. This entails that the estimated OIS rate and NIBOR risk premium may occasionally deviate somewhat from what the real values would have been if there had been a Norwegian OIS market. However, Norges Bank's estimations are arguably the best approximations that exist and we have no reason to believe that there is any systematic misrepresentation in the data.

The fact that the OIS rate is close to the key policy rate, suggests that it to a great extent can be controlled by Norges Bank. In this analysis, we are most interested in the NIBOR risk premium. The risk premium is to a greater extent dependent on factors that are out of Norges Bank's control. This may have consequences for the monetary policy transmission mechanism and the effectiveness of monetary policy tools, particularly when rates are close to or have surpassed the theoretical zero lower bound, as in recent years.

The NIBOR risk premium is our key variable of interest. We find the risk premium by subtracting Norges Bank's estimated OIS rate from NIBOR. One should note that Norges Bank's estimated OIS rate is a five day moving average.

In figure 6.2, we see how the NIBOR risk premium has developed during our analysis period. The red lines mark the announcement of MMR and its implementation on 23 July 2014 and 14 October 2016, respectively. NIBOR risk premium is to a great extent affected by short-term fluctuations. However, in the time period between these dates, the risk premium increased from approximately 0.2 to approximately 0.6, close to 0.4 percentage points. The risk premium is subject to a lot of volatility and erratic movements. It seems that there was a trend that was stable for most of the time after the announcement of the reform until the implementation of the reform. However, we notice that between the announcement and implementation, there is a positive spike and a negative spike on 19 March 2015 and 24 September 2015, respectively. Disregarding the initial and most notable negative deviation from the trend, approximately 0.3 percentage points of the increase in the risk premium took place after the latter date.

Figure 6.2: The NIBOR risk premium. Percentage points.



In the time in between, the development deviates from the trend that appears to be present both before 19 March 2015 and after 24 September 2015. These dates coincide exactly with Norges Bank's monetary policy meetings, so it may be the case that the market responded to unanticipated signals given in Norges Bank's key policy rate decisions and assessments of the economic prospects. In order to learn more about this, we also need to look at the Norwegian OIS rate and Norges Bank's key policy rate.

Figure 6.3: NIBOR, the OIS rate, the key policy rate and USD LIBOR. Percentage points.

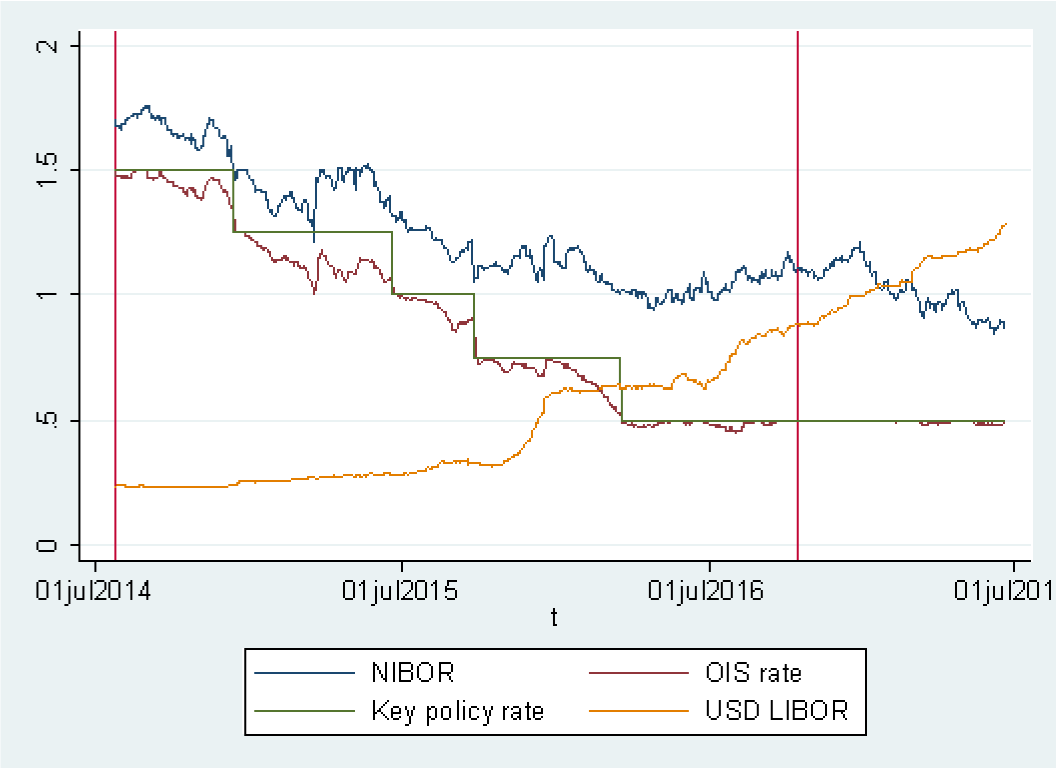


Figure 6.3 shows NIBOR, the Norwegian OIS rate, Norges Bank's key policy rate and the USD LIBOR. The risk premium in NIBOR is given as the difference between the two former. There is no notable movement or deviation in USD LIBOR between 19 March and 24 September 2015, which suggests that the deviation from the trend in the NIBOR risk premium is distinctive for Norway. As in the NIBOR risk premium, we see that there was a sudden increase and decrease in the OIS rate on 19 March 2015 and 24 September 2015, respectively. In parts of the period the OIS rate is volatile, which may suggest the presence of some uncertainty about the prospects of the economy and key policy rate decisions in the market. Sometimes the OIS rate is considerably lower than the key policy rate, which suggests that the market is inclined to expect a reduction in the key policy rate.

Because of a considerable decrease in the oil prices, Norges Bank reduced the key policy rate on the monetary policy meeting in December 2014 (Norges Bank, 2014). The consecutive weaker prospects of the Norwegian economy, as well as lower international rates and Norges Bank's wish to maintain a weak NOK exchange rate, led analysts to predict a key policy rate reduction before the monetary policy meeting on 19 March 2015 as well (Stensaker & Lingaas, 2015a).

A diminishing OIS rate was the case in the few months leading up to the meeting, which suggests that the rest of the market, consistent with the analysts' prediction, expected Norges Bank to reduce the key policy rate. When that did not happen, the market was surprised (Stensaker & Lingaas, 2015b). The market adapted and consequently, the OIS rate increased abruptly. However, NIBOR increased more than the increase in the OIS rate on 19 March 2015 would imply. The surprise in the market does not explain why also the NIBOR risk premium increased. One explanation may be that Norges Bank's unexpected decision to maintain the key policy rate unchanged caused NOK to appreciate relative to USD, which in turn caused the implicit USD rate in NIBOR to increase. An increase in the Norwegian money market rates associated with an increase in the expected Norwegian key policy rate over the next three months would be consistent with the theory of covered interest rate parity.

Before the monetary policy meeting on 24 September 2015, analysts meant that it was an open question whether the key policy rate would be reduced (Stensaker & Lingaas, 2015c). However, the Norwegian growth, inflation and mortgage rates in addition to low oil prices were not considered compelling enough to justify a reduction in the key policy rate to 0.5 percent. In the end, the market was not prepared for the reduction that took place on 24 September (Løtvedt & Lingaas, 2015). Correspondingly, the difference between the key policy rate and the OIS rate suggests that the reduction in the former on the monetary policy meeting was not entirely expected by the market, which caused the sudden decrease in the estimated OIS rate rather than a smooth transition. Furthermore, except for the initial short-lived decrease on 24 September 2015, NIBOR did not decrease as the OIS rate decreased. The difference between NIBOR and the OIS rate increased in the time afterwards. From the implementation of MMR or a short time afterwards, the risk premium has a downward trend.

6.3 Determinants of the NIBOR risk premium

In what follows, we will assess the recent development in the variables which we will apply as explanatory variables. In contrast to other researchers, we seek to explain the NIBOR risk premium not with the Kliem rate, OIS bases or the risk premiums of other rates, but with the market conditions that in turn are determinants of the latter variables as well.

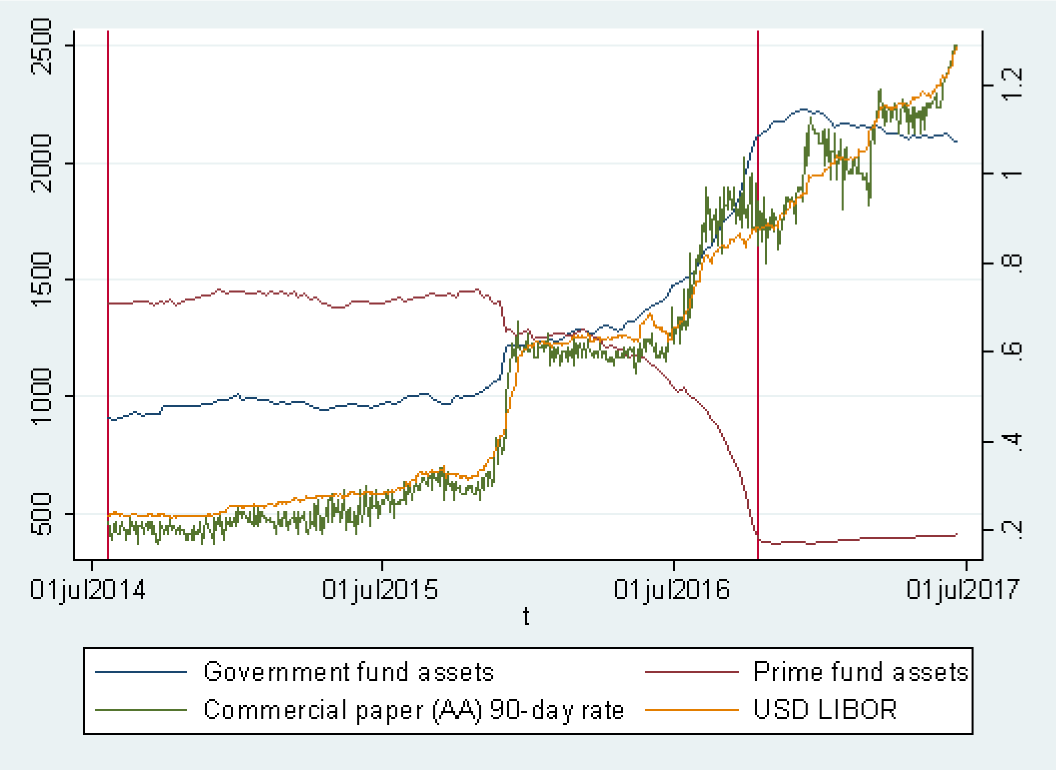
With these variables, we believe that we avoid problems associated with endogeneity and simultaneous equation bias. Norway is a small, open economy and Norwegian financial institutions are reasonably considered price takers in the international money market. Whereas the NIBOR risk premium is arguably affected by the level of US prime fund assets, excess liquidity in the eurozone, total liquidity in the Norwegian banking system, market risk and balance dates, the NIBOR risk premium has a negligible to non-existent reciprocal effect on these variables.

6.3.1 US prime fund total assets

The primary channel through which MMR has affected the risk premium in NIBOR is a decrease in US prime fund assets. Because of the floating net asset value and the possibility of liquidity fees or suspended redemptions, prime funds are perceived as riskier and less attractive investments. Consequently, prime funds have to some extent been converted to government funds and the rate of commercial papers in which money market funds invest, has increased.

Figure 6.4 shows the development of government fund and prime fund total assets, the AA commercial paper 90-day rate and USD LIBOR. The 90-day and three-month rates are the ones that correspond the most to three-month NIBOR. As before, the red lines mark the announcement of MMR and its implementation on 23 July 2014 and 14 October 2016, respectively.

Figure 6.4: Government fund total assets, prime fund total assets, AA commercial paper 90-day rate and three-month USD LIBOR. Billions of USD on LHS. Percentage points on RHS.



The figure shows that prime fund assets and government fund assets were stable for the first seventeen months after the announcement of the reform. There was a sudden decrease in prime fund assets a little more than 270 days before the implementation of the reform. The reason is probably that commercial papers have maturities of up to 270 days, such that the prime funds that invested in commercial papers with the longest maturities converted into government funds at this point.

Afterwards, the prime fund assets decreased progressively up to the implementation of MMR before it shortly afterwards stabilized at a level that is considerably lower than the level of assets by the announcement of the reform. More specifically, disregarding replaced missing observations in between, prime fund assets decreased from 1404.502 billion USD on 25 November 2015 to 382.97 billion USD on 19 October 2016, which amounts to a decrease of 1021.532 billion USD. The stable level after the implementation may suggest that MMR has affected NIBOR less after the implementation than in the time leading up to it.

The government fund assets have to a corresponding extent decreased as prime fund assets have increased. There is an almost one-to-one relationship between the changes in prime fund and government fund assets. The total level of assets in prime and government funds has not changed notably during the analysis period. This suggests that the changes in the level of prime fund and government fund assets during the period can be explained almost exclusively by MMR and that a large share of the former prime fund assets were converted into government fund assets.

The AA commercial paper 90-day rate is more erratic than the levels of prime fund and government fund assets. However, its trend was relatively stable for seventeen months after the announcement of MMR. Then it increased considerably about 270 days before the implementation of MMR, equivalently to the reduction in prime fund assets. The reason is probably that a number of the first prime funds that converted into government funds also stopped investing in 90-day commercial papers. Then it stabilized for a few months before it increased again from July 2016.

As expected, the commercial paper rate has to a great extent increased as the prime fund assets have decreased. However, it moves more erratically, has not decreased in the same pace and has continued increasing after the implementation of MMR and after prime fund assets have stabilized. USD LIBOR is less erratic. Otherwise, it is highly correlated with the commercial paper rate. This suggests that although a considerable part of the increase in the commercial paper rate and USD LIBOR can be explained by a decrease in the supply of assets in the commercial paper market segment, there is also apparent movements in the rates that are caused by other factors.

