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Non-Standard Liquidity Measures and International Interbank Term Structure Dynamics

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Abstract

Throughout the financial crisis central banks experienced a situation where standard monetary measures failed to create stability and restore growth to the financial markets and the overall economy. Therefore new response methods where introduced. One of the key responses was to extend longer maturity loans through auctions supported by a wider range of collateral (The Term Auction Facility or TAF program). In the aftermath of the crisis in financial markets the effect of this monetary measure has been widely discussed. A key topic of interest is how it affected the term structure of interbank interest rates and whether it restored access to liquidity for financial institutions.

In this thesis we develop and apply three statistical tests to study if the TAF had the intended effect on US interbank rates, and whether or not spillover effects to other markets have been seen as well. First we compute the frequency of a directional move following term auctions, and compare this with the frequency in the overall financial crisis. Then we compute the expected size in such a move following auction dates, and compare expected sizes in such moves during the rest of the financial crisis. Third we use an event study to look for abnormal movements following auction dates. Here we estimate an affine term structure model driven by a vector autoregressive model with the credit premium, liquidity premium and short rate as driving factors in an affine term structure model.

The thesis has four major findings;

First, we find that the probability of drops in interbank interest rates and spreads tended to be more likely and larger in size following the notification of information regarding the results of TAF-auctions.

Second, the Term Auction Facility caused international spillover effects which varied from market to market. Specifically we found that unsecured loans with more than 5 months to maturity became less expensive compared to unsecured loans with less than 5 months to maturity. These results were found in the UK and EU, and were highly significant. The same results indicate that interest rate levels tended to fall, but these results were not significant.

Third, interest rates on loans with more than 4 months to maturity dropped more than what could be expected, even when credit and liquidity factors could be perfectly predicted. This suggests that the results from TAF-auctions went a long way in reducing premiums on unsecured loans in the interbank marked with longer maturities (5-12 months).

Last, the Term Auction Facility seem to have pulled down premiums on credit and liquidity beyond what could be expected following the notification of results from the TAF auctions. These effects were seen to spill over to the settlement day as well.

Contents

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Chapter 1

Introduction and Background

1.1 Introduction

The roles of modern central banks are monetary policy and support for financial stability. The last was a function which was prominent under the recent financial turmoil, with substantial need for intervention and extraordinary measures (Martnez, 2009).

Even though key policy rates were cut to almost zero during the financial turmoil, the liquidity squeeze remained. The failed transmission mechanisms of monetary management using standing facilities forced central banks to introduce non-standard or extraordinary measures to address the ultimate goal, financial and macroeconomic stability in the economy. Many new measures were put into place, among these the Term Auction Facility (TAF)(FED, 2009).

Through the TAF, between USD30bn and USD141bn were lent from the central bank to financial institutions bi-weekly in an attempt to provide liquidity to institutions which suddenly had a hard time getting access to sufficient liquidity. In contrast to similar standing facilities the TAF program avoided creating stigma effects by keeping participants anonymous.[1]. The interconnectedness[2] of banks suggests that such a large non standard measure could have effect across the global money market. The facility remained in place throughout the crisis until demand vanished in the beginning of 2010.

Policy rate changes are normally followed by liquidity measures to back up the "new" poalicy rate, ensuring that LOIS spreads do not increase. It is therefore natural to expect TAF auctions to have a similar effect. Each TAF auction increases monetary base (total available liquidity in the market) hopefully causing reduced pressure on money market rates and reduced LOIS-spreads.

A wide range of research is already conducted through various approaches in an attempt to answer the question "Was there an effect?" (Taylor and Williams (2008a), Taylor and Williams (2008b), McAndrews, Sarkar, and Wang (2008), Ait-Sahalia, Andritzky, Jobst, Nowak, and Tamirisa (2012)). Conclusions vary with methodologies, approaches and choices of variables. In any case none of these papers seeks to answer the questions given that there was an effect, "How did the TAF impact Money Market

[1]For more information about the TAF program see section 1.2.3.
[2](May, Levin, & Sugihara, 2008).

Spreads?"

This thesis shed light on whether the TAF program had the intended effect, pulling down money market premiums. Three parts of a possible effect is studied; "Was the probability of movements in any part of the term structure impacted?", "Was expected movements in these parts larger than what was else observed in the crisis?", and, "When did impacts occur, and how did the translate into term structure moves?".

To study these questions three tests are performed; the frequency of directional moves is computed, then the expected size of these moves, both for days with TAF operations and for the rest of the financial crisis. The frequencies and expected sizes are then compared to see whether there exist any effects on TAF operation dates different from other days during the crisis. Finally an event study is performed in an attempt to locate the source of any such abnormal movements following TAF operation days. Different from present day prevailing research an affine term structure model is motivated and used as the normal movement scenario. This model is driven by a vector autoregressive stochastic process with credit premium, liquidity premium and short rate as driving factors.

Firstly of all, the research seem to uncover the possibility of the presence of an impact from the TAF. This is most apparent in the event study, where a pattern of significant abnormal movement is detected on the day when information concerning results from the auctions is released and on the following day. Secondly, the first and second test indicates impact especially on the slope of the term structure, in particular for the short end. This follows from both a higher probability of movement and a larger expected size in movement on dates surrounding the auction. Lastly the first and second test insinuate effects on international interbank spreads. These effects do primarily occur through a flattening of the term structure in particular for the short maturity part.

The remainder of this paper is as follows: In the rest of this chapter a detailed background for the overall situation is presented, as well as previous research and literature related to our research questions. In Chapter 2 the methodology and variables used are motivated. In Chapter 3 empirical evidence is presented and discussed, as well as potential paths for future research.

1.2 Motivating the Study of Interbank OIS Spread Term Structures

This section provides an overview of the progression of events during the financial crisis as well as the measures taken by central banks during this period. The key connections between interbank rates, Overnight Indexed Swap (OIS) rates and the TAF are made, and a detailed overview of the term auction facility is provided. A key focus is the role of the Term Auction Facility (TAF) as one of the largest and most important measures implemented during the crisis by the Federal Reserve (FED) in the US to stabilize financial markets, and especially interbank markets.

1.2.1 The Financial Crisis

Starting August 9th 2007, money market spreads experiences an unprecedented jump following BNP halting redemption on three of their funds. Combined with reports of decreased levels of issuance in asset backed commercial paper markets, this represents the first indication of the build-up of global financial crisis. A crisis that turned out to be one of the worst financial crisis since the Great Depression, - the decade preceding world war II.

Before the financial crisis struck the world economy, the United States experienced one of the longest lasting bull markets[3] in history. This situation was in large part fueled by low interest rates due to large capital inflow from Asian countries, and the adoption of a lax interest rate policy (Hemmelgarn & Nicodeme, 2010).

The Federal Reserve avoided to counteract the build-up of a housing bubble as they still feared a deflationary period after the Internet Bubble, which ravaged the US between 1997 and 2000 climaxing 10th March 2000 (Brunnermeier, 2008). The banking system went from what Brunnermeier called the traditional banking model, to the originate and distribute banking model (Brunnermeier, 2008).

This new development led banks to pool and sell mortgages to investment banks, who then sliced and re-pooled them before reselling them as collateralized debt obligation (hereafter, CDO) tranches to investors. As residential housing prices had been booming for what seemed to be decades, financial markets assessed these securities to be as safe as government debt. They later turned out to be "the bull that broke the banks back", bringing cascading effects through the entire banking system (May et al., 2008).

During spring 2007, walkouts[4] became the start of the financial crisis. As American borrowers struggled to keep up with their growing (and sometimes jumping) interest rate and principal payments, combined with dropping house prices and excess supply of houses, it created a negative spiral causing even more walkouts. As a result, banks and CDO investors become property owners rather than cash flow owners, forcing them to take losses.

Over the summer 2007, the US sub-prime [5] crisis spread to a number of advanced economies in the world. These countries were often exposed directly through a combination of sub-prime assets, loss of confidence to a variety of asset classes and non-functional dry financial markets. These factors provoked severe disruptions in funding sources and asset bubbles (Nier & Merrouche, 2010).

As more and more sub-prime loans began to decay, mortgage backed notes became worthless. Many international banks held worthless bonds and had to take write-downs. In the absence of any records on which banks held such bonds, the financial market became sceptical of whom they could safely lend money to. The fear of a borrower's creditworthiness and lenders capacity and willingness to lend, resulted in unpredicted jump in unsecured money market spreads. (Abbassi & Linzert, 2011). Banks would rather keep their excess cash than lend it to a counterpart in risk of default, a situation referred to as precautionary hoarding (Brunnermeier, 2008). These conditions drove spreads further up, causing more expensive borrowing, tighter credit supply, more strict credit standards and in the end exploded

[3] A *Bull market* is characterized by a group of securities that are rising or expected to rise. The opposite is called bear market.

[4] In the US mortgages are written on the property itself, not the purchaser of the property. If the persons residing on that property are unable to pay their liabilities, they can walk away from the property without the risk of prosecution, hence the term "walkout". The property then belongs to the owner of the liabilities, often the bank.

[5] *Subprime*: Borrowers whose credit has been impaired, in some cases due to life events such as unemployment or illness. At the same time, these borrowers have sufficient equity in their homes to mitigate the lender's exposure, thereby allowing the lender to place lesser weight on the credit profile. (Fabozzi, 2005).

into a credit crisis for both business and household segments.

A combination of lower growth and many financial institutions on the verge of bankruptcy forced governments around the world to intervene in order to stimulate the economies and prevent a global recession.

Among other governmental measures the reserve supply (liquidity) to banks was an important instrument from the central banks. In many countries this implied a changing systems for managing bank reserves. This became a global approach that central banks around the world adopted to stimulate and help banks and financial institutions through the liquidity crisis.

1.2.2 Crisis-related Monetary Policy Measures

By January 2013, central banks around the world have massively expanded their balance sheets. This was the result when Taylor's rules[6] for monetary management failed to stimulate growth (e.g. short term interest rates close to zero without effect) (Martin & Milas, 2012). During such a long and deep crisis as the recent one, it became necessary to enact "non-standard" or "unconventional" monetary policy measures in order to stimulate growth. Taylor's theory provides no clear definition of what constitutes non-standard monetary policy measures. We therefore classify them as extraordinary actions taken and implemented by central banks in connection to a financial crisis, such as the recent on. These actions are supposed to be terminated when the crisis is determined to be "over". In the case of the recent financial crisis this involves mainly non-standard measures that goes beyond the standing facilities.

Largely monetary management from central banks during the financial turmoil can be categorized into five main measures:

- *Reduced key policy rates to historically low levels and communicated that they would keep it low for a long time.*
- *Intervention into wide segments of the financial market.*
- *Purchase of long term government bonds.* This was part of the "Quantitative Easing" (QE) where the goal was to lower the interest rate on medium and long term non-defaultable government bonds by selling short and purchasing long.
- *Support for specific important institutions.*
- *Expanded liquidity provisions to financial institutions.* This involved relaxing collateral on liquidity offers, opening central bank facilities to more institutions, providing liquidity in foreign currency and finally providing longer-term liquidity which in the US was done through the TAF program.

The different non-standard measures taken by the FED in response to the financial crisis can be summarized in the timeline below (figure 1.1). We note that the TAF program was early adopted and one of the

[6]Taylors rule is a monetary policy rule introduced by John Taylor in 1993. The rules are guidelines for interest rate manipulation to stabilize the economy in the short term and on the same time maintain long-term growth. The rule implies interest increase when inflation is below target or actual employment is below the full employment level, and the opposite when the contrary is the case.

measures FED kept on providing for a very long time.

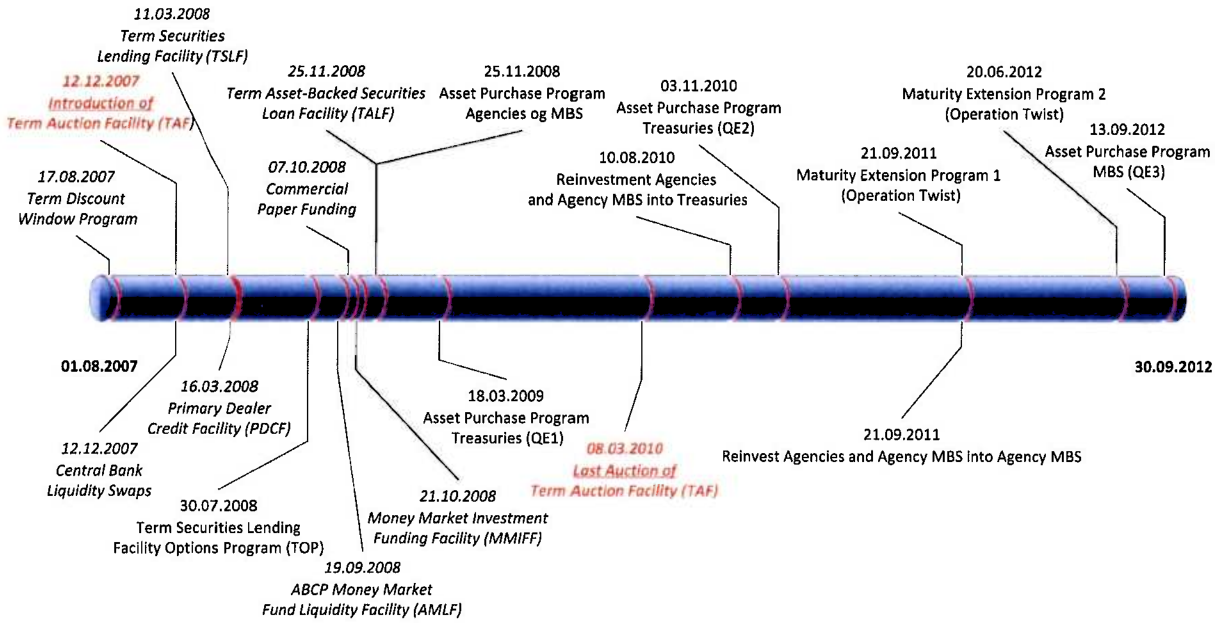


Figure 1.1: *Federal Reserve (FED) crisis related measures*
Italic indicates liquidity monetary measure, Red colour indicates TAF relevant dates.

1.2.3 Term Auction Facility

The Term Auction Facility (TAF) was initiated by the FED at the end of 2007 to address the elevated pressure in short-term funding markets and was one of the first non-standard monetary measures taken as a response to the crisis. Appendix 4.4 shows in detail the different TAF-auctions with key data.

The TAF program aimed to provide capital for financial and depository institutions at a longer duration (28 days, later increased the longest maturity to 85 days). It was initially communicated that the program would last as long as necessary.

Any depository institutions in generally sound financial condition and certified to borrow under the primary credit discount windows could participate. A key advantage of the TAF program was the removal of any stigma effects associated with borrowing under the primary credit discount window. As Bernanke described in a speech held on April 2009 illustrating the stigma effect FED attempted to resolve through its initiated measures; *"In August 2007, (...) banks were reluctant to rely on discount window credit to address their funding needs. The banks concern was that their recourse to the discount window, if it became known, might lead market participants to infer weakness - the so-called stigma problem."* (Bernanke, 2009).

In order to create a theory on the effects of the TAF we need to review in some detail the execution of the program. The program and auction process is described in figure 1.2. Note in particular that no results are publicized before the notification date.

At the end of June 2009 Federal Reserve announced that a range of modifications would be made to the

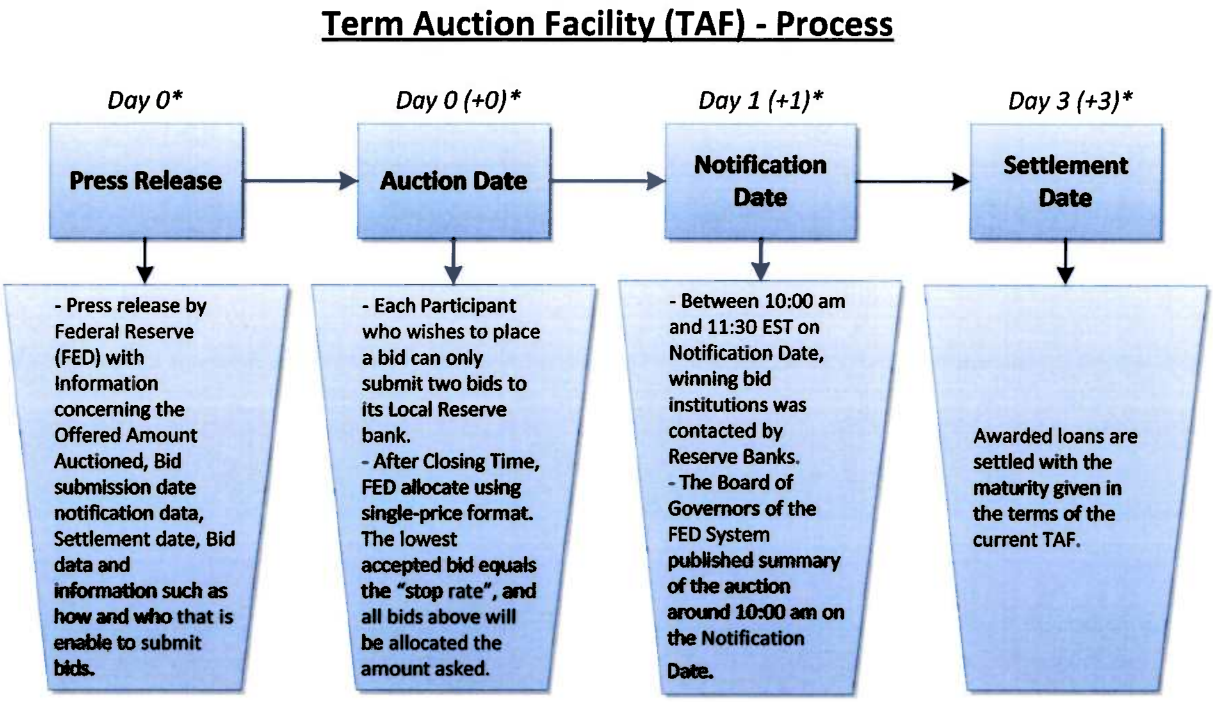


Figure 1.2: The figure above shows the usual path of any Term Auction held from December 2007 until March 2010, with some information related to each event.
** Days are valuable for all TAF dates except the first 6. Hence, as of TAF Auction number 7 (10th March 2008) of a total of 60 TAF Auctions, the days between are correct.*

credit and liquidity programs at that time active. One of the modification was to reduce the amount of funds available in the TAF auctions from $\$150Bn$ to $\$125Bn$ per auction, as the amounts of bids had fallen short of the auctioned amounts. If conditions in funding markets were to improve in the future coming months, the board would further reduce the funds available. The program was terminated March 11 2010 (FED, 2009).

1.2.4 Interbank Interest Rates

The interbank interest rate is an indication of the average rate a participating institution can obtain for unsecured funding for a given maturity in the local currency. Different interbank rates are calculated through different procedures, described below.

The US, the EU and the UK have their own money market, consequently banks trade in their local currency, and hence these interest rates are not in the same manner affected by the US dollar as NIBOR, which is closely linked to US dollars (Bergman, Juel and Steigum 2009). The most important money market rates are respectively for these countries USD LIBOR, EURIBOR (The EU) and GBP LIBOR, which all are quoted as the average interest rate of the selected banks. The regulatory authorities (e.g. British Bankers Association with assistance from Foreign exchange and Market Committee for LIBOR rates) regulate in all countries the panel banks that are included in the interbank rates.

Unlike the other countries in this analysis Norway does not have enough transaction volume to have their own interbank market in NOK. Therefore the Norwegian banks trade with each other through the Eurokrone-market in USD, where the most important interest rate is Norwegian Interbank Offered Rate (NIBOR). However not all banks have access to the USD market and as a result these are only active in the Norwegian interbank market. Larger banks are normally active in both. As a result the direct NOK interbank rate must be close to the implied NOK interest rate through the USD market because participants would borrow where they get the cheapest funding, meaning that in equilibrium these interest rates are equal and one could say that the NIBOR rate represent the NOK-USD swap rate (Akram & Christophersen, 2010).

EURIBOR-rates

Every panel bank report to Thomson Reuters before 10.45 am CET, then the highest and lowest 15 % are eliminated and the average of the remaining 70 % of banks represent the EURIBOR rate. Eurobor rates are calculated the same way as the regular LIBOR rates (see below).

GBP/USD LIBOR-rates

Panel banks inform Thomson Reuters around 11 am CET, then the highest and lowest 25 % values is eliminated and the average of the remaining 50 % represents the official LIBOR rate. LIBOR rates are calculated on the basis of actual days funding period/360, except for GBP LIBOR which is divided by 365 (BBA, 2013).

$$\text{Interest Due} = \text{Principal Sum} \times \frac{\text{BBA LIBOR Rate}}{100} \times \frac{\text{Number of days in interest period}}{360} \tag{1.1}$$

It is important to note that USD LIBOR and EURIBOR was reported to be exposed to manipulation between January and July 2008 (FSA, 2012).

NIBOR-rates

NIBOR is fixed on daily basis and calculated as a simple average of the interest rates published by Thomson Reuters just before 12 noon every day for each term by the six largest banks, the NIBOR panel banks, after exclusion of the lowest and highest reported interest rates, in accordance with the regulations (FNO, 2013b). NIBOR should reflect the interest rates that lenders require for unsecured loans in Norwegian kroner, based on what the bank will demand for loans to leading banks that are active in the Norwegian money market and foreign exchange market. The interest rates should not be regarded as binding offers, rather best estimates for the market interest rates (FNO, 2013a).

Movements During the Financial Crisis Figure 1.3 shows the money market rates for the sample countries/areas, together with the time frame when the TAF was active. It is not readily apparent from this image when the financial crisis starts, but it is obvious that the Lehman Brother event can be characterized as a global event. A clear tendency is a general drop in all interbank rates during most of the financial crisis. This is mostly a function of reduced policy rates, and is an effect we wish to exclude from our analysis.

In addition two dates creating sever turmoil is included. These two dates has the potential of causing bias in our tests. For both dates we observe interbank rates sharply inclines. This is followed by a sharp drop as all the respective Central Banks responded by heavily decreasing policy rates combined with non-standard measures over the following months. The dollar dry out combined with credit and liquidity risk imposed after the bankruptcy of Lehman Brothers, further increased the money market rates the following days. The disentanglement following after policy rates hit rock bottom is reflected in the different exposures and choice of monetary management strategies in respective nations, and therefore the movements in key policy rates.

Statistical Properties of Interbank Rates First note the almost complete lack of co-movement in interbank rates before the Lehman Brothers bust. The reason for this is the differences in local key policy rates. This provides us with the insight that any modelling requires an adjustment for the differences between these rates which in large part are exogenous, and outside the frame of this thesis. To adjust for this we study the spread between Interbank rates and OIS rates.

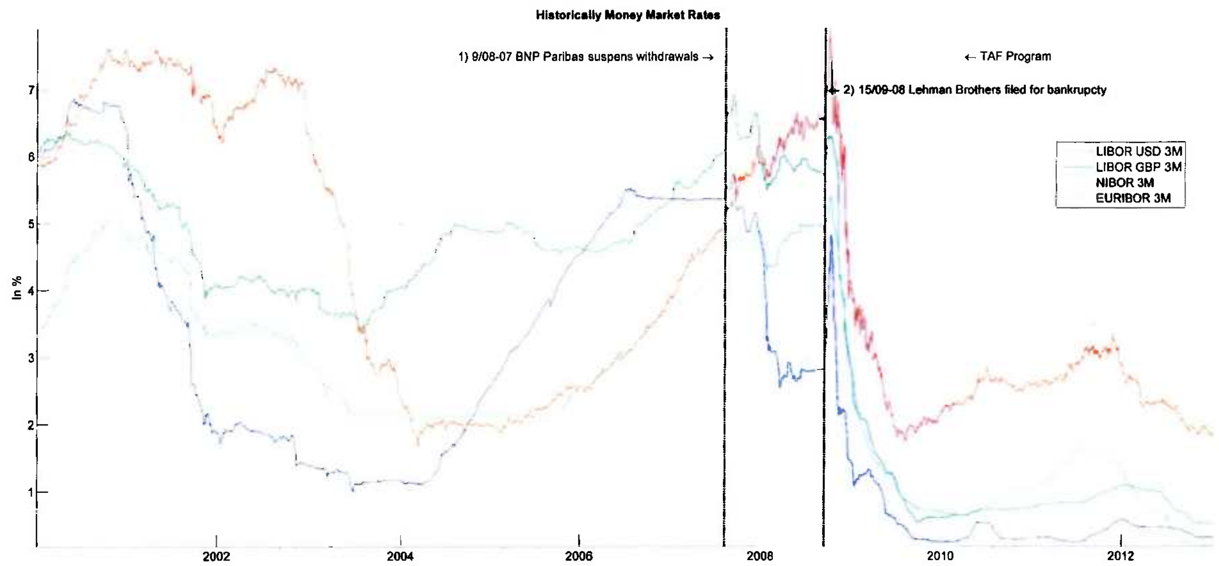


Figure 1.3: *Historically Interbank Rates*

Statistical Properties of Term Structures Figure 1.4 illustrates clear signs of relationships between LIBOR rates at different maturities, - a relationship in need of disentanglement. As highlighted through numerical results in Cajueiro and Tabak (2007), LIBOR interest rate term structures show clear signs of long-term memory and persistence. Furthermore it illustrates through clustering estimations that LIBOR rates show signs of moving in sub groups. These findings are intuitive when observing figure 1.4. One can see that while short interest rates moves above and below each other and close to the Federal Funds Target Rate, the medium term interest rates hardly change direction at all, moving linearly throughout this period. A period full of policy rate hikes from the FED. Meanwhile long term interest rates seem to be fluctuating somewhat as well, but in a different and less erratic manner than the shortest maturity rates. These observations have probably created some of the foundation for the expectations hypothesis and illustrate a clear need for taking into account the entire term structure of interest rates.

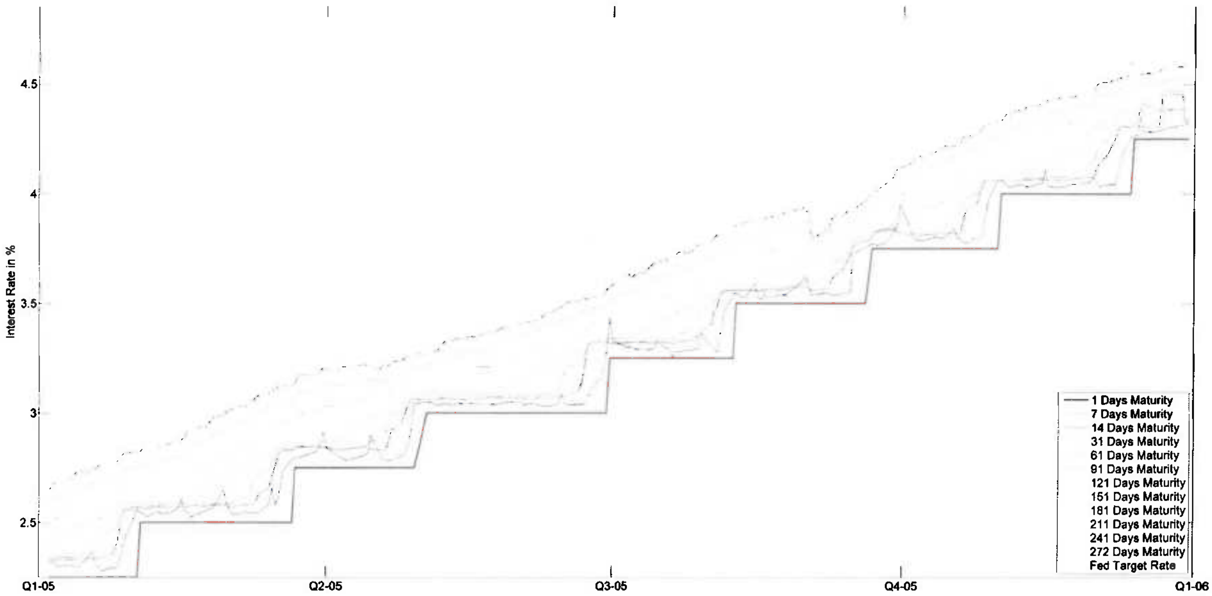


Figure 1.4: *Illustration of the Term Structure of LIBOR USD Rates.*

Another observation which might not be as easy to see, is the shape of the term structure on any given day. Throughout this period one will never observe a term structure of interest rates with a negative slope. The market is likely to expect interest rate hikes over the future, and therefore require to be compensated for possible future rate hike when pricing interbank loans. This is not astonishing, and has been commented on already in this chapter. What is interesting to observe is that when long term interest rates drop towards the beginning of Q4-2005 all other interest rates drop with them (except the overnight and the 7 days rates), not breaking the sign of the slope for the term structure but none the less moving almost the entire structure downwards. This reflects the interdependency property in the term structure, and in particular the slope-factors as the expected direction of future interest rates. What is not illustrated here is that when the LIBOR 3M rate hits its plateau of 5.5%, the yield curve at first remains upward sloping, then changes and looses its shape. When the BNP Paribas withdrawals suspension occurs, the sign of this slope changes and follows the policy rate downwards. As such the entire term structure reflects obvious signs of expectations for future overnight rates, which provides support for the expectations hypothesis.

These results show a need for an attempt to model the entire yield curve and study its entire structure over the period. In addition, there is a need to find a method for removing this significant sign of future expectation from the term structure in order to purify the analysis with respect to the effects of the term auctions (TAF). The observations made here are some of the reasons for the methodology we will use to test the effects of monetary policy commented on under *Literature Review* (section 1.4). As such, and especially when observing the flattening of the curve Q4-2005, the methodology to be used must account for the entire curve, not only the 3M LIBOR, which has been the topic of research so far.

As described by Cajueiro and Tabak (2007), and further illustrated in figure 1.4, the movement in the shortest maturity rates (specifically 1-14 days) shows clear signs of movements based on other factors than much of the remaining term structure, and should as such be considered for separate analysis. The same might apply for longer term interest rates, but here the argument is not as clear cut. This is because the movement in longer term interest rates relative to shorter maturity could help explain an increased optimism through a raised slope (or a slope with a less negative sign than before) when announcing the TAF program or results from the auction volumes.

1.2.5 Central Bank Rates and Overnight Indexed Swaps (OIS)

Key policy rate(s) or target rate(s) are the official rates set by the authorities to regulate the monetary management in countries. They are mainly used to point out the direction that interbank rates, particularly overnight rates, will be steered through monetary measures. The policy rate does however vary when it comes to the monetary system. FED is an exception that has a target rate which could be compared to key policy rate or official rates in other countries, and two key rates, namely the discount rate and the Federal Funds rate. These rates are normally managed at committee meetings scheduled with 4-8 weeks in between. The rules differs somewhat between the different countries, but this is the general procedure.

Expectations of Key Policy Rates - The Overnight Indexed Swap (OIS)

An Overnight Index Swap (OIS) is a fixed/floating interest swap whereas the floating rate is determined by the geometric average of published overnight rates over each time interval of a contract period[7]. In other words, two players are involved (see figure 1.5 below), one who pay a fixed rate (the swap rate), and one paying a floating rate (e.g. Eonia). The initial value of this contract is by default set to zero, so that no cash exchange is required at initiation. As such, for these cash streams to have the same expected value, the geometric average of each of the periods interest rates must be the same by the Law of One Price. The rate published on such a contract is the fixed paying rate. Since the two streams are equal in value, if the fixed rate differs from the floating rate, the floating rate must be expected to move in the direction of the fixed rate. This is the argument why one assumes to observe expectations in this market. In contracts where large amounts of money is involved, the different parties may impose credit premiums. However, in the OIS contract only interest payments are exchanged (where the cash amounts are relatively small compared to contracts where notional is exchanged) and as such these contracts

[7]The US, the EU and the UK all have functioning OIS markets. Conversely, there exist no operational OIS market in Norway and hence the OIS rate in Norway is estimated by Norges Bank using other rates available in the market and discretion.

contain very small amounts of credit premium. The volume of trade in this market provides a similar argument for the absence of a liquidity premium.

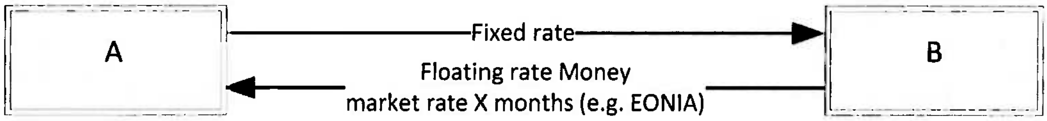


Figure 1.5: *Two parties involved in an OIS-swap agreement*

It could be argued that the estimate of the expected policy rate is not perfect since it is a measure of the expected overnight rate. Nevertheless, in normal times the OIS would be close to the policy interest rate, but in periods of turmoil in the financial markets there may be discrepancies between the policy rate and the overnight rate. Among other countries, the EU area with their excess supply of liquidity during the recent years pushed the overnight interest rate below the base rate.

These contracts are meant to contain expectations for future changes in the Federal Funds Target Rate in the US. The same information regarding term structures apply here when it comes to long memory, persistence and the co-relationship. Since OIS contracts do not swap any notional, only a fixed for a floating interest rate tied to the notional of the contract, they carry very little credit risk.

As the short maturity contracts are frequently used by banks to hedge interest rate risk on short maturity loans, they form one of the most liquid interest rate markets. Furthermore, the shortest OIS rate (1 month to maturity) seems to move flat relative to the target federal funds rate, as the Federal Open Market Committee are unlikely to meet over the rates contracted period. As such, this interest rate will from time to time move differently than the remaining term structure, allowing this rate to form its own cluster when it comes to movement dynamics.

Term Structure of LOIS-Spread Figure 1.6 illustrates the movement of the term structure of the LOIS [8]. As commented in plot 1.4 the LIBOR interest rates contains market expectations regarding the movement of the target federal funds rate. The same goes for the OIS term structure. As the contracts have the same maturity these expectations will probably cancel out.

Through estimation we find that the term premium on overnight index swaps are smaller for the entire sample period than for LIBOR contracts. This reflects a potential excess expectation regarding movements in the other risk factors relative to the target federal funds rate for the LIBOR rate, causing the LOIS to widen whenever expectations are formed regarding the federal funds rate. As such we can propose that the LOIS do not contain any expectations regarding the federal funds rate. It does not solely contain the instantaneous credit and liquidity risk, but also the expected future movements in the same factors.

Key components in need of commenting is the initial period until the beginning of Q3-07, compared to the period of which goes under the "After Crisis Period" from Q2-10 when the TAF was terminated. The spreads were extremely small initially, until the shift caused by the events related to BNP Paribas. Until then it seems the US interbank market was absent of credit and liquidity spreads, as the spread is

[8] LOIS spread is the difference between a LIBOR rate and a OIS contract with the same time to maturity.

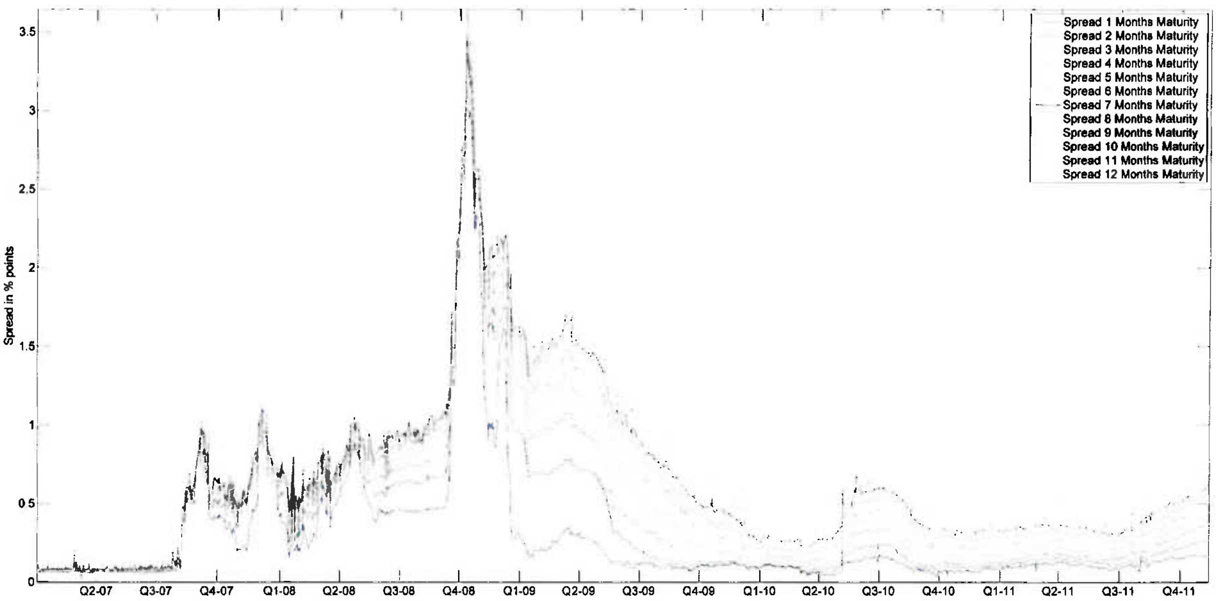


Figure 1.6: *Illustration of the Term Structure of LOIS USD Rates.*

as close to zero as possible, and with a close to flat term structure of interest rates. The largest jump comes from the Lehman Brothers bankruptcy. One can observe that the term premium in the LOIS has far from returned to historical level. It is likely that the recent events have caused a regime shift in the interbank markets, where one now puts a premium on liquidity for long term funding, in comparison to the past, where one could borrow to possibly the same rate for any maturity.

International Interbank OIS spreads Following the rational from the last two paragraphs we compare 3M international interbank OIS spreads in figure 1.7.