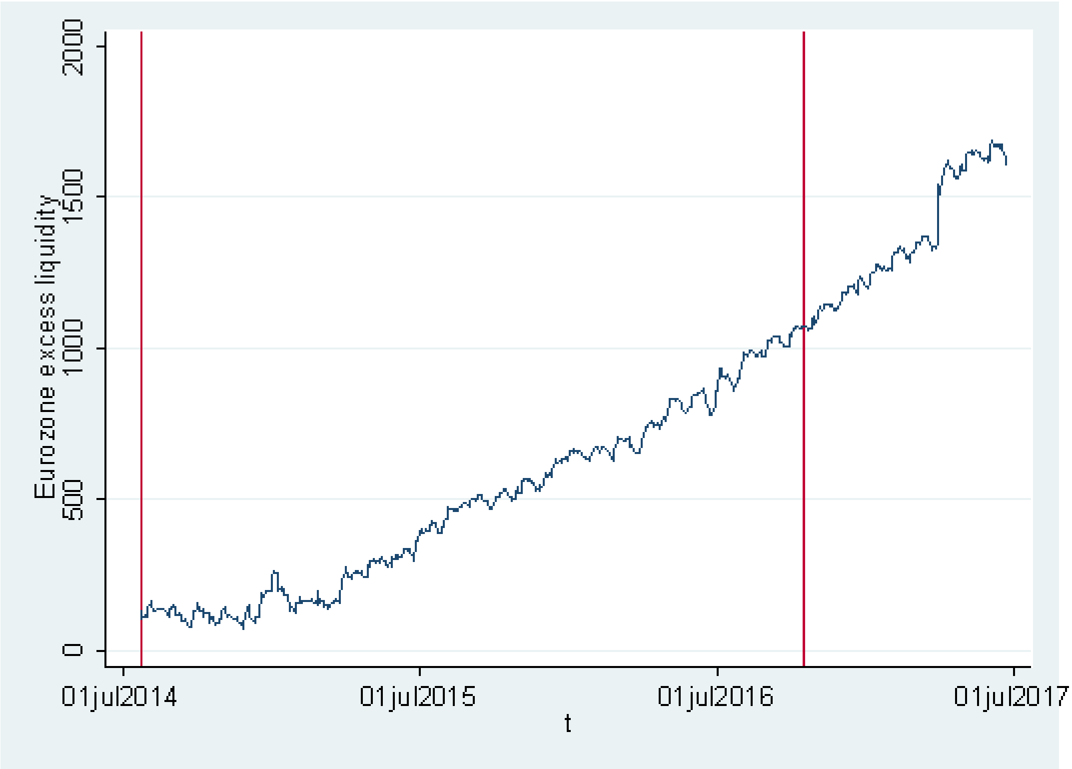
We will utilize prime fund total assets as a variable for capturing the effect of MMR, which has entered the commercial paper and money market rates through a reduced demand for commercial papers and consequently, a smaller supply of prime fund assets. However, changes in the level of prime fund assets may not have a stable effect on the NIBOR risk premium. The reason is that the first prime funds to convert to government funds were probably those that to the greatest extent invested in commercial papers with relatively long maturities rather than commercial papers with maturities close to three months. NIBOR panel banks are probably more dependent on the latter when considering funding costs and using their discretion to determine the three-month NIBOR. Alternatively, we could utilize the AA commercial paper 90-day rate or USD LIBOR, which both may covary more closely with the NIBOR panel banks' perceived funding cost. However, the tradeoff is that the commercial paper rate is subject to more unexplained volatility and that both the commercial paper rate and USD LIBOR would to a greater extent capture other developments than those related to MMR.

6.3.2 Eurozone excess liquidity

Quantitative easings have created a surplus of liquidity in the eurozone. This has caused the liquidity premium of EUR relative to USD to decrease, which has affected NIBOR through the Kliem rate on which the NIBOR panel banks base their submissions. To account for this, we include the eurozone excess liquidity in our analysis.

In figure 6.5, we see that although there is some volatility in the series, the eurozone excess liquidity has had a steady upward trend for most of the analysis period and has increased considerably. Between the announcement on 23 July 2014 and implementation of MMR on 14 October 2016, eurozone excess liquidity increased from 129.407 to 1070.97 billion EUR, which amounts to an increase of 941.563 billion EUR. The corresponding increase between 25 September 2015, the day after the second monetary policy meeting associated with a spike in the NIBOR risk premium, and the implementation of MMR, from 470.913 to 1070.97 billion EUR, amounts to 600.057 billion EUR.

Figure 6.5: Eurozone excess liquidity. Billions of EUR.

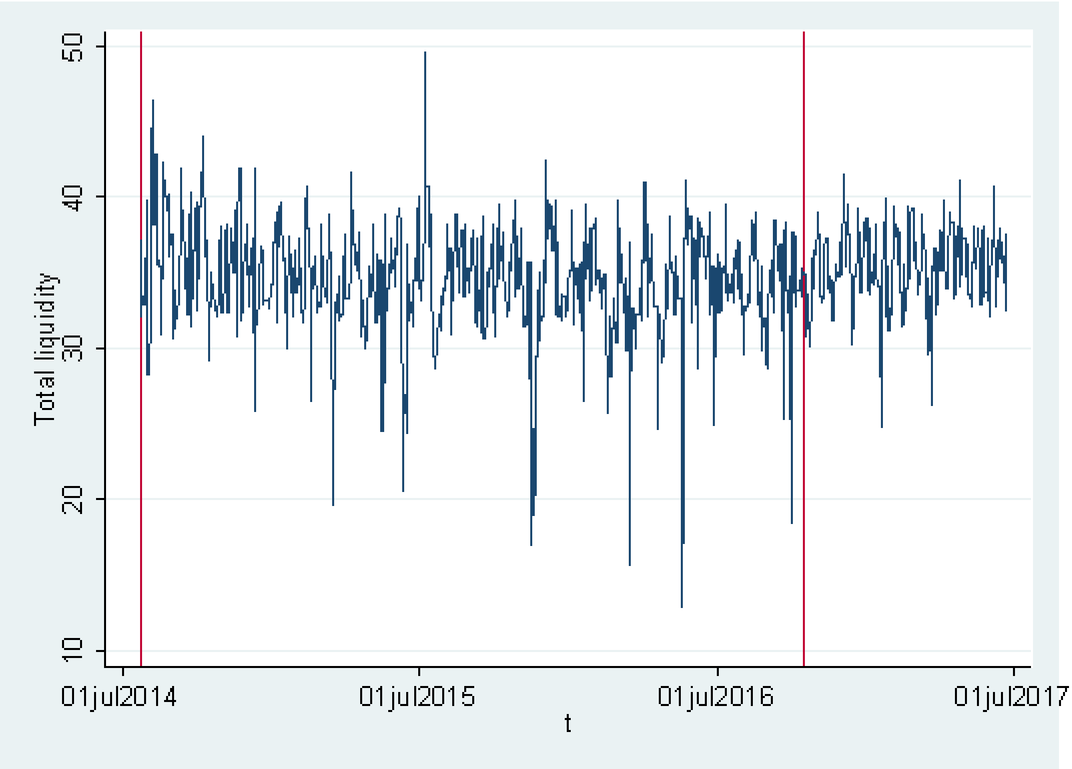


6.3.3 Total liquidity in the Norwegian banking system

Money market rates depend on the level of available reserves. Thus, we will also control for the total liquidity in the Norwegian banking system. This is the sum of the structural liquidity and the market operations performed by Norges Bank in order to manage liquidity.

The level of total liquidity in the Norwegian banking system in figure 6.6 is very erratic. Norges Bank targets a total liquidity between 30 and 40 billion NOK. It usually fluctuates within this interval. However, there is also regularly outliers of which some deviate far from the target level of liquidity. The trend is stable, which suggests that total liquidity cannot explain the increase in the NIBOR risk premium throughout the period. However, it can possibly explain some of its short-term dynamics.

Figure 6.6: Total liquidity in the Norwegian banking system. Billions of NOK.



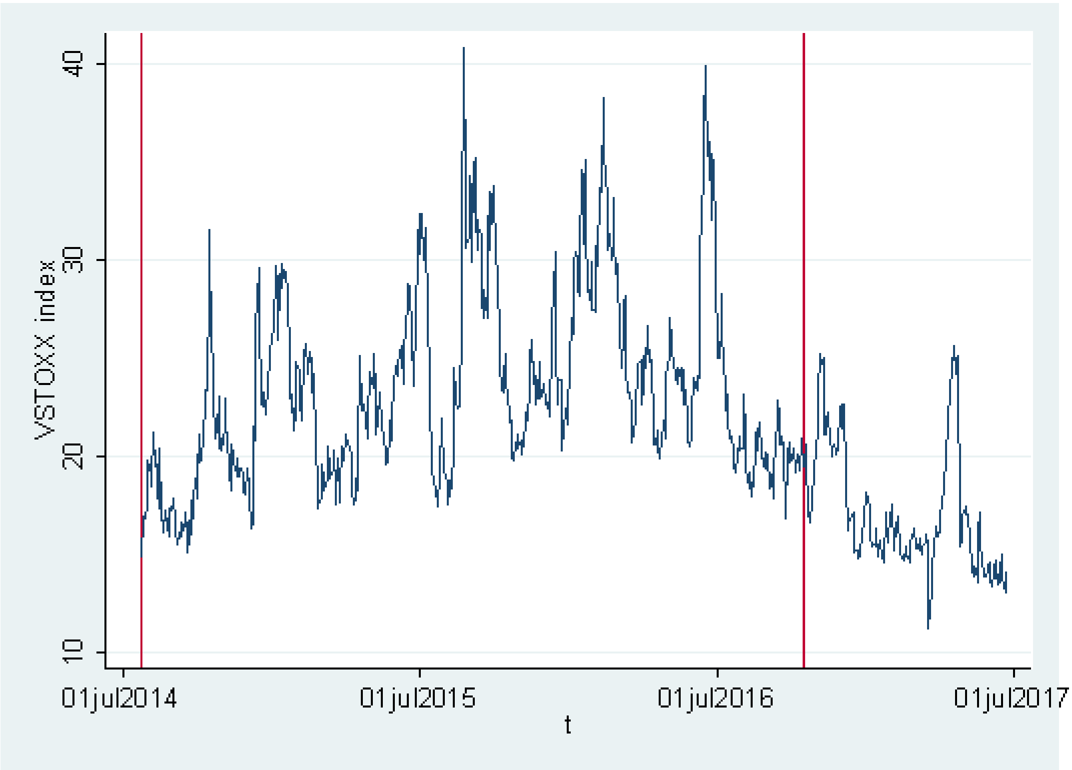
6.3.4 The VSTOXX index

We recall that the capital asset pricing model regards the return on an asset as a function of the asset's systematic risk and the market risk, that NIBOR is dependent on other market rates and particularly the Kliem rate, and that financial unrest in the eurozone has an effect on NIBOR. To account for the market risk that may affect the NIBOR risk premium, we will utilize the VSTOXX index.

The VSTOXX index shows implied volatility in OTM options on the underlying securities in the EURO STOXX 50 index (STOXX Limited, 2017). The purpose of the implied volatility index is to show what the market expects about future volatility of the underlying index (Siriopoulos & Fassas, 2009). OTM options are "out-of-money" options, which means that the underlying security is priced in disfavor to the option contract. That is, if time to maturity for the option were zero, the option value would have been zero. However, since there is still time to maturity, the option has some time value. The higher the volatility of the underlying security, the higher the time value is. The reason is that the probability of a favorable price change increases with higher volatility.

The methodology used for calculation of the VSTOXX index is based on observable OTM option prices and linear interpolation. VSTOXX is calculated by taking the square root of the implied variance for the observed OTM options with rolling maturities fixed at 30 days (Siriopoulos & Fassas, 2009). Findings suggest that VSTOXX is the leading indicator of uncertainty in European markets (Siriopoulos & Fassas, 2009).

Figure 6.7: The VSTOXX index.



In figure 6.7, we see that the VSTOXX index is highly volatile and fluctuates around a non-zero mean. However, to a small extent it seems like it may have an upward trend until early 2016 and then a downward trend until the end of the period. This suggests that although it is highly unstable in the short-term, the risk in the European market increased in the first half of the period and has decreased afterwards.

Alternatively, we could have used credit default swap prices for NIBOR banks to account for risk in the Norwegian interbank market. However, considering that NIBOR panel banks base their NIBOR submissions on the Kliem rate, NIBOR is implicitly based on the risk premium for European banks. Another advantage with utilizing the VSTOXX index is that it to a great extent reflects market risk for NIBOR panel banks.

6.4 An error correction model

Both the Engle-Granger and Gregory-Hansen cointegration tests indicate that the NIBOR risk premium, prime fund assets and eurozone excess liquidity series are cointegrated in the period between the announcement and implementation of MMR on 23 July 2014 and 14 October 2016, respectively. Consequently, although the variables are non-stationary, we can project the former variable on the other variables without having spurious results for that period.

A system of cointegrated variables may be utilized in an error correction representation as described by Engle & Granger (1987) and applied to housing prices by Jacobsen & Naug (2004). We are going to apply Engle & Granger's two-step estimator in order to estimate an error correction model (ECM) for the NIBOR risk premium. The advantage of the error correction model is that it maintains the long-term information inherent in the levels of the variables as well as the short-term dynamics, which allows for inferences in both levels and differences. However, one should be aware that the two-step estimator has low power, which means that the estimated standard errors may be incorrect.

6.4.1 First step of the two-step estimator

We estimate an error correction model for the period between the announcement and implementation of MMR, on 23 July 2014 and 14 October 2016, respectively, in which the non-stationary variables NIBOR risk premium, prime fund assets and eurozone excess liquidity are cointegrated. We include the original spikes coinciding with the monetary policy meetings on 19 March 2015 and 24 September 2015, respectively. In order to assess the robustness of the model, we will also estimate an equivalent error correction model for the period from 25 September 2015 to 14 October 2016, starting right after the monetary policy meeting on 24 September 2015, which is associated with a possible structural break.

The shorter time interval both avoids the inclusion of any known structural break and provides us with a basis for comparison and assessment of the sensitivity and reliability of the model with respect to the time interval. It includes the entire reduction in prime fund assets caused by MMR. However, the increase in eurozone excess liquidity in the longer time interval is only partly included. Even though the Gregory-Hansen cointegration test indicates that the structural break is six business days afterwards, we choose to make 14 October 2016, on which day MMR was implemented, the last day of both the time intervals.

In the first step of Engle & Granger's two-step estimator in the ECM, we estimate the long-run relationship between the cointegrated, non-stationary variables. We estimate a model given by

$$Nrp_t = \gamma_0 + \gamma_1 Pf_t + \gamma_2 Ex_t + \epsilon_{EG,t}\,, \tag{6.5}$$

where Nrp_t is the NIBOR risk premium, Pf_t is US prime fund assets, Ex_t is eurozone excess liquidity and $\epsilon_{EG,t}$ is the "Engle-Granger residual". The coefficients γ_1 and γ_2 provide information about the long-run effect of prime fund assets and eurozone excess liquidity, respectively, on the NIBOR risk premium. The Engle-Granger residuals are given by

$$\epsilon_{EG,t} = Nrp_t - \gamma_1 Pf_t - \gamma_2 Ex_t - \gamma_0\,, \tag{6.6}$$

which is equation 6.5 solved for the Engle-Granger residual.

Table 6.3: First step of the Engle-Granger two-step estimator.