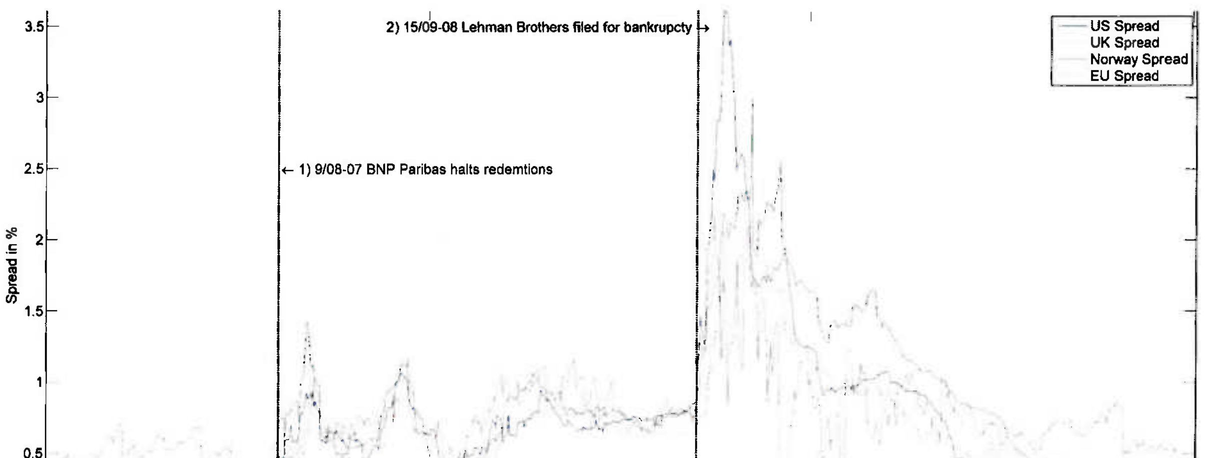
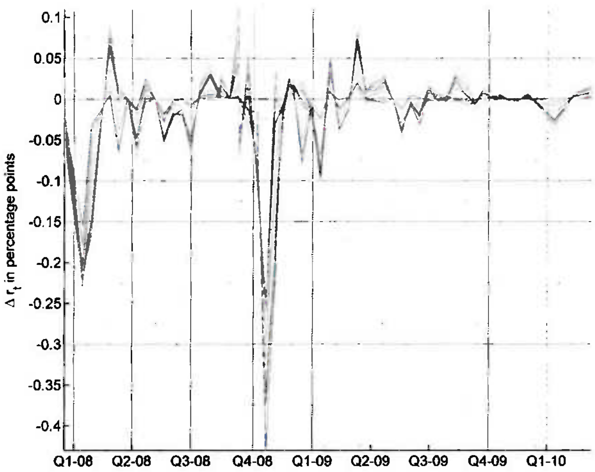


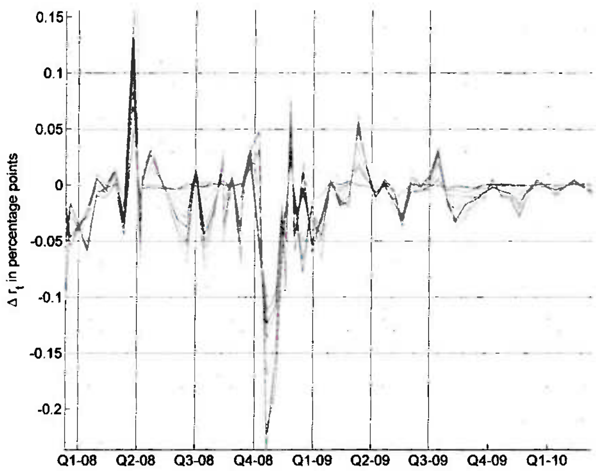
Figure 1.7: *Historically International 3M LOIS Spreads.*

From figure 1.7 we see from the spreads, although not moving exactly alike, that the differences in interest rates are likely to follow from differences in forwards on currency exchange rates, (ref. covered interest rate parity)[9].

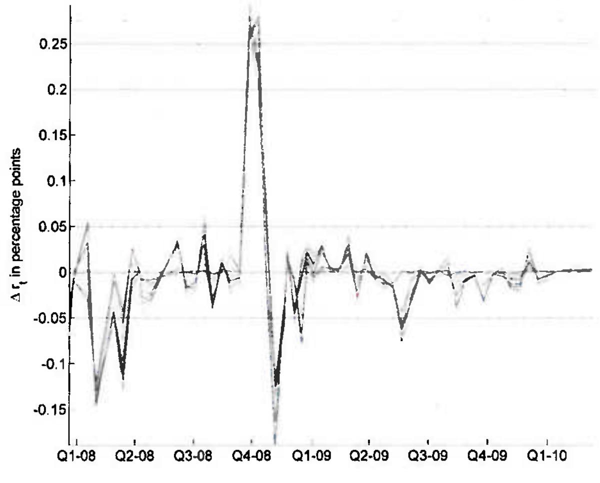
LIBOR USD change on Term Auction (TAF) related dates In this paragraph we provide an overview of the spread movements on Term Auction Dates. Figure 1.8 depicts the movement for different parts of the term structure over the days where the TAF occurs. Specifically we observe a slight downward tendency on the Auction Dates and Notification Dates, while the movement is opposite for the Settlement date. It is important to notice that rates move in this period not because spreads move, but because this is shortly after the Lehman Brothers Bankruptcy when the Federal Reserve changes its target rate. This bias is necessary to account for in the testing methodology.



(a) Auction Date



(b) Notification Date



(c) Settlement Date

Figure 1.8: *The figures above show the change (Δ_{Spread}) in the spreads of different maturities. The spread indicate the difference between LIBOR USD and FED Target Rate in the United States. It is important to* ***Note*** *that the data points forming the plots is generated from the change ($\Delta Spread$) the day of interest (Auction Date, Notification Date or Settlement Date) for the 60 TAF auctions held over the period. Hence, the points forming the plot can be described as follows:* $\Delta_{Spread} = LIBOR_t - Fed_t$.

[9]Covered interest rate parity states that interest rates in two countries must be related through the price of currency spot and forward rates of the same maturity to avoid arbitrage. For more information on this relationship see any international finance text book or the NIBOR interest rate in this thesis.

1.3 Research Questions

In this past section we have explained how the financial crisis started, some of the symptoms central banks observed, and the measures they used in their attempt to nurture the global economy back to health. Specifically it was noted that banks suddenly met a liquidity dry out following stronger suspicions of higher credit risk levels. Furthermore, banks became large scale property owners, started hoarding cash, causing money markets to freeze for several maturities. As a result, Central Banks enacted extraordinary monetary policy measures such as the TAF. These measures were non-standard, it is therefore of interest ot study whether they have had the intended effect. The following set of hypotheses is formulated and argued for;

Hypothesis 1: Initiation of non-standard measures affect money market term structures The efficient markets hypothesis claims that all new information is immediately priced into assets which concerns itself with that information. As the facility is provided to banks and other financial institutions the facility should directly impact interbank rates. A sudden shock to liquidity (as a surprising monetary measure like the TAF was) should then provide an instantaneous drop in interbank rates.

Hypothesis 2: The following term auctions caused an increased probability of downward movements in interbank term rates In the same way as for hypothesis 1 the notification date provides new information to markets regarding its present state. Since the participants in the auctions are anonymous the mare part-taking in the auctions is a positive sign regarding future development, all other things being equal. Therefore interbank rates should observe a higher probability of downward movement, relatively or in absolute form, especially following the notification dates.

Hypothesis 3: During the following term auctions downward movements in interbank rates and spreads were likely to be larger than what was normally observed The size in auction volumes and unrestricted access to the auctions for depository and other financial institutions, suggests that movements in interbank rates should be larger in the downward direction on days surrounding the auctions, than what was normally seen when observing spread falls.

Hypothesis 4: The TAF resulted in effects in related international interbank markets The interconnectedness in interbank markets indicates that movements in one market should affect connected markets. If so then the TAF should cause a higher probability of downward movements following notification dates and these moves should be larger in size than what was normally observed during the crisis.

Hypothesis 5: TAF auctions resulted in abnormal movements in interbank rates beyond what can be explained by movements in credit or liquidity premiums. Two types of liquidity exits. The first is market liquidity, the second is funding liquidity. This last measure should be somewhat different from the first and consists of the supply of cash in the interbank market (an institutions willingness to put its own money at risk when it may face the need for cash in the immediate future it self). Any such moves not picked up by the first measure should be reflected here.

Hypothesis 6: TAF auctions resulted in abnormal movements in interbank rates, as a result of movements in liquidity and/or credit premiums The main intention of the TAF was to provide sufficient liquidity for financial institutions in need of this. Key causes for bankruptcy and financial distress is insufficient liquidity. Therefore the TAF should result in less bankruptcy risk and lower credit premiums. The access to cash became less immediate too and less premium should therefore be placed on the ability to immediately liquidate assets.

Answering these hypotheses should provide further predictability into the possible future effects of similar measures and a valuable contribution to future monetary management.

1.4 Current Research into TAF Effects - A Litterature Review

When reviewing the present state of research on the TAF topic it is made clear that there are questions that remains unanswered.

The first paper written on the financial crisis was "A Black Swan in the Money Market" (Taylor & Williams, 2008b). The purpose was to examine alternative explanations to the unusual development in the money market with high spreads during the financial turmoil, and further to evaluate the impact of policy actions taken to address them. A simple regression is performed on the LIBOR-OIS (LOIS) spread with a counterpart risk factor and an indicator variable for the term auctions. Their empirical research provide evidence for counterpart risk and expectations for future interest rates as major explanatory factors for the interest spread. But, they are unable to provide conclusive answers regarding the effect of the term auctions.

Abbassi and Linzert (2011) looked at the effectiveness of ECBs monetary policy on steering the money market rates during the financial crisis. They use a time-series regression on the change of the interest rates for 3M, 6M and 12M EURIBOR. As predictors they use the future expectation on short rates, VIX[10], Corporate Bond Spreads, Eurepo-OIS spread, outstanding Main Refinancing Operations (MRO) and Long-Term Refinancing Operation (LTRO) volumes and dummy variables for announcements of term auctions and other monetary policy measures. Their results indicate that ECBs non-standard crisis related monetary policy were effective measures to reduce money market rates. During the financial crisis, the expansion of ECBs balance sheet as well as the fixed rate tenders with full allotment, had a significant influence on the dynamics of money market rates for three, six and twelve-month maturities.

McAndrews et al. (2008) look at the effect of the Term Auction Facility (TAF) program on the liquidity risk premium on LIBOR three-month. They use a simple econometric test where the LIBOR-OIS spread is assumed to be linearly associated with the TAF announcements and operations as independent dummy variables. They find that the cumulative reduction in LIBOR-OIS spreads can be associated with around

[10]Chicago Board Option Exchange (CBOE) Volatility Index.

50 basis point reduction. The test is limited to the 3M LIBOR and therefore only contribute to the level of term structure, not the slope, curvature or other factors.

This is further investigated by Kamps (2009) who analyze the long run drivers for money market rates, LIBOR-OIS spread, through a cointegrated VAR approach. He has several findings; He finds that credit risk and liquidity uncertainty are to be considered as the main driving forces for the EURIBOR-OIS spread. Further non-standard or unconventional measures taken by central banks appear to have a negative effect on permanently reducing both the spread and the money market rates, most likely according to Kamps through lightening the liquidity uncertainty. Thirdly, Kamps shows that in the long run, EURIBOR/LIBOR tend to move together when controlling for non-standard policy measures, credit and funding risk. However, in the short run he shows that they can diverge due to e.g. monetary easing.

The review of these papers illustrate what was highlighted in the introduction. None review the movements in the term structure, or their sources.

Chapter 2

Developing a Methodology

The questions posed towards the end of the previous chapter can not all be answered with the same methodology, and none directly with methodology applied so far in present day TAF research. We must therefore develop three new and separate methodologies, one design for each category of questions.

First, in order to test hypotheses 2 and 4 we develop a non-parametric bootstrapping based test to study the frequencies in directional moves. Second, to test hypotheses 3 and 4 we develop a difference-of-means-test to test the size in directional moves during TAF auctions, compared to directional moves regardless of whether or not TAF operations are in place. Finally, to test hypotheses 1 and 5-7 we develop an event study approach, combined with an affine term structure model to look for abnormal movements and their possible sources.

2.1 Test 1: The Conditional Probability of Interbank Spread Drop

[1]To assess whether or not the presence of a the TAF program resulted in a higher probability/frequency for interest rate drops we use a difference in frequency test. We coin this test the DMFR ("Downward Movement Frequency Ratio"). Such a test allow us to study whether or not one would see the same frequency of downward interest rates movements during any sample of 60 randomly chosen days during the financial crisis.

Stated mathematically:

$$\mathbb{P}\left[\Delta r_t < 0 | I_t = 1\right] > \mathbb{P}\left[\Delta r_t < 0\right]$$

$$\theta = \frac{\mathbb{P}\left[\Delta r_t < 0, I_t = 1\right]}{\mathbb{P}\left[\Delta r_t < 0\right]} = \frac{\text{\# Downward Movements on Specified Dates}}{\text{\# Downward Movements on All Dates}} > 1 \tag{2.1}$$

We bear in mind when constructing this test the research by Di Matteo and Aste (2002). They find several signs of non-Gaussian behaviour in interest rate movements, and possibly therefore a tendency

[1]The theoretical foundation for the methods described and applied in this section and the next was obtained through the document Storvik, Geir *Bootstrapping - Additional Literature for STK2120*, University of Oslo Department of Mathematics, March 2011.

for asymmetric behaviour. As we separate size in movements from frequency in direction of movements such properties may appear even though the time series looks symmetric at a first glance. We therefore relax the assumption of Gaussian distributed rate and spread changes for this test. It is important to note that even for very large samples the test statistic is non-normal (Brown, Cai, & DasGupta, 2001). Several methods attempt to account for this deviation, for instance the Agresti-Coull method (Agresti & Coull, 1998). Our choice falls on the bootstrap because of our ability to automate the test, because of its non-parametric form and because of the relatively small amount of variables the statistic will be computed for.

When relaxing the Gaussian assumption we must either put in place another assumed probability distribution or find a way to approximate it. In this case we rely on an approximation of the empirical distribution. The following example provides an intuitive interpretation of the test.

Example We claim that if the TAF had an effect on, say interest rate spreads, then one should see a higher number of downward movements in these spreads on the notification days, where auction volumes became public knowledge, than you would normally see in a day. Suppose we were aware of 60 TAF auction days in a 619 days period. Our claim would then suggest that if you were to choose ten days at random from those 619 days you would rarely observe the same frequency[2] of downward interest rate movements in that sample as when you pick those 60 specific TAF notification days. Basically we therefore draw 60 random days over and over, 20 000 times and measure the frequency of downward term structure movements in each sample. Then we record how often we pick a sample with the same or higher frequency as what we observed during days of TAF operations. If we rarely pick this number, we can claim that the difference between frequencies is significantly different. Otherwise we must admit that even though there is a difference this might just be a result of random chance.

One caveat is that sample size governs the test-uncertainty. In this case, more TAF auctions translates into a more accurate estimate of the difference in frequencies, and whether or not it is positive. As such, if one had 200 auction dates, we would be more able to tell if there were a difference, even if this difference is small. For a sample of 10 days, 90% of the frequencies lies within 70% and 20% when the true frequency of interest rate drops is 40%. These confidence intervals narrows to $(25\%, 60\%)$ for a sample of 20 days and $(33\%, 55\%)$ when the sample size is 60 days, as was the number of TAF auctions (and as such notifications). As such, there must be a large difference in frequency of drops for this test to work, and as such the test is crude. On the other hand, if the test show a significant difference then this difference is large and therefore the test is worth the while.

Further the test assumes interest rate changes to be independent and identically distributed with respect to sign. This is a second caveat. When tested most of the data seemed to obey this property.

To provide evidence for hypotheses 2 and 4 apply this test to the LOIS spread and international IOIS[3] spreads for movements, slopes [4] and curvatures[5].

[2]Frequency: number of negative interest rate changes relative to total number of days drawn.

[3]IOIS Spread$\equiv r_t^i(\tau) - r_t^o(\tau)$ where $r_t^i(\tau)$ is the interbank rate for a loan with residual maturity τ and $r_t^o(\tau)$ is the OIS rate with corresponding maturity.

[4]Slope$\equiv \frac{r(1)-r(1/12)}{1-(1/12)}$

[5]Curvature$\equiv 0.5(r(1) + r(1/12)) - r(1/2)$ where $r(i)$ is the interest rate on a loan with i years to maturity.

The formal procedure for executing the test is as follows

Algorithm 1 The Conditional Probability of Interest Rate Drop Test

```
H_0 : θ ≤ 1        H_A : θ > 1 ⇔ δ_L(α) > 1
B ← 20000
N ←size([Δr_1 ··· Δr_N])
Δr_t ← r_t − r_{t−1}        ∀t ∈ [1, N]
γ_1 ← P[Δr_t < 0|I_t = 1]
for b ∈ [1, B] do
    i ← N random integers from [1, N], drawn with replacement
    [Δr_1^{temp} ··· Δr_N^{temp}] ← [Δr_{i_1} ··· Δr_{i_N}]
    γ_2^b ← (1/N) Σ_{t=1}^{N} 1_{{(−∞,0]}}(Δr_t^{temp})
    θ̂_b ← γ_1/γ_2^b
end for
α ← 0.05
k = round(B × α)
Θ ← sort(θ̂)
δ_L = Θ(k)
if δ_L(α) > 1 then
    Reject H_0
else
    Keep H_0
end if
```

2.2 Test 2: The Expected Drop Size Test

To test whether or not moves in the term structure of interbank rates and interbank spreads were different in size from normal than when following TAF operations, we construct a non-parametric difference-of-means-test. A standard approach here would be to use a U-test for the difference in means. However, the violation of normality following the argument in the previous section, suggest that a non-parametric bootstrapping approach provides the best estimate of confidence intervals for these means (Yitzhaki, 2003). This will allow us to sidestep the bias following the Lehman Brothers, as well as any non-normality in the empirical distributions of means.

Simply put, if we again look at 60 random days out of 619, we might observe 27 spread drops on those days. If we measure the average size of spread movements for these dates we might see the figure 0.3 or 30 basis points. This is the average sample drop size. Repeat the draw enough times and you will get a good idea of the distribution of the average size in these movements, and as such confidence interval. This exercise is performed for both the Conditional and unconditional frequency. This way we obtain expected directional movement distribution for both the TAF dates and the period as a whole. From these distributions we create confidence intervals for the preferred significance levels ($1\%, 5\%$ and 10% in our case).

If these bootstrapped basic confidence intervals for the conditional averages do not overlap we conclude with a significant difference in directional movement size. The procedure provided in detail in the following algorithm.

Algorithm 2 The Conditional Probability of Interest Rate Drop Test

$\delta_L^0(\alpha), \delta_U^0(\alpha)$ is the α confidence levels for the mean θ^0
$H_0 : (\delta_L^0(\alpha), \delta_U^0(\alpha)) \cap (\delta_L^1(\alpha), \delta_U^1(\alpha)) \neq \emptyset$
$H_A : (\delta_L^0(\alpha), \delta_U^0(\alpha)) \cap (\delta_L^1(\alpha), \delta_U^1(\alpha)) = \emptyset$
$N \leftarrow$ number of sample interest rate changes during the financial crisis
$N_1 \leftarrow$ number of sample interest rate changes during Term Auctions
$B \leftarrow 20000$
$\Delta r_t \leftarrow r_t - r_{t-1} \qquad \forall t \in [1, N]$
$\gamma_0 \leftarrow \mathbb{P}[\Delta r_t < 0]$
$\gamma_1 \leftarrow \mathbb{P}[\Delta r_t < 0 | I_t = 1]$
for $b \in [1, B]$ **do**
  $i \leftarrow N_1$ random integers from $[1, N]$, drawn with replacement
  $j \leftarrow N_1$ random integers from $[1, N_1]$, drawn with replacement
  $\begin{bmatrix} \Delta r_1^{temp} & \cdots & \Delta r_{N_1}^{temp} \end{bmatrix} \leftarrow \begin{bmatrix} \Delta r_{i_1} & \cdots & \Delta r_{i_{N_1}} \end{bmatrix}$ Drawn from the entire sample
  $\begin{bmatrix} \Delta r_1^{temp} & \cdots & \Delta r_{N_1}^{temp} \end{bmatrix}_1 \leftarrow \begin{bmatrix} \Delta r_{j_1} & \cdots & \Delta r_{j_{N_1}} \end{bmatrix}_1$ Drawn from the TAF sample
  $\hat{\gamma}_0^b \leftarrow \frac{1}{N} \sum_{t=1}^{N} 1_{\{(-\infty,0]\}}(\Delta r_t^{temp})$ Average Drop in general
  $\hat{\gamma}_1^b \leftarrow \frac{1}{N} \sum_{t=1}^{N} 1_{\{(-\infty,0]\}}(\Delta r_t^{temp})$ Average Drop on TAF date
end for
$\text{bias}_0 \leftarrow E[\hat{\gamma}_0] - \gamma_0$
$\text{bias}_1 \leftarrow E[\hat{\gamma}_1] - \gamma_1$
$\alpha \leftarrow 0.05$ Setting the confidence level
$kL = round(B \times \frac{\alpha}{2})$
$kU = round\left(B \times \left(1 - \frac{\alpha}{2}\right)\right)$
$\Theta_0 \leftarrow sort(\hat{\gamma}_0)$
$\Theta_1 \leftarrow sort(\hat{\gamma}_1)$
$\delta_L^0 = \Theta(kL) - \gamma_0$
$\delta_L^1 = \Theta(kL) - \gamma_1$
$\delta_U^0 = \Theta(kU) - \gamma_0$
$\delta_U^1 = \Theta(kU) - \gamma_1$
if $\left(\delta_L^0 + (\gamma_0 - \text{bias}_0), (\gamma_0 - \text{bias}_0) + \delta_U^0\right) \cap \left(\delta_L^1 + (\gamma_1 - \text{bias}_1), (\gamma_1 - \text{bias}_1) + \delta_U^1\right) = \emptyset$ **then**
  Reject H_0
else
  Keep H_0
end if

This hypothesis is rejected if the confidence intervals overlap for the given α. In the next chapter this test will be performed on a range of indicators relating to the LIBOR interest rate term structure.

2.3 Test 3: An Affine Term Structure based Event Study

2.3.1 The Event Study Set-Up

To answer hypotheses 5-7 we construct an event study. This is a methodology mainly used to study whether economic events have effects on the value of firms. The methodology is here generalized to determine if economic events have effects on the movements in interest rate spreads. As normal movement we use an affine term structure model (hereafter ATS model). MacKinlay (1997) outline the procedure, which is adapted to the interest rate spread case:

1. Events to study: TAF Auction Dates, Notification Dates, Settlement Dates and the day following Settlement days.
2. Normal spreads are defined at the expected spread in a ATS model governed by VAR[6] dynamics. Abnormal movements is the difference beyond what is expected and what is realized.
3. As time window for estimating the VAR and term structure model we use the time spanning from the beginning of the financial crisis, up to the day before the event occurs.
4. The VAR model and ATS model are estimated. The expected spread for the days of events is computed, as well as the abnormal movement defined as the difference between expected and realized spread
5. The abnormal spread is regressed onto a constant to obtain the expected abnormal spread movement on days of TAF operations.
6. Confidence intervals for the abnormal spread move is obtained through bootstrapping the regression parameter. We conclude with an abnormal effect if the confidence interval for the expected abnormal spread move do not contain zero.

Prior to estimating the VAR model the information set included in the model is optimized by minimizing the out-of-sample squared forecast error. Then the forecast is adjusted for any bias highlighted prior to the initiation of the TAF program.

The following section motivates the model and its usage.

2.3.2 Motivation for the Affine Term Structure Model

A wide range of research have applied the affine factor based term structure model to study interbank and other interest rate markets (see for instance (Ang & Piazzesi, 2003), (Duffie & Singleton, 1999),(Backus, Foresi, & Telmer, 1998), Smith (2010), Hamilton and Wu (2012),Monfort and Renne (n.d.), de Almeida (2004) and Pagčs (1999)). A wide variety of factor combinations have been applied in order to estimate the term structure model. Most commonly one see either only latent variables (unobservable factors), macroeconomic factors and latent variables, or credit premium and liquidity premium proxies. The choice is governed by the application of the model, the data frequency required, and the overall objective with the research.

[6]VAR Process: Vector Autoregressive Process.

This paper is best served by observable factors working as proxy for factors driving the interbank spread term structure. The volatility in interbank market during the period further suggest that data of daily frequency is required to be able to capture any abnormal effects following the bi-weekly auctions in the term auction facility. These requirements suggests that a model with observable traded proxies for liquidity and credit premiums serves the overall objective best.

Such a model was applied in Smith (2010) and used to study the time varying term premiums in the same interbank markets. The model provided a good fit to data in the short rate dynamic, and was well founded.

The affine term structure model has its name from its relationship to factors assumed to govern the interest rate dynamics. The model implies that interest rates are affine in its relationship to the governing factors, separated by a system of non linear difference equations of coefficients. These equations account for market participants uncertain view of the future, expressed through a term premium. Since factors are observable and assumed to be governed by a VAR model they attain a conditional expected future term structure, an important feature for the purpose of this problem. Computing this expectation can be done by forecasting the factors (the forecasted term structure) or simply by studying the expected term structure (where the factors are perfectly forecasted). It is through this model possible to provide an explanation for the shape of the term structure through the interpretation of model parameters, as well as determine when other factors drive the term-structure.

2.3.3 Factor Dynamics

To fully parametrize the model tradeable proxies for credit and liquidity risk must be both observable and possible to forecast. The most common and practical way to do this is through a vector autoregressive model. It is possibly necessary to include further factors to better explain term structure more accurate. Figure 1.4, which depicts the movement in US interbank rates relative to the US policy rate[7], illustrate that the term structure level for interbank rates is almost completely driven by the sovereign policy rate of that currency (in this case the USD). For instance, the market rate for USD denoted loans is mostly determined by the target federal funds rate, and at least never drops below it. Since the policy rate is set by the central bank (The Open Market Committee in the United States), and this thesis attempts to expand on the impact of additional measures, the effects caused by the management of the key policy rate must be excluded somehow. This exclusion is achieved by studying the spread between the interbank rate and the OIS rate, since this last includes any expectation driven effects too.

Through repeated analysis following the multivariate version of the Box-Jenkins methodology (Enders, 2010) an inability to remove empirical autocorrelation was discovered. A possible reason for this inability could be non-linearities in the drift component of factors. This observation suggests that the best model is a Gaussian AR(1) process. The observed shortcomings should not cause any major inaccuracy as the time span for any factor forecast is maximum one week.

[7]The US policy rate is the target federal funds rate, which financial institutions must pay to borrow federal funds overnight. Any US based financial institution is required to have a certain amount of funds at federal bank of reserves (called federal funds) to cover its outstanding obligations. Any bank short of federal funds will borrow from banks with excess funds here. The rate paid for this loan is the federal funds rate.

Consequently the choice fell on the most parsimonious model. The following equation describes its VAR dynamics;

$$X_t = \mu + \Phi X_{t-1} + \Xi a_t \qquad\qquad a_t \sim MVN\left(\mathbf{0}, I\right) \tag{2.2}$$

where $X_t = \begin{bmatrix} r_t & C_t & L_t \end{bmatrix}$ is a 3×1 vector containing risk factors. r_t is the 1 month OIS rate, C_t is a credit risk factor and L_t is a liquidity risk factor proxy. Here μ is a 3×1 vector of constants, Φ is the 3×3 AR1 matrix, a_t is a vector of independent Gaussian Distributed random shocks related through the covariance matrix Ξ. From equation 2.2 we see that the marginal processes takes the following form:

$$\begin{aligned} r_t =& \mu_1 + \phi_{1,1} r_{t-1} + \phi_{1,2} C_{t-1} + \phi_{1,3} L_{t-1} + \\ &+ \xi_{1,1} a_{1,t} + \xi_{1,2} a_{2,t} + \xi_{1,3} a_{3,t} + \xi_{1,4} a_{4,t} \end{aligned} \tag{2.3a}$$

$$\begin{aligned} C_t =& \mu_2 + \phi_{2,1} r_{t-1} + \phi_{2,2} C_{t-1} + \phi_{2,3} L_{t-1} + \\ &+ \xi_{1,2} a_{1,t} + \xi_{2,2} a_{2,t} + \xi_{2,3} a_{3,t} + \xi_{2,4} a_{4,t} \end{aligned} \tag{2.3b}$$

$$\begin{aligned} L_t =& \mu_3 + \phi_{3,1} r_{t-1} + \phi_{3,2} C_{t-1} + \phi_{3,3} L_{t-1} \\ &+ \xi_{3,1} a_{1,t} + \xi_{3,2} a_{2,t} + \xi_{3,3} a_{3,t} + \xi_{3,4} a_{4,t} \end{aligned} \tag{2.3c}$$

As seen from equations 2.3a-2.3c the factors are assumed to be marginally normal distributed, coupled by a Gaussian copula with a covariance matrix Ξ. The model aims to estimate the dynamics of the factors affecting the term structure over time.

2.3.4 The LOIS Short Spread Dynamics

Suppose $r_t^{O(n)}$ is the OIS rate with n periods to maturity at time t, while $r_t^{L(1)}$ is the corresponding LIBOR rate. Then the "Short Spread Dynamics" is defined as the spread between the OIS rate and the LIBOR rate with 1 month to maturity. As a concequence the model implies;

$$\begin{aligned} r_t^{O(1)} &= r_t \\ r_t^{L(1)} - r_t^{O(1)} &= \gamma_t \\ \gamma_t &= \gamma_0 + \gamma X_t \\ \gamma &= \begin{bmatrix} 0 & \gamma_{11} & \gamma_{12} \end{bmatrix} \end{aligned} \tag{2.4}$$

γ_t is the linear displacement terms picking up movements in the credit and liquidity factors. This assumption has good visual empirical support (see figure 2.1). Equation 2.4 reveals the assumption that the interbank rate with the shortest time to maturity is a affine combination of the risk factors.

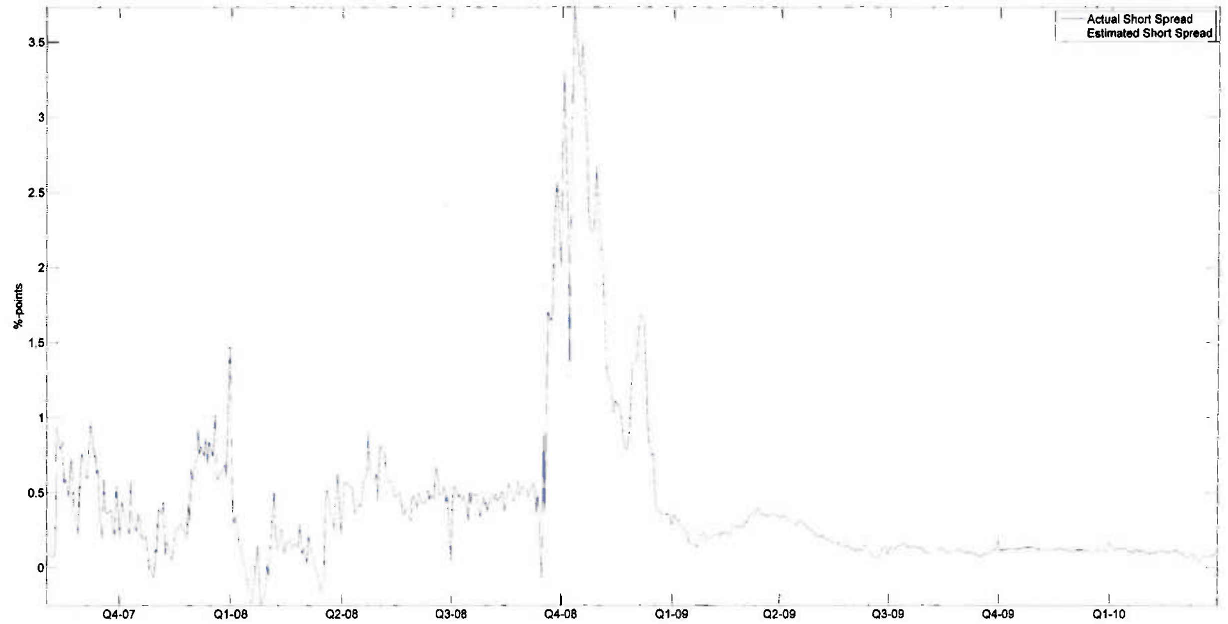


Figure 2.1: *Actual vs Estimated 1 month LIBOR USD-OIS Spread*

2.3.5 Pricing Kernel

In order to develop a term structure model it must be shown how non-defaultable zero coupon bonds with different time to maturity is priced differently through a no-arbitrage relationship. Following from such a pricing relationship it should be possible to construct a term structure for interest rates. The bond pricing here relies on the stochastic discount factor methodology. (Harrison & Kreps, 1979) and (Duffie, 2008) provides the necessary result which states that in any arbitrage free environment there exists a single random variable $M_{t,t+k}$, such that:

$$P_t = E_t \left[M_{t,t+k} P_{t+k} \right] \tag{2.5}$$

$M_{t,t+k}$ has many names, but is most commonly referred to as a stochastic discount factor, pricing kernel, state prices or the marginal rate of substitution. The key property of M is the way it relates level and price of risk factors to the pricing of time dependent contracts, just as CAPM relates the level of systematic risk and the price of that risk to the price of a stock in a stock pricing model. As long as $M_{t,t+k}$ is defined relative to the risk a_t any asset or derivative relating to that asset, exposed to the risk a_t can be priced. Hence, the challenge is to approximate M. A common approach for affine term structure is to assume that M takes the following form:

$$M_{t,t+1} = \exp\{-r_t - \lambda_t' a_{t+1} - \frac{1}{2}\lambda_t'\lambda_t\} \qquad \lambda_t = l_0 + l_1 X_t \tag{2.6}$$

Here λ_t is the source of the term premium.

2.3.6 The Market Prices of Risk

The main objective for the term auction facility was to lower interbank interest rate spreads.There are two key ways to lower the interest rates on loans. The first is through a reduction in the price of risk, the second is through lowering the level of the risk factors. So far we have covered two sources of risk and how it relates to the pricing of fixed income instruments. The first market price of risk was γ_t. This factor is the short term difference between the interest rate paid on an OIS contract and the interest rate paid on a LIBOR loan. This varies through time and is affected by the differences in characteristics between the contracts, mainly market liquidity, probability of default, exposure at default. As such any movement in γ_t follows from a move in the liquidity and credit proxies, related to how these factors are priced. In comparison λ_t covers the market term premium through the correlation in the risk factors and their dynamics over time. It will attempt to capture how the liquidity, credit and spread level factors affect interest rate uncertainty for longer term loans, such as 4-12 months. This component will therefore help explain the differences in prices on long term liquidity, compared to short term liquidity.

2.3.7 Arbitrage Free Pricing Functions

Following from expression 2.5 it is easy to show that the price of a zero coupon bond with h periods to maturity is given as:

$$\begin{aligned} B(t,t+h) &= E_t[M_{t,t+1}B(t+1,t+h)] \\ &= E_t[M_{t,t+1}E_t[M_{t+1,t+2}B(t+2,t+h)]] \\ &= E_t[M_{t,t+1}M_{t+1,t+2}B(t+2,t+h)] \\ &= E_t[\prod_{i=0}^{h-1} M_{t+i,t+i+1}] \\ &= E_t[\prod_{i=0}^{h-1} \exp\{-r_{t+i} - \lambda'_{t+i}a_{t+i+1} - \frac{1}{2}\lambda'_{t+i}\lambda_{t+i}\}] \end{aligned} \tag{2.7}$$

This price relationship holds for any term structure driven by these factors in this fashion. From here this paper part with Smith (2010), and assume that a small term premium is present in the overnight indexed interest rate swap market too.

These term premiums are expected to differ in factors and to vary to some extent over time. This leads to slightly different stochastic discount factor. Our reasoning behind these choices comes from the differences in risk in the OIS market and the LIBOR market, but we argue that since one is exposed to some interest rate risk for longer term OIS contracts there should still be a positive term premium in this market. Following from expression 2.7 we use the following:

$$\begin{aligned} B^L(t,t+h) &= \exp\{A_{L,h} + B'_{L,h}X_t\} \\ B^O(t,t+h) &= \exp\{A_{O,h} + B'_{O,h}X_t\} \end{aligned} \tag{2.8}$$

In appendix 4.3 it is showed that this relationship holds whenever $A_{,h}$ and $B'_{,h}$ follows the following recursive equations for the LIBOR term structure

$$\begin{aligned} A_{L,h} &= A_{L,h-1} + B'_{L,h-1}(\mu - \Xi l_0^L) + \frac{1}{2}B'_{L,h-1}\Xi\Xi' B_{L,h-1} - \gamma_0 \\ B_{L,h} &= B'_{L,h-1}(\Phi - \Xi l_1^L) - \gamma \end{aligned} \tag{2.9}$$

where $A_{L,1} = -\gamma_0$ and $B'_{L,1} = -\begin{bmatrix}1 & \gamma_{1,1} & \gamma_{1,2}\end{bmatrix}'$. For the OIS term structure we have;

$$\begin{aligned} A_{O,h} &= A_{O,h-1} + B'_{O,h-1}(\mu - \Xi l_0^O) + \frac{1}{2}B'_{O,h-1}\Xi\Xi' B_{O,h-1} - \gamma_0 \\ B_{O,h} &= B'_{O,h-1}(\Phi - \Xi l_1^O) - \gamma \end{aligned} \tag{2.10}$$

where $A_{O,1} = 0$ and $B'_{O,1} = -\begin{bmatrix}1 & 0 & 0\end{bmatrix}'$. Equations 2.9 and 2.11 illustrate that we are dealing with non-linear parameter relationships, and that we can write the term structure of interbank rates and OIS rates as:

$$\begin{aligned} r_t^{L(h)} &= -\frac{1}{h}\left(A_{L,h} + B'_{L,h}X_t\right) \\ r_t^{O(h)} &= -\frac{1}{h}\left(A_{O,h} + B'_{O,h}X_t\right) \end{aligned} \tag{2.11}$$

2.3.8 LOIS Spreads and Term Premiums

Given the closed form term structure equations developed in the previous section it is now possible to see that the spread between interbank rates and OIS rates can be written as a closed form function itself.

$$\begin{aligned} r_t^{L(h)} - r_t^{O(h)} &= -\frac{1}{h}\left(A_{L,h} + B'_{L,h}X_t\right) + \frac{1}{h}\left(A_{O,h} + B'_{O,h}X_t\right) \\ &= -\frac{1}{h}\left((A_{L,h} - A_{O,h}) + (B_{L,h} - B_{O,h})'X_t\right) \\ r_t^{S(h)} &= -\frac{1}{h}\left(A_{S,h} + B'_{S,h}X_t\right) \end{aligned} \tag{2.12}$$

Where $A_{S,h}$ and $B'_{S,h}$ denote the coefficients for the term structure of the LOIS spread, again as an affine function of the model factors. An interesting property of this term structure is to understand how forward rates perform as expectations of future spot rates. From this procedure the expected future term structure can be expressed as:

$$\begin{aligned} E_t[r_{t+1}^{S(h)}] &= E_t\left[-\frac{1}{h}\left(A_{S,h} + B'_{S,h}X_{t+1}\right)\right] \\ &= -\frac{1}{h}\left(A_{S,h} + B'_{S,h}E_t\left[X_{t+1}\right]\right) \\ &= -\frac{1}{h}\left(A_{S,h} + B'_{S,h}(\mu + \Phi X_t)\right) \end{aligned} \tag{2.13}$$

The product is an expected future term structure which works as a short term forecast for the term structure of LOIS spreads. Another bi-product is the possibility of obtaining non-parametric, historical forecasting errors, and as such we can study whether or not the movement in the different parts of the term structure moved as expected during the initial announcement of the TAF program.