	NIBOR risk premium	
VARIABLES	23.07.2014 - 14.10.2016	25.09.2015 - 14.10.2016
Prime fund assets	-0.000066***	-0.000052**
	(0.000017)	(0.000024)
Eurozone excess liquidity	0.00037***	0.00031***
	(0.000012)	(0.000035)
Constant	0.28**	0.32***
	(0.026)	(0.052)
Observations	583	276
R-squared	0.862	0.769
F-statistic	1813.64	455.21
Prob > F	0.000	0.000

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The first step of the two-step estimators for both the periods is presented in table 6.3. In the long-run estimation, both the explanatory variables are statistically significant in the time interval from 23 July 2014 to 14 October 2016. The coefficient of prime fund assets suggests that it has a negative effect on the NIBOR risk premium. In other words, the model predicts that an increase (reduction) in the supply of USD liquidity in the form of an increased (reduced) level of prime fund assets, would create a downward (upward) pressure on the money market rates. Consequently, MMR has had a long-run positive effect on the NIBOR risk premium. This is consistent with the suggestions of the literature and the theoretical framework.

Furthermore, the model predicts that excess liquidity caused by quantitative easings in the eurozone has a positive effect on the NIBOR risk premium. This is also consistent with the literature and the theoretical framework. An increase in excess liquidity in the eurozone enters the NIBOR risk premium through a lower liquidity in EUR relative to USD, which enters the Kliem rate on which the NIBOR submissions are based.

The long-run estimation in the time interval from 25 September 2015 to 14 October 2016 does not differ considerably from the estimation in the longer time interval. The absolute values of the estimated coefficients are slightly smaller. However, they are both significant at a five percent level of significance and their signs are consistent with the estimated long-run relationship in the longer time interval, the literature and the theoretical framework.

We recall that the NIBOR risk premium increased by approximately 0.4 percentage points between the announcement and the implementation of MMR on 23 July 2014 and 14 October 2016, respectively. Prime fund assets decreased by about 1021.532 billion USD from 25 November 2015 whereas eurozone excess liquidity increased by 941.563 billion EUR between the announcement and the implementation. These changes and the long-run coefficients imply that MMR and the reduction in prime fund assets account for $(-0.000066) \times (-1021.532) = 0.067$ percentage points of the increase in the risk premium.

The increase in eurozone excess liquidity accounts for $0.00037 \times 941.563 = 0.348$ percentage points of the increase in the risk premium.

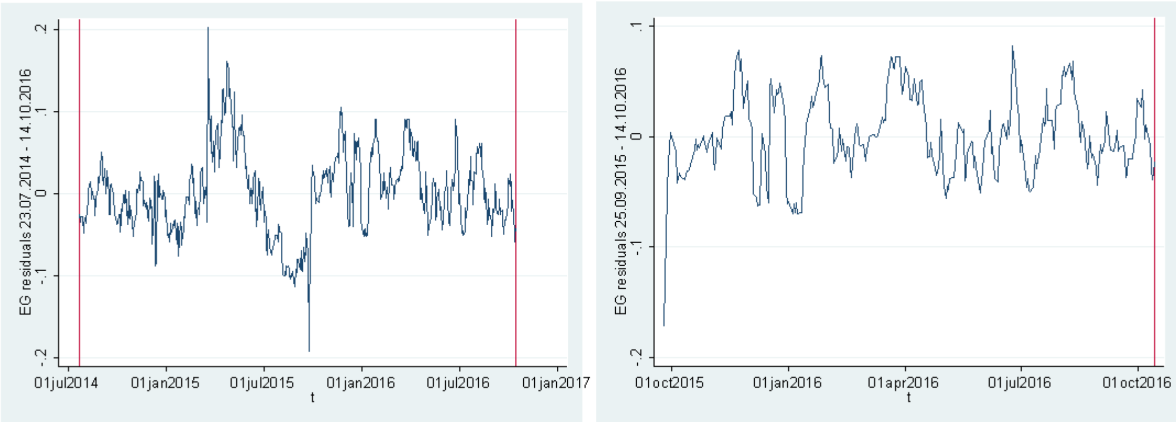
After the monetary policy meeting on 24 September 2015 to the implementation of MMR on 14 October 2016, the NIBOR risk premium increased by approximately 0.3 percentage points, disregarding the initial negative deviation. Eurozone excess liquidity increased by 600.057 billion EUR. Consequently, the estimated total effect of prime fund assets amounts to an increase of $(-0.000052) \times (-1021.532) = 0.053$ percentage points in the risk premium. Eurozone excess liquidity has caused an increase of $0.00031 \times 600.057 = 0.186$ percentage points in the risk premium. The estimations of the effect of prime fund assets in the two ECMs are within one standard error of each other and not significantly different.

The literature and theoretical framework indicate that the coefficients of prime fund assets and eurozone excess liquidity should be negative and positive, respectively. Consequently, the long-run effects of MMR and quantitative easings in the eurozone should both be positive. This is confirmed by the estimated long-run coefficients, which are both significant at a level of less than one percent, and their corresponding calculations. However, the literature does not indicate the exact magnitude of these effects. The long-run estimations of the ECMs suggest that the long-run effect of MMR on the NIBOR risk premium is relatively small compared to the effect of the quantitative easings in the eurozone.

6.4.2 Engle-Granger residuals

In order to consider the fit of the estimated long-run relationship, we consider the residuals of the second step of Engle & Granger's estimator. If the series are cointegrated, the Engle-Granger residuals of the first step of Engle & Granger's estimator should be stationary. The Engle-Granger residuals are plotted in figure 6.8

Figure 6.8: Engle-Granger residuals. 23 July 2014 - 14 October 2016 and 25 September 2015 - 14 October 2015, respectively. Percentage points.



The Engle-Granger residuals appear to have a zero mean. To some extent, there seems to be positive autocorrelation in both the series. This is particularly the case for the irregular period between the monetary policy meetings on 19 March 2015 and 24 September 2015, respectively. This is confirmed by regressions of the residuals on their first lags in table 6.4. The estimated coefficients of the first lagged residuals are statistically significant whereas the constants are insignificant. Most of the residuals are within -0.1 and 0.1 percentage points.

Table 6.4: Regressions of the Engle-Granger residuals on their first lags.

	EG residuals	
VARIABLES	23.07.2014 - 14.10.2016	25.09.2015 - 14.10.2016
L.EG residuals	0.89***	0.80***
	(0.019)	(0.030)
Constant	-0.000058	0.00058
	(0.00093)	(0.0011)
Observations	583	276
R-squared	0.794	0.727
F-statistic	2234.95	731.18
Prob > F	0.000	0.000

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

L. = lag

Two Dickey-Fuller unit root tests confirm that the Engle-Granger residuals are stationary. The test statistics are found in tables B.6 - B.7 in appendix B.

6.4.3 Second step of the two-step estimator

In the second step of Engle & Granger's two-step estimator, we estimate the short-term relationships. Here, we include the short-term effects of prime fund assets and eurozone excess liquidity as well as the total liquidity in the Norwegian banking system, the VSTOXX index and the year-end effect. The dependent variable is the first difference of the NIBOR risk premium from one day to the next, whereas the explanatory variables are given as the lags in the first-differenced NIBOR risk premium and the other time series variables, dummy variables and an error correction term, given by the lagged Engle-Granger residuals from the first step in the two-step estimator.

According to the Akaike information criterion, the optimal number of lags in the model is three when testing the Engle-Granger residuals from the first step of the estimator. The test statistic and the partial autocorrelation plot are found in table D.1 and figure D.1, respectively, in appendix D. Consequently, we estimate the model

$$\Delta Nrp_t \;=\; \beta_0 + \alpha\epsilon_{EG,t-1} + \sum_{\tau=-3}^{-1}\beta_{1,t+\tau}\Delta Nrp_{t+\tau} + \sum_{\tau=-3}^{-1}\beta_{2,t+\tau}\Delta Pf_{t+\tau} + \sum_{\tau=-3}^{-1}\beta_{3,t+\tau}\Delta Ex_{t+\tau} + \sum_{\tau=-3}^{-1}\beta_{4,t+\tau}\Delta Tot_{t+\tau} + \sum_{\tau=-3}^{-1}\beta_{5,t+\tau}\Delta VX_{t+\tau} + Ddecw1_t + Ddecw2_t + Ddecw3_t + Ddecw4_t + \epsilon_t \tag{6.7}$$

where $\epsilon_{EG,t-1}$ is the error correction term, $Tot_{t+\tau}$ is total liquidity in the Norwegian banking system, $VX_{t+\tau}$ is the VSTOXX index and $Ddecw1_t$, $Ddecw2_t$, $Ddecw3_t$ and $Ddecw4_t$ are dummy variables capturing the year-end effect in the last four weeks of December, respectively. Δ denotes the first differences of the variables and $t+\tau$, ranging from *t-3* to *t-1*, is the time of the estimated lags.

The error correction term, $\epsilon_{EG,t-1}$, is the lagged Engle-Granger residual of the long-run relationship in the first step of the two-step estimator. It measures the deviation from the estimated long-term relationship between the NIBOR risk premium, prime fund assets and eurozone excess liquidity. The coefficient α indicates by how much the NIBOR risk premium increases (decreases) at day *t* if NIBOR risk premium is below (above) the estimated long-term relationship at day *t-1*. The coefficient of the Engle-Granger residual should be between -1 and 0, which indicates the speed of adjustment. If α is equal to -1, any deviation from the estimated long-run relationship will be adjusted immediately. If α is equal to 0, there is no adjustment in deviations from the estimated long-run relationship. The second step of the error correction model estimation is presented in table 6.5.

Table 6.5: Second step of the Engle-Granger two-step estimator.

	D.NIBOR risk premium	
VARIABLES	23.07.2014 - 14.10.2016	25.09.2015 - 14.10.2016
L.Engle-Granger residual	-0.071***	-0.21***
	(0.020)	(0.033)
LD.NIBOR risk premium	-0.051	0.14**
	(0.043)	(0.057)
L2D.NIBOR risk premium	-0.21***	-0.082
	(0.042)	(0.056)
L3D.NIBOR risk premium	-0.0054	0.098*
	(0.042)	(0.057)
LD.Prime fund assets	-0.000062	-0.000029
	(0.000061)	(0.000055)
L2D.Prime fund assets	-0.000083	-0.000013
	(0.000068)	(0.000062)
L3D.Prime fund assets	0.000011	0.000010
	(0.000062)	(0.000055)
LD.Eurozone excess	-0.0000027	-0.00011
liquidity	(0.000068)	(0.000085)

L2D.Eurozone excess liquidity	0.000035	-0.000015
	(0.000068)	(0.000085)
L3D.Eurozone excess liquidity	-0.000012	-0.000025
	(0.000068)	(0.000084)
LD.Total liquidity	-0.00016	-0.000020
	(0.00024)	(0.00028)
L2D.Total liquidity	0.00011	0.00017
	(0.00025)	(0.00030)
L3D.Total liquidity	-0.00057**	-0.00014
	(0.00024)	(0.00028)
LD.VSTOXX index	0.00045	-0.00050
	(0.00054)	(0.00071)
L2D.VSTOXX index	-0.00077	-0.00064
	(0.00054)	(0.00071)
L3D.VSTOXX index	0.00038	0.00034
	(0.00054)	(0.00070)
Ddecw1	-0.0067	-0.014*
	(0.0070)	(0.0083)
Ddecw2	0.0091	0.0086
	(0.0070)	(0.0083)
Ddecw3	0.0041	0.0040
	(0.0071)	(0.0083)
Ddecw4	-0.011	-0.014*
	(0.0069)	(0.0083)
Constant	0.00064	0.0017
	(0.00097)	(0.0013)

Observations	583	276
R-squared	0.118	0.214
F-statistic	3.76	3.47
Prob > F	0.000	0.000

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

L. = lag, D. = first difference

In the ECM estimation for the period from 23 July 2014 to 14 October 2016, the error correction term, the lagged Engle-Granger residual, is significant and implies that any deviation from the long-run relationship will be corrected by approximately 7 percent the next business day.

Aside from the error correction term, most of the coefficients are statistically insignificant. Prime fund assets and eurozone excess liquidity do not have short-term effects on the NIBOR risk premium other than through adjustments to the long-run relationship in the error correction term. Neither the VSTOXX index has any short-term effects on the risk premium. Furthermore, there is no indication of any significant year-end effect in the coefficients of the dummy variables. Consequently, the dummy variables neither capture any significant effect of the Liquidity Coverage Ratio requirements which coincide with the year-end effect.

The coefficient of the second lag of the first-differenced NIBOR risk premium is negative and significant. This suggests that there is negative autocorrelation in the first-differenced NIBOR risk premium. This is consistent with the apparent volatility in the series. Furthermore, the coefficient of the third lag of first-differenced total liquidity in the Norwegian banking system is significant and negative. This suggests that an increase in the liquidity will have a negative effect on the risk premium three days afterwards. This is in accordance with the theoretical framework which predicts that an increase (reduction) in liquidity will lead to a reduction (increase) in the money market rates, equivalent to the long-term effect of prime fund assets.

When comparing with the period from 25 September 2015 to 14 October 2016, the absolute value of the Engle-Granger residual coefficient of the latter is larger. This implies a higher speed of adjustment in deviations from the long-term relationship. Furthermore, there is only one coefficient aside from the error correction term that is significant at a five percent level of significance. The first lag of the first-differenced NIBOR risk premium is significant and positive. This suggests that there is positive autocorrelation in the first-differenced NIBOR risk premium.

The ECM is to a great extent a plausible model with regard to literature and the theoretical framework. Error correction is present and the long-term effects as well as the significant short-term effects are as we would expect. However, a few of the short-term effects included in the model are insignificant and may be superfluous. Furthermore, when comparing the two time intervals for which the model is estimated, the magnitude and/or level of significance of the coefficients are sensitive with regard to the time interval. In the autocorrelation of the first-differenced NIBOR risk premium, even the sign is sensitive with regard to the time interval. This suggests that the model is somewhat unreliable.