2.3.9 Abnormal Movement in the Term Structure of Spreads

According to the event study test normal movements in the spread constitutes those predicted by 2.13. Abnormal movements the constitutes any movement above or below this level.

$$Ar_t^{S(h)} = r_t^{S(h)} - E_{t-1}[r_{t+1}^{S(h)}] \tag{2.14}$$

We conclude that if $Ar_t^{S(h)} > 0$ in a significant way, then there has been movements in the term structure following the TAF.

2.3.10 Econometric Methodology

Sever complications normally (Smith, 2010) arise when attempting to estimate this model directly. It is therefore natural that a large part of the research related to this model is focusing on estimating it. Since the application of the model is the event study, the best possible forecast is our goal. Recognizing this and the issues related to estimating l_0 and l_1 we sidestep this problem by directly estimating the coefficients $A_{S(h)}$ and $B'_{S(h)}$ through a least squares regression, since the model assumes these coefficients to be constants. Expression 2.13 indicates that interest rates only follows an autoregressive dynamic whenever certain requirements are placed on the relationship between the AR1 matrix for the VAR dynamics, its eigenvalues, eigenvectors and the autocorrelation in the interest rate dynamics. The result for these dynamics will not be provided here but a comment can be found in Appendix 5.

Algorithm 3 Parameter Estimation Procedure

1. Estimate $\Theta_1 = \begin{bmatrix}\mu & \Phi & \Xi & \gamma_0 & \gamma_1\end{bmatrix}$ in the vector autoregressive process via a OLS procedure
2. Hold Θ_1 fixed and use the following equations to estimate $\forall h \quad A_{S,h}, B_{S,h}$.

For each $h \in \begin{bmatrix}1 & \dots & H\end{bmatrix}$ we estimate the coefficients $A_{S(h)}$ and $B'_{S(h)}$ through an OLS procedure.

$$-h \cdot R_t(h) = \begin{bmatrix}1 & X_t\end{bmatrix} \begin{bmatrix}A_{S(h)} \\ B_{S(h)}\end{bmatrix} + \epsilon \tag{2.15}$$

where $R_t(h) = \begin{bmatrix}R_{t-k}(h) & R_{t-k+1}(h) & \cdots & R_t(h)\end{bmatrix}'$ is a vector of interest rates maturing h periods from now, and $X_t = \begin{bmatrix}X_{t-k} & \cdots & X_t\end{bmatrix}'$ is a matrix of factor realizations up to and including date t

2.4 Variables

To estimate the model provided in the previous sections LIBOR USD rates from 15 different maturities(from 1 day to 1 year) were collected from Datastream. Sampled rates contained 2683 daily observations between December 23rd 2003 and November 14th 2011. Similarly daily OIS rates for 12(1 - 12 months) different maturities were collected from data stream, containing 2432 observations between December 23rd 2003 and April 17th 2013. In addition the overnight federal funds rate was used as a proxy for the overnight rate in the OIS term structure. For maturities where only one of the term structures had an observable rate the rate for the other term structure was interpolated using the methodology of Adams and Van Deventer (1994). The related MATLAB function is provided in appendix 6.

Similar data sets was downloaded for UK (LIBOR GBP and OIS GBP) and EU (EURIBOR and EURIOIS). As no functioning OIS market exists for Norway only Interbank rates for 9 Maturities was obtained, but the data set was of similar size as those already mentioned.

The total dataset used consist of more than 1812 dates of observations from a total of 143 time series, totalling more than 259 000 data points. The remainder of this section discusses the various proxies applied in the different tests. First proxies for slope and curvature are commented. Then proxies for factors in the VAR model are reviewed.

2.4.1 Slope and Curvature Factor

To study whether or not the term structure moved as a complete object and not as a set of independent rates, it is necessary to find proxies that can summarize the movements of the entire set of rates. Principal Component Analysis provides evidence of the possibility to summarize term structure movements through three factors; Level, Slope and Curvature. These factors explain up to 99.36% of all yield curve variation. As a proxy for level the short rate is used. As a proxy for the slope we use the following expressesion

$$S_t = \frac{r_t(1) - r_t(1/12)}{1 - 1/12} \qquad \textit{Slope Factor} \tag{2.16}$$

in a similar fashion

$$C_t = \frac{1}{2}(r_t(1) + r_t(1/12)) - r_t(1/2) \textit{Curvature Factor} \tag{2.17}$$

A downward movement in the slope factor coefficient a smaller difference between long and short rates and therefore a flatter spread structure. This holds when the coefficient is positive, which it is for the spread in 91% of our sample, and in the entire financial crisis set.

A downward movement in the curvature coefficient (or convexity coefficient) indicate that medium term rates move even further away from the average of long and short term rates. This coefficient is negative for 91% the sample dates. When this occurs the 1-6 months part of the term structure becomes flatter relative to the 6-12 months part of the term structure. Based on which hypothesis you prescribe to this can imply different effects.

The effects are illustrated in figure 2.2.

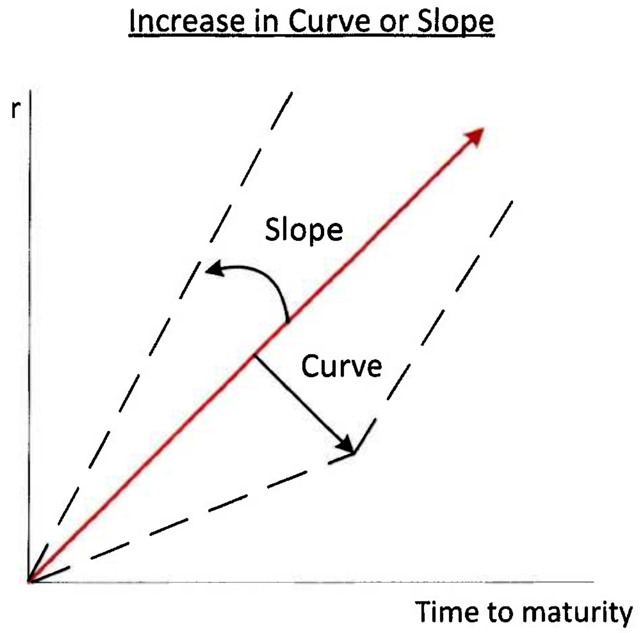


Figure 2.2: Effects of Increased Slope and Curvature on the Term Structure

2.4.2 Repurchase Agreements (REPO)

Repurchase Agreements (REPOs) are contracts for sale and future (re)purchase of financial assets, most often Treasury securities. The price of a REPO should be higher than the sales price, representing the premium of time and referred to as the Repo rate. REPO rates can be of any duration. On termination date, the seller pays interest for the use of funds and repurchase the asset at the price agreed (price it was sold for). Therefore a REPO is in effect a short term interest bearing loan agreement against collateral.

The REPO rate can be expressed as follows:

$$Principal = Par\ value \times Dirty\ price \times \frac{1}{Hair\ Cut} \times \frac{1}{100} \tag{2.18}$$

Such that,

$$Repo\ Interest = Principal \times Rate \times \frac{(Days\ Trade\ is\ on)}{360} \tag{2.19}$$

The 3 months composite offered REPO rate was downloaded through Datastream for the same time span as the remaining variables.

2.4.3 Factor Proxies

The term structure model is chosen to be governed by credit and liquidity premiums. This is the price of liquidity risk and credit risk. Credit risk involves the risk that borrowers fail to repay or meet contractual obligations to a lender, making the lender loose the financial reward or the principal. Liquidity risk implies that an investment cannot be bought or sold quickly enough in the market to limit or prevent losses. During the time path of the financial crisis these two risks affected the premium and hence the OIS-spread.

(Market) Liquidity risk should not be confused with liquidity funding risk which is an aggregate for lack of willingness to lend money in the interbank market, in order to make sure once own liquidity access is secured. No tradeable proxy is well established for this type of risk, and it is thus excluded from explicit participation in the model.

One can decompose and proxy the money market spread into a credit and liquidity factor as follows;

$$\begin{aligned} \text{(LIBOR-OIS)} &\simeq \text{(LIBOR-Repo)} + \alpha\text{(OfTR-OnTR)+Term Premium} \\ \text{Money Marke Spread} &= \text{Credit risk} + \text{Liquidity risk} \end{aligned} \tag{2.20}$$

where the REPO market is absent credit risk while the Off-the Run/On-The-Run spread is a proxy for liquidity risk.

Note that such a decomposition is problematic since credit and liquidity risk are intertwined. A bank facing problems raising funds will also face a greater risk of default. Raising funds will be categorized as liquidity risk, while greater probability of default represent increased credit risk (Wells, 2007).

We will therefore use the following proxies for liquidity and credit risk to be implemented in our model:

Credit proxy As credit proxy we use the LIBOR-REPO spread. LIBOR contracts that are *unsecured*, while REPOs are collaterlized and *secured* cash loans at fixed rates. We use 1 month, 3 month and 12 month maturities for respectively money market and REPO rates. The collateral in the REPO contract is U.S. Treasury securities, UK gilts and EURIBOR composite, enabling us to identify these REPO rates as risk free, while money market rates are unsecured and hence the spread between the two, respectively the LIBOR-REPO spread, is a good proxy for credit risk since it reflects the credit risk premium involved in the money market rates.(Taylor (2009) Taylor and Williams (2008b) and Smith (2010))

Liquidity proxy As liquidity proxy we will use the the Off-The-Run On-The-Run spread for 10 year US Treasury Notes.

A treasury security is considered on the run until the auction day of its next issuance. This relationship was studied in Barclay, Hendershott, and Kotz (2006) where one finds that trades drop on average 86% in value and 92% in number of trades when these securities go off the run. It is clear that when such assets goes off-the-run liquidating them becomes much harder. Brunnermeier and Pedersen (2009) provides a model separating market liquidity risk and funding risk, which is a traders unwillingness to put its employers/banks money at risk, while asset is as described above. Chordia, Sarkar, and Subrahmanyam (2005) finds considerable levels of correlation across assets classes when studying liquidity across markets.

To compute the liquidity premium Gürkaynak, Sack, and Wright (2007) method is applied to the relating dataset, taking the difference between the implied off-the-run 10 year treasury-note (Gürkaynak, Sack, & Wright, 2013) and the on-the run version of the same contract (Datastream). This combination provides a liquidity premium.

Chapter 3

Evidence and Conclusions

This chapter reports and comments on the empirical evidence. First; hypotheses 1 is analysed graphically. Second; hypotheses 2 and 4 is reported through an application of Test 1. Third; hypothesis 3 and 4 is reported from an application of Test 2. Fourth; hypotheses 5-7 is reported through an application of Test 3. Last; an overall conclusion and concluding remarks are provided.

3.1 Hypothesis 1: The TAF Initiation

Hypothesis 1: Initiation of non-standard measures affect money market term structures. An initial question for the interbank market is whether the initiation of the TAF impacted interest rates. Figure 3.1 illustrates that shorter maturity rates were abnormally affected by this initiation. The result is obtained in the following manner; First, the VAR-AST model estimated in section 3.5.1 was applied. Second, historical forecast-errors were used to create empirical confidence intervals. Third, the expected term structure was calculated based on a perfect forecast of factors (for more detail on this procedure, see section 3.5.1 and onwards). Last, the realized term structure is compared to the expected term structure and its confidence intervals. The conclusion is further supported by the reversion to the confidence interval for forecast when studying the forecast for the December 14th Term Structure.

The finding is supported by the efficient markets hypothesis, stating that markets should immediately react to new information and reprice itself accordingly. The measure seemed to have an effect on the short term interest rates beyond what the model could predict, and might therefore be seen as a reaction in a latent factor. It is possible that the deviation could be a change in the funding liquidity premium. However, since no exiting satisfactory proxy exists for this risk, such an impact could not be confirmed.

Findings from Ait-Sahalia et al. (2012) support hypothesis 1, indicating that initiation of non-standard policy measures provided an impact on interest rates.

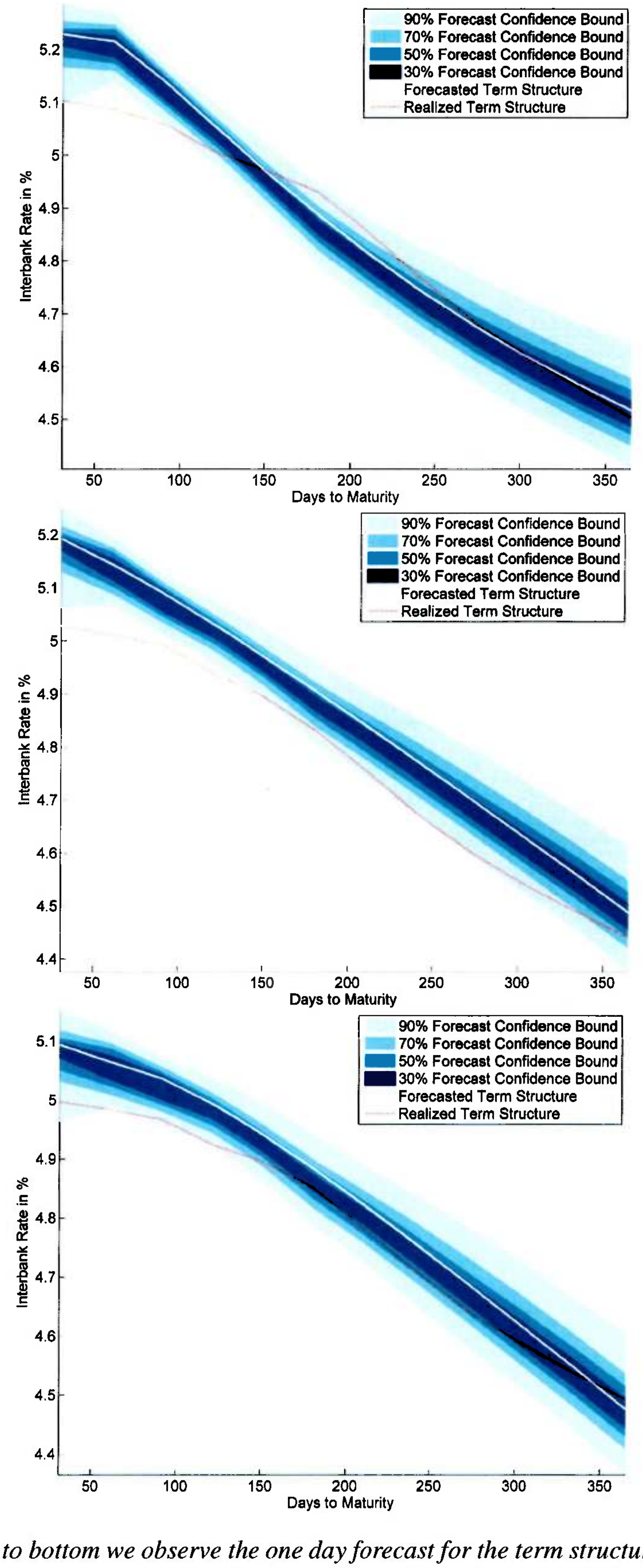


Figure 3.1: *From top to bottom we observe the one day forecast for the term structure for the day of TAF initiation press-release, one day after the initiation and two days after respectively. Dates are December 12th 2007, December 13th 2007 and December 14th 2007.*

3.2 Hypothesis 2: Probability for Interbank Rates and Spreads to tighten Increased following The Term Auctions

This hypothesis was tested through an application of Test 1 (see section 2.1 for the test and appendix 4.2 the for results).

The US interbank rates showed a significantly higher propensity to fall on notification dates than otherwise during the financial crisis. The tendency to drop was in particular strong for rates on loans with maturity ranging 1-6 months .

The probability of downward movements in the curvature index was also significantly higher than normal. Such an observation indicate that medium term rates moved, while short and long parts of the term structure remained unchanged.

These two effects could be results of both actual and expected future cuts in the federal funds target rate, and needs to be adjusted for. For the LOIS spread, which contains these adjustments, both the slope and curvature had a significantly higher probability of falling on TAF auction dates.

Overall the premium paid on longer maturity loans (12 months) tends to drop relative to the interest paid on shorter term loans (indicated from the slope). Such an effect is the consequence of a convex [1] term structure for the LOIS spread, becoming even more convex on TAF dates.

3.3 Hypothesis 3: Interest Rates and Spreads Tended To Move More following TAF auctions

This hypothesis was tested through an application of Test 2 (see section 2.2 for the test and appendix 4.3 for the results).

The LIBOR USD rates showed a tendency to decline more following TAF auctions than on other days during the financial crisis, provided that they fell. The difference was in particular apparent on TAF-notification dates, but was not significant.

On the one hand, no single rate in the LIBOR USD term structure seemed to experience any drops significantly larger than normal following TAF-auction dates. The same is true for LOIS spreads in general, except for the spread with 3 months to maturity. This seemed to drop about twice as far as normal, (3 compared to 1.7 Basis points) provided the TAF auction was followed by a drop.

On the other hand, even though no single rate or spread tended to move more than normal, the story is quite different for the term structure as a whole. First, the slope tended to move far less on TAF auction dates than normal (-2.4 vs -3.3 basis points). Second, the spread curvature moved much more on both notification dates and settlement dates (-3.8 and -3.7 vs -2.4 basis points). Last, the term structure became more flat or convex following auction dates. This last finding follows from the negative correlation between convexity and slope (A correlation of -0.28).

[1] Convexity is the same as a negative curvature measure

The results in this section suggest that no conclusion may be drawn regarding the drop size of any single part of the term structure, but that longer maturity rates tends to fall further relative to rates with shorter maturity.

3.4 Hypothesis 4: The TAF Impacted International Interbank Markets

This hypothesis was tested through an application of both Test 1 and Test 2 (see section 2.1 and 2.2 for tests, and appendix 4.2 and 4.3 for results).

Interbank interest rates on all maturities for *all markets* in the sample showed a higher propensity to decline on notification dates than what was normally observed during the crisis. These declines were furthermore larger on average than what was else observed in the period. Even though a zero hypothesis of no difference, in either drop-size or drop-frequency, could not be rejected at any standard confidence levels for any single rate, the overall pattern is clear.

EURIBOR Empirical tests suggest that in the EURIBOR term structure, the short term rates was the part most sensitive to TAF auctions. This suggestion is confirmed by the following two observations;

First, the short term EURIOIS spread tended to fall both farther (2.7 basis points compared to 1.3 basis points normally) and more frequent following TAF auctions. No such evidence is found for longer maturity rates. Second, the first observation is supported by a tendency for a steeper, but not necessarily more convex interbank interest rate curve.

Three observations suggest there might be different overall effects to the term structure from the TAF auctions;

First, no changes seem to be apparent regarding the frequency for directional change following TAF auctions for individual maturities. Second, the same conclusion can be drawn for the size in any declines for the same dates. Third, short term rates seem to become more expensive compared to longer term rates (6-12 months) overall.

However, the contradicting evidence did not adjust for changes and expected future changes in policy rates. Therefore the initial conclusion remains; the short term part of the EURBOR term structure is the only part showing significant signs of being affected by the TAF auctions.

LIBOR GBP For the LIBOR GBP term structure long term rate was the part most sensitive to the TAF-auctions. This conclusion follows from three observations.

First, the 12 months LOIS GBP spread tended to drop further and more frequent on TAF-settlement dates. Second, the slope of the LOIS GBP term structure fell on average twice as far and 24% more frequently on the same dates. Last, the term structure was 39% more likely to become less convex on TAF settlement days.

So, even though the LIBOR GBP term structure tended to drop overall and become more convex, but not steeper, these effects are mostly the result of changes in BoE policy rate, and expectations for their future levels.

NIBOR In Norway the short term rates was the part most strongest influenced by the TAF program, but only relative to the longer term rates, not in absolute levels. This indication is a result of three observations.

First, the NIBOR term structure tended to be more likely to become steeper on TAF settlement dates. Second, it was more likely to become more convex. Last, it showed no consistent change in probability of decline for any single rate.

As the Norwegian Interbank Market lack a well functioning OIS market the analysis becomes less substantial here. Since information regarding TAF results (released on Notification Dates) become available first the day after in Norway, it is likely that this is the effect observed here.

In General The TAF program impacted international interbank term structures, but this was felt in different ways. While the GBP market reacted by on average letting long term rates drop, the EUR market dropped short term rates. The Norwegian market is not comparable in the same way, as the observations were not adjusted for changes in the policy rates.

What was common for all, was that the effect was most strongly felt on settlement days for the program. This is most likely because it was the day when information concerning results from TAF auctions is released in Europe.

3.5 ATSM-VAR based Event Study Estimation

3.5.1 VAR Dynamics

In hypotheses 5 and 6 an Affine Term Structure (ATS) model is applied to look for abnormal movements in interest rates. For the dynamics governing this model we estimate the parameters for a VAR(1) process with three factors: the shortest OIS rate in the dataset (1 month), the credit proxy and the liquidity premium proxy defined in section 2.4. These parameters were estimated using data ranging from December 23rd 2003 to November 14th 2011. The entire data set was used to estimate the model parameters, as the motivation for the model usage is not forecasts but descriptive analysis. If the model were estimated with the objective to forecast and not describe in-sample-dynamics, then this procedure

	VAR DYNAMICS							SHORT RATE DYNAMICS	
X_t	Φ_1			μ	$\Xi\Xi'$			γ_0	γ_1
r_t	0.9503	0.0430	-0.5237	0.2401	0.2099	0.0046	0.0021	-0.1355	1.0000
	(0.0099)	(0.0192)	(0.1023)	(0.0434)				(0.0225)	
C_t	0.0069	0.9694	0.0108	0.0112		0.1398	0.0016		0.8111
	(0.0066)	(0.0128)	(0.0681)	(0.0289)					(0.0145)
L_t	-0.0027	0.0085	0.9616	0.0123			0.0145		-0.2299
	(0.0007)	(0.0013)	(0.0072)	(0.0031)					(0.0555)

Table 3.1: *This figure reports the estimates of parameters for the VAR(1) model and the short rate dynamics. All the Eigenvalues of Φ_1 are below 1 and as such the process do not explode. The short rate dynamics parameters are obtained by estimating the regression equation LIBOR-OIS $= \gamma_0 + \gamma_1' X_t$, where the short rate in X_t is set to zero, and the credit variable and liquidity proxy are kept unchanged. We report standard errors under assumption of Gaussian residuals. $\Xi\Xi'$ is the Cholesky decomposed covariance matrix.*

would be flawed, as it would only describe parts of the dynamics experienced.

$$X_t = \begin{bmatrix} r_t & C_t & L_t \end{bmatrix} \tag{3.1a}$$

$$X_t = \mu + \Phi X_{t-1} + \Xi a_t \tag{3.1b}$$

$$LIBOR_t - r_t = \gamma_0 + \begin{bmatrix} 0 & \gamma_{1,1} & \gamma_{1,1} \end{bmatrix} X_t \tag{3.1c}$$

γ_0, $\gamma_{1,1}$ and $\gamma_{1,2}$ are found by estimating regression equation 3.1c. Then the parameters in equation 3.1a are estimated using an OLS procedure. The results are reported in table 3.1.

The first line shows the relationship between the short rate and the other variables. Three properties are worth mentioning here. First, the short rate has a positive drift. Second, a positive shock in the credit factor results in a upward move in the short rate the following day. Third, a shock to the liquidity factor has the opposite effect. Both of these effects are significant at the 1% level.

The second line explains how the credit factor (C_t) is related to the two other variables in the model. It is seemingly independent from both, as a shock to either the short rate or the liquidity factor result only in insignificant moves in the credit factor.

The third line explains how the liquidity factor (L_t) is affected by moves in either the short rate or credit premium. A move in the short rate will create a downward movement in the liquidity factor, while the opposite is true for a move in the credit factor. Both of these effects are significant.

The credit factor is Granger-causing both the liquidity factor and the short rate factor, as both these factors are significantly affected, but do not affect the credit factor. It is thus contributing significant predictive power to the movements in these two factors. These observations are very similar to those obtained in Smith (2010), but in our estimates there are also an interdependence relationship between the liquidity factor and the short rate.

As hypothesized in chapter 2 the credit exposure in the overnight indexed swaps (OIS) with short time to maturity is very small. It should therefore only be marginally affected by an increase in the credit premium, a property reflected in the estimated parameters. A raise in the liquidity premium indicates a market fleeing to more liquid instruments and a fear for worse economic conditions in the immediate future. Such fears create expectations for policy rate cuts, causing the shortest OIS rates to drop. These are the intuitive reasons for relationships observed in the estimates.

In a similar fashion the liquidity premium is expected to move in the same direction as the credit premium. An environment with climbing credit premiums increases fears for default. In order to mitigate such risk, a logical strategy is to move into more liquid securities. On a grand scale this creates a flight to liquidity, triggering higher prices and reduced returns on these liquid instruments. This is a possible theory explaining the movements observed in the model.

The dynamics for the one month LIBOR rate is given by the parameters in γ_0 and γ_1. These parameters provides an intuition concerning how movements in the credit and liquidity factors affect the spread. In more specific terms, a shock in the credit factor would contribute to an almost equal movement in the LOIS spread (on average 0.81 percentage points). This indicates that a large part of the spread between loans, where the Notional/Face Value is exposed and those where it is not (Swaps), mainly consists of credit risk. Notice also that, given a realized value for the credit factor, an increase in the liquidity premium causes a drop in the short term LIBOR rate. This could be a result of expected interest rate cuts/drops.

3.5.2 Main Estimation

A more detailed study is performed for the US interbank term structure of interest rate spreads in this section. This procedure is limited to the US, partially because this was the market where the effect of the TAF was intended, partially because of the lack of factor proxies for the other sample markets.

Two different measures are used to define normal movements. In the first model the factors are assumed to be perfectly forecasted (No forecasting error). In the second, factors are forecasted, hence the model contains forecasting errors. The source of any difference between the two models abnormal movement-estimate, can be determined in such a set-up. This determination is made through the knowledge of sources for errors. It is known that the output from the first model contains no forecasting errors for the VAR dynamics, while the second one does.

To determine an abnormal movement a prerequisite is an estimate of a normal movement, and normal movement is then a result of a forecast. For this forecast to be as precise as possible, two key tasks are performed; First, an adjustment is made for any bias. Second, a determination of how much historical data to include. The first part of the data set[2] is used to detect and adjust for these two issues.

Results from trial estimations indicate that, including more historical data when producing term structure forecasts, will generate larger forecasting-errors (SSE). When minimizing the squared errors of the historical term structure forecasts, the least amount of historical data included seems to be optimal. This in turn suggests that an exact[3] estimate of factor loadings will produce the smallest forecasting

[2]August 9th 2007 - December 12th - 2007, which is the the time span ranging from the BNP Paribas event to the initiation of the TAF.

[3]The Model has 4 factor loadings per maturity. The model assumes that these loadings should be somewhat constant over time. Therefore an exact estimate in turn suggests the usage of the interest rates the previous four days to compute these loadings exactly, that is without errors.

errors.

The optimality of excluding historical data is most likely caused by the complete change in dynamics from before to after the BNP event. As such we will proceed with the exact estimates of the term structure factor loadings.

Estimation where Factor Realizations are Known

The expected term structure model is tested for any bias during the pre-TAF part of the financial crisis, and no significant bias is found in the out-of-sample forecasts. Factor loadings are estimated using the term structures for the four previous days. The expected term structure is then forecasted using the computed factor loadings and the realized factor values.

The estimated abnormal movements are computed through equation 2.14 for all the identified date groups[4]. Then abnormal movements are regressed onto a constant, and the corresponding regression coefficient is estimated through an OLS procedure. This exercise is performed for each of the date groups and each of the maturities. The resulting coefficients are known as the expected abnormal movements, and are summarized as $\hat{\theta}$ in tables 3.2 for the different date groups. To account for any estimators not following the t-distribution, we used a non-parametric regression bootstrap to construct the confidence intervals for the parameters (δ_L and δ_U denote the 5% confidence intervals), instead of using the standard t-test. The confidence intervals are reported next to the corresponding estimators.

Estimation where Factor Values are Estimated/Forecasted

When factors are forecasted, the least amount of historical information is still empirically optimal. Therefore the method employed here is the same as the one in the case where factors are known. In this forecasting problem a small bias of three basis points was found in the pre-TAF part of the dataset. This bias was adjusted for when estimating abnormal movements. The adjustment procedure assumed that the level of this bias was constant throughout the crisis.

In this case we use forecasted factors instead of realized factors as input in the term structure forecasting model. Beyond this, the same procedure as in the case with know factors, is used to compute expected abnormal movemements and their confidence intervals. Results are reported in table 3.3.

[4] Date groups: Auction Dates, Notification Dates, Settlement Dates and Settlement Dates +1.

DTM	$\hat{\theta}$	δ_L	δ_U
1	-0.0674	-0.0038	-0.1540
7	0.0405	-0.0555	0.1889
14	0.0309	-0.0333	0.1300
30	0.0006	-0.0204	0.0225
60	0.0103	-0.0131	0.0366
90	0.0021	-0.0199	0.0248
121	0.0084	-0.0131	0.0320
152	0.0042	-0.0205	0.0307
183	-0.0052	-0.0317	0.0230
214	-0.0018	-0.0286	0.0268
244	-0.0018	-0.0292	0.0278
274	-0.0085	-0.0421	0.0263
305	0.0000	-0.0334	0.0370
335	-0.0067	-0.0476	0.0344
365	-0.0052	-0.0427	0.0336

(a) *Auction Date*

DTM	$\hat{\theta}$	δ_L	δ_U
1	-0.0935	-0.2276	0.0074
7	-0.0438	-0.1472	0.0618
14	-0.0745	-0.1469	-0.0104
30	-0.0061	-0.0446	0.0301
60	-0.0020	-0.0389	0.0344
90	-0.0054	-0.0407	0.0292
121	-0.0229	-0.0569	0.0082
152	-0.0330	-0.0693	-0.0005
183	-0.0569	-0.1025	-0.0165
214	-0.0202	-0.0540	0.0118
244	-0.0362	-0.0732	-0.0023
274	-0.0537	-0.0973	-0.0143
305	-0.0431	-0.0862	-0.0044
335	-0.0432	-0.0866	-0.0039
365	-0.0558	-0.1019	-0.0137

(b) *Notification Date*

DTM	$\hat{\theta}$	δ_L	δ_U
1	0.0166	-0.0891	0.1593
7	0.0001	-0.0932	0.1172
14	0.0244	-0.0400	0.1051
30	0.0134	-0.0134	0.0413
60	0.0123	-0.0121	0.0368
90	0.0100	-0.0125	0.0317
121	0.0031	-0.0229	0.0254
152	-0.0038	-0.0307	0.0198
183	-0.0076	-0.0363	0.0182
214	-0.0218	-0.0603	0.0106
244	-0.0164	-0.0533	0.0164
274	-0.0254	-0.0669	0.0101
305	-0.0387	-0.1069	0.0139
335	-0.0359	-0.1048	0.0168
365	-0.0325	-0.0863	0.0113

(c) *Settlement Date*

DTM	$\hat{\theta}$	δ_L	δ_U
1	-0.0069	-0.0995	0.0936
7	-0.0481	-0.1672	0.0492
14	-0.0073	-0.1205	0.0732
30	-0.0483	-0.1845	0.0405
60	-0.0363	-0.1193	0.0201
90	-0.0206	-0.0970	0.0294
121	-0.0283	-0.1178	0.0266
152	-0.0247	-0.1090	0.0261
183	-0.0362	-0.1382	0.0271
214	-0.0074	-0.0678	0.0383
244	-0.0175	-0.0913	0.0309
274	-0.0258	-0.1063	0.0253
305	-0.0480	-0.1638	0.0231
335	-0.0488	-0.1574	0.0185
365	-0.0281	-0.0987	0.0209

(d) *Settlement Date+1*

Table 3.2: *Expected Abnormal Movements when factor values are known.*
DTM: Days to Maturity. $\hat{\theta}$: Estimated expected abnormal movement. (δ_L, δ_U): Basic confidence intervals at 5% significance level.

DTM	$\hat{\theta}$	δ_L	δ_U
1	-0.0818	-0.0195	-0.1703
7	-0.0478	-0.1166	0.0205
14	-0.0231	-0.0818	0.0305
30	0.0117	-0.0045	0.0281
60	0.0139	0.0007	0.0289
90	0.0120	-0.0024	0.0271
121	0.0132	-0.0021	0.0297
152	0.0103	-0.0069	0.0284
183	-0.0085	-0.0444	0.0196
214	-0.0144	-0.0508	0.0144
244	-0.0220	-0.0680	0.0121
274	-0.0251	-0.0650	0.0077
305	-0.0359	-0.0826	0.0031
335	-0.0409	-0.0930	0.0016
365	-0.0349	-0.0858	0.0053

(a) *Auction Date*

DTM	$\hat{\theta}$	δ_L	δ_U
1	-0.1022	-0.2099	-0.0237
7	-0.0939	-0.1594	-0.0425
14	-0.0632	-0.1210	-0.0175
30	-0.0056	-0.0245	0.0123
60	-0.0060	-0.0266	0.0138
90	-0.0102	-0.0304	0.0084
121	-0.0108	-0.0294	0.0064
152	-0.0157	-0.0352	0.0022
183	-0.0290	-0.0664	0.0016
214	-0.0316	-0.0677	-0.0039
244	-0.0396	-0.0849	-0.0072
274	-0.0402	-0.0799	-0.0085
305	-0.0474	-0.0907	-0.0159
335	-0.0465	-0.0938	-0.0135
365	-0.0450	-0.0937	-0.0089

(b) *Notification Date*

DTM	$\hat{\theta}$	δ_L	δ_U
1	-0.0324	0.0074	-0.0662
7	-0.0779	-0.1537	-0.0263
14	-0.0258	-0.0847	0.0173
30	0.0050	-0.0126	0.0246
60	-0.0020	-0.0169	0.0118
90	0.0016	-0.0095	0.0128
121	-0.0005	-0.0097	0.0090
152	-0.0047	-0.0137	0.0046
183	-0.0127	-0.0226	-0.0028
214	-0.0198	-0.0325	-0.0078
244	-0.0173	-0.0292	-0.0057
274	-0.0243	-0.0355	-0.0131
305	-0.0356	-0.0501	-0.0216
335	-0.0359	-0.0496	-0.0228
365	-0.0267	-0.0419	-0.0119

(c) *Settlement Date*

DTM	$\hat{\theta}$	δ_L	δ_U
1	-0.058	-0.13901	0.0405
7	-0.0233	-0.0797	0.0402
14	-0.0016	-0.0416	0.0445
30	-0.0019	-0.0226	0.0162
60	-0.0113	-0.0299	0.0039
90	-0.0137	-0.0343	0.0055
121	-0.0114	-0.0292	0.0062
152	-0.0104	-0.0265	0.0062
183	-0.0144	-0.0311	0.0031
214	-0.0059	-0.0249	0.0161
244	-0.0134	-0.0300	0.0042
274	-0.0225	-0.0406	-0.0030
305	-0.0190	-0.0404	0.0026
335	-0.0203	-0.0400	-0.0006
365	-0.0179	-0.0382	0.0034

(d) *Settlement Date+1*

Table 3.3: *Expected Abnormal Movements when factor values are unknown.*
DTM: Days to Maturity. $\hat{\theta}$: Estimated expected abnormal movement. (δ_L, δ_U): Basic confidence intervals at 5% significance level.

3.6 Hypothesis 5: TAF Auctions were associated with Abnormal Movements in Interbank Spreads beyond what can be explained by changes in Credit andor Liquidity Premiums

This hypothesis was tested by using the results from table 3.2. The negated form of the hypothesis is rejected at a significance level of 5%, due to the significant abnormal moves for maturities above 4 months.

The Notification dates for TAF auctions show a strong association to abnormal movements for the Interbank spread term structure. The association is limited to the long term parts of the term structure, but indicate that movements in the liquidity and credit premium are unable to explain the variation in the entire term structure.

The results furthermore show strong signs connecting the abnormal movements to the TAF. The following observations support this conclusion. The moves are limited to the Notification date of the TAF Auctions. This is the date where the market receives information regarding auction results, and thus the day when re-pricing should occur if one assumes an efficient market. Second, there is no abnormal moves on the other days, with the exception of the overnight rate. If other days showed clear but different patterns of abnormal movement, there would either be something wrong with the model, or other systemic events creating a problem separating the sources of any effects. Third, the direction of the abnormal moves are consistent with the programs intention. They are consistently producing rates that are lower than expected, even under the assumption of perfect forecasts of future credit conditions.

3.7 Hypothesis 6: TAF Auctions were associated with Abnormal Movements in Interbank Spreads, as a result of changes in credit andor liquidity premiums

This hypothesis was tested by using the results from table 3.3. The negated form of the hypothesis is rejected at a significance level of 5%. The conclusion follows as a range of new maturities experience abnormal movements, which did not do so at the previous test (results in table 3.2). Notice in particular the short term spread for the term structure on Notification dates, and the spreads on longer maturities on Settlement dates. These spreads now show signs of abnormal moves (marked gray in table 3.3) resulting from systemic, but unpredictable moves in the factors governing the term structure dynamics. The idea behind the reasoning is that these spreads did not show signs of such behaviour in the previous test, and the only thing that has changed is the new unpredictability in factors.

The new abnormal movements follow from a combination of variation in factor loading and the forecasting errors for factor forecasts. Thus the source is time-varying risk and risk premiums.

3.8 Conclusion

This thesis has reported on the possible effects of the Term Auction Facility (TAF) on international interbank interest rate spread dynamics.

A wide range of research have been conducted on this program, but none seem to answer the question "How is the interbank term structures impacted by the TAF?" 6 hypotheses are motivated, and three tests are constructed to test them. In particular an event study was constructed based on VAR(1) dynamics and an affine term structure model in order to describe expected movements.

First, we find an indication of a decline in the interest rates on unsecured loans, at the initiation of the Term Auction Facility. This observation is limited to loans with less than 3 months to maturity, and is consistent with what should be expected in an efficient market. The unpredictable fall in short rates coincides with the maturity of the loans offered in TAF.

Second, the US interbank rates showed a significantly higher propensity to fall on notification dates than otherwise during the financial crisis. The tendency to drop was in particular strong for rates on loans with maturity ranging 1-6 months .

Third, the LIBOR USD rates showed a tendency to decline more following TAF auctions than on other days during the financial crisis, provided that they fell. The difference was in particular apparent on TAF-notification dates, but was not significant.

Fourth, the TAF program impacted international interbank term structures, but this was felt in different ways. While the GBP market reacted by on average letting long term rates drop, the EUR market dropped short term rates. For all international markets effects were most strongly felt on the day auction results were made available.

Fifth, the event study provided conclusive answers regarding the effect of the Term Auction Facility on LIBOR USD term structure of interest rate spreads.

Interest rates on loans with more than 4 months to maturity rates declined more than could be explained from the VAR-ATS model, when factors were perfectly predicted. This suggests that the results from TAF auctions went a long way in reducing premiums on unsecured loans in the interbank marked with longer maturities (5-12 months). The robustness of these results follows as no abnormal movements are observed on days leading up to, or following the notification of auction-results.

Last, the TAF caused abnormal movements in time varying risk and risk premiums. These moves affected the long and short term rates on both notification and settlement dates.