6.4.4 Multiplier effects in the ECM

The literature does not comment on the exact magnitude or characteristics of the dynamic effects on NIBOR. We study the dynamic effects of the estimated error correction model in more detail (Nielsen, 2005). A general dynamic model with three lags of both the dependent variable and one explanatory variable can be written as

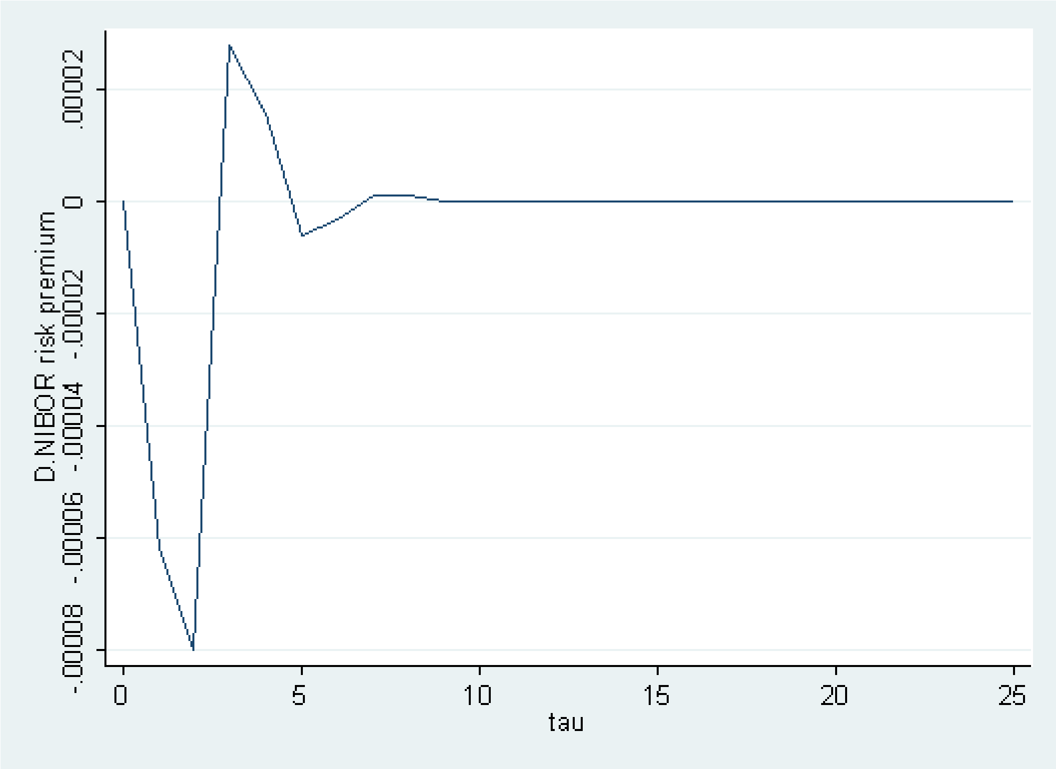
$$Y_t = \beta_0 + \beta_{1,t-1}Y_{t-1} + \beta_{1,t-2}Y_{t-2} + \beta_{1,t-3}Y_{t-3} + \beta_{1,t-1}X_{t-1} + \beta_{1,t-2}X_{t-2} + \beta_{1,t-3}X_{t-3} + \epsilon_t \quad , \tag{6.8}$$

where Y_t is the dependent variable and $X_{t+\tau}$ is the explanatory variable. The dynamic multiplier is the marginal effect of one unit increase in X_t on the dependent variable after $t + \tau$ business days. Consequently, we can find the dynamic multipliers as the derivatives of $Y_{t+\tau}$ with respect to X_t on business day $t + \tau$.

In the ECM for the period from 23 July 2014 to 14 October 2016, only total liquidity in the Norwegian banking system has any significant short-term effect on the NIBOR risk premium. Prime fund assets have no significant short-term effect on the risk premium through the lagged first-differenced prime fund assets. Nonetheless, the dynamic multipliers of prime fund assets may provide some insight into the dynamic effects of MMR on the risk premium. We do not calculate dynamic multipliers for the other variables with no significant coefficients.

Equation 6.8 can be generalized as an equation for $Nrp_{t+\tau}$ after τ ("tau") business days. We find the dynamic effect of an increase of one billion USD in the prime fund assets at time *t* as the derivative of $Nrp_{t+\tau}$ with respect to Pf_t. The dynamic multipliers can be found in table E.1 in appendix E. Figure 6.9 illustrates what dynamic effect a one billion USD increase in prime fund assets at time *t* would have on the risk premium after τ business days from zero to 25 business days.

Figure 6.9: Response in the NIBOR risk premium to an impulse in prime fund assets in the ECM. Percentage points. 23 July 2014 - 14 October 2016.



In the impulse response function in figure 6.9, we see that an impulse in prime fund assets has a negative effect on the NIBOR risk premium the first two days after an increase of one billion USD in prime fund assets[4]. It is greatest two days afterwards with a negative effect of $\frac{8}{100000}$ percentage points on the risk premium. The effect turns positive three days after the impulse and stabilizes at approximately zero after seven business days.

[4] We could have constructed confidence intervals by using the "bootstrapping" method, in which one takes random samples from the analysis period in order to generate a sampling distribution, and calculating corresponding dynamic multipliers (Runkle, 1987). That is beyond the scope of this dissertation.

Figure 6.10: Response in the NIBOR risk premium to an impulse in total liquidity in the ECM. Percentage points. 23 July 2014 - 14 October 2016.

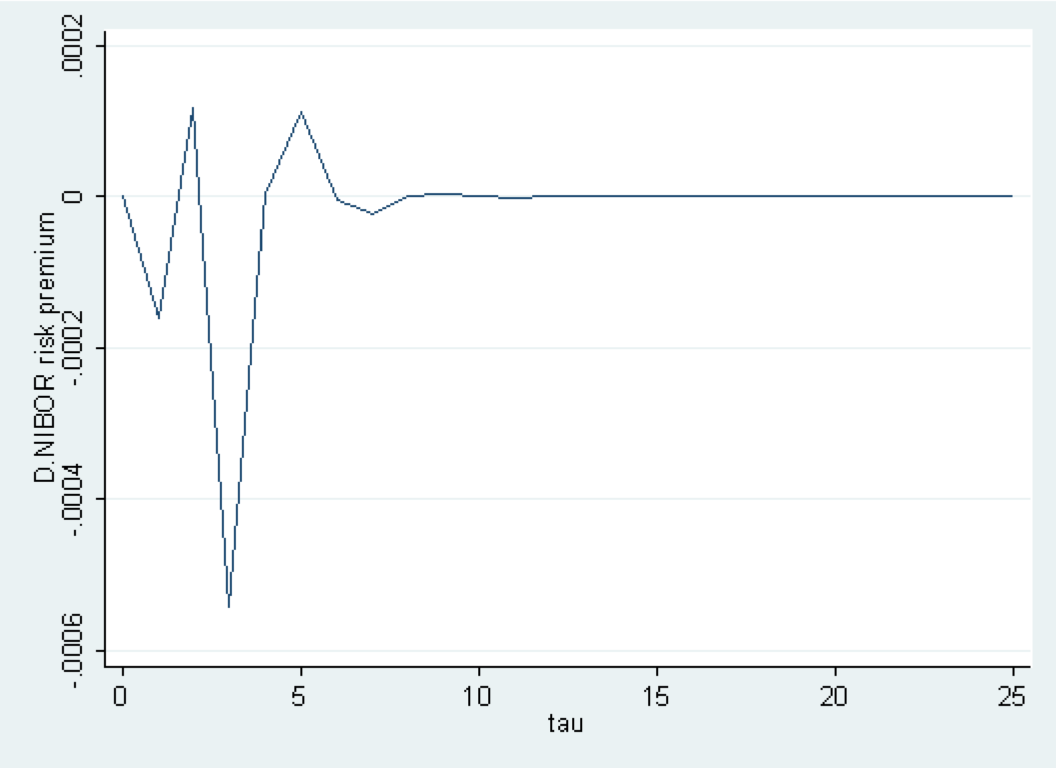


Figure 6.10 shows what dynamic effect a one billion NOK increase in total liquidity at time t would have on the NIBOR risk premium after. The dynamic multipliers are calculated as the derivative of $Nrp_{t+\tau}$ with respect to Tot_t and can be found in table E.2 in appendix E. We see that the dynamic effect arises one business day after the increase in total liquidity and that it is greatest after three business days with a negative effect of a little more than $\frac{5}{10000}$ percentage points. This confirms the indications in the literature and the theoretical framework that the effect should be negative. However, the literature does not indicate the exact magnitude of the dynamic effects of total liquidity on the risk premium. The effect stabilizes at approximately zero after eight business days.

Furthermore, the impulse response functions of both prime fund assets and total liquidity fluctuate around zero. That is an effect caused by the negative autocorrelation in the first-differenced NIBOR risk premium and is amplified by the fact that the coefficients of the lagged first-differences of the respective variables change from positive to negative and/or the other way around.

We can also calculate the long-run multiplier in order to find the effect a permanent increase of one unit in a short-term variable would have on the NIBOR risk premium. We recall equation 6.8 and assume that there is a long-run steady state where

$$Y_t = Y_{t-1} = Y_{t-2} = Y_{t-3} = Y \tag{6.9}$$

and

$$X_{t-1} = X_{t-2} = X_{t-3} = X \tag{6.10}$$

Then we have that

$$Y(1 - \beta_{1,t-1} - \beta_{1,t-2} - \beta_{1,t-3}) = \beta_0 + (\beta_{2,t-1} + \beta_{2,t-2} + \beta_{2,t-3})X + \epsilon_t \tag{6.11}$$

$$\Updownarrow$$

$$Y = \frac{\beta_0}{1 - \beta_{1,t-1} - \beta_{1,t-2} - \beta_{1,t-3}} + \frac{\beta_{2,t-1} + \beta_{2,t-2} + \beta_{2,t-3}}{1 - \beta_{1,t-1} - \beta_{1,t-2} - \beta_{1,t-3}} X_t + \frac{\epsilon_t}{1 - \beta_{1,t-1} - \beta_{1,t-2} - \beta_{1,t-3}} \tag{6.12}$$

where

$$\frac{\beta_{2,t-1} + \beta_{2,t-2} + \beta_{2,t-3}}{1 - \beta_{1,t-1} - \beta_{1,t-2} - \beta_{1,t-3}}$$

is the long-run multiplier of variable *X*. The long-run multiplier is equal to the sum of the dynamic multipliers.

Prime fund assets have a negative long-run effect on the NIBOR risk premium through the long-term relationship estimated in the first step of the two-step estimator in the ECM. The sum of the short-term dynamics of a one billion USD increase is equal to

$$\frac{-0.000062 - 0.000083 + 0.000011}{1 + 0.051 + 0.21 + 0.0054} = -0.0001 \tag{6.13}$$

percentage points, which, had it been significant, would imply that the short-term effect of prime fund assets, as the long-term effect, is negative.

In the case of total liquidity, the long-run effect of a permanent one billion NOK increase in the NIBOR risk premium is equal to

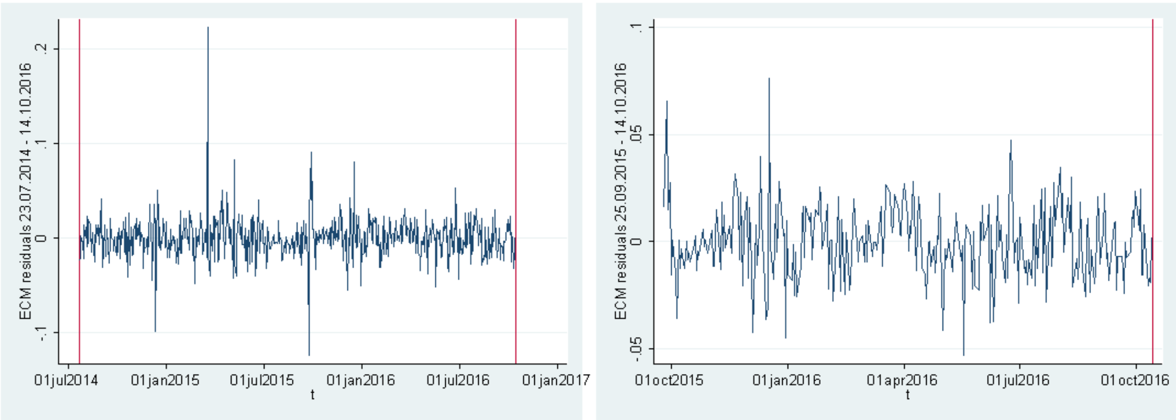
$$\frac{-0.00016 + 0.00011 - 0.00057}{1 + 0.051 + 0.21 + 0.0054} = -0.0005 \tag{6.14}$$

percentage points according to the long-run multiplier derived from the ECM, which is in accordance with the theoretical framework. Regressions performed by Pedersen & Pettersen (2017) indicate, contrary to the theoretical framework, that the long-run effect of total liquidity should be positive. However, they untimely mix structural liquidity into their regressions. Otherwise, the literature does not indicate the exact magnitude of the long-run effect.

6.4.5 Residuals of the error correction model

In order to consider the fit of the model, it is also interesting to consider the residuals of the second step of Engle & Granger's estimator. Figure 6.11 shows the plotted residuals of the estimated ECMs for both the periods.

Figure 6.11: Residuals of the error correction model estimations. 23 July 2014 - 14 October 2016 and 25 September 2015 - 14 October 2015, respectively. Percentage points.



Apparently, the residuals have a zero mean and no autocorrelation. This is confirmed by regressions of the residuals on their first lags in table 6.6, in which neither the estimated coefficients of the first lagged residuals or the constants are statistically significant.

Table 6.6: Regressions of the ECM residuals on their first lags.

	ECM residuals	
VARIABLES	23.07.2014 - 14.10.2016	25.09.2015 - 14.10.2016
L.ECM residuals	-0.0044	0.0089
	(0.041)	(0.054)
Constant	0.000000015	0.0000046
	(0.00088)	(0.0010)
Observations	583	276
R-squared	0.000	0.000
F-statistic	0.01	0.03
Prob > F	0.916	0.870

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

L. = lag

There is some notable spikes in the residuals in figure 6.11. In the period from 23 July 2014 to 14 October 2016, there is two prominent spikes on 19 March 2015 and 24 September 2015, respectively, coinciding with Norges Bank’s monetary policy meetings. Otherwise, most of the residuals are within -0.05 and 0.05 percentage points. However, there appears to be time-varying volatility present in the residuals and NIBOR risk premium of both the ECMs. We take that into account in the next model specification of the analysis.

6.5 An ECM-GARCH model

6.5.1 A time-varying conditional error

The error term, ϵ_t, is normally assumed to have a constant and unconditional variance. An autoregressive conditional heteroscedasticity (ARCH) model allows for stochastic processes with a time-varying conditional error, which may often be present in economic and financial series (Engle, 1982). In such processes, information about the variance is given in the standard error in the recent past. The unconditional variance of ϵ_t is given as

$$\sigma^2 = E\{\epsilon_t^2\} = \omega + \rho E\{\epsilon_{t-1}^2\}, \tag{6.15}$$

where $E\{\}$ denotes expectations and ω denotes a constant. Positive variances imply that $\omega, \rho \geq 0$. The conditional variance is

$$\sigma_t^2 = \omega + \rho\epsilon_{t-1}^2 . \tag{6.16}$$

The standard error, ϵ_t, may have a slowly decaying autocorrelation function, in which case an extended ARCH model with long lags or lags of conditional variances are required. The latter can be added in a generalized autoregressive conditional heteroscedasticity (GARCH) model (Bollerslev, 1986). In a GARCH model, the conditional variance of ϵ_t is given as

$$\sigma_t^2 = \omega + \rho\epsilon_{t-1}^2 + \varrho\sigma_{t-1}^2 , \tag{6.17}$$

where positive variances imply $\omega, \rho, \varrho \geq 0$. Stationarity in the conditional variance requires that the persistency of the shocks to variance is less than one, $\rho + \varrho < 1$.