3.9 Comments for Further Research

Two key potentials for future research were uncovered. First, there are clear issues with performing regressions on interest rate levels, and only using one or two interest rates. The results in this paper suggest that expecting conclusive and sound answers using simple-rate-regression approaches seem unrealistic. It is often observed that while individual interest rates show no significant signs for movement, the case is quite different for term structure proxy (such as the slope or curvature). This thesis provides a clear indication that when analysing the effects of monetary policy to term structures, proxies for the entire term structure provide a better image of effects than individual maturity rates.

They are also more likely to reflect effects when individual rates do not. It is therefore a need for developing standards in research for studying the dynamics of such proxies. One such standard is the Diebold and Li (2006) model.

Second, there is a potential to perform event studies and obtain results regarding how these proxies are affected by monetary policy. In regard to the last potential there is a further need to develop a theory for what is considered normal movement for such proxies.

Chapter 4

Appendices

4.1 Appendix 1 - Abbreviations

Abbreviation	Description
Ar	Abnormal Rate Difference
Ar1	The first matrix in an autoregressive process
ATS	Affine Term Structure
BoE	Bank of England (UK Central bank)
CBOE	Chicago Board Exchange
CDO	Collateralized Debt Obligation
CET	Central European Time
DMFR	Downward Movement Frequency Ratio
DTM	Days To Maturity
ECB	European Central Bank
EONIA	Euro OverNight Index Average
EST	Eastern Standard Time (CET -6)
EURIBOR	European Interbank Offered Rate
EURIOIS	(EURIBOR - OIS)
FED	Federal Reserve (US Central bank)
CET	Central European Time (EST +6)
LIBOR	London Interbank Offered Rate
LOIS	(LIBOR - OIS)
LTRO	Long Term Refinancing Operations (monetary measure used by ECB)
MRO	Main Refinancing Operation (monetary measure used by ECB)
MOVE	Merrill Option Volatility Estimate Indexes
NB	Norges Bank (The Norwegian Central Bank)
NIBOR	Norwegian Interbank Offered Rate
OIS	Overnight Indexed Swap
OLS	Ordinary Least Squares (Statistic estimation method)
OMO	Open Market Operation (monetary measure used by BoE)
QE	Quantitative Easing (monetary measure used by FED and BoE)
REPO	Repurchase Agreement
SLTRO	Supplementary Long Term Refinancing Operations (monetary measure used by ECB)
SSE	Sum of Squared Errors
STIBOR	Stockholm Interbank Offered Rate
TAF	Term Auction Facility (monetary measure used by FED)
TED	Acronym for T-Bill and ED (ticker for Eurodollar future contracts)
VAR	Vector AutoRegression
VIX	Volatility index by CBOE

4.2 Appendix 2 - Test 1

Days	1	7	14	31	61	91	121	151	181	211	241	272	302	333	365
Drops	0.42	0.42	0.41	0.41	0.42	0.45	0.48	0.50	0.51	0.51	0.50	0.51	0.50	0.50	0.50
C Drops	0.47	0.51	0.49	0.59	0.61	0.63	0.68	0.73	0.73	0.71	0.68	0.63	0.63	0.63	0.64
θ	1.14	1.22	1.20	1.43	1.44	1.39	1.42	1.46	1.44	1.41	1.35	1.24	1.25	1.25	1.28
$\delta_L(1\%)$	0.83	0.89	0.89	1.04	1.07	1.04	1.09	1.11	1.11	1.09	1.03	0.96	0.96	0.96	0.98
$\delta_L(5\%)$	0.92	0.98	0.95	1.15	1.14	1.14	1.16	1.21	1.17	1.15	1.12	1.01	1.04	1.04	1.07
$\delta_L(10\%)$	0.95	1.02	1.02	1.19	1.22	1.17	1.23	1.24	1.24	1.21	1.16	1.07	1.07	1.07	1.10

Table 4.1: *Empirical results of LIBOR USD rates drop frequencies on TAF notification dates (DMFR). Drops is the frequency of drops in the total sample, C Drops the frequency of drops on notification dates, and θ the test statistic described in expression 1. $\delta_L(x)$ is the x lower confidence level of θ, where the θ rejects H_0 at a x confidence level whenever $\delta_L(x) > 1$ (Marked white).*

Days	7	15	21	30	60	90	120	150	180	210	240	300	330	360
Drop	0.48	0.46	0.49	0.49	0.51	0.52	0.52	0.53	0.53	0.53	0.54	0.55	0.54	0.55
C Drop	0.54	0.53	0.54	0.54	0.63	0.63	0.54	0.54	0.54	0.58	0.63	0.68	0.64	0.73
θ	1.13	1.13	1.11	1.12	1.24	1.21	1.05	1.03	1.02	1.08	1.16	1.24	1.19	1.33
$\delta_L(1\%)$	0.74	0.76	0.74	0.88	0.96	0.91	1.01	0.83	0.91	0.93	0.98	0.98	0.98	0.94
$\delta_L(5\%)$	0.81	0.83	0.79	0.95	1.01	0.98	1.09	0.88	0.98	1.01	1.03	1.06	1.03	1.01
$\delta_L(10\%)$	0.83	0.86	0.83	0.98	1.07	1.01	1.12	0.93	1.01	1.04	1.09	1.09	1.09	1.04

Table 4.2: *Empirical results of EURIBOR rate drop frequencies on TAF notification dates. Drops is the frequency of drops in the total sample, C Drops the frequency of drops on notification dates, and θ the test statistic described in expression 1. $\delta_L(x)$ is the x lower confidence level of θ, where the θ rejects H_0 at a x confidence level whenever $\delta_L(x) > 1$ (Marked white).*

Days	1	7	14	30	60	91	181	271	365
Drops	0.50	0.44	0.40	0.41	0.40	0.41	0.41	0.41	0.43
C Drops	0.54	0.47	0.41	0.51	0.47	0.37	0.44	0.42	0.37
θ	1.08	1.08	1.02	1.23	1.18	0.92	1.08	1.04	0.88
$\delta_L(1\%)$	0.83	0.81	0.74	0.89	0.86	0.68	0.80	0.77	0.64
$\delta_L(5\%)$	0.90	0.86	0.81	0.98	0.92	0.72	0.85	0.82	0.70
$\delta_L(10\%)$	0.93	0.92	0.84	1.02	0.98	0.77	0.91	0.88	0.75

Table 4.3: *Empirical results of NIBOR rate drop frequencies on TAF notification dates. Drops is the frequency of drops in the total sample, C Drops the frequency of drops on notification dates, and θ the test statistic described in expression 1. $\delta_L(x)$ is the x lower confidence level of θ, where the θ rejects H_0 at a x confidence level whenever $\delta_L(x) > 1$ (Marked white).*

Days	1	7	14	30	60	91	181	271	365
Drops	0.50	0.44	0.40	0.41	0.40	0.41	0.41	0.41	0.43
C Drops	0.53	0.58	0.53	0.49	0.32	0.39	0.36	0.42	0.49
θ	1.05	1.31	1.32	1.18	0.80	0.96	0.87	1.04	1.16
$\delta_L(1\%)$	0.80	0.98	0.95	0.86	0.58	0.71	0.65	0.77	0.84
$\delta_L(5\%)$	0.87	1.04	1.05	0.95	0.62	0.75	0.69	0.82	0.92
$\delta_L(10\%)$	0.90	1.11	1.09	0.98	0.67	0.81	0.74	0.88	0.98

Table 4.4: *Empirical results of LIBOR GBP interest rate drop frequencies on TAF notification dates. Drops is the frequency of drops in the total sample, C Drops the frequency of drops on notification dates, and θ the test statistic described in expression 1. $\delta_L(x)$ is the x lower confidence level of θ, where the θ rejects H_0 at a x confidence level whenever $\delta_L(x) > 1$ (Marked white).*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
Auction Dates	0.97	1.08	0.98	1.07	0.99	1.06	1.02
Notification Dates	0.99	1.10	1.00	1.08	1.01	1.08	1.04
Settlement Date	0.97	1.08	0.98	1.06	0.99	1.06	1.02

Table 4.5: *DMFR for the LIBOR USD Term Structure Slope*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
Auction Dates	1.05	1.17	1.07	1.16	1.07	1.15	1.11
Notification Dates	1.04	1.15	1.05	1.14	1.06	1.13	1.09
Settlement Date	0.91	1.01	0.92	1.00	0.93	0.99	0.96

Table 4.6: *DMFR for the LIBOR USD Term Structure Curvature*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
Auction Dates	1.09	1.21	1.10	1.19	1.11	1.19	1.15
Notification Dates	1.04	1.16	1.05	1.14	1.06	1.13	1.10
Settlement Date	1.06	1.18	1.07	1.16	1.08	1.16	1.12

Table 4.7: *DMFR for the EURIBOR Term Structure Slope*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
Auction Dates	0.86	0.96	0.87	0.95	0.88	0.94	0.91
Notification Dates	1.22	1.35	1.23	1.33	1.24	1.32	1.28
Settlement Date	0.85	0.95	0.86	0.94	0.87	0.93	0.90

Table 4.8: *DMFR for the EURIBOR Term Structure Curvature*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
Auction Dates	0.86	0.96	0.87	0.95	0.88	0.94	0.91
Notification Dates	0.94	1.05	0.96	1.04	0.96	1.03	1.00
Settlement Date	1.03	1.15	1.04	1.14	1.05	1.13	1.09

Table 4.9: *DMFR for the LIBOR GBP Term Structure Slope*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
Auction Dates	1.12	1.26	1.14	1.24	1.15	1.23	1.19
Notification Dates	1.11	1.24	1.12	1.22	1.13	1.21	1.17
Settlement Date	0.89	1.00	0.91	0.99	0.91	0.98	0.95

Table 4.10: *DMFR for the LIBOR GBP Term Structure Curvature*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
Auction Dates	0.98	1.10	1.00	1.08	1.00	1.08	1.04
Notification Dates	1.07	1.20	1.08	1.18	1.09	1.17	1.13
Settlement Date	0.81	0.90	0.82	0.89	0.82	0.89	0.85

Table 4.11: *DMFR for the NIBOR Term Structure Slope*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
Auction Dates	0.83	0.94	0.85	0.93	0.85	0.92	0.89
Notification Dates	0.92	1.04	0.93	1.02	0.94	1.01	0.98
Settlement Date	1.16	1.30	1.17	1.28	1.18	1.27	1.22

Table 4.12: *DMFR for the NIBOR Term Structure Curvature*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
Auction Dates	1.13	1.28	1.15	1.26	1.15	1.25	1.20
Notification Dates	1.01	1.14	1.02	1.12	1.03	1.11	1.07
Settlement Date	0.91	1.03	0.92	1.01	0.93	1.00	0.96

Table 4.13: *DMFR for the LOIS USD Term Structure Slope*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
Auction Dates	1.23	1.39	1.24	1.37	1.25	1.36	1.30
Notification Dates	0.97	1.09	0.98	1.08	0.99	1.07	1.03
Settlement Date	0.90	1.02	0.91	1.00	0.92	0.99	0.95

Table 4.14: *DMFR for the LOIS USD Term Structure Curvature*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
Auction Dates	0.84	0.95	0.85	0.93	0.85	0.92	0.89
Notification Dates	0.90	1.01	0.91	1.00	0.91	0.99	0.95
Settlement Date	0.96	1.09	0.98	1.07	0.98	1.06	1.02

Table 4.15: *DMFR for the EURIOIS Term Structure Slope*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
Auction Dates	0.87	0.99	0.88	0.97	0.89	0.97	0.93
Notification Dates	0.94	1.06	0.95	1.04	0.96	1.04	0.99
Settlement Date	0.83	0.94	0.84	0.93	0.85	0.92	0.88

Table 4.16: *DMFR for the EURIOIS Term Structure Curvature*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
Auction Dates	0.64	0.72	0.65	0.71	0.65	0.71	0.68
Notification Dates	1.02	1.16	1.04	1.14	1.05	1.13	1.09
Settlement Date	1.16	1.32	1.18	1.30	1.19	1.29	1.24

Table 4.17: *DMFR for the LOIS GBP Term Structure Slope*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
Auction Dates	1.03	1.17	1.04	1.15	1.05	1.14	1.09
Notification Dates	0.86	0.97	0.87	0.96	0.88	0.95	0.91
Settlement Date	0.68	0.77	0.69	0.75	0.69	0.75	0.72

Table 4.18: *DMFR for the LOIS GBP Term Structure Curvature*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
1 M	0.9996	1.2444	1.0265	1.2050	1.0370	1.1909	1.1086
2 M	0.9834	1.2146	1.0062	1.1863	1.0196	1.1681	1.0888
3 M	1.0027	1.2404	1.0256	1.2071	1.0392	1.1888	1.1090
4 M	1.0615	1.3005	1.0817	1.2667	1.0956	1.2481	1.1669
5 M	1.0582	1.3005	1.0817	1.2667	1.0956	1.2481	1.1669
6 M	1.1007	1.3320	1.1208	1.2991	1.1347	1.2854	1.2054
7 M	0.9963	1.2181	1.0183	1.1911	1.0313	1.1738	1.0980
8 M	1.0084	1.2333	1.0303	1.1977	1.0433	1.1849	1.1096
9 M	1.1880	1.4654	1.2148	1.4265	1.2307	1.4052	1.3122
10 M	1.0886	1.3415	1.1099	1.3055	1.1245	1.2858	1.1998
11 M	1.0313	1.2759	1.0549	1.2415	1.0689	1.2227	1.1406
12 M	1.1496	1.4233	1.1760	1.3795	1.1916	1.3586	1.2719

Table 4.19: *The DMFR for the LOIS spread on Auction Dates for the TAF program.*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
1 M	1.0036	1.2494	1.0272	1.2147	1.0412	1.1957	1.1131
2 M	0.9606	1.1873	0.9796	1.1550	0.9927	1.1373	1.0601
3 M	0.9187	1.1366	0.9397	1.1017	0.9522	1.0892	1.0161
4 M	0.8930	1.0934	0.9158	1.0650	0.9246	1.0533	0.9848
5 M	0.8958	1.0975	0.9158	1.0690	0.9246	1.0533	0.9848
6 M	0.8887	1.0794	0.9077	1.0526	0.9161	1.0379	0.9732
7 M	0.8615	1.0541	0.8778	1.0268	0.8891	1.0119	0.9465
8 M	0.8458	1.0345	0.8642	1.0082	0.8751	0.9938	0.9307
9 M	0.8486	1.0467	0.8677	1.0189	0.8791	1.0037	0.9373
10 M	0.9483	1.1732	0.9700	1.1373	0.9796	1.1201	1.0452
11 M	0.9453	1.1732	0.9700	1.1416	0.9829	1.1243	1.0489
12 M	0.9216	1.1456	0.9428	1.1102	0.9553	1.0934	1.0197

Table 4.20: *The DMFR for the LOIS spread on Notification Dates for the TAF program.*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
1 M	0.7560	0.9373	0.7737	0.9150	0.7843	0.9007	0.8384
2 M	0.9297	1.1483	0.9512	1.1215	0.9639	1.1043	1.0293
3 M	0.9822	1.2151	1.0047	1.1824	1.0180	1.1645	1.0863
4 M	0.9577	1.1689	0.9760	1.1386	0.9885	1.1261	1.0528
5 M	1.0176	1.2467	1.0403	1.2098	1.0503	1.1965	1.1186
6 M	0.8629	1.0481	0.8787	1.0184	0.8896	1.0077	0.9450
7 M	0.8006	0.9863	0.8183	0.9572	0.8287	0.9432	0.8823
8 M	0.7908	0.9643	0.8056	0.9398	0.8157	0.9264	0.8675
9 M	0.9092	1.1171	0.9297	1.0917	0.9419	1.0754	1.0042
10 M	0.7343	0.9078	0.7510	0.8834	0.7610	0.8701	0.8119
11 M	0.7390	0.9113	0.7560	0.8868	0.7635	0.8734	0.8147
12 M	0.7390	0.9150	0.7560	0.8868	0.7660	0.8767	0.8176

Table 4.21: *The DMFR for the LOIS spread on Settlement Dates for the TAF program.*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
Auction Date	0.9975	1.1328	1.0148	1.1139	1.0226	1.1060	1.0621
Notification Date	0.9341	1.0572	0.9482	1.0408	0.9544	1.0322	0.9924
Settlement Date	0.7248	0.8212	0.7358	0.8094	0.7414	0.8037	0.7709

Table 4.22: *The DMFR for the LOIS spread slope.*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
Auction Dates	0.79	0.88	0.80	0.87	0.81	0.86	0.83
Notification Dates	1.01	1.13	1.03	1.12	1.03	1.11	1.07
Settlement Date	0.85	0.95	0.86	0.93	0.86	0.93	0.89

Table 4.23: *The DMFR for the LOIS Curvature on dates for the TAF program.*

4.3 Appendix 3 - Test 2

Days	$\delta_L^1(5\%)$	$\delta_U^1(5\%)$	$\delta_L^2(5\%)$	$\delta_U^2(5\%)$	θ_1	θ_2
1	-0.289	-0.049	-0.073	-0.029	-0.133	-0.049
7	-0.102	-0.028	-0.039	-0.007	-0.060	-0.019
14	-0.096	-0.029	-0.040	-0.008	-0.058	-0.021
31	-0.070	-0.022	-0.042	-0.007	-0.043	-0.022
61	-0.061	-0.020	-0.044	-0.008	-0.038	-0.023
91	-0.058	-0.017	-0.050	-0.011	-0.034	-0.027
121	-0.059	-0.020	-0.048	-0.013	-0.037	-0.028
151	-0.056	-0.021	-0.044	-0.015	-0.036	-0.028
181	-0.058	-0.022	-0.048	-0.019	-0.038	-0.032
211	-0.060	-0.025	-0.050	-0.021	-0.040	-0.034
241	-0.061	-0.026	-0.052	-0.023	-0.041	-0.036
272	-0.062	-0.028	-0.053	-0.024	-0.043	-0.037
302	-0.062	-0.028	-0.051	-0.024	-0.043	-0.037
333	-0.063	-0.030	-0.051	-0.024	-0.045	-0.037
365	-0.066	-0.032	-0.052	-0.025	-0.047	-0.038

Table 4.24: *Summary of Expected Drop Size Result for the* ***LIBOR USD*** *Term Structure. Empirical confidence intervals for the unconditionally expected drop size* $\hat{\theta}_1$, $(\delta_L^1(5\%), \delta_U^1(5\%))$ *compared with the confidence interval for the conditional expected drop size* $\hat{\theta}_2$, $(\delta_L^1(5\%), \delta_U^1(5\%))$. *(Significantly different expected dropsizes marked in white). Values Measured in Percentage Points.*

Days	$\delta_L^1(5\%)$	$\delta_U^1(5\%)$	$\delta_L^2(5\%)$	$\delta_U^2(5\%)$	θ_1	θ_2
7	-0.067	-0.029	-0.041	-0.010	-0.046	-0.024
15	-0.068	-0.025	-0.041	-0.011	-0.043	-0.024
21	-0.059	-0.023	-0.034	-0.011	-0.038	-0.021
30	-0.051	-0.023	-0.029	-0.012	-0.035	-0.020
60	-0.047	-0.023	-0.024	-0.011	-0.034	-0.017
90	-0.041	-0.021	-0.024	-0.011	-0.030	-0.017
120	-0.042	-0.021	-0.027	-0.012	-0.030	-0.019
150	-0.040	-0.021	-0.026	-0.011	-0.030	-0.018
180	-0.042	-0.021	-0.028	-0.012	-0.030	-0.019
210	-0.041	-0.021	-0.026	-0.011	-0.030	-0.018
240	-0.041	-0.021	-0.026	-0.011	-0.030	-0.018
300	-0.042	-0.022	-0.025	-0.010	-0.030	-0.017
330	-0.041	-0.022	-0.024	-0.010	-0.030	-0.017
360	-0.040	-0.021	-0.026	-0.011	-0.029	-0.018

Table 4.25: *Summary of Expected Drop Size Result for the* ***EURIBOR*** *Term Structure. Empirical confidence intervals for the unconditionally expected drop size* $\hat{\theta}_1$, $(\delta_L^1(5\%), \delta_U^1(5\%))$ *compared with the confidence interval for the conditional expected drop size* $\hat{\theta}_2$, $(\delta_L^1(5\%), \delta_U^1(5\%))$. *(Significantly different expected dropsizes marked in white). Values Measured in Percentage Points.*

Days	$\delta^1_L(5\%)$	$\delta^1_U(5\%)$	$\delta^2_L(5\%)$	$\delta^2_U(5\%)$	θ_1	θ_2
1	-0.207	-0.042	-0.031	-0.007	-0.102	-0.017
7	-0.124	-0.031	-0.050	-0.012	-0.067	-0.029
14	-0.083	-0.026	-0.040	-0.013	-0.047	-0.025
31	-0.076	-0.018	-0.032	-0.013	-0.035	-0.022
61	-0.072	-0.017	-0.027	-0.012	-0.033	-0.019
91	-0.060	-0.016	-0.028	-0.013	-0.029	-0.020
121	-0.063	-0.016	-0.026	-0.013	-0.030	-0.019
181	-0.062	-0.016	-0.028	-0.015	-0.030	-0.021
211	-0.062	-0.017	-0.026	-0.014	-0.029	-0.019
241	-0.059	-0.017	-0.026	-0.014	-0.029	-0.019
271	-0.064	-0.019	-0.027	-0.015	-0.032	-0.020
301	-0.058	-0.017	-0.026	-0.015	-0.029	-0.020
331	-0.061	-0.017	-0.026	-0.015	-0.030	-0.020
365	-0.069	-0.018	-0.027	-0.015	-0.031	-0.021

Table 4.26: *Summary of Expected Drop Size Result for the **LIBOR Sterling** Term Structure. Empirical confidence intervals for the unconditionally expected drop size $\hat{\theta}_1$, $(\delta^1_L(5\%), \delta^1_U(5\%))$ compared with the confidence interval for the conditional expected drop size $\hat{\theta}_2$, $(\delta^1_L(5\%), \delta^1_U(5\%))$. (Significantly different expected dropsizes marked in white). Values Measured in Percentage Points.*

Days	$\delta^1_L(5\%)$	$\delta^1_U(5\%)$	$\delta^2_L(5\%)$	$\delta^2_U(5\%)$	θ_1	θ_2
1	-0.219	-0.100	-0.183	-0.096	-0.151	-0.136
7	-0.211	-0.086	-0.138	-0.060	-0.139	-0.097
14	-0.216	-0.078	-0.115	-0.040	-0.135	-0.072
30	-0.239	-0.081	-0.126	-0.033	-0.146	-0.075
60	-0.183	-0.085	-0.134	-0.043	-0.129	-0.083
91	-0.164	-0.072	-0.122	-0.046	-0.114	-0.081
181	-0.192	-0.071	-0.097	-0.039	-0.126	-0.064
271	-0.156	-0.065	-0.079	-0.036	-0.106	-0.055
365	-0.130	-0.058	-0.063	-0.030	-0.090	-0.045

Table 4.27: *Summary of Expected Drop Size Result for the **NIBOR** Term Structure. Empirical confidence intervals for the unconditionally expected drop size $\hat{\theta}_1$, $(\delta^1_L(5\%), \delta^1_U(5\%))$ compared with the confidence interval for the conditional expected drop size $\hat{\theta}_2$, $(\delta^1_L(5\%), \delta^1_U(5\%))$. (Significantly different expected dropsizes marked in white). Values Measured in Percentage Points.*

1 Month	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
TAF Auction	-0.054	-0.015	-0.048	-0.019	-0.046	-0.021	-0.033
TAF Notification	-0.059	-0.008	-0.051	-0.011	-0.047	-0.013	-0.029
TAF Settlement	-0.054	-0.008	-0.047	-0.011	-0.043	-0.012	-0.026
Otherwise	-0.025	-0.014	-0.023	-0.015	-0.022	-0.015	-0.018
3 Months	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
TAF Auction	-0.050	-0.014	-0.045	-0.017	-0.043	-0.019	-0.030
TAF Notification	-0.061	-0.010	-0.052	-0.012	-0.048	-0.014	-0.029
TAF Settlement	-0.029	-0.009	-0.026	-0.010	-0.025	-0.011	-0.018
Otherwise	-0.021	-0.014	-0.020	-0.015	-0.019	-0.015	-0.017
6 Months	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
TAF Auction	-0.044	-0.019	-0.040	-0.021	-0.038	-0.022	-0.030
TAF Notification	-0.055	-0.016	-0.049	-0.019	-0.046	-0.020	-0.032
TAF Settlement	-0.027	-0.012	-0.025	-0.014	-0.024	-0.014	-0.019
Otherwise	-0.026	-0.020	-0.025	-0.021	-0.025	-0.021	-0.023
12 Months	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
TAF Auction	-0.052	-0.024	-0.048	-0.027	-0.046	-0.028	-0.037
TAF Notification	-0.062	-0.024	-0.056	-0.027	-0.053	-0.029	-0.041
TAF Settlement	-0.051	-0.027	-0.048	-0.030	-0.046	-0.031	-0.038
Otherwise	-0.038	-0.030	-0.037	-0.031	-0.036	-0.031	-0.034

Table 4.28: *Expected Drop Size for 1 month, 3 months 6 months and 12 months LOIS USD spread. Hypothesis of equality in movement sizes rejected at indicated significance level marked grey.*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
TAF Auction	-0.034	-0.016	-0.031	-0.018	-0.030	-0.018	-0.024
TAF Notification	-0.062	-0.026	-0.056	-0.029	-0.053	-0.030	-0.040
TAF Settlement	-0.071	-0.027	-0.063	-0.030	-0.060	-0.031	-0.044
Otherwise	-0.037	-0.029	-0.036	-0.030	-0.036	-0.030	-0.033

Table 4.29: *Expected Drop Size LOIS USD spread slope. Hypothesis of equality in movement sizes rejected at indicated significance level marked grey.*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
TAF Auction	-0.034	-0.016	-0.031	-0.018	-0.030	-0.019	-0.024
TAF Notification	-0.056	-0.023	-0.052	-0.026	-0.049	-0.028	-0.038
TAF Settlement	-0.054	-0.024	-0.049	-0.026	-0.047	-0.028	-0.037
Otherwise	-0.030	-0.021	-0.029	-0.021	-0.028	-0.022	-0.024

Table 4.30: *Expected Drop Size LOIS USD spread Curvature. Hypothesis of equality in movement sizes rejected at indicated significance level marked grey.*

1 Month	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
TAF Auction	-0.043	-0.011	-0.037	-0.013	-0.035	-0.014	-0.023
TAF Notification	-0.025	-0.008	-0.023	-0.009	-0.021	-0.010	-0.015
TAF Settlement	-0.044	-0.015	-0.040	-0.017	-0.038	-0.018	-0.027
Otherwise	-0.015	-0.012	-0.015	-0.012	-0.015	-0.012	-0.013
3 Months	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
TAF Auction	-0.025	-0.012	-0.023	-0.013	-0.022	-0.014	-0.018
TAF Notification	-0.026	-0.010	-0.024	-0.012	-0.023	-0.013	-0.017
TAF Settlement	-0.035	-0.013	-0.032	-0.015	-0.030	-0.016	-0.023
Otherwise	-0.015	-0.012	-0.015	-0.012	-0.014	-0.012	-0.013
6 Months	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
TAF Auction	-0.031	-0.015	-0.029	-0.017	-0.028	-0.018	-0.023
TAF Notification	-0.027	-0.012	-0.025	-0.013	-0.024	-0.014	-0.018
TAF Settlement	-0.036	-0.014	-0.033	-0.016	-0.032	-0.018	-0.024
Otherwise	-0.018	-0.014	-0.018	-0.015	-0.017	-0.015	-0.016
12 Months	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
TAF Auction	-0.044	-0.023	-0.041	-0.025	-0.040	-0.026	-0.033
TAF Notification	-0.034	-0.018	-0.032	-0.019	-0.031	-0.020	-0.025
TAF Settlement	-0.044	-0.017	-0.041	-0.020	-0.039	-0.021	-0.030
Otherwise	-0.028	-0.023	-0.027	-0.024	-0.027	-0.024	-0.025

Table 4.31: *Expected Drop Size for 1 month, 3 months 6 months and 12 months EURIOIS spread. Hypothesis of equality in movement sizes rejected at indicated significance level marked grey.*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
TAF Auction	-0.045	-0.022	-0.042	-0.024	-0.040	-0.025	-0.032
TAF Notification	-0.054	-0.019	-0.048	-0.021	-0.045	-0.022	-0.032
TAF Settlement	-0.048	-0.017	-0.042	-0.019	-0.040	-0.021	-0.029
Otherwise	-0.029	-0.023	-0.028	-0.024	-0.028	-0.024	-0.026

Table 4.32: *Expected Drop Size EURIOIS spread slope. Hypothesis of equality in movement sizes rejected at indicated significance level marked grey.*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
TAF Auction	-0.058	-0.016	-0.050	-0.018	-0.047	-0.020	-0.032
TAF Notification	-0.024	-0.012	-0.023	-0.013	-0.022	-0.014	-0.018
TAF Settlement	-0.035	-0.016	-0.032	-0.017	-0.030	-0.018	-0.024
Otherwise	-0.020	-0.016	-0.019	-0.017	-0.019	-0.017	-0.018

Table 4.33: *Expected Drop Size EURIOIS spread Curvature. Hypothesis of equality in movement sizes rejected at indicated significance level marked grey.*

1 Month	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
TAF Auction	-0.019	-0.005	-0.017	-0.006	-0.016	-0.007	-0.011
TAF Notification	-0.034	-0.009	-0.030	-0.010	-0.028	-0.012	-0.019
TAF Settlement	-0.161	-0.009	-0.129	-0.011	-0.116	-0.012	-0.055
Otherwise	-0.021	-0.019	-0.021	-0.019	-0.021	-0.019	-0.020
3 Months	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
TAF Auction	-0.021	-0.008	-0.019	-0.009	-0.018	-0.010	-0.014
TAF Notification	-0.030	-0.010	-0.027	-0.012	-0.025	-0.013	-0.018
TAF Settlement	-0.160	-0.011	-0.129	-0.013	-0.115	-0.014	-0.056
Otherwise	-0.019	-0.011	-0.018	-0.012	-0.017	-0.012	-0.014
6 Months	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
TAF Auction	-0.027	-0.011	-0.025	-0.013	-0.024	-0.014	-0.018
TAF Notification	-0.032	-0.014	-0.030	-0.016	-0.028	-0.017	-0.022
TAF Settlement	-0.181	-0.016	-0.144	-0.019	-0.132	-0.021	-0.066
Otherwise	-0.024	-0.017	-0.023	-0.017	-0.022	-0.018	-0.020
12 Months	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
TAF Auction	-0.039	-0.018	-0.036	-0.020	-0.035	-0.021	-0.027
TAF Notification	-0.044	-0.020	-0.040	-0.022	-0.039	-0.023	-0.031
TAF Settlement	-0.227	-0.023	-0.183	-0.029	-0.165	-0.032	-0.087
Otherwise	-0.031	-0.023	-0.030	-0.023	-0.029	-0.024	-0.026

Table 4.34: *Expected Drop Size for 1 month, 3 months 6 months and 12 months LOIS GBP spread. Hypothesis of equality in movement sizes rejected at indicated significance level marked grey.*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
TAF Auction	-0.053	-0.014	-0.046	-0.016	-0.043	-0.018	-0.029
TAF Notification	-0.046	-0.014	-0.041	-0.016	-0.039	-0.018	-0.028
TAF Settlement	-0.056	-0.019	-0.051	-0.022	-0.049	-0.024	-0.036
Otherwise	-0.019	-0.015	-0.018	-0.016	-0.018	-0.016	-0.017

Table 4.35: *Expected Drop Size LOIS GBP spread slope. Hypothesis of equality in movement sizes rejected at indicated significance level marked grey.*

	$\delta L(1\%)$	$\delta U(1\%)$	$\delta L(5\%)$	$\delta U(5\%)$	$\delta L(10\%)$	$\delta U(10\%)$	θ
TAF Auction	-0.039	-0.017	-0.036	-0.019	-0.035	-0.021	-0.027
TAF Notification	-0.040	-0.017	-0.037	-0.019	-0.035	-0.020	-0.028
TAF Settlement	-0.066	-0.017	-0.058	-0.021	-0.054	-0.023	-0.037
Otherwise	-0.029	-0.023	-0.028	-0.024	-0.028	-0.024	-0.026

Table 4.36: *Expected Drop Size LOIS GBP spread Curvature. Hypothesis of equality in movement sizes rejected at indicated significance level marked grey.*

4.4 Appendix 4 - TAF Auction Data

Press release date	Auction date	Notification date	Settement date	Term (days)	Amount offered (bn)	Proportion accepted (bn)	# bidders	Proportion submitted (bn)
14.12.2007	17.12.2007	19.12.2007	20.12.2007	28	20	20.000	93	61.553
19.12.2007	20.12.2007	12.12.2007	27.12.2007	35	20	20.000	73	57.664
11.01.2008	14.01.2008	15.01.2008	17.01.2008	28	30	30.000	56	55.526
25.01.2008	28.01.2008	29.01.2008	31.01.2008	28	30	30.000	52	37.452
08.02.2008	11.02.2008	12.02.2008	14.08.2008	28	30	30.000	66	58.400
22.02.2008	25.02.2008	26.02.2008	28.02.2008	28	30	30.000	72	67.958
10.03.2008	10.03.2008	11.03.2008	13.03.2008	28	50	50.000	82	92.592
24.03.2008	24.03.2008	25.03.2008	27.03.2008	28	50	50.000	88	88.869
07.04.2008	07.04.2008	08.04.2008	10.04.2008	28	50	50.000	79	91.569
21.04.2008	21.04.2008	22.04.2008	24.04.2008	28	50	50.000	83	88.288
05.05.2008	05.05.2008	06.04.2008	08.04.2008	28	75	75.000	71	96.618
19.05.2008	19.05.2008	22.04.2008	24.04.2008	28	75	75.000	75	84.438
02.06.2008	02.06.2008	03.06.2008	05.06.2008	28	75	75.000	73	95.914
16.06.2008	16.06.2008	17.06.2008	19.06.2008	28	75	75.000	76	89.377
30.06.2008	30.06.2008	01.07.2008	03.07.2008	28	75	75.000	77	90.881
14.07.2008	14.07.2008	15.07.2008	17.07.2008	28	75	75.000	82	93.344
28.07.2008	28.07.2008	29.07.2008	31.07.2008	28	75	75.000	70	90.555
11.08.2008	11.08.2008	12.08.2008	14.08.2008	84	25	25.000	64	54.800
12.08.2008	12.08.2008	13.08.2008	14.08.2008	28	50	50.000	65	75.462
25.08.2008	25.08.2008	26.08.2008	28.08.2008	28	75	75.000	66	84.168
08.09.2008	08.09.2008	09.09.2008	11.09.2008	84	25	25.000	38	31.638
09.09.2008	09.09.2008	10.09.2008	11.09.2008	28	25	25.000	53	46.237
22.09.2008	22.09.2008	23.09.2008	25.09.2008	28	75	75.000	85	113.562
06.10.2008	06.10.2008	07.10.2008	09.10.2008	85	150	138.092	71	138.092
10.11.2008	10.11.2008	12.11.2008	22.11.2008	17	150	12.629	16	12.629

Table 4.37: ***Continues on the next page...***
Term Auction Facility (TAF) data from December 2007 untill March 2010 - source FED.

Press release date	Auction date	Notification date	Settement date	Term (days)	Amount offered (bn)	Proportion accepted (bn)	# bidders	Proportion submitted (bn)
17.11.2008	17.11.2008	18.11.2008	20.11.2008	28	150	104.478	80	104.478
24.11.2008	24.11.2008	25.11.2008	26.11.2008	13	150	31.075	16	31.075
01.12.2008	01.12.2008	02.12.2008	04.12.2008	84	150	66.471	80	66.471
15.12.2008	15.12.2008	15.12.2008	15.12.2008	28	150	63.014	71	63.014
29.12.2008	29.12.2008	30.12.2008	02.01.2009	83	150	102.979	72	102.979
12.01.2009	12.01.2009	13.01.2009	15.01.2009	28	150	107.747	97	107.747
26.01.2009	26.01.2009	27.01.2009	29.01.2009	84	150	136.051	102	136.051
09.02.2009	09.02.2009	10.02.2009	12.02.2009	28	150	142.448	117	142.448
23.02.2009	23.02.2009	24.02.2009	26.02.2009	84	150	111.683	96	111.683
09.03.2009	09.03.2009	10.03.2009	12.03.2009	28	150	117.872	116	117.872
23.03.2009	23.03.2009	24.03.2009	26.03.2009	84	150	101.642	103	101.642
06.04.2009	06.04.2009	07.04.2009	09.04.2009	28	150	106.251	105	106.251
20.04.2009	20.04.2009	21.04.2009	23.04.2009	84	150	83.830	98	83.830
04.05.2009	04.05.2009	05.05.2009	07.05.2009	28	150	131.562	124	131.562
18.05.2009	18.05.2009	19.05.2009	21.05.2009	84	150	55.570	96	55.570
01.06.2009	01.06.2009	02.06.2009	04.06.2009	28	150	95.588	103	95.588
15.06.2009	15.06.2009	16.06.2009	18.06.2009	84	150	48.023	97	48.023
29.06.2009	29.06.2009	30.06.2009	02.07.2009	28	150	86.337	106	86.337
13.07.2009	13.07.2009	14.07.2009	16.07.2009	84	125	47.768	87	47.768
27.07.2009	27.07.2009	28.07.2009	30.07.2009	28	125	82.375	103	82.375
10.08.2009	10.08.2009	11.08.2009	13.08.2009	84	100	106.251	105	106.251
24.08.2009	24.08.2009	25.08.2009	27.08.2009	28	100	73.404	97	73.404
08.09.2009	08.09.2009	09.09.2009	10.09.2009	84	75	31.908	75	31.908
21.09.2009	21.09.2009	22.09.2009	24.09.2009	28	75	55.763	83	55.763
05.10.2009	05.10.2009	06.10.2009	08.10.2009	70	50	24.830	75	24.830
19.10.2009	19.10.2009	20.10.2009	22.10.2009	28	75	39.566	83	39.566
02.11.2009	02.11.2009	03.11.2009	05.11.2009	70	25	13.152	53	13.152
16.11.2009	16.11.2009	17.11.2009	19.11.2009	28	75	31.119	82	31.119
30.11.2009	30.11.2009	01.12.2009	03.12.2009	42	25	16.730	49	16.730
14.12.2009	14.12.2009	15.12.2009	17.12.2009	28	75	46.035	102	46.035
11.01.2010	11.01.2010	12.01.2010	14.01.2010	28	75	38.531	121	38.531
08.02.2010	08.02.2010	09.02.2010	10.02.2010	28	50	15.426	103	15.426
08.03.2010	08.03.2010	09.03.2010	11.03.2010	28	25	3.410	53	3.410

Table 4.38: *Term Auction Facility (TAF) data from December 2007 untill March 2010- source FED.*

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