We expand our error correction model by adding lagged standard errors and lagged conditional variances, otherwise known as ARCH- and GARCH-terms, as explanatory variables for the conditional variance. This way, we allow for stochastic processes in the NIBOR risk premium. The result is an error correction generalized autoregressive conditional heteroscedasticity (1,1) model with one lagged standard error (ARCH) term and one lagged conditional variance (GARCH) term. The Engle-Granger residuals are the same as in the original ECMs.

Table 6.7: The ECM-GARCH(1,1) model.

	D.NIBOR risk premium	
	23.07.2014 - 14.10.2016	25.09.2015 - 14.10.2016
ECM		
L.Engle-Granger residual	-0.063***	-0.16***
	(0.016)	(0.033)
LD.NIBOR risk premium	-0.17***	0.16***
	(0.055)	(0.052)
L2D.NIBOR risk premium	-0.083*	-0.087
	(0.045)	(0.059)
L3D.NIBOR risk premium	0.070*	0.094
	(0.041)	(0.070)

LD.Prime fund assets	-0.000018	-0.000033
	(0.000057)	(0.000056)
L2D.Prime fund assets	-0.0000052	-0.0000078
	(0.000056)	(0.000065)
L3D.Prime fund assets	0.000018	-0.000013
	(0.000051)	(0.000054)
LD.Eurozone excess liquidity	-0.00011*	-0.00012
	(0.000055)	(0.000089)
L2D.Eurozone excess liquidity	0.000072	0.000045
	(0.000055)	(0.00010)
L3D.Eurozone excess liquidity	0.0000045	-0.000019
	(0.000058)	(0.000080)
LD.Total liquidity	-0.00034*	0.000056
	(0.00019)	(0.00032)
L2D.Total liquidity	-0.00056***	0.00028
	(0.00014)	(0.00032)
L3D.Total liquidity	-0.00043***	-0.00015
	(0.00016)	(0.00024)
LD.VSTOXX index	0.00077**	-0.00047
	(0.00034)	(0.00076)
L2D.VSTOXX index	-0.00037	-0.00025
	(0.00044)	(0.00073)

L3D.VSTOXX index	0.000076	0.000027
	(0.00046)	(0.00073)
Ddecw1	-0.034***	-0.017***
	(0.0038)	(0.0059)
Ddecw2	0.022**	0.021***
	(0.010)	(0.0061)
Ddecw3	0.0015	0.0032
	(0.011)	(0.031)
Ddecw4	-0.0033	-0.020***
	(0.0060)	(0.0065)
Constant	0.0015**	0.0010
	(0.00073)	(0.0013)
GARCH		
L.Standard error	0.67***	0.14*
	(0.10)	(0.070)
L.Conditional variance	0.19***	0.73***
	(0.069)	(0.16)
Constant	0.00014***	0.000041
	(0.000023)	(0.000030)
Observations	583	276

Wald chi-squared	197.04	91.12
Prob > chi-squared	0.000	0.000

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

L. = lag, D. = first difference

In the estimated conditional variance in the ECM-GARCH model for the period from 23 July 2014 to 14 October 2016, both the lagged standard error and the lagged conditional variance are significant. This suggests that the conditional variance is dependent on both the most recent variance and has a slowly decaying autocorrelation. The coefficient, and consequently the impact, of the former, is considerably larger than the coefficient of the latter. We see that the sum of the coefficients is less than 1, otherwise stated as $\rho + \varrho < 1$, which implies that the conditional variance is stationary.

The absolute value of the coefficient of the error correction term, the lagged Engle-Granger residual, is slightly smaller than in the original ECM. This implies a slower speed of adjustment in deviations from the long-term relationship. Prime fund assets and eurozone excess liquidity do still not have any other significant short-term effect on the NIBOR risk premium. The coefficient of the first lag of the first-differenced NIBOR risk premium is negative and significant, which suggests that there is negative autocorrelation in the first-differenced NIBOR risk premium.

The coefficients of both the second and third lags of total liquidity are negative and significant. As in the original ECM, this is consistent with the theoretical framework with the regard to how the amount of liquidity affects money market rates. Furthermore, the coefficient of the first lag of the first-differenced VSTOXX index is positive and significant. This is in accordance with the theoretical framework with respect to how risk affects interest rates. An increase in the VSTOXX index is associated with an increase in the NIBOR risk premium because it suggests an increase in the market risk. The coefficient of the dummy variable *Ddecw1* is negative and significant. This is unexpected given that there should be a positive year-end effect in NIBOR risk premium in December. The coefficient of *Ddecw2* is positive and significant, which complies with the expectation of a positive year-end effect. However, the coefficients of *Ddecw3* and *Ddecw4* are insignificant. Consequently, there is no indication of neither a year-end effect or an effect that increases in the last business days of the year or a positive effect of the Liquidity Coverage Ratio requirements.

The ECM-GARCH model for the time interval from 25 September 2015 to 14 October 2016 differs in several respects. In the estimated conditional variance, the lagged standard error is not significant at a five percent level of significance. In contrast to the conditional variance for the longer time interval, the conditional variance is considerably larger than the standard error. This implies that the conditional variance is less dependent on the recent standard error and to a greater extent has a slowly decaying autocorrelation. It is still the case that $\rho + \varrho < 1$ and that the conditional variance is stationary.

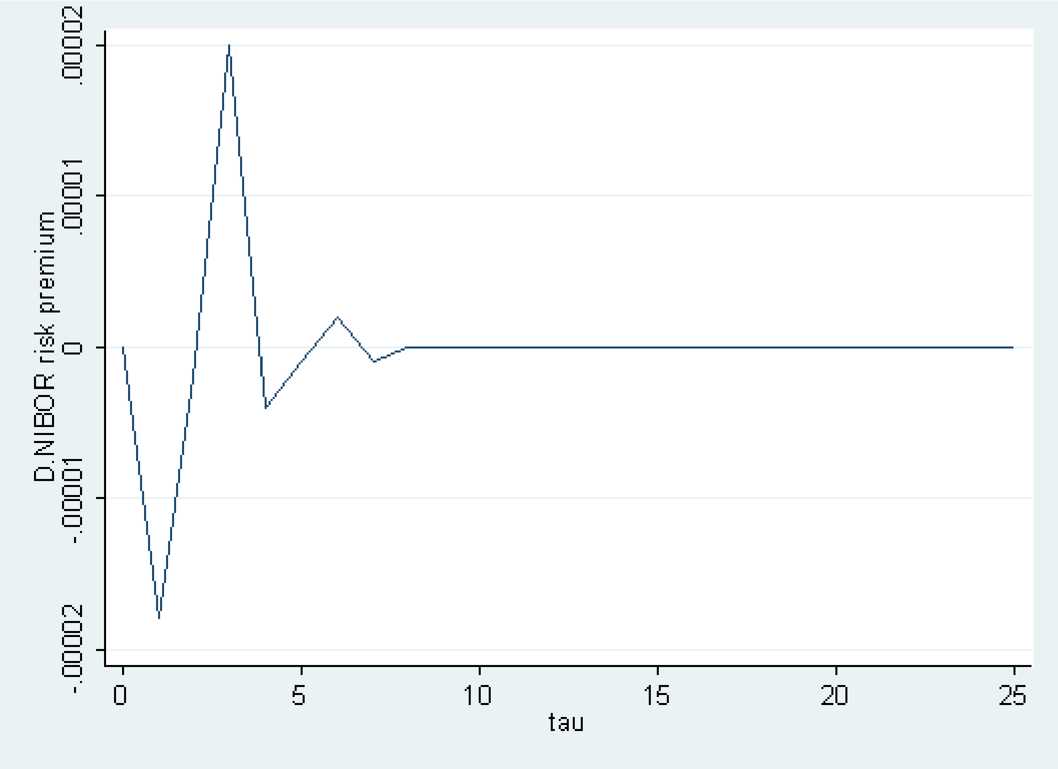
Furthermore, the estimated ECM coefficients differ in the shorter time interval. The absolute value of the error correction term is larger, which still implies a faster speed of adjustment in deviations from the long-term relationship. However, it is still smaller than in the original ECM. As in the original ECM, the coefficient of the first lag of the first-differenced NIBOR risk premium is positive and significant. Prime fund assets, eurozone excess liquidity, total liquidity and the VSTOXX index have no significant short-term effects on the NIBOR risk premium. The coefficients of *Ddecw1* and *Ddecw2* are still significant and are negative and positive, respectively. However, the coefficient of *Ddecw4* is also significant and negative in the shorter time interval. This is a strong rejection of any positive year-end effect in the risk premium.

As the original ECM, the ECM-GARCH model is to a great extent a plausible model. In the conditional variance, there is mixed indications of the effect of the lagged error term. The lagged conditional variance has a significant effect in both the periods. The error correction is a little slower than in the original ECM for both time intervals, but is still significant. When expanding the model and allowing for stochastic processes, more of the short-term effects are significant than in the original ECM. Another coefficient of total liquidity, a coefficient of the VSTOXX index and the coefficients of the dummy variables *Ddecw1* and *Ddecw2*, are significant in the ECM-GARCH model. Furthermore, except for the estimated negative year-end effect, the coefficient are plausible and comply with expectations. However, as in the original ECM, the magnitude and level of significance of the coefficients, and even the sign of the autocorrelation in the first-differenced NIBOR risk premium, are somewhat sensitive with regard to the time interval for which they are estimated. Consequently, the model is somewhat unreliable.

6.5.2 Multiplier effects in the ECM-GARCH model

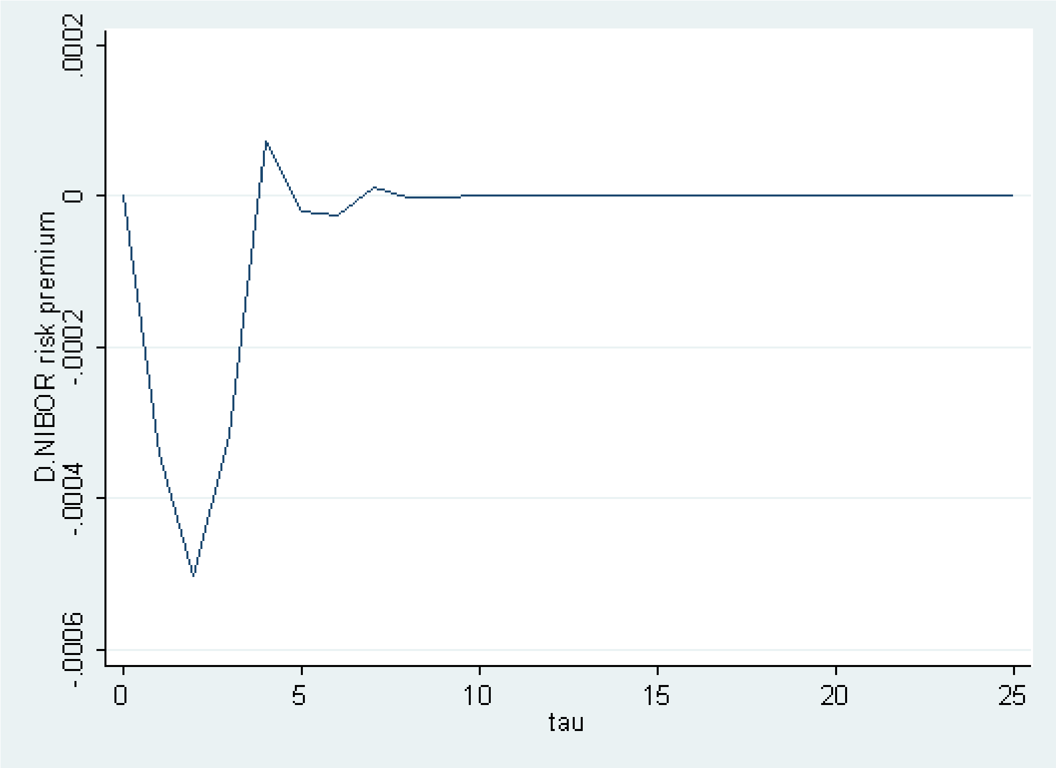
As in the ECM, we also study the dynamic effects of prime fund assets and the variables with a significant short-term effect in the ECM-GARCH model. In the ECM-GARCH model for the period from 23 July 2014 to 14 October 2016, there is significant short-term effects in total liquidity, the VSTOXX index and the dates in two of the year-end dummies. We recall the general dynamic model in equation 6.8 and find the derivatives of $Nrp_{t+\tau}$ with respect to the respective variables. The calculated dynamic multipliers are found in tables E.3 - E.6 in appendix E. The multipliers are illustrated in impulse response functions in figures 6.12 - 6.15. We recall that the literature does not comment on the exact magnitude or characteristics of the dynamic effects on NIBOR.

Figure 6.12: Response in the NIBOR risk premium to an impulse in prime fund assets in the ECM-GARCH(1,1) model. Percentage points. 23 July 2014 - 14 October 2016.



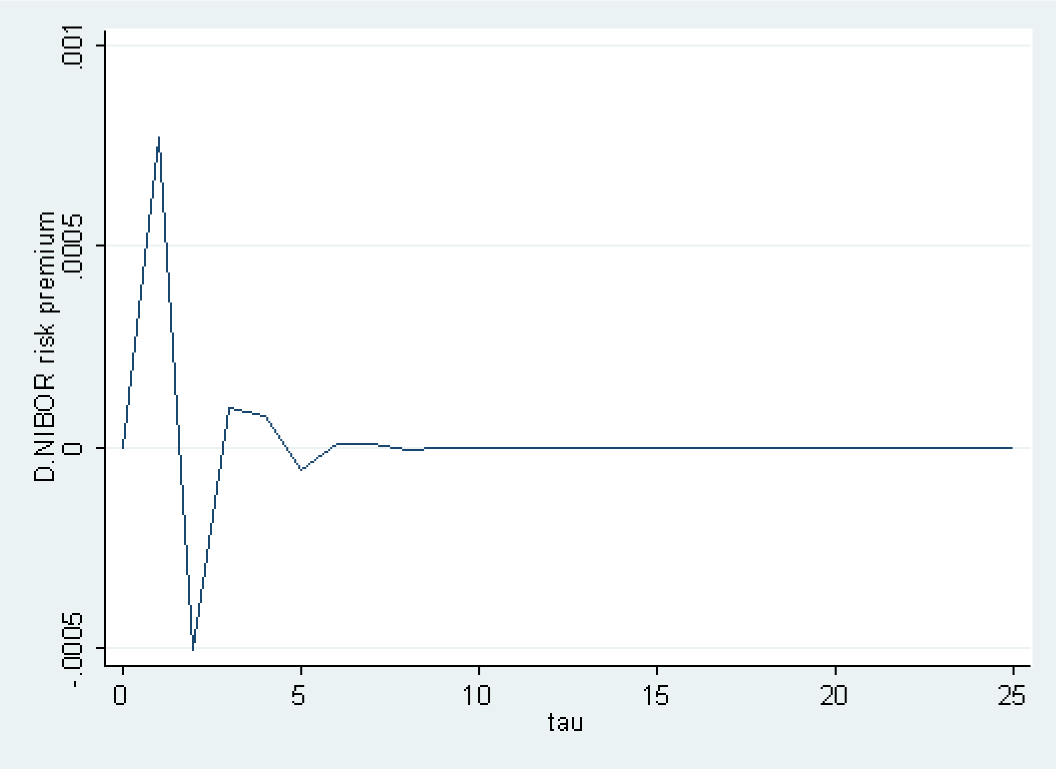
We see in figure 6.12 that an impulse in prime fund assets has a negative effect on the NIBOR risk premium the first two days afterwards. It is greatest after three days with a positive effect of $\frac{2}{100000}$ percentage points on the risk premium. It stabilizes at approximately zero after seven or eight business days. Compared to the impulse response function for prime fund assets in the ECM in figure 6.9, the initial negative effect is considerably smaller.

Figure 6.13: Response in the NIBOR risk premium to an impulse in total liquidity in the ECM-GARCH(1,1) model. Percentage points. 23 July 2014 - 14 October 2016.



In figure 6.13, we see that the dynamic effect of a one billion NOK increase in total liquidity arises one business day afterwards and that it is greatest after two business days with a negative effect of approximately $\frac{5}{10000}$ percentage points. It stabilizes at approximately zero after eight business days. In figure 6.14, we see that the dynamic effect of a one unit increase in the VSTOXX index arises one business day afterwards and that it is greatest after one business day with a positive effect of a little less than $\frac{8}{10000}$ percentage points. Regressions performed by Pedersen & Pettersen (2017) indicate that the VSTOXX index has no significant long-run effect. Otherwise, the literature does not indicate the exact magnitude of the long-run effects of neither total liquidity or the VSTOXX index.

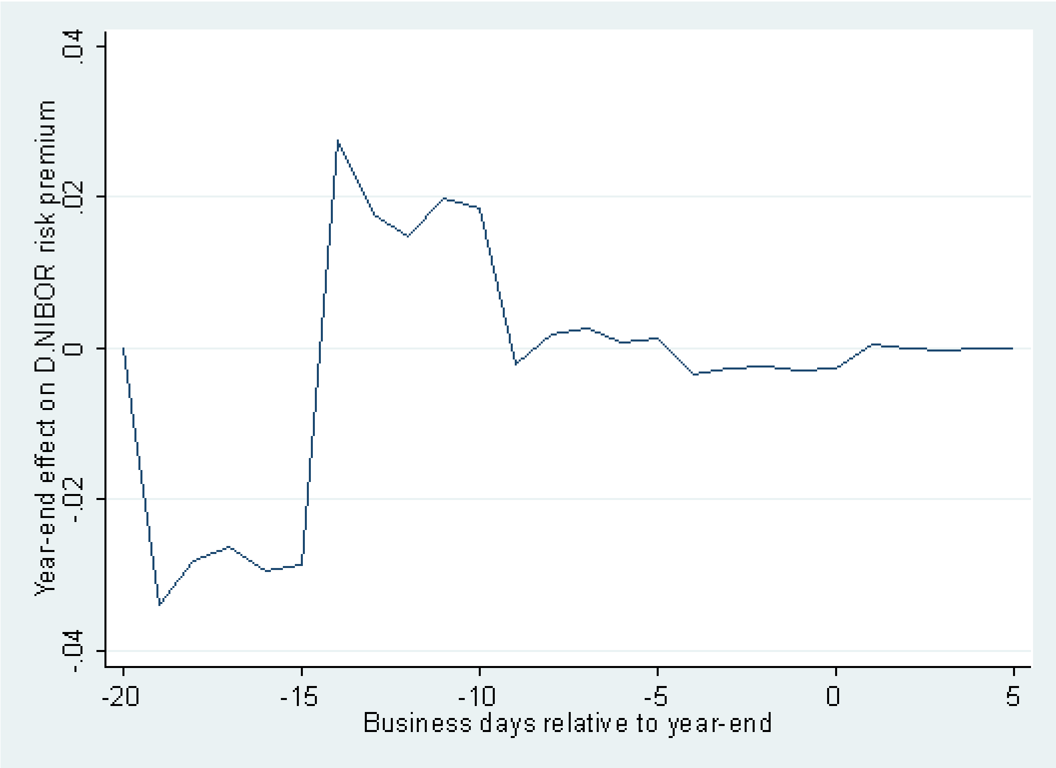
Figure 6.14: Response in the NIBOR risk premium to an impulse in the VSTOXX index in the ECM-GARCH(1,1) model. Percentage points. 23 July 2014 - 14 October 2016.



The dynamic multipliers fluctuate somewhat around zero in all three of the previous impulse response functions. As in the ECM, this is caused by negative autocorrelation in the first-differenced NIBOR risk premium as well as coefficients switching between positive and negative.

The impulse response function in figure 6.15 differs from the other impulse response functions. It is not the impulse in the NIBOR risk premium caused by an impulse in a single variable, but the combined impulses of the dates captured by all of the dummy variables $Ddecw1_t$, $Ddecw2_t$, $Ddecw3_t$ and $Ddecw4_t$, which are equal to *1* on 19 to 15, 14 to 10, 9 to 5 and 4 to 0 business days before the end of the year, respectively. The year-end effect is the sum of the derivatives of $Nrp_{t+\tau}$ with respect to the four dummy variables. The year-end effect is illustrated as an effect on the risk premium on business days relative to the end of the year instead of days relative to the impulse, which would not be meaningful in the particular case of a year-end effect, which arises on certain dates.

Figure 6.15: Response in the NIBOR risk premium to the year-end in the ECM-GARCH(1,1) model. Percentage points. 23 July 2014 - 14 October 2016.



We see that the estimated year-end effect is largest 19 business days before the end of the year with a negative effect of a little more than 0.03 percentage points on the NIBOR risk premium. The year-end effect abruptly changes and is at its most positive 14 business days before the end of the year with a positive effect of a little less than 0.03 percentage points. The year-end effect is relatively close to zero nine business days before the end of the year and onwards. It is almost non-existent in the business days following the end of the year. This is not in accordance with the literature, which suggests that the year-end effect is unambiguously positive and should gradually and temporarily increase up to zero days before the year-end.

We also calculate the long-run multipliers of prime fund assets, total liquidity and the VSTOXX index in order to find the sum of the short-term effects of prime fund assets and the effect of a permanent increase of one billion NOK in total liquidity or a permanent increase of one unit in the VSTOXX index, respectively, on the NIBOR risk premium. We do not calculate a long-run multiplier for the year-end effect because it per definition is a temporary effect. We recall equation 6.8 and the following long-run multiplier in equation 6.12. Then we find that the long-run multiplier of prime fund assets is equal to

$$\frac{-0.000018 - 0.0000052 + 0.000018}{1 + 0.17 + 0.083 - 0.07} = -0.000004 \tag{6.18}$$

percentage points, which is not significant and practically indifferent from zero. It implies that prime fund assets would have to increase by 2500 billion USD for the NIBOR risk premium to increase by 0.01 percentage points.

The ECM-GARCH long-run multipliers of total liquidity and the VSTOXX index are

$$\frac{-0.00034 - 0.00056 - 0.00043}{1 + 0.17 + 0.083 - 0.07} = -0.0011 \tag{6.19}$$

and

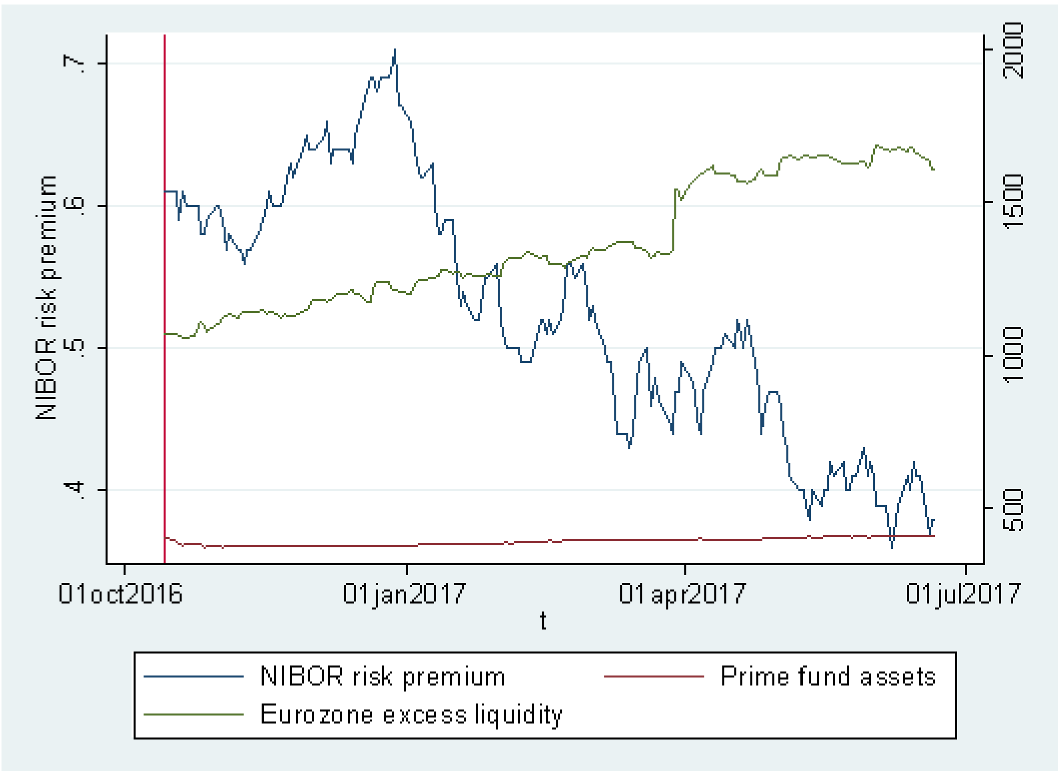
$$\frac{0.00077 - 0.00037 + 0.000076}{1 + 0.17 + 0.083 - 0.07} = 0.0004 \tag{6.20}$$

percentage points, respectively. It is notable that the long-run multiplier of total liquidity in the ECM-GARCH model is approximately twice the magnitude of the long-run multiplier of total liquidity in the ECM.

6.6 The post-reform period

As we have discussed, there is likely a structural break on or around the implementation of MMR on 14 October 2016. The Gregory-Hansen cointegration test indicates that there is a structural break on 24 October 2016, six business days after the implementation of MMR. Now we assess more closely the development in the NIBOR risk premium in the aftermath of the implementation of MMR from 14 October 2016 to 21 June 2017.

Figure 6.16: NIBOR risk premium, prime fund assets and eurozone excess liquidity. Percentage points on LHS. Billions of USD or EUR on RHS. 14 October 2016 - 21 June 2017.



Before the implementation of MMR, the NIBOR risk premium and eurozone excess liquidity series were non-stationary with a positive trend whereas the prime fund assets series was non-stationary with a negative trend. Figure 6.16 shows the development of the series after the implementation of MMR. The NIBOR risk premium still appears to be non-stationary. However, in contrast to before the implementation, the trend turns negative sometime between the implementation on 14 October 2016 and the end of 2016. The NIBOR risk premium decreases by a little more than 0.2 percentage points from the implementation and up to 21 June 2017. The prime fund assets series stabilized after the implementation of MMR and is stationary in the following time. Eurozone excess liquidity still has a positive trend. This is confirmed by Dickey-Fuller unit root tests in tables B.8 - B.10 in appendix B.

An Engle-Granger cointegration test indicates that the relationship between the non-stationary series, NIBOR risk premium and eurozone excess liquidity, is not cointegrated. Table C.3 in appendix C shows the test statistic. Furthermore, the estimated relationship in the cointegration test is negative, which is an indication of spurious regression. MMR should not alter the relationship between the NIBOR risk premium and excess liquidity in the eurozone. The latter would be reasonably expected to still have a positive effect on the former through a smaller liquidity premium in EUR relative to USD and an increase in the Kliem rate.

Since there is no cointegrating relationship between the variables after the implementation of MMR, we do not estimate a long-run relationship. In order to determine the relationship between variables that are not cointegrated, one should transform the series by subtracting the value of the first lagged observation from each observation in the series. That way, it is possible to estimate a relationship between the *changes* in the variables with no adjustment to any long-run relationship. However, that is beyond the scope of this dissertation.

The fact that the trend of the NIBOR risk premium turns so evidently and shortly after the implementation of MMR whereas eurozone excess liquidity increases like before, strongly suggests that the reduction in the risk premium is related to the reform. Prime fund assets stabilizes after the implementation of MMR. According to the estimated models, prime fund assets should not affect the risk premium notably after the implementation. However, one may consider the possibility that the long-term effect of MMR and the decrease in prime fund assets decays after the implementation of MMR.

The estimated error correction models indicate that the long-term effect of MMR on the NIBOR risk premium was an increase of 0.067 or 0.053 percentage points whereas the post-reform risk premium decreased by more than 0.2 percentage points. Either the relationship between the risk premium and MMR and/or prime fund assets is more complex than the linear relationship estimated in the model, or there is one or more other explanations for the reduction in the risk premium. If the estimations are close to the correct effect, the decay of the effect of MMR could not be an adequate explanation for all of the post-implementation reduction in the NIBOR risk premium, which amounts to a little more than 0.2 percentage points.

7. Concluding remarks

In this dissertation, we have described the money market, NIBOR and how interest rates are affected by risk. According to the literature, the risk premium in NIBOR has increased in the recent years. Reportedly, the causes are that quantitative easings in the eurozone have created a surplus supply of EUR and caused the liquidity premium in EUR relative to USD to decrease, new liquidity coverage ratio requirements in the regulatory framework named Basel III and a US money market fund reform (MMR) that was introduced on 23 July 2014 and implemented on 14 October 2016. We have argued that NIBOR is an interesting subject for an empirical study because it is an important reference rate for financial products in the Norwegian market, it may interfere with the monetary policy transmission mechanism and it is affected by the money market fund reform that was recently implemented.

In the analysis, we study the long-term and dynamic effects of the US money market fund reform on NIBOR. We start with an analysis period that goes from the announcement of MMR on 23 July 2014 to 21 June 2017 and focus on the effect of US prime fund assets on the NIBOR risk premium. The NIBOR risk premium increased by approximately 0.4 percentage points up to 14 October 2016. In order to control for the effect of quantitative easings in the eurozone, we also include eurozone excess liquidity as a long-term explanatory variable. Two Gregory-Hansen cointegration tests on our analysis period indicate that there is structural breaks on 23 September 2014 and 24 October 2016. These dates are one day before one of Norges Bank's key policy rate meetings and six business days after the implementation of MMR, respectively. We find that the NIBOR risk premium has a cointegrating relationship with prime fund assets and eurozone excess liquidity from the announcement of MMR on 23 July 2014 to the implementation on 14 October 2016.

We estimate two error correction models (ECMs) with Engle & Granger's two-step estimator. The first model is estimated for the period from 23 July 2014 to 14 October 2016 and includes the entire time window between the announcement and implementation of MMR. For avoidance of known structural breaks, comparison and assessment of the reliability, we also estimate the model for the period from 25 September 2015 to 14 October

2016. In accordance with the associated literature and theoretical framework, we find that prime fund assets have a significant long-term negative effect whereas eurozone excess liquidity has a positive effect on the NIBOR risk premium. We include an error correction term, total liquidity in the Norwegian banking system, the VSTOXX index and dummy variables for the last weeks of the year as short-term explanatory variables.

The total effect of MMR through the decrease in prime fund assets corresponds to a significant increase of 0.067 and 0.053 percentage points in the risk premium according to the ECM estimations for the long and short time intervals, respectively. These estimations are not significantly different. However, the effect is small compared to the estimated effect of quantitative easings through eurozone excess liquidity, which corresponds to an increase of 0.348 and 0.186 percentage points in the long and short time intervals, respectively. There is significant estimated error corrections of 7 and 21 percent of the deviation from the long-run relationship in the two time intervals, respectively. Otherwise, prime fund assets have no significant short-term effect on the risk premium.

In order to take time-varying volatility in the first-differenced NIBOR risk premium into account, we also estimate error correction generalized autoregressive conditional heteroscedasticity (ECM-GARCH) (1,1) models for the two time intervals. We find that the conditional heteroscedasticity has a significant slowly decaying autocorrelation. However, the estimated models differ with regard to the significance of the effect of the most recent variance on the conditional heteroscedasticity. The speed of the estimated error corrections in the ECM-GARCH models is slightly lower than in the ECMs, but still significant. Otherwise, there is still no significant short-term effects of prime fund assets on the risk premium. Neither eurozone excess liquidity has any significant short-term effect.

In addition to the long-term and dynamic effects of MMR and prime fund assets on the NIBOR risk premium, we find mixed evidence of significant short-term effects of total liquidity in the Norwegian banking system and the VSTOXX index on the risk premium. We also find mixed evidence of a year-end effect or a coinciding positive effect of the Liquidity

Coverage Ratio requirements on the risk premium. Contrary to what the literature suggests, we even find indications of a negative year-end effect.

In the post-reform period from 14 October 2016 to 21 June 2017, the NIBOR risk premium decreased by more than 0.2 percentage points. Prime fund assets stabilized whereas eurozone excess liquidity increased. This suggests that the effect of MMR and the prime fund assets on the risk premium decayed after the implementation of the reform. Furthermore, it may suggest that the increase in the risk premium caused by MMR is greater than what the ECMs and ECM-GARCH models estimate.

The results in this analysis confirm Lund, Tafjord & Øwre-Johnsen's (2016) assertion of positive effects of MMR and quantitative easings and Pedersen & Pettersen's (2017) finding that the prime fund assets affect the NIBOR risk premium. However, we estimated the effect of prime fund assets on the risk premium directly whereas Pedersen & Pettersen found it indirectly through the Kliem rate. We have also taken more of the determinants on the NIBOR risk premium into account and studied their dynamic effects in addition to their long-run effects. Furthermore, we would argue that we have to a great extent avoided the problems associated with their OLS regressions, on which we commented in chapter 1.

The estimated models are to a great extent plausible. However, the results and reliability of the analysis may be affected by choices, weaknesses and limitations of the analysis. In the data series that we have utilized, there is some missing observations. We created a business calendar with five-day business weeks through all of the year. Where we only had weekly data, we assumed that the change between the observations could be approximated linearly and filled in the missing values accordingly. Where there was occasional missing values because of holidays or other reasons, we assumed that the value was equal to the last reported observation in the series. The problem of missing values in data series can be approached in different ways. However, the relative amount of missing observations is tolerable and we would not expect the analysis to provide significantly different results if another reasonable approach had been utilized.

Both the magnitude and level of significance and to a small extent also the sign of the estimated coefficients in the ECMs and ECM-GARCH models differ somewhat with regard to the time period for which they are estimated. This suggests that the estimations are sensitive to what period and part of the NIBOR risk premium one chooses to study and that the models are somewhat unreliable. Moreover, the power of the ECM and the ECM-GARCH is low, such that the estimated standard errors may be incorrect.

The choice of explanatory variables may also affect the results of the analysis. As we have explained, the MMR is also reflected in rates such as the USD LIBOR and the commercial papers 90-day rate. We have also used the VSTOXX index, which is based on “out-of-money” options as a variable for market risk. Although we decided to utilize the VSTOXX index, we briefly considered credit default swap prices as well. It is possible that also other variables to a great extent could reflect the market risk that the NIBOR panel banks face.

The most conspicuous attribute of the estimated models is the inconsistency between the estimated effect of MMR on the NIBOR risk premium between the announcement and the implementation and the post-reform reduction in the risk premium. This suggests that the effect of MMR and possibly prime fund assets on the risk premium is greater than estimated by the ECMs and the ECM-GARCH models. One explanation may be that we have left out an important factor unknown both to us and the literature that we have reviewed. Another explanation may be that the relationship between the risk premium and prime fund assets is non-linear. A third possibility may be that MMR has affected the risk premium through other channels in addition to prime fund assets. Possible examples of such factors are market sentiment and uncertain anticipations to the development of prime fund assets rather than prime fund assets themselves.

Future research on the subject of NIBOR and the money market fund reform may concern itself with those questions. It would be beneficial to our understanding of the effects of the US money market fund reform if other important factors, a fitting non-linear relationship between the NIBOR risk premium and prime fund assets, or other channels through which the reform has affected the risk premium, could be identified and confirmed through econometric analysis.

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Appendix A: Data

Data sources

For illustrative and analytical purposes, we have obtained data on different interest rates, liquidity and risk. Where possible, we have obtained data ranging from 1 January 2008 to 20 September 2017 when discussing events and developments of the respective series. All original series contain daily observations except for US prime fund assets and US government fund assets, which contain weekly observations. All web links were functioning on 19 December 2017.

Norges Bank

Data on the three-month NIBOR up to 6 December 2013 is obtained from Norges Bank at: http://www.norges-bank.no/en/Statistics/Historical-monetary-statistics/Short-term-interest-rates/

Data on Norges Bank's key policy rate, reserve rate and overnight lending rate is obtained from Norges Bank at: http://www.norges-bank.no/en/Statistics/Interest-rates/Key-policy-rate-daily/

Upon request, Norges Bank has also provided us with data on structural liquidity and total liquidity in the Norwegian banking system, the five-day moving average of the estimated risk premium in three-month NIBOR and implicitly the estimated Norwegian OIS rate.

Oslo Stock Exchange

Data on the three-month NIBOR from 7 December 2013 is obtained from Oslo Stock Exchange at: https://www.oslobors.no/ob_eng/markedsaktivitet/#/details/NIBOR3M.NIBOR/overview

Federal Reserve Economic Data

Data on the three-month USD LIBOR is obtained from Federal Reserve Economic Data at: https://fred.stlouisfed.org/series/USD3MTD156N

Bloomberg

Data on the eurozone excess liquidity, the VSTOXX index, US prime fund assets and US government fund assets is obtained from Bloomberg.

Thomson Reuters Datastream

Data on the AA commercial paper 90-day rate is obtained from Thomson Reuters Datastream.

Table A.1: Summary statistics for the original obtained series.

DATA SERIES	Time period (Obs)	Mean	S. d.	Min	Max
NIBOR (percentage points)	2.1.2008 - 20.9.2017 (2,450)	2.345	1.487	0.780	7.910
OIS rate	1.1.2008 - 21.6.2017	1.823	1.310	0.450	5.870

(percentage points)	(3,460)				
USD LIBOR (percentage points)	2.1.2008 - 20.9.2017 (2,455)	0.736	0.830	0.223	4.819
Key policy rate (percentage points)	2.1.2008 - 20.9.2017 (2,457)	1.811	1.317	0.500	5.750
Reserve rate (percentage points)	3.10.2011 - 20.9.2017 (1,502)	0.180	0.485	-0.500	1.250
Overnight lending rate (percentage points)	2.1.2008 - 20.9.2017 (2,450)	2.815	1.317	1.500	6.750
Structural liquidity (millions of NOK)	1.1.2008 - 18.9.2017 (3,549)	22,276	42,060	-105,336	123,038
Total liquidity (millions of NOK)	1.1.2008 - 18.9.2017 (3,549)	41,882	18,057	12,889	129,596
Eurozone excess liquidity (millions of EUR)	1.1.2008 - 20.9.2017 (2,468)	391,827	435,451	-134,833	1.786e+06
VSTOXX index	2.1.2008 - 18.9.2017 (2,471)	25.14	9.317	11.16	87.51
Prime fund assets (millions of USD)	2.1.2008 - 20.9.2017 (508)	1.444e+06	428,274	372,735	2.136e+06
Government fund assets (millions of USD)	2.1.2008 - 20.9.2017 (508)	1.129e+06	394,853	766,829	2.231e+06
Commercial paper (AA) 90-day rate (percentage points)	1.1.2008 - 20.9.2017 (2,537)	0.693	0.860	0.140	5.250

Table A.1 shows the summary statistics for the original data series which we have obtained for illustrative and analytical purposes. These include the period for which we have obtained data, the number of observations, the mean values of the series, the standard deviations and the minimum and maximum values. Note that total liquidity, structural liquidity, eurozone excess liquidity, prime fund assets and government fund assets were originally quoted in *millions* of NOK, EUR and USD, respectively, whereas they are quoted in *billions* of their respective currencies in the literature review and analysis of this dissertation.

Appendix B: Unit root tests

Table B.1: Dickey-Fuller unit root test. NIBOR risk premium. 23 July 2014 – 21 June 2017.

Dickey-Fuller test for unit root Number of obs = 761

	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
		Interpolated Dickey-Fuller		
Z(t)	-3.098	-3.960	-3.410	-3.120

MacKinnon approximate p-value for Z(t) = 0.1067

D.niborris~m	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
niborriskp~m						
L1.	-.0295983	.0095541	-3.10	0.002	-.0483539	-.0108427
_trend	.0000134	6.09e-06	2.20	0.028	1.44e-06	.0000253
_cons	.0072147	.0025073	2.88	0.004	.0022925	.0121369

Table B.2: Dickey-Fuller unit root test. Prime fund assets. 23 July 2014 – 21 June 2017.

Dickey-Fuller test for unit root Number of obs = 761

	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
		Interpolated Dickey-Fuller		

Z(t)	-1.722	-3.960	-3.410	-3.120

MacKinnon approximate p-value for Z(t) = 0.7413

D.primefun~s	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
primefunda~s						
L1.	-.0046657	.00271	-1.72	0.086	-.0099858	.0006544
_trend	-.011583	.0052406	-2.21	0.027	-.0218709	-.0012951
_cons	8.135898	4.805888	1.69	0.091	-1.298533	17.57033

Table B.3: Dickey-Fuller unit root test. Eurozone excess liquidity. 23 July 2014 – 21 June 2017.

Dickey-Fuller test for unit root Number of obs = 761

	Test Statistic	Interpolated Dickey-Fuller 1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-2.713	-3.960	-3.410	-3.120

MacKinnon approximate p-value for Z(t) = 0.2306

D.eurozone~y	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
eurozoneex~y						
L1.	-.0158027	.0058244	-2.71	0.007	-.0272365	-.0043689

_trend	.0364757	.012358	2.95	0.003	.0122158	.0607356
_cons	-1.058925	1.236723	-0.86	0.392	-3.486734	1.368884

Table B.4: Dickey-Fuller unit root test. Total liquidity. 23 July 2014 – 21 June 2017.

Dickey-Fuller test for unit root Number of obs = 761

	Test Statistic	Interpolated Dickey-Fuller 1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-17.203	-3.430	-2.860	-2.570

MacKinnon approximate p-value for Z(t) = 0.0000

D. totalliqui~y	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
totalliqui~y						
L1.	-.5613784	.0326322	-17.20	0.000	-.6254384	-.4973183
_cons	19.4474	1.136712	17.11	0.000	17.21593	21.67888

Table B.5: Dickey-Fuller unit root test. VSTOXX index. 23 July 2014 – 21 June 2017.

Dickey-Fuller test for unit root Number of obs = 761

	Test	Interpolated Dickey-Fuller 1% Critical	5% Critical	10% Critical

	Statistic	Value	Value	Value
Z(t)	-4.180	-3.430	-2.860	-2.570

MacKinnon approximate p-value for Z(t) = 0.0007

D. vstoxxindex	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
vstoxxindex						
L1.	-.0455036	.0108857	-4.18	0.000	-.0668732	-.0241339
_cons	.9946489	.245102	4.06	0.000	.5134904	1.475807

Table B.6: Dickey-Fuller unit root test. Engle-Granger residuals. 23 July 2014 - 14 October 2016.

Dickey-Fuller test for unit root Number of obs = 583

	Test Statistic	Interpolated Dickey-Fuller 1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-5.763	-2.580	-1.950	-1.620

D.egresidu~s	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
egresiduals |						
L1. |	-.1085788	.0188398	-5.76	0.000	-.1455812	-.0715764

Table B.7: Dickey-Fuller unit root test. Engle-Granger residuals. 25 September 2015 - 14 October 2016.

Dickey-Fuller test for unit root Number of obs = 276

	Test Statistic	Interpolated Dickey-Fuller 1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-6.859	-2.580	-1.950	-1.620

D.egresidu~s |	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
egresiduals |						
L1. |	-.2021445	.0294724	-6.86	0.000	-.2601647	-.1441243

Table B.8: Dickey-Fuller unit root test. NIBOR risk premium. 14 October 2016 – 21 June 2017.

Dickey-Fuller test for unit root Number of obs = 179

	Test Statistic	Interpolated Dickey-Fuller 1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-2.511	-4.014	-3.439	-3.139

MacKinnon approximate p-value for Z(t) = 0.3226

D.niborris~m	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
niborriskp~m						
L1.	-.0634211	.02526	-2.51	0.013	-.1132726	-.0135696
_trend	-.0001086	.0000435	-2.49	0.014	-.0001946	-.0000227
_cons	.0417983	.0168111	2.49	0.014	.008621	.0749756

Table B.9: Dickey-Fuller unit root test. Prime fund assets. 14 October 2016 – 21 June 2017.

Dickey-Fuller test for unit root Number of obs = 179

	Test Statistic	Interpolated Dickey-Fuller 1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-4.090	-4.014	-3.439	-3.139

MacKinnon approximate p-value for Z(t) = 0.0065

D.primefun~d	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
primefunds~d						
L1.	-.1693443	.0414066	-4.09	0.000	-.2510618	-.0876269
_trend	.0371663	.0094247	3.94	0.000	.0185664	.0557663

_cons	62.9924	15.38984	4.09	0.000	32.62003	93.36478

Table B.10: Dickey-Fuller unit root test. Eurozone excess liquidity. 14 October 2016 – 21 June 2017.

Dickey-Fuller test for unit root Number of obs = 179

	Test Statistic	Interpolated Dickey-Fuller 1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-2.319	-4.014	-3.439	-3.139

MacKinnon approximate p-value for Z(t) = 0.4234

D.eurozone~y	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
eurozoneex~y						
L1.	-.066464	.0286594	-2.32	0.022	-.1230243	-.0099037
_trend	.2393738	.1110907	2.15	0.033	.0201324	.4586152
_cons	72.1296	29.58668	2.44	0.016	13.73926	130.5199

Appendix C: Cointegration tests

Table C.1: Engle-Granger cointegration test. NIBOR risk premium, prime fund assets and eurozone excess liquidity. 23 July 2014 – 21 June 2017.

```
Engle-Granger test for cointegration                 N (1st step)  =      761
                                                     N (test)      =      760
-------------------------------------------------------------------------------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic          Value             Value             Value
-------------------------------------------------------------------------------
 Z(t)             -2.759            -4.313            -3.752            -3.460
-------------------------------------------------------------------------------

Critical values from MacKinnon (1990, 2010)

-------------------------------------------------------------------------------
Engle-Granger 1st-step regression

-------------------------------------------------------------------------------
niborriskp~m |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------------------------------------------------------------------------

primefunda~s |  -.0000554   .0000205    -2.71   0.007    -.0000956   -.0000152
eurozoneex~y |   .0001765   .0000186     9.47   0.000     .0001399    .0002131
       _cons |   .3472564   .0343943    10.10   0.000     .2797371    .4147757

-------------------------------------------------------------------------------
Engle-Granger test regression

-------------------------------------------------------------------------------
  D._egresid |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------------------------------------------------------------------------

    _egresid |
```

L1.	-.0228432	.0082799	-2.76	0.006	-.0390975	-.0065889

Table C.2: Engle-Granger cointegration test. NIBOR risk premium, prime fund assets and eurozone excess liquidity. 23 July 2014 – 14 October 2016.

Engle-Granger test for cointegration N (1st step) = 583

N (test) = 582

	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-5.766	-4.319	-3.755	-3.463

Critical values from MacKinnon (1990, 2010)

Engle-Granger 1st-step regression

niborriskp~m	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
primefunda~s	-.0000663	.0000166	-3.99	0.000	-.0000989	-.0000337
eurozoneex~y	.000372	.0000122	30.54	0.000	.000348	.0003959
_cons	.2798542	.0264962	10.56	0.000	.2278141	.3318944

Engle-Granger test regression

D._egresid	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]

```
    _egresid |
         L1. |   -.108633   .0188402    -5.77   0.000    -.1456362   -.0716298
```

Table C.3: Engle-Granger cointegration test. NIBOR risk premium and eurozone excess liquidity. 14 October 2016 – 21 June 2017.

```
Engle-Granger test for cointegration                  N (1st step)  =      179
                                                      N (test)      =      178
-------------------------------------------------------------------------------
                  Test          1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
-------------------------------------------------------------------------------
 Z(t)            -2.250            -3.959            -3.371            -3.068
-------------------------------------------------------------------------------
Critical values from MacKinnon (1990, 2010)

-------------------------------------------------------------------------------
Engle-Granger 1st-step regression
-------------------------------------------------------------------------------
niborriskp~m |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------------------------------------------------------------------------
eurozoneex~y |  -.0003812   .0000177   -21.53   0.000    -.0004161   -.0003462
       _cons |   1.044722   .0244073    42.80   0.000     .9965557    1.092889
-------------------------------------------------------------------------------
Engle-Granger test regression
-------------------------------------------------------------------------------
  D._egresid |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------------------------------------------------------------------------
```

```
  _egresid |
        L1. |  -.0583386   .0259247    -2.25   0.026    -.1094999   -.0071773
```

Table C.4: Gregory-Hansen cointegration test. NIBOR risk premium, prime fund assets, and eurozone excess liquidity. 23 July 2014 – 21 June 2017.

```
Gregory-Hansen Test for Cointegration with Regime Shifts
Model: Change in Regime and Trend                 Number of obs   =       761
Lags  =  0  chosen by Akaike criterion            Maximum Lags    =        10
```

	Test Statistic	Breakpoint	Date	Asymptotic Critical Values 1%	5%	10%
ADF	-6.58	175	24mar2015	-6.45	-5.96	-5.72
Zt	-7.29	306	23sep2015	-6.45	-5.96	-5.72
Za	-104.96	306	23sep2015	-79.65	-68.43	-63.10

Table C.5: Gregory-Hansen cointegration test. NIBOR risk premium, prime fund assets, and eurozone excess liquidity. 24 September 2015 – 21 June 2017.

```
Gregory-Hansen Test for Cointegration with Regime Shifts
Model: Change in Regime and Trend                 Number of obs   =       455
Lags  =  8  chosen by Akaike criterion            Maximum Lags    =        10
```

	Test Statistic	Breakpoint	Date	Asymptotic Critical Values 1%	5%	10%
ADF	-6.57	344	17jan2017	-6.45	-5.96	-5.72

Zt	-9.29	283	24oct2016	-6.45	-5.96	-5.72
Za	-107.01	283	24oct2016	-79.65	-68.43	-63.10

Appendix D: Optimal lags in the error correction model

Table D.1: Optimal number of lags information criterions. Engle-Granger residuals.

Selection-order criteria

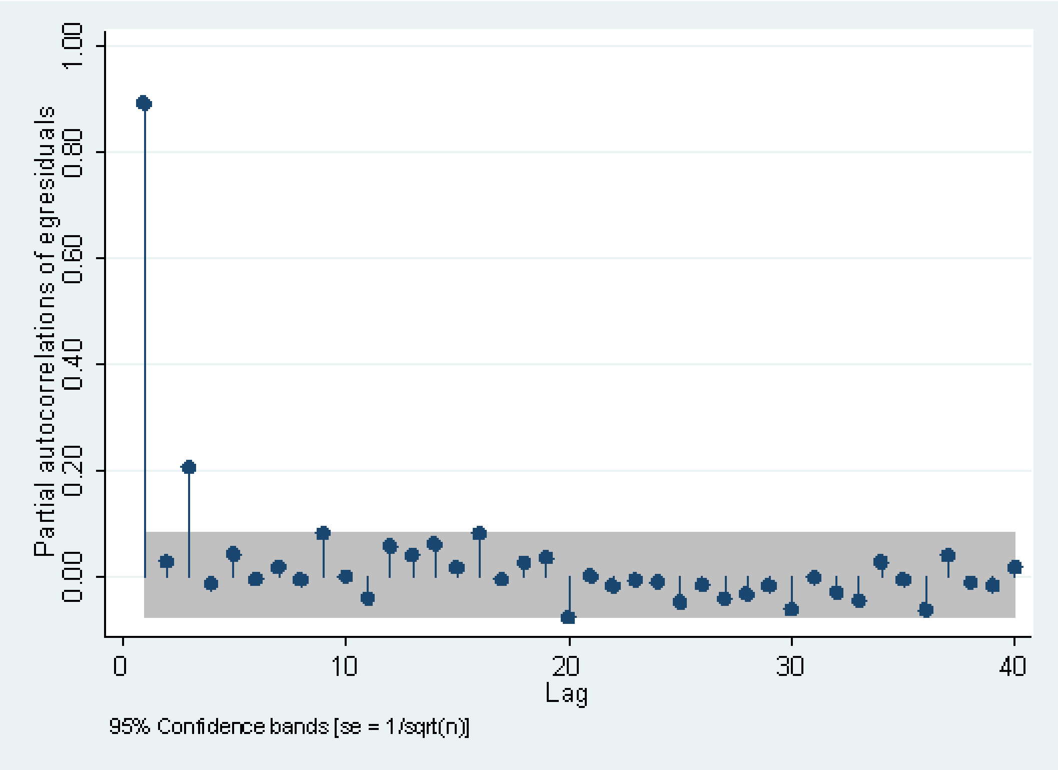
Sample: 23jul2014 - 14oct2016 Number of obs = 583

lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	924.783				.002462	-3.16907	-3.16615	-3.16158
1	1384.86	920.15	1	0.000	.00051	-4.74394	-4.7381	-4.72896
2	1385.09	.45726	1	0.499	.000511	-4.7413	-4.73253	-4.71882
3	1397.49	24.798*	1	0.000	.000491*	-4.7804*	-4.76872*	-4.75043*
4	1397.55	.13314	1	0.715	.000493	-4.7772	-4.7626	-4.73974
5	1398.06	1.0138	1	0.314	.000494	-4.77551	-4.75798	-4.73055
6	1398.08	.03054	1	0.861	.000495	-4.77213	-4.75169	-4.71968
7	1398.16	.17643	1	0.674	.000497	-4.769	-4.74564	-4.70906
8	1398.19	.0592	1	0.808	.000499	-4.76567	-4.73939	-4.69824
9	1400.07	3.7568	1	0.053	.000497	-4.76869	-4.73948	-4.69376
10	1400.07	.00233	1	0.961	.000499	-4.76526	-4.73313	-4.68284

Endogenous: egresiduals

Exogenous: _cons

Figure D.1: Partial autocorrelation of Engle-Granger residuals. 23 July 2014 – 14 October 2016.



Appendix E: Dynamic multipliers

Table E.1: Calculated dynamic multipliers of prime fund assets in the ECM. 23 July 2014 – 14 October 2016.

The dynamic multipliers are equal to the derivatives of $Nrp_{t+\tau}$ with respect to Pf_t.

tau		Multiplier
0		0,000000
1		-0,000062
2		-0,000080
3		0,000028
4		0,000016
5		-0,000006
6		-0,000003
7		0,000001
8		0,000001
9		0,000000
10		0,000000
11		0,000000
12		0,000000
13		0,000000
14		0,000000
15		0,000000
16		0,000000
17		0,000000
18		0,000000
19		0,000000
20		0,000000
21		0,000000
22		0,000000
23		0,000000
24		0,000000
25		0,000000

Table E.2: Calculated dynamic multipliers of total liquidity in the ECM. 23 July 2014 – 14 October 2016.

The dynamic multipliers are equal to the derivatives of $Nrp_{t+\tau}$ with respect to Tot_t.

tau		Multiplier
0		0,000000
1		-0,000160
2		0,000118
3		-0,000542
4		0,000004
5		0,000113
6		-0,000004
7		-0,000024
8		0,000001
9		0,000005
10		0,000000
11		-0,000001
12		0,000000
13		0,000000
14		0,000000
15		0,000000
16		0,000000
17		0,000000
18		0,000000
19		0,000000
20		0,000000
21		0,000000
22		0,000000
23		0,000000
24		0,000000
25		0,000000

Table E.3: Calculated dynamic multipliers of prime fund assets in the ECM-GARCH model. 23 July 2014 – 14 October 2016.

The dynamic multipliers are equal to the derivatives of $Nrp_{t+\tau}$ with respect to Pf_t.

tau		Multiplier
0		0,000000
1		-0,000018
2		-0,000002
3		0,000020
4		-0,000004

5		-0,000001
6		0,000002
7		-0,000001
8		0,000000
9		0,000000
10		0,000000
11		0,000000
12		0,000000
13		0,000000
14		0,000000
15		0,000000
16		0,000000
17		0,000000
18		0,000000
19		0,000000
20		0,000000
21		0,000000
22		0,000000
23		0,000000
24		0,000000
25		0,000000

Table E.4: Calculated dynamic multipliers of total liquidity in the ECM-GARCH model. 23 July 2014 – 14 October 2016.

The dynamic multipliers are equal to the derivatives of $Nrp_{t+\tau}$ with respect to Tot_t.

tau		Multiplier
0		0,000000
1		-0,000340
2		-0,000502
3		-0,000316
4		0,000072
5		-0,000021
6		-0,000025
7		0,000011
8		-0,000001
9		-0,000002
10		0,000001
11		0,000000
12		0,000000

13		0,000000
14		0,000000
15		0,000000
16		0,000000
17		0,000000
18		0,000000
19		0,000000
20		0,000000
21		0,000000
22		0,000000
23		0,000000
24		0,000000
25		0,000000

Table E.5: Calculated dynamic multipliers of the VSTOXX index in the ECM-GARCH model. 23 July 2014 – 14 October 2016.

The dynamic multipliers are equal to the derivatives of $Nrp_{t+\tau}$ with respect to VX_t.

tau		Multiplier
0		0,000000
1		0,000770
2		-0,000501
3		0,000097
4		0,000079
5		-0,000057
6		0,000010
7		0,000009
8		-0,000006
9		0,000001
10		0,000001
11		-0,000001
12		0,000000
13		0,000000
14		0,000000
15		0,000000
16		0,000000
17		0,000000
18		0,000000
19		0,000000
20		0,000000

21		0,000000
22		0,000000
23		0,000000
24		0,000000
25		0,000000

Table E.6: Sum of the calculated dynamic multipliers of Ddecw1, Ddecw2, Ddecw3 and Ddecw4 in the ECM-GARCH model. 23 July 2014 – 14 October 2016.

The dynamic multipliers are equal to the sum of the derivatives of $Nrp_{t+\tau}$ with respect to $Ddecw1_t$, $Ddecw2_t$, $Ddecw3_t$ and $Ddecw4_t$.

Days relative to year-end		Multiplier
-20		0,0000
-19		-0,0340
-18		-0,0282
-17		-0,0264
-16		-0,0296
-15		-0,0288
-14		0,0275
-13		0,0176
-12		0,0147
-11		0,0200
-10		0,0186
-9		-0,0023
-8		0,0017
-7		0,0027
-6		0,0007
-5		0,0013
-4		-0,0034
-3		-0,0028
-2		-0,0025
-1		-0,0029
0		-0,0028
1		0,0005
2		-0,0001
3		-0,0002
4		0,0001
5		0,0